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Presenting an Integrated Quasi-Data Envelopment Analysis Model Based on Fuzzy Goal Programming for Performance Evaluation of Iran's Petrochemical Industries

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A B S T R A C T

The importance of the petrochemical industry as a dynamic and leading sector in the economies of countries producing these products is undeniable. According to experts, this industry generates an added value approximately ten to thirty times greater than that obtained from the export of crude oil and natural gas. Nevertheless, examining the optimal combination of input factors in these industries, including raw materials and feedstock consumption, human resources, and investment costs, in order to achieve optimal production and, in summary, to evaluate the efficiency of these industries in the country, is an issue that has not yet been comprehensively assessed. The present study was conducted with the aim of presenting an integrated quasi-data envelopment analysis model based on fuzzy goal programming for evaluating the performance of Iran's petrochemical industries. To achieve this objective, four research questions and subsidiary objectives were investigated. This study is applied and descriptive in nature, and the statistical population consisted of petrochemical companies located in Assaluyeh, Iran. The data collection instruments used in this study included documents and records, interviews, and questionnaires. Based on the results obtained from the interviews (qualitative research for identifying efficiency indicators from the perspective of data envelopment analysis), as well as questionnaires and documents (quantitative research for obtaining cost, time, profit, production, and related data), the statistical sample size comprised 43 participants. Confirmatory factor analysis was employed as the analytical tool for interview results, and the findings indicated appropriate validity and reliability of the measurement model for the identified indicators. The mathematical model of quasi-data envelopment analysis and fuzzy goal programming was designed and solved. Based on the results, twenty-two petrochemical companies were evaluated in terms of efficiency, ranked according to performance and efficiency, and their deviations from predetermined goals were identified. The proposed model was also validated, and practical recommendations were presented at the conclusion of the study.

Keywords: *Quasi-Data Envelopment Analysis, Fuzzy Goal Programming, Petrochemical Industries*

1. Introduction

The petrochemical industry is recognized as one of the most strategic and value-generating sectors in modern economies due to its critical role in industrial development, employment generation, export diversification, and sustainable economic growth. The increasing complexity of global markets, rapid technological transformation, environmental challenges, and heightened international competition have intensified the necessity of evaluating and improving organizational performance in industrial sectors, particularly in petrochemical industries. In recent years, researchers and practitioners have increasingly emphasized the importance of applying advanced mathematical and decision-making models to optimize industrial performance, improve operational efficiency, and enhance organizational competitiveness under uncertain and dynamic environments (Agrawal et al., 2025; Yao et al., 2024). Petrochemical industries are inherently capital-intensive and involve complicated interactions among production processes, financial resources, energy consumption, environmental impacts, and human resource management. Consequently, traditional evaluation methods are often insufficient for accurately measuring organizational efficiency and performance in such multifaceted environments. Therefore, the integration of intelligent quantitative approaches with uncertainty-based decision-making techniques has become a significant research priority in industrial management and operations research (Shojaie et al., 2024; Wang et al., 2024).

Performance evaluation has long been considered one of the most fundamental managerial functions because it enables organizations to identify operational weaknesses, allocate resources more efficiently, improve productivity, and develop strategic improvement programs. In industrial systems, especially in petrochemical complexes, performance assessment plays a crucial role in determining the extent to which organizational resources are transformed into valuable outputs. The multidimensional nature of performance in petrochemical companies necessitates the simultaneous consideration of multiple inputs and outputs, including production costs, energy consumption, labor force, operational capacity, customer satisfaction, environmental performance, production volume, and profitability. In this regard, data envelopment analysis (DEA) has emerged as one of the most widely used approaches for evaluating the relative efficiency of decision-making units under multiple input–output structures (Gupta et al., 2024; Özdağoğlu et al., 2024).

DEA is a non-parametric mathematical programming technique that evaluates the efficiency of homogeneous decision-making units by comparing weighted combinations of inputs and outputs. One of the primary advantages of DEA is its capability to analyze systems with multiple and heterogeneous variables without requiring predetermined functional relationships between inputs and outputs. This characteristic has significantly contributed to its extensive application in manufacturing systems, logistics, healthcare systems, supply chain management, and industrial performance evaluation (Abdallah et al., 2024; Ecer, 2024). However, despite the substantial advantages of DEA models, conventional DEA approaches face important limitations when dealing with uncertain, ambiguous, or imprecise data. In real-world industrial systems, many operational variables are inherently fuzzy due to subjective judgments, incomplete information, fluctuating operational conditions, and dynamic market environments. Consequently, classical DEA models may fail to adequately capture the uncertain nature of industrial decision-making environments (Ulutaş et al., 2023; Zuluaga-Ortiz et al., 2023).

To address uncertainty and vagueness in organizational evaluation processes, fuzzy set theory has been increasingly integrated with DEA and multi-criteria decision-making methods. Fuzzy approaches enable researchers to model ambiguous information and linguistic judgments more effectively by transforming uncertain variables into fuzzy numbers and membership functions. The integration of fuzzy logic with DEA has significantly improved the realism and applicability of efficiency evaluation models in complex industrial systems (Noruzi et al., 2023; Regragui et al., 2023). In recent years, fuzzy DEA models have been widely employed in sustainability assessment, supplier selection, transportation systems, healthcare management, and manufacturing optimization. These models provide more flexible and realistic evaluation frameworks by incorporating uncertainty into both input and output variables (Keshavarz-Ghorabaee, 2023; Lee & Kang, 2023).

