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Strategic Evaluation of Ethylene Projects under Uncertainty Using an Integrated AHP–TOPSIS Model

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Abstract

The petrochemical industry plays a significant role in Iran's economy, contributing to added value and supporting the development of downstream industries. Among its key products, ethylene—recognized as a fundamental building block in the petrochemical value chain—plays a crucial role in industrial policymaking and investment planning. Since implementing ethylene production projects requires substantial financial and human resources and is associated with various technical, economic, and environmental challenges, the need for scientific tools to prioritize these projects has become increasingly important. This study aims to prioritize ethylene production projects and units in Iran using the integrated multi-criteria decision-making model Analytical Hierarchy Process (AHP)–Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS). First, evaluation criteria—including economic, technical, environmental, geographical, and managerial indicators—were identified and weighted based on expert opinions. The performance of production units was then compared and ranked using the TOPSIS method. The results indicated that Unit D, with a score of 0.98 in the AHP method and the highest closeness coefficient to the ideal solution in the TOPSIS method, is the most suitable option for investment and future development in the petrochemical industry. Sensitivity analysis further revealed that Unit D's ranking remained stable across most scenarios. Overall, the findings highlight the decisive role of advanced technologies and environmental requirements, alongside economic factors, demonstrating that multi-criteria models can serve as powerful tools for strategic decision-making in Iran's petrochemical sector.

Keywords: Petrochemical projects, Ethylene, Multi-attribute decision making, Analytical hierarchy process–technique for order of preference by similarity to the ideal solution.

1 | Introduction

The petrochemical industry holds a strategic position in Iran's economy due to its substantial contribution to value creation and the development of downstream industries. Among the various petrochemical products,

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ethylene is recognized as a fundamental building block, serving as a key input for polymers, resins, synthetic fibers, and numerous other chemical products. The critical role of ethylene in industrial planning and investment makes its production projects particularly resource-intensive, involving considerable financial, technical, and human capital commitments, alongside environmental considerations [1], [2].

Given these challenges, effective prioritization of ethylene production units is essential to optimize resource allocation and support sustainable development in the sector. Multi-Criteria Decision-Making (MCDM) approaches, particularly hybrid methods integrating AHP and Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS), have proven effective in addressing such complex decisions by considering economic, technical, environmental, and managerial criteria simultaneously [3], [4]. These methods provide a structured framework for quantifying expert judgments, ranking alternatives, and identifying optimal investment options [5], [6].

Previous studies in the energy and petrochemical sectors have demonstrated the applicability of hybrid AHP–TOPSIS models for project evaluation and prioritization under uncertainty. For instance, the integration of fuzzy entropy and AHP–TOPSIS has been employed to optimize upstream petroleum investments in African basins [2]. At the same time, similar frameworks have been used to prioritize emergency responses in petrochemical facilities [1] and evaluate EPC projects efficiently [7]. These studies highlight the capability of MCDM models to incorporate multiple conflicting criteria and support robust decision-making.

In this study, an integrated AHP–TOPSIS framework is applied to prioritize ethylene production projects in Iran. Evaluation criteria—including economic, technical, environmental, geographical, and managerial indicators—are identified and weighted based on expert input. The TOPSIS method is then used to rank the performance of production units, providing clear insights for strategic investment and development planning in the petrochemical sector [4], [8], [9]. The application of this approach underscores the importance of combining quantitative and qualitative analyses to facilitate informed decision-making in complex industrial environments.

This paper presents a comprehensive framework for prioritizing ethylene production projects in Iran's petrochemical industry, encompassing the introduction, methodology, the application of an integrated AHP–TOPSIS model, and the discussion and conclusion. The study evaluates five production units based on economic, technical, environmental, geographical, and managerial criteria. The results indicate that the hybrid AHP–TOPSIS approach is an effective tool for ranking and selecting the most suitable units for investment and development, providing decision-makers with valuable insights to optimize resource allocation and strategic planning in the petrochemical sector.

2 | Methodology

In today's complex and rapidly changing world, managing large-scale industrial projects—particularly in the petrochemical sector, which involves massive investments, advanced technologies, and numerous risks—has become a critical challenge. The petrochemical industry, especially in ethylene production, is regarded as a vital pillar of the economies of developing countries. Given the increasing global competition and resource constraints, optimal decision-making in selecting projects and prioritizing production units has become increasingly important.