Simultaneously, the growing complexity of industrial decision-making has increased the importance of multi-objective optimization methods capable of handling conflicting managerial goals. Organizations frequently seek to optimize multiple objectives simultaneously, such as minimizing costs, maximizing production quality, improving customer satisfaction, reducing environmental impacts, and enhancing operational flexibility. Goal programming has emerged as one of the most effective techniques for solving multi-objective optimization problems because it enables decision-makers to minimize deviations from predefined organizational goals (Harale et al., 2023; Hariri et al., 2023). Goal programming models have demonstrated significant applicability in production planning, resource allocation, supply chain optimization, logistics management, and strategic industrial planning.

Among the various forms of goal programming, fuzzy goal programming has gained substantial attention due to its ability to incorporate uncertainty and human judgment into optimization processes. In fuzzy goal programming, aspiration levels and constraints can be represented using fuzzy numbers, allowing decision-makers to deal more effectively with uncertain operational conditions and subjective managerial preferences. This approach has proven particularly valuable in industrial systems characterized by incomplete information, uncertain market conditions, and dynamic operational environments (Deepika et al., 2023; Duc et al., 2023). Researchers have increasingly combined fuzzy goal programming with DEA and multi-criteria decision-making approaches to develop more robust and realistic performance evaluation frameworks capable of addressing uncertainty and multiple objectives simultaneously (Akhtar et al., 2023; Yazdani et al., 2022).

The integration of fuzzy DEA and fuzzy goal programming has become an emerging area of research in operations management and industrial engineering. Hybrid models combining these methodologies can simultaneously evaluate efficiency, prioritize organizational objectives, and optimize resource allocation under uncertain conditions. Such integrated frameworks provide decision-makers with comprehensive analytical tools for evaluating organizational performance while considering uncertainty, multiple criteria, and strategic organizational goals (Omrani, Emrouznejad, et al., 2022; Omrani, Fahimi, et al., 2022). In recent years, hybrid fuzzy optimization approaches have been increasingly adopted in manufacturing systems, green supply chains, sustainable production planning, and industrial resource management due to their superior capability to handle complex real-world problems (Khattak et al., 2022; Lavanpriya et al., 2022).

The emergence of Industry 4.0 technologies has further increased the necessity of advanced performance evaluation systems in manufacturing and petrochemical industries. Digital transformation, automation, artificial intelligence, smart manufacturing, and data-driven decision-making have significantly altered industrial operational structures and performance expectations. Modern industrial systems generate massive volumes of operational data that require sophisticated analytical tools for performance assessment and strategic decision-making (Ali et al., 2022; Kao, 2022). Moreover, sustainable industrial development has become a major strategic priority for organizations worldwide, particularly in environmentally sensitive industries such as petrochemicals. Consequently, performance evaluation frameworks must increasingly integrate economic, operational, environmental, and social dimensions into unified decision-making models (Yazdani et al., 2021; Zarte et al., 2021).

Sustainability considerations have substantially reshaped the evaluation criteria used in industrial performance assessment. Contemporary organizations are no longer evaluated solely based on financial profitability; instead, dimensions such as environmental sustainability, operational resilience, energy efficiency, waste reduction, and social responsibility are also considered critical determinants of organizational success. Researchers have therefore emphasized the importance of sustainable and resilient evaluation frameworks capable of balancing economic efficiency with environmental and social performance indicators (Thu et al., 2021; Tırkolaee et al., 2021). In petrochemical industries, where environmental impacts and energy consumption are highly significant, integrating sustainability considerations into efficiency evaluation models has become increasingly necessary.

In addition, uncertainty management has become one of the central challenges in industrial operations and strategic management. Fluctuating energy prices, geopolitical instability, supply chain disruptions, environmental regulations, technological uncertainty, and market volatility continuously influence the operational efficiency of petrochemical industries. Traditional deterministic models are often unable to adequately address such uncertainties. Therefore, fuzzy-based optimization and evaluation methods provide valuable alternatives for handling uncertainty in industrial decision-making processes (Nabizadeh et al., 2021; Pang et al., 2021). The flexibility of fuzzy approaches allows organizations to model uncertain parameters more realistically and develop adaptive strategic responses under dynamic operational conditions.

Despite the extensive development of DEA, fuzzy logic, and goal programming methodologies in recent years, significant research gaps remain regarding the integrated application of these approaches in petrochemical industries, particularly within developing economies. Most existing studies have focused on supplier selection, logistics optimization, sustainability assessment, and manufacturing systems, while relatively limited attention has been devoted to developing integrated fuzzy DEA and fuzzy goal programming frameworks for evaluating the performance of petrochemical companies. Furthermore, many previous studies have employed conventional DEA models without adequately considering uncertainty, fuzziness, and multi-objective strategic goals simultaneously. Consequently, there remains a substantial need for comprehensive integrated models capable of evaluating petrochemical industry performance under uncertain operational environments while incorporating multiple organizational objectives.

Iran possesses one of the world's largest petrochemical industries due to its extensive oil and gas reserves and strategic geographical position. The petrochemical sector plays a pivotal role in Iran's industrial development, export revenues, and economic diversification. Nevertheless, Iranian petrochemical companies face numerous managerial and operational challenges, including technological limitations, resource allocation inefficiencies, international sanctions, environmental concerns, fluctuating market conditions, and increasing global competition. Therefore, improving operational efficiency and developing advanced performance evaluation frameworks have become critical strategic priorities for this industry. The implementation of integrated fuzzy DEA and fuzzy goal programming models can provide petrochemical managers with valuable analytical insights for identifying inefficiencies, optimizing resource utilization, reducing operational deviations, and improving organizational competitiveness.

Moreover, the complexity of petrochemical production systems necessitates the use of sophisticated decision-support tools capable of evaluating organizational performance across multiple dimensions simultaneously. Input variables such as labor force, operational costs, energy consumption, maintenance expenditures, and production resources interact dynamically with output variables such as production volume, profitability, customer satisfaction, operational reliability, and environmental performance. Traditional single-dimensional evaluation methods cannot adequately capture these intricate interrelationships. Therefore, integrated fuzzy mathematical programming approaches provide more comprehensive and realistic frameworks for industrial performance evaluation (Agrawal et al., 2025; Shojaie et al., 2024).

Another important issue concerns the practical applicability of integrated performance evaluation models. Decision-makers in industrial environments require models that are not only theoretically rigorous but also operationally implementable within real organizational settings. Hybrid fuzzy DEA and fuzzy goal programming models offer practical advantages by enabling managers to evaluate performance under uncertainty, identify optimal operational targets, and quantify deviations from organizational goals. These capabilities are particularly valuable in petrochemical industries where operational decisions directly affect profitability, safety, environmental sustainability, and market competitiveness (Gupta et al., 2024; Omrani, Emrouznejad, et al., 2022).

Furthermore, the integration of fuzzy approaches with DEA contributes to improving the discriminatory power of traditional efficiency models. One criticism frequently directed at classical DEA models concerns their limited ability to discriminate effectively among highly efficient decision-making units. By incorporating fuzzy logic and goal programming mechanisms, researchers can improve model flexibility, reduce ambiguity in efficiency rankings, and generate more robust comparative evaluations among organizations (Ecer, 2024; Keshavarz-Ghorabaee, 2023). Such improvements are particularly important in industries where managerial decisions rely heavily on accurate performance rankings and operational benchmarking.

Recent studies have also highlighted the growing importance of hybrid multi-criteria decision-making approaches in industrial management. Integrating DEA, fuzzy logic, goal programming, and sustainability indicators enables organizations to simultaneously address efficiency, uncertainty, strategic priorities, and sustainability objectives within unified analytical frameworks. Such integrated approaches are increasingly regarded as essential tools for modern industrial management under uncertain and dynamic environments (Hariri et al., 2023; Yazdani et al., 2021). Accordingly, the development of integrated fuzzy quasi-data envelopment analysis models based on fuzzy goal programming can significantly contribute to advancing both theoretical knowledge and practical industrial management applications.

Given the strategic importance of petrochemical industries, the growing complexity of industrial operations, the limitations of traditional efficiency evaluation methods, and the increasing necessity of uncertainty-based multi-objective decision-making models, the present study aimed to develop an integrated quasi-data envelopment analysis model based on fuzzy goal programming for evaluating the performance of Iran's petrochemical industries.

2. Methods and Materials

This study is developmental and applied in terms of purpose. In this research, the effective performance variables of the petrochemical industry were identified, and the required framework was developed through the integration of the quasi-data envelopment analysis approach based on fuzzy goal programming in order to calculate efficiency levels. Considering the nature, objectives, number, and type of variables examined in the present study, the research method is descriptive and survey-based, since the objective of the researcher was to describe the various indicators affecting performance and efficiency. In terms of the investigation method, the study is analytical–mathematical; statistically, it is model-based; and regarding the data collection procedure, it is an empirical study grounded in the analysis of information gathered from the target statistical population. The data collection method and the selected research methodology are applied in terms of objective, field-based in terms of data collection procedure, and descriptive–survey in terms of the degree of control over variables. In order to cover the theoretical foundations of the study, specialized and general books, scientific articles, and academic journals were reviewed. Furthermore, interviews and questionnaires were used to collect data for identifying indicators, while financial, production, commercial, and related records of petrochemical companies located in Assaluyeh were utilized for efficiency calculations.

In summary, the following methods were employed for data collection in this study:

Library Studies: The theoretical foundations and literature of the research were developed through the review of books, domestic and international journals, and topics related to petrochemical performance indicators, as well as the extraction of relevant articles from scientific databases and websites.

Interviews and Questionnaires: In order to examine expert and scientific perspectives for identifying performance indicators (inputs and outputs), interviews were initially conducted, followed by the use of a weighted questionnaire analyzed through factor analysis (Questionnaire No. 1).

Documents and Records: Financial, production, commercial, and related records of petrochemical companies located in Assaluyeh were also utilized for performance evaluation and efficiency calculation.

The statistical population and sample for the data required for factor analysis and inferential statistics included chief executive officers, senior managers, heads of financial, production, maintenance, commercial, and quality control departments of petrochemical companies located in Assaluyeh. (At the request of industry managers, company names were anonymized and labeled with letters from *a* to *e*.) These experts possessed at least a bachelor's degree and a minimum of three years of relevant work experience. Accordingly, the statistical sample was selected from this population based on Cochran's formula. In principle, the number of decision-making units (i.e., companies) required for data envelopment analysis should exceed five units; however, due to restrictions in access to documentary and archival data, only five companies were included. This arrangement was approved under the conditions that, first, all data would remain confidential, and second, a constant value would be subtracted from all data points to preserve confidentiality while ensuring that this adjustment would not affect the final results.

Since the data collection instruments in this study consisted of interviews, questionnaires, and documents and records, and because only managers and experts actively engaged in petrochemical production activities were included, with the population size considered indefinite, Cochran's formula for an unlimited population was employed.

$$n = \frac{Z^2 S^2}{d^2}$$

In this formula, the most important parameter requiring estimation is S^2, which represents the variance of the preliminary sample. To calculate S^2, a number of questionnaires were distributed and the variance of the preliminary sample was computed. The value of $Z^2$is a constant dependent on the confidence interval and error level (α). Typically, an error level of 5%or 1%is considered. For example, if the error level or significance level is assumed to be 5%, the confidence level will be 95%. Accordingly, based on statistical tables, the value of Zequals 1.96. The value of $d$was likewise considered equal to 0.05. Based on the above formula, the sample size for interviews and questionnaires was determined to be 43 participants.