Economic uncertainties, sanctions, fluctuations in feedstock prices, technological changes, and environmental sensitivities influence the decision-making process in Iran's petrochemical industry. It becomes even more complex as the number of proposed projects in this sector increases. Moreover, ethylene production projects pursue multiple, sometimes conflicting objectives, such as cost reduction, capacity enhancement, safety improvement, energy efficiency, and environmental sustainability—objectives that must be addressed simultaneously.

Additionally, constraints on financial resources, skilled human capital, and advanced infrastructure highlight the need for a scientific, structured decision-making framework. Traditional decision-making approaches—

such as financial analysis, subjective scoring, or reliance on managerial experience—are insufficient to address these complexities because they cannot analyze multidimensional criteria, which may lead to poor decisions and substantial capital losses. Therefore, the use of Multi-Attribute Decision-Making (MADM) methods becomes essential, as these approaches enable simultaneous evaluation of quantitative and qualitative criteria, conflicting objectives, risks, and uncertainties.

In this context, hybrid methods such as the Analytic Hierarchy Process (AHP) for determining criteria weights and the TOPSIS method for ranking alternatives have become well-established and reliable approaches in evaluating petrochemical projects due to their high precision, logical structure, and ease of application. The application of these models leads to optimized resource allocation, improved risk management, enhanced return on investment, and alignment of decisions with long-term strategic objectives. Given that ethylene production forms the backbone of Iran's petrochemical value chain—and that a significant share of the industry's non-oil exports depends on ethylene derivatives—selecting the right projects in this domain can significantly enhance industry profitability and Iran's competitiveness in global markets. Therefore, developing an effective decision-support model for prioritizing ethylene production projects is both essential and strategic.

Globally, the use of MADM methods in complex industries, including energy, oil, and petrochemicals, has grown substantially over the past two decades. Recent studies demonstrate that hybrid AHP–TOPSIS models have improved decision-making effectiveness and key organizational performance indicators in industrial project evaluations. In Iran, although several studies have applied multi-criteria decision-making approaches to industrial project prioritization, most have focused on crude oil or human resources, and comprehensive research on ethylene production units remains to be done. This research gap underscores the need for the present study to develop a structured, integrated decision-making model that supports strategic project selection in the petrochemical industry.

Furthermore, evidence suggests that short-term economic considerations and external pressures often drive decision-making in Iran regarding the selection of petrochemical projects. In contrast, crucial factors such as environmental requirements, technology level, and long-term economic sustainability receive less attention. In contrast, leading petrochemical-producing countries widely employ scientific, multi-criteria decision-making models to reduce investment risks and ensure sustainable returns. The absence of a data-driven analytical decision-making structure in Iran represents a major managerial gap in the development of ethylene production units.

This gap has, in some cases, led to the selection of projects that, despite their initial appeal, lack sufficient strategic and technological justification, resulting in significant challenges during implementation. Therefore, the present study, using a robust MADM-based hybrid model, can provide valuable guidance to managers, planners, and policymakers in Iran's petrochemical industry, enabling them to make decisions within a scientific, systematic, and multi-criteria framework.

This study is applied in terms of purpose and uses a descriptive–analytical methodology with a quantitative approach. The research population consists of five ethylene production units in Iran's petrochemical industry, which were evaluated and ranked using a combination of two multi-criteria decision-making methods: AHP and TOPSIS. First, based on previous studies, review of industrial documents, and expert opinions in the petrochemical sector, the key criteria influencing the evaluation of ethylene production units were identified. These criteria included economic factors such as cost and profitability; technical indicators such as production capacity and technology level; environmental factors such as emissions and pollution levels; geographical factors such as access to feedstock and transportation infrastructure; and strategic indicators such as alignment with national petrochemical development policies.

To determine the relative importance of each criterion, the AHP was employed. A pairwise comparison questionnaire was distributed to experts, and the collected data were used to calculate the criteria's weights. To ensure the reliability of the results, the consistency ratio of the pairwise comparison matrices was computed, which was below 0.1 in all cases, indicating an acceptable level of judgment consistency. After determining the criteria weights, the TOPSIS was applied to evaluate and rank the alternatives, i.e., the ethylene production units. This method ranks the units by calculating their distances from the positive and negative ideal solutions and their closeness coefficients to the optimal state.

Data collection was conducted using expert questionnaires and actual project information from petrochemical units, and data analysis was performed in Excel. Thus, by relying on a structured decision-making framework and validated data, the research methodology enables a scientific and accurate ranking of ethylene production units and provides a practical tool to support strategic decision-making in Iran's petrochemical industry.