After collecting data through structured interviews, documents and records, and questionnaires, the data were first coded and subsequently analyzed using PLS software (for factor analysis), LINGO and MATLAB software packages (for solving the FDP and FDEA models), and SPSS software for inferential statistics, graphical analysis, and model validation. The face validity and content validity of the semi-structured interviews and questionnaires, as well as the reliability of the questionnaire, were examined and confirmed.

3. Findings and Results

Calculating efficiency and evaluating the performance of petrochemical industries using mathematical models is of great importance. This issue is considered for several reasons, including productivity improvement, cost reduction, profitability enhancement, and the promotion of competitiveness in domestic and international markets.

The statistical population of this study, from the perspective of quantitative and documentary data, consisted of twenty-two petrochemical product manufacturing companies located in Assaluyeh, Iran. From the perspective of the qualitative research, it included 43 managers, experts, and engineers working in these industries who responded to the designed questions, including semi-structured interviews and questionnaires, regarding the identification of efficiency indicators and other fuzzy data required to solve the mathematical model of the study. Of the respondents, 18% were female and 82% were male. This indicates that most individuals in the sample were men. The results showed that, in terms of age, 7% of respondents were between 25 and 35 years old, 65% were between 35 and 45 years old, and 28% were over 45 years old. Most respondents were between 35 and 45 years old, with a mean age of 40.13, a standard deviation of 6.69, and an age coefficient of variation of $CV = 0.17$, indicating normality and low dispersion among respondents' ages. In terms of work experience, 12% had less than 10 years, 58% had 10 to 20 years, and 30% had more than 20 years of work experience. Accordingly, it appears that more than 60% of individuals in the selected sample had more than 20 years of work experience. This indicates that the participants had the necessary experience to contribute to the study. Based on the defined educational criterion, 23% held bachelor's degrees, 67% held master's degrees, and 10% held doctoral degrees. In terms of organizational position, 27% of respondents were experts, 26% were senior experts, 12% were technical personnel, 10% were financial personnel, 7% were department heads, 16% were production managers, and 2% held other positions.

Based on the Kolmogorov–Smirnov test, all data related to the identified input and output indicators were normally distributed, given that the significance levels of all variables were above 0.05. Since factor analysis was used to identify the utility indicators of emergency services, it was necessary to conduct a sampling adequacy test. One method for assessing the appropriateness of sample size for factor analysis is the Kaiser–Meyer–Olkin (KMO)index and Bartlett's test. The range of the KMOindex is between 0 and 1; the closer the value is to 1, the more suitable the data are for factor analysis. The minimum acceptable value recommended for this index is 0.60. The KMOvalues for all variables were above 0.60, and the significance level of Bartlett's test was below 0.05. Therefore, it can be concluded that the research data were suitable for factor analysis.

The purpose of evaluating the measurement model is to examine the relationships between observed variables, namely questionnaire items, and latent variables. In the variance-based approach, evaluation of the measurement model includes two components: validity and reliability. The validity of the measurement model includes convergent validity, assessed through the average variance extracted, while reliability includes unidimensional reliability, assessed through factor loadings, and internal consistency, assessed through Cronbach's alpha and composite reliability.

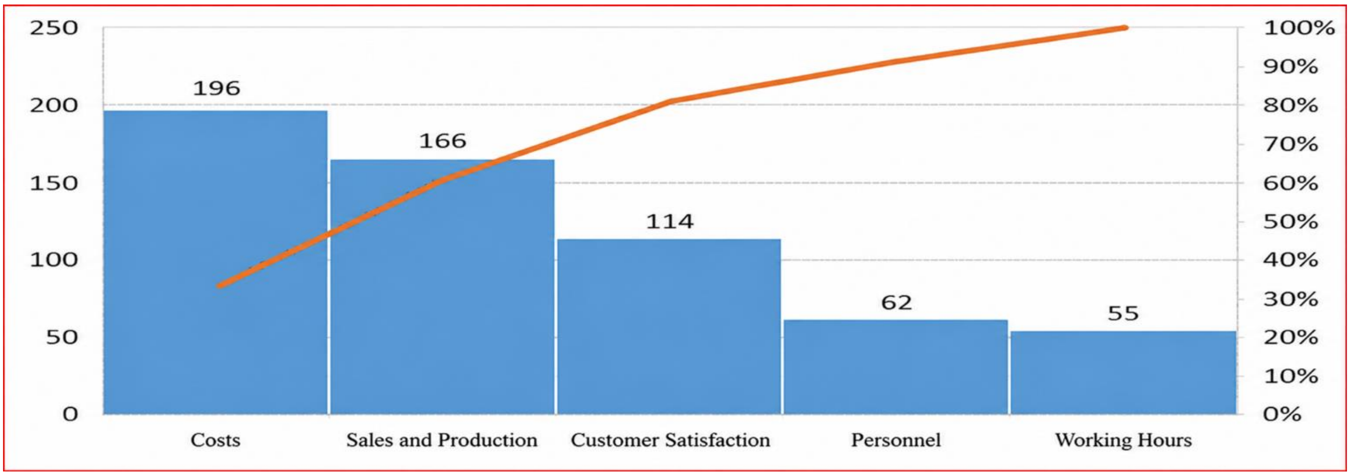
Since the AVEvalue for all construct variables was greater than 0.50, convergent validity was confirmed for these constructs. Moreover, since the $CR$and alpha values were greater than 0.70, composite reliability was also confirmed. In addition, because all factor loadings for the items were greater than 0.40, it can be concluded that all items related to the five constructs, including sales and production indicators, cost-related indicators, customer satisfaction indicators, working-hours indicators, and personnel-number indicators, had appropriate factor analysis results, and all items were confirmed.