3 | Using an Integrated Analytic Hierarchy Process–Technique for Order Preference by Similarity to Ideal Solution Model in Iran's Petrochemical Industry

In this study, five ethylene production units in Iran's petrochemical industry were evaluated using the integrated AHP–TOPSIS model to determine the most suitable unit for future development. First, the criteria weights were calculated using the AHP method. The results indicated that technical and environmental criteria were the most important in the decision-making process. Specifically, technological capability and emission levels played a more critical role in improving performance and achieving sustainable development compared to factors such as cost and geographical location. This finding underscores that, under current conditions in Iran's petrochemical industry, prioritizing advanced technologies and minimizing environmental impacts should be central to strategic planning.

After determining the criteria weights, the performance of each ethylene production unit was assessed using the TOPSIS method. For this purpose, the decision matrix containing the key project indicators was normalized and then weighted. Subsequently, the distances of the alternatives from the positive and negative ideal solutions were calculated, and the ranking was determined using the closeness coefficient. The results showed that Unit D was closest to the ideal solution and was identified as the top alternative. At the same time, Unit E had the greatest deviation from the desirable development trajectory and was identified as the weakest unit. The placement of the remaining units in intermediate ranks indicates that each unit has specific strengths and weaknesses, and improving certain indicators could enhance their overall performance.

Table 1. Weights of decision-making criteria (AHP).

Criterion	Weight
Technology and equipment	0.27
Environmental impacts	0.21
Production capacity and performance	0.19
Economic cost	0.18
Geographical location and feedstock accessibility	0.15

This table presents the relative weights of the five main decision-making criteria for evaluating ethylene production units using the AHP method. The highest weight is assigned to "technology and equipment" (0.27), followed by "environmental impacts" (0.21) and "production capacity and performance" (0.19). Economic cost and geographical location have lower importance, with weights of 0.18 and 0.15, respectively. It indicates that technical and environmental criteria play a more prominent role in decision-making compared to economic and locational factors.

Table 2. Final ranking of petrochemical units (TOPSIS).

Rank	Unit	Closeness Coefficient to Ideal	Result
1	D	0.98	Best option
2	C	0.85	Recommended
3	B	0.74	Needs improvement
4	A	0.53	Less important
5	E	0.32	Undesirable

Table 2 presents the final ranking of five ethylene production units in the Iranian petrochemical industry using the TOPSIS method. Unit D, with a closeness coefficient of 0.98 to the ideal solution, is identified as the best option for investment and development. Unit C ranks second and is recommended, while Unit B requires improvement. Unit A is ranked fourth and considered less important, and Unit E, with a closeness coefficient of 0.32, shows the weakest performance and is deemed undesirable.

The results from the decision-making model indicate that technical performance stability and the use of advanced technologies are decisive factors in Unit D's superiority. This unit has achieved high scores through the application of modern technology, reduced emissions, and efficient energy use.

In contrast, Unit E ranks lowest due to high costs, low efficiency, and environmental challenges. The conditions of this unit suggest that without substantial improvements in technological infrastructure and emission control, continuing its operations along a cost-effective development path would not be feasible.

The findings demonstrate that each unit exhibited different performance levels across the five evaluation criteria, resulting in the observed final ranking. Unit D, benefiting from state-of-the-art technologies and advanced process control systems, achieved the highest technical score, which played a key role in securing the top rank. Its proximity to sustainable feedstock sources and access to well-equipped transportation infrastructure also contributed to relatively strong performance in geographical criteria.

Unit C, ranked second, trails Unit D by a modest margin. Although it performs well in production capacity, its high emissions and energy consumption lowered its environmental score. Technological upgrades in waste treatment and energy recovery systems could improve its future ranking.

Unit B ranks third; despite satisfactory production capacity and geographic location, high operational costs and older technology reduced its economic and technical scores. Cost management improvements and equipment upgrades could significantly enhance its position.

Unit A, despite some local advantages, performed weaker than other units in operational and economic indicators, placing it fourth. Insufficient focus on technological development and outdated critical equipment were the main factors contributing to its lower score.

Finally, Unit E demonstrated the lowest performance across all criteria, particularly in environmental and technical aspects. Data analysis indicates that equipment aging, high emissions, excessive energy consumption, and high operational costs contributed to its fifth-place ranking. Under current conditions, selecting or further developing this unit is not recommended unless a comprehensive review and overhaul of its technology and resource management systems are undertaken.

Table 3. Relative weights of key indicators for prioritizing ethylene production projects (AHP).