The purpose of evaluating the structural model is to examine the quality of fit between the theories and the research data.

To examine the significance of the items and generated categories, and to determine whether the items developed based on the questionnaires were statistically significant in the examined sample, the Student's t-test was used. All main themes extracted from the interviews were confirmed in the statistical analysis. Therefore, the identified components, dimensions, and indicators were also influential in the examined sample in relation to the criteria for calculating the performance efficiency of the petrochemical companies in the statistical sample. Diagram 1 presents an overview of the extracted main themes.

Figure 1

Thematic Distribution



As observed, the highest indicator weight was assigned to costs with 196 points (33%), followed by sales and production with 166 points (28%), customer satisfaction with 114 points (19%), personnel with 62 points (10%), and working hours with 55 points (10%). At this stage, in order to weight the factors and classify each efficiency indicator and the data required for the model, a 15-item questionnaire based on triangular fuzzy distribution was designed and administered to the 43-member statistical sample.

Efficiency calculation of companies using the fuzzy quasi-data envelopment analysis method:

$$u = 30u_1 + 31u_2 + 1.5u_3 + 8u_4 + 4.85u_5 + 9u_6$$

Subject to:

$$1v_1 + 0.2v_2 + 30v_3 + 0.02v_4 + 0.02v_5 + 0.02v_6 \geq 0.567$$

$$16v_1 - 3.1v_2 - 160v_3 - 0.22v_4 - 0.12v_5 - 0.21v_6 - (1 - 0.9)(1v_1 + 0.2v_2 + 30v_3 + 0.02v_4 + 0.02v_5 + 0.02v_6) = 1 - (1 - 0.9) \times 0.122$$

$$16v_1 - 3.1v_2 + 160v_3 + 0.22v_4 + 0.12v_5 + 0.21v_6 + (1 - 0.9)(1v_1 - 0.2v_2 - 30v_3 - 0.02v_4 - 0.02v_5 - 0.02v_6) = 1 + (1 - 0.9) \times 0.122$$

$$30u_1 - 31u_2 - 1.5u_3 - 8u_4 - 4.85u_5 - 9u_6 \leq 16v_1 - 3.1v_2 - 160v_3 - 0.22v_4 - 0.12v_5 - 0.21v_6 - (1 - 0.9)(1v_1 + 0.2v_2 + 30v_3 + 0.02v_4 + 0.02v_5 + 0.02v_6)$$

$$30u_1 + 31u_2 + 1.5u_3 + 8u_4 + 4.85u_5 + 9u_6 \leq 16v_1 + 3.1v_2 + 160v_3 + 0.22v_4 + 0.12v_5 + 0.21v_6 + (1 - 0.9)(1v_1 + 0.2v_2 + 30v_3 + 0.02v_4 + 0.02v_5 + 0.02v_6)$$

$$30u_1 - 26u_2 - 1.2u_3 - 8u_4 - 4.34u_5 - 9u_6 \leq 19v_1 - 3.2v_2 - 120v_3 - 0.22v_4 - 0.12v_5 - 0.22v_6 - (1 - 0.9)(1v_1 + 0.2v_2 + 20v_3 + 0.02v_4 + 0.01v_5 + 0.04v_6)$$

$$30u_1 + 26u_2 + 1.2u_3 + 8u_4 + 4.34u_5 + 9u_6 \leq 19v_1 + 3.2v_2 + 120v_3 + 0.22v_4 + 0.12v_5 + 0.22v_6 + (1 - 0.9)(1v_1 + 0.2v_2 + 20v_3 + 0.02v_4 + 0.01v_5 + 0.04v_6)$$

$$33u_1 - 33u_2 - 2.2u_3 - 8u_4 - 4.8u_5 - 9u_6 \leq 21v_1 - 31v_2 - 125v_3 - 0.26v_4 - 0.14v_5 - 0.03v_6 - (1 - 0.9)(2v_1 + 0.2v_2 + 20v_3 + 0.03v_4 + 0.04v_5 + 0.03v_6)$$

$$33u_1 + 33u_2 + 2.2u_3 + 8u_4 + 4.8u_5 + 9u_6 \leq 21v_1 + 31v_2 + 125v_3 + 0.26v_4 + 0.14v_5 + 0.03v_6 + (1 - 0.9)(2v_1 + 0.2v_2 + 20v_3 + 0.03v_4 + 0.04v_5 + 0.03v_6)$$

$$29u_1 - 32u_2 - 0.12u_3 - 8u_4 - 4.7u_5 - 9u_6 \leq 18v_1 - 3.4v_2 - 120v_3 - 0.22v_4 - 0.13v_5 - 0.22v_6 - (1 - 0.9)(2v_1 + 0.2v_2 + 30v_3 + 0.01v_4 + 0.02v_5 + 0.02v_6)$$

$$29u_1 + 32u_2 + 0.12u_3 + 8u_4 + 4.7u_5 + 9u_6 \le 18v_1 + 3.4v_2 + 120v_3 + 0.22v_4 + 0.13v_5 + 0.22v_6 + (1 - 0.9)(2v_1 + 0.2v_2 + 30v_3 + 0.01v_4 + 0.02v_5 + 0.02v_6)$$

$$32u_1 - 30u_2 - 0.8u_3 - 9u_4 - 5.3u_5 - 9u_6 \le 19v_1 - 3v_2 - 130v_3 - 0.24v_4 - 0.15v_5 - 0.24v_6 - (1 - 0.9)(2v_1 + 0.3v_2 + 30v_3 + 0.02v_4 + 0.01v_5 + 0.02v_6)$$

$$32u_1 + 30u_2 + 0.8u_3 + 9u_4 + 5.3u_5 + 9u_6 \le 19v_1 + 3v_2 + 130v_3 + 0.24v_4 + 0.15v_5 + 0.24v_6 + (1 - 0.9)(2v_1 + 0.3v_2 + 30v_3 + 0.02v_4 + 0.01v_5 + 0.02v_6)$$

$$u_1, u_2, u_3, u_4, u_5, u_6, v_1, v_2, v_3, v_4, v_5, v_6 \ge 0$$

The linear programming model was solved using LINGO software for all twenty-two petrochemical companies at the confidence level of 0.90. Table 2 shows the calculated efficiency values for five decision-making units at the confidence level of 0.90. These values are asymmetric triangular fuzzy numbers. The middle number indicates the center of the fuzzy number, the right-hand number indicates the right-side spread, and the left-hand number indicates the left-side spread of the fuzzy number.

Table 1

Defuzzified Efficiency Using the Fuzzy Quasi-Data Envelopment Analysis Model

Decision-Making Unit DMU_i	Fuzzy Efficiency	Fuzzy Efficiency Rank
1	(0.0417، 0.9752، 0.0512)	3
2	(0.0358، 0.9707، 0.0331)	4
3	(0.0311، 0.9818، 0.0335)	1
4	(0.0151، 0.9606، 0.0238)	8
5	(0.0363، 0.9777، 0.0430)	2
6	(0.0069، 0.7391، 0.0129)	22
7	(0.0088، 0.9207، 0.0196)	11
8	(0.0255، 0.9418، 0.0311)	10
9	(0.0143، 0.9546، 0.0221)	9
10	(0.0167، 0.9091، 0.0229)	12
11	(0.0122، 0.7404، 0.0301)	21
12	(0.0125، 0.8818، 0.0222)	14
13	(0.0044، 0.8866، 0.0154)	13
14	(0.0267، 0.8491، 0.0409)	15
15	(0.0128، 0.7901، 0.0292)	18
16	(0.0055، 0.8331، 0.0142)	16
17	(0.0051، 0.7566، 0.0200)	20
18	(0.0347، 0.9612، 0.0401)	7
19	(0.0118، 0.7607، 0.0222)	19
20	(0.0255، 0.9618، 0.0312)	6
21	(0.0181، 0.9638، 0.0231)	5
22	(0.0174، 0.8054، 0.0320)	17

Table 2

Ranking of Decision-Making Units Using the Fuzzy Quasi-Data Envelopment Analysis Model

Decision-Making Unit DMU_i	Name of Decision-Making Unit	Fuzzy Efficiency Rank
1	a	3
2	b	4
3	c	1
4	d	8
5	e	2

6	f	22
7	g	11
8	h	10
9	i	9
10	j	12
11	k	21
12	l	14
13	m	13
14	n	15
15	o	18
16	p	16
17	q	20
18	r	7
19	s	19
20	t	6
21	u	5
22	v	17

Using the above relationships and defuzzification through the mean method, the ranking of decision-making units, namely petrochemical companies, was performed as shown in Table 3. The superiority of one company over another in the above table indicates that one petrochemical company outperformed another. For example, the superiority of petrochemical company $a$over petrochemical company $c$indicates that the key petrochemical company a, compared with company c, had a superior ratio of output indicators to input indicators. Accordingly, in terms of efficiency, petrochemical companies a, e, d, b, and $c$ranked first to fifth. To evaluate the performance of the twenty-two petrochemical companies, calculate their efficiency scores, minimize their negative deviations, and maximize their positive deviations, the following integrated model of quasi-data envelopment analysis and fuzzy goal programming was used.

$$\min Z = P_1 d_1^+ + P_2 d_2^+ + P_3 d_3^+ + P_4 d_4^+ + P_5 d_5^+ + P_6 d_6^+ + P_7 d_7^+ + P_8 d_8^+ + P_9 d_9^+ + P_{10} d_{10}^+ + P_{11} d_{11}^+ + P_{12} d_{12}^+ + P_{13} d_{13}^+ + P_{14} d_{14}^+ + P_{15} d_{15}^+ + P_{16} d_{16}^+ + P_{17} d_{17}^+ + P_{18} d_{18}^+ + P_{19} d_{19}^+ + P_{20} d_{20}^+ + P_{21} d_{21}^+ + P_{22} d_{22}^+$$

Subject to:

$$0.975 + d_1^- + d_1^+ = 1$$
$$0.970 + d_2^- + d_2^+ = 1$$
$$0.981 + d_3^- + d_3^+ = 1$$
$$0.960 + d_4^- + d_4^+ = 1$$
$$0.977 + d_5^- + d_5^+ = 1$$
$$0.739 + d_6^- + d_6^+ = 1$$
$$0.920 + d_7^- + d_7^+ = 1$$
$$0.941 + d_8^- + d_8^+ = 1$$
$$0.954 + d_9^- + d_9^+ = 1$$
$$0.909 + d_{10}^- + d_{10}^+ = 1$$
$$0.740 + d_{11}^- + d_{11}^+ = 1$$
$$0.881 + d_{12}^- + d_{12}^+ = 1$$
$$0.886 + d_{13}^- + d_{13}^+ = 1$$
$$0.849 + d_{14}^- + d_{14}^+ = 1$$
$$0.790 + d_{15}^- + d_{15}^+ = 1$$
$$0.833 + d_{16}^- + d_{16}^+ = 1$$
$$0.756 + d_{17}^- + d_{17}^+ = 1$$
$$0.961 + d_{18}^- + d_{18}^+ = 1$$
$$0.760 + d_{19}^- + d_{19}^+ = 1$$
$$0.961 + d_{20}^- + d_{20}^+ = 1$$
$$0.963 + d_{21}^- + d_{21}^+ = 1$$
$$0.805 + d_{22}^- + d_{22}^+ = 1$$