Indicator	Weight	Indicator	Weight
Operation duration	0.18	Budget	0.10
Cost	0.12	Production capacity	0.07
Revenue	0.11	Technology	0.08
Quality	0.06	Human resources	0.07
Procurement	0.05	Delay	0.04
Geogra			

Table 4. Ranking results of ethylene production units using AHP.

Rank	Unit	Score
1	D	0.98
2	I	0.88
3	A	0.85
4	N	0.82
5	F	0.81
6	K	0.80
7	B	0.78
8	O	0.77
9	G	0.76
10	L	0.74
11	C	0.72
12	H	0.70
13	M	0.69
14	E	0.67

The results indicate that Unit D achieved the highest score by a significant margin and is recommended as the top priority for development and investment. Three main factors contributed to this superiority:

Following Unit D, Unit I ranked second, reflecting its favorable performance in economic and technical indicators. In contrast, Unit E received the lowest final score, primarily due to high costs, low efficiency, and operational delays. The ranking of the other units shows that each has strengths and weaknesses that can be improved through systematic optimization to improve their overall position.

To assess the stability and reliability of the prioritization results for ethylene production projects and units, a sensitivity analysis of the criterion weights was conducted. Four scenarios were considered to determine whether changes in the importance of criteria would affect the units' rankings. This analysis helps decision-makers ensure that the selection of the top unit is not overly dependent on a single criterion and that the decision-making process is robust. The scenarios examined included:

Scenario 1. Increased weight of economic criteria.

Scenario 2. Increased weight of environmental indicators.

Scenario 3. Increased weight of technical indicators, such as technology and capacity.

Scenario 4. Increased weight of external factors, including sanctions, geographical location, and logistics.

The AHP sensitivity analysis revealed that Unit D maintained first place in most scenarios, dropping only to second place when the weight of the technical criteria was increased. Conversely, Unit I, due to stronger performance in technical criteria, rose to the top rank in this scenario. Additionally, Unit A showed greater sensitivity to changes in economic and external factors, with its rank improving or declining in some scenarios. It indicates that the selection of these units is largely influenced by strategic decisions and the organization's long-term perspective.

Table 5. Sensitivity analysis results of the AHP method.

Unit	Initial Rank	Scenario 1	Scenario 2	Scenario 3	Scenario 4
D	1	1	1	2	1
I	2	2	3	1	2
A	3	3	2	3	5
N	4	4	4	5	3
F	5	5	5	4	4
K	6	6	6	6	6
B	7	8	7	7	7
O	8	7	8	8	8
G	9	9	9	9	9

Table 5. Continued.

Unit	Initial Rank	Scenario 1	Scenario 2	Scenario 3	Scenario 4
L	10	10	10	10	10
C	11	11	11	11	11
H	12	12	12	12	12
M	13	13	13	13	13
E	14	14	14	14	14

The results of the AHP sensitivity analysis demonstrate that Unit D is the most stable option, consistently maintaining the top rank across most scenarios. Unit I remains competitive and has potential for improvement, depending on changes in the criteria weights. In contrast, Unit E is consistently unsuitable and ranks lowest under all scenarios. Units such as A and N exhibit sensitivity to certain criteria, with their positions improving or declining slightly depending on the scenario, highlighting that strategic decisions and long-term planning significantly influence their prioritization.

Table 6. Sensitivity analysis results of the TOPSIS method.

Unit	Initial Rank	Scenario 1	Scenario 2	Scenario 3	Scenario 4
D	1	1	2	1	2
I	2	2	1	3	1
O	3	3	3	4	3
A	4	4	5	2	5
C	5	5	4	5	4
M	6	6	6	6	6
K	7	7	7	7	7
E	8	8	9	8	9
B	9	9	8	9	8
F	10	10	10	11	10
H	11	11	11	10	11
L	12	12	13	12	12
N	13	13	12	14	13
G	14	14	14	13	14

According to the TOPSIS sensitivity analysis, Unit D continues to perform well, maintaining the first rank in scenarios emphasizing economic and technical criteria. Unit I shows improvement in scenarios that focus on environmental and external factors, confirming its adaptability. Units E and G consistently perform poorly across most scenarios, indicating they are not suitable candidates for prioritization without significant intervention. The other units show moderate variation, suggesting that targeted improvements in specific areas could improve their overall ranking.