$$(30u_1 + 31u_2 + 1.5u_3 + 8u_4 + 4.85u_5 + 9u_6) - (16v_1 + 3.1v_2 + 160v_3 + 0.22v_4 + 0.12v_5 + 0.21v_6) \leq 0$$

$$(30u_1 + 26u_2 + 1.2u_3 + 8u_4 + 4.35u_5 + 9u_6) - (19v_1 + 3.2v_2 + 120v_3 + 0.22v_4 + 0.12v_5 + 0.22v_6) \leq 0$$

$$(33u_1 + 33u_2 + 2.2u_3 + 8u_4 + 4.8u_5 + 9u_6) - (21v_1 + 31v_2 + 125v_3 + 0.26v_4 + 0.14v_5 + 0.03v_6) \leq 0$$

$$(29u_1 + 32u_2 + 0.12u_3 + 8u_4 + 4.7u_5 + 9u_6) - (18v_1 + 3.4v_2 + 120v_3 + 0.22v_4 + 0.13v_5 + 0.22v_6) \leq 0$$

$$(32u_1 + 30u_2 + 0.8u_3 + 9u_4 + 5.3u_5 + 9u_6) - (19v_1 + 3v_2 + 130v_3 + 0.24v_4 + 0.15v_5 + 0.24v_6) \leq 0$$

$$(27u_1 + 33u_2 + 1.2u_3 + 8u_4 + 4.5u_5 + 9u_6) - (18v_1 + 3.1v_2 + 130v_3 + 0.23v_4 + 0.12v_5 + 0.19v_6) \leq 0$$

$$(30u_1 + 29u_2 + 1.1u_3 + 7u_4 + 4.4u_5 + 9u_6) - (19v_1 + 3.2v_2 + 100v_3 + 0.21v_4 + 0.11v_5 + 0.16v_6) \leq 0$$

$$(32u_1 + 31u_2 + 1.8u_3 + 8u_4 - 4u_5 + 9u_6) - (17v_1 - 3.1v_2 + 120v_3 + 0.26v_4 + 0.12v_5 + 0.21v_6) \leq 0$$

$$(25u_1 + 22u_2 + 0.11u_3 + 6u_4 + 4u_5 + 9u_6) - (17v_1 + 3.4v_2 + 95v_3 + 0.24v_4 + 0.15v_5 + 0.12v_6) \leq 0$$

$$(29u_1 + 30u_2 - 0.6u_3 + 11u_4 + 5.1u_5 + 9u_6) - (17v_1 + 5v_2 + 122v_3 + 0.21v_4 + 0.15v_5 + 0.26v_6) \leq 0$$

$$(22u_1 + 21u_2 + 0.13u_3 + 6u_4 + 4u_5 + 9u_6) - (16v_1 + 3.1v_2 + 95v_3 + 0.24v_4 + 0.16v_5 + 0.12v_6) \leq 0$$

$$(25u_1 + 20u_2 + 0.10u_3 + 6u_4 + 3u_5 + 9u_6) - (18v_1 + 3.8v_2 + 95v_3 + 0.21v_4 + 0.17v_5 + 0.13v_6) \leq 0$$

$$(24u_1 + 22u_2 + 0.11u_3 + 6u_4 + 5u_5 + 9u_6) - (19v_1 + 3.4v_2 + 90v_3 + 0.24v_4 + 0.12v_5 + 0.12v_6) \leq 0$$

$$(26u_1 + 21u_2 + 0.10u_3 + 6u_4 + 5u_5 + 9u_6) - (19v_1 + 3.2v_2 + 95v_3 + 0.22v_4 + 0.17v_5 + 0.12v_6) \leq 0$$

$$(26u_1 + 21u_2 + 0.11u_3 + 6u_4 + 3u_5 + 9u_6) - (18v_1 + 3.3v_2 + 110v_3 + 0.25v_4 + 0.18v_5 + 0.13v_6) \leq 0$$

$$(30u_1 + 25u_2 + 1.8u_3 + 8u_4 + 2u_5 + 9u_6) - (19v_1 + 3.1v_2 + 160v_3 + 0.23v_4 + 0.14v_5 + 0.17v_6) \leq 0$$

$$(26u_1 + 23u_2 + 0.12u_3 + 6u_4 + 5u_5 + 9u_6) - (13v_1 + 2.2v_2 + 110v_3 + 0.22v_4 + 0.17v_5 + 0.13v_6) \leq 0$$

$$(31u_1 + 24u_2 + 1.3u_3 + 8u_4 + 1u_5 + 9u_6) - (14v_1 + 2.3v_2 + 140v_3 + 0.28v_4 + 0.10v_5 + 0.15v_6) \leq 0$$

$$(24u_1 + 20u_2 + 0.3u_3 + 10u_4 + 5.1u_5 + 9u_6) - (16v_1 + 4v_2 + 102v_3 + 0.21v_4 + 0.15v_5 + 0.26v_6) \leq 0$$

$$(28u_1 + 25u_2 + 0.3u_3 + 7u_4 + 5.2u_5 + 9u_6) - (18v_1 + 6v_2 + 112v_3 + 0.21v_4 + 0.15v_5 + 0.20v_6) \leq 0$$

$$(30u_1 + 27u_2 + 1.3u_3 + 8u_4 + 4u_5 + 9u_6) - (16v_1 + 2.7v_2 + 145v_3 + 0.22v_4 + 0.10v_5 + 0.15v_6) \leq 0$$

$$(28u_1 + 24u_2 + 0.9u_3 + 8u_4 + 4.3u_5 + 9u_6) - (17v_1 + 3.1v_2 + 155v_3 + 0.2v_4 + 0.14v_5 + 0.21v_6) \leq 0$$

$$u_1, u_2, u_3, u_4, u_5, u_6, v_1, v_2, v_3, v_4, v_5, v_6 \geq 0$$

$$d_i^-, d_i^+ \geq 0$$

Table 3

Results of the Integration of Goal Programming and Quasi-Data Envelopment Analysis