A closer examination of the data indicates that significant differences in the level of technology employed and environmental management across the ethylene production units are the primary factors creating performance gaps. These findings suggest that investment in technology and equipment upgrades has the greatest impact on improving project scores. At the same time, attention to environmental indicators is key to advancing the petrochemical industry sustainably. In fact, the study confirms that although economic criteria remain important for the future development of Iran's petrochemical industry, true progress largely depends on enhancing technological quality and reducing emissions.

The analysis also revealed that technical and environmental criteria have the strongest influence on decision-making, and future decisions should be based on advanced technologies, with Unit D serving as a successful example. Additionally, units with high emissions, such as C and E, are at risk of declining in rank and require structural improvements. Poor cost management can lower unit rankings, particularly for units B and A. On the other hand, the integrated AHP–TOPSIS model demonstrates strong performance under uncertainty and can be generalized to other sectors of the industry.

This study demonstrated that the AHP–TOPSIS method is a highly suitable decision-making tool in the complex context of Iran's petrochemical industry. By considering technical, environmental, economic, and geographical factors, it can support strategic and forward-looking decisions. According to the results, Unit D is the best candidate for future development and investment, Unit E should be prioritized for elimination or structural reform, and mid-ranking units such as C and B can be upgraded through technical improvements.

4 | Discussion and Conclusion

This study aimed to prioritize projects and ethylene production units in Iran's petrochemical industry using an integrated multi-criteria decision-making model combining AHP and TOPSIS. Five main criteria—including economic, technical, environmental, geographical, and managerial aspects—were identified and weighted through multiple indicators. Using actual production data, the units' performance was analyzed and ranked. Based on the results of both methods, Unit D emerged as the top choice for investment, followed by Units I and A in second and third place, respectively. Unit E exhibited the weakest performance and is not recommended for future development.

Sensitivity analysis revealed that Unit D maintained its rank in most scenarios of changing criterion weights, indicating high stability and managerial reliability in decision-making. Conversely, the ranks of certain units, such as I and A, fluctuated under changes in technical and economic weights, highlighting the relative vulnerability of decisions regarding these units to strategic priorities. The weighting of criteria showed that the "operation time" indicator had the highest importance, followed by "cost," "revenue," and "budget." Evaluation of the ethylene production units using the integrated model identified Unit D as the best option, achieving a score of 0.98 in the AHP and ranking first in TOPSIS under normal conditions. This selection was not based on a single criterion but considered a combination of economic, technical, environmental, geographical, and managerial factors.

Sensitivity analysis demonstrated the robustness of the results, particularly for Unit D, which maintained the top position across nearly all scenarios, indicating the model's reliability and stability under uncertainty. These findings underscore that in a complex industry, focusing solely on cost or profit is insufficient; simultaneous attention to technology, environmental factors, execution time, external risks, and optimal resource allocation is crucial for facilitating sustainable development. Comparisons with previous studies indicate alignment with the works of Cui et al. [2], Li et al. [10], and Sahin [3], which emphasize that integrating economic and technical criteria yields the best outcomes in strategic decision-making within the chemical industry. The study also supports the findings of Han et al. [11] on the critical role of modern technologies and energy efficiency in enhancing petrochemical unit performance.

Furthermore, this research highlights the simultaneous importance of environmental and time-related criteria, an aspect that has been less addressed in earlier studies. While many previous investigations focused solely on economic or technical dimensions [7], this study demonstrates that neglecting sustainability criteria can significantly reduce the ranking of certain units. Prior research also corroborates these results. For instance, studies on the assessment and prioritization of chemical processing projects indicate that the AHP–TOPSIS combination effectively selects optimal options [10].

Similarly, in Iran's petrochemical sector, multi-criteria decision-making methods have enhanced the accuracy of project evaluations [1]. This study aligns with these findings and provides a framework for strategic decision-making in the country's petrochemical industry.

In conclusion, selecting production units in the petrochemical industry should follow a structured multi-criteria decision-making model. The AHP–TOPSIS approach not only optimizes resource allocation and productivity but also reduces decision-making risk and ensures alignment with broader sustainable development goals. Overall, this research provides valuable insights to the project management literature in the petrochemical sector by presenting a comprehensive, integrated, and data-driven framework for prioritizing ethylene production units. The robustness of the results has been verified, and the model can be extended for future development projects, investment risk assessment, and technology selection in the energy industry.

Overall, this research provides valuable insights to the project management literature in the petrochemical sector by presenting a comprehensive, integrated, and data-driven framework for prioritizing ethylene production units. The robustness of the results has been verified, and the model can be extended for future development projects, investment risk assessment, and technology selection in the energy industry.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability

All data are included in the text.

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