Undesirable Deviation	d_1^-	d_2^-	d_3^-	d_4^-	d_5^-	d_6^-
Value	0.059	0.089	0.120	0.088	0.068	—
Inputs	V_1	V_2	V_3	V_4	V_5	V_6
Value	17.3	3.05	137.1	0.22	0.15	0.23
Outputs	U_1	U_2	U_3	U_4	U_5	U_6
Value	36.2	33.1	0.9	9	5.2	9

As shown by the results presented in Table 5, based on the solution of the integrated goal programming and quasi-data envelopment analysis problem, the deviations from 100%efficiency for the companies, respectively petrochemical companies a, b, c, d, and e, were 0.059, 0.089, 0.120, 0.088, and 0.068. To achieve 100%efficiency, the companies should have input values $V_1$to V_6equal to 17.3, 3.05, 137.1, 0.22, 0.15, and 0.23, respectively, and output values $u_1$to $u_6$equal to 36.2, 33.1, 0.9, 9, 5.2, and 9, respectively. However, despite the coordination in setting the measurement units of the inputs and outputs of the above-mentioned companies, given the differences in production capacity, the companies can be adjusted according to these ratios to achieve the above results.

By examining and comparing the results of the basic data envelopment analysis model $(DEA_CCR)$and the proposed model $(FGPDEA\_CCR)$, it is possible to comment on the discriminatory power of these models. First, sensitivity analysis should be conducted for the $FDEA_CCR$results at different confidence levels, and the results should then be solved for the integrated quasi-data envelopment analysis and fuzzy goal programming model. If the results show a significant correlation, this will indicate the validity of the integrated quasi-data envelopment analysis and fuzzy goal programming model.

4. Discussion and Conclusion

The findings of the present study demonstrated that the integrated quasi-data envelopment analysis model based on fuzzy goal programming provided an effective framework for evaluating the performance and efficiency of petrochemical companies under uncertain conditions. The results indicated that among the identified efficiency indicators, cost-related indicators had the greatest weight and importance in the efficiency evaluation process, followed respectively by sales and production indicators, customer satisfaction indicators, personnel indicators, and working-hours indicators. These findings reveal that financial and operational dimensions remain the dominant determinants of efficiency within petrochemical industries, although customer-oriented and human-resource-related indicators also play meaningful roles in organizational performance evaluation. The predominance of cost indicators in the current study can be explained by the highly capital-intensive structure of petrochemical industries, where operational expenditures, energy consumption, maintenance costs, and resource utilization directly influence organizational profitability and competitiveness. These findings are consistent with previous studies emphasizing the importance of operational cost management and efficiency optimization in industrial and supply-chain systems (Agrawal et al., 2025; Gupta et al., 2024). Similarly, studies conducted by (Berberoğlu et al., 2023) and (Duc et al., 2023) highlighted that cost efficiency and operational optimization constitute central components of industrial performance evaluation frameworks in modern production systems.

The results also demonstrated that the proposed fuzzy quasi-data envelopment analysis model was capable of effectively ranking the petrochemical companies and distinguishing between efficient and inefficient decision-making units. The obtained fuzzy efficiency scores revealed significant differences among the examined companies, indicating the existence of considerable variability in operational performance and resource utilization within the petrochemical sector. The identification of efficient and inefficient units provides valuable managerial insights because it enables organizations to benchmark best-performing companies and identify operational weaknesses requiring strategic improvement. This finding aligns with previous research emphasizing the capability of DEA-based models to evaluate organizational efficiency in multi-input and multi-output environments (Omrani, Fahimi, et al., 2022; Zuluaga-Ortiz et al., 2023). The results are also compatible with the findings of (Shojaie et al., 2024), who demonstrated that advanced DEA models under uncertain data environments improve the reliability and discriminatory power of productivity evaluation systems.

One of the most significant findings of the study concerns the successful integration of fuzzy logic into the quasi-data envelopment analysis framework. The incorporation of fuzzy concepts enabled the model to address ambiguity and uncertainty associated with operational and managerial data in petrochemical companies. Real-world industrial environments are characterized by incomplete information, subjective judgments, fluctuating operational conditions, and dynamic market uncertainties, all of which limit the applicability of conventional deterministic models. The findings of the present study indicate that fuzzy modeling can significantly improve the realism and flexibility of performance evaluation systems. This finding supports earlier studies that emphasized the importance of fuzzy-based approaches in uncertain decision-making environments (Keshavarz-Ghorabaee, 2023; Ulutaş et al., 2023). Similarly, (Lee & Kang, 2023) concluded that fuzzy multi-criteria decision-making approaches improve evaluation precision under uncertain operational conditions. Furthermore, the findings correspond with the conclusions of (Noruzi et al., 2023), who demonstrated that fuzzy decision-making frameworks are highly effective in evaluating complex systems characterized by uncertainty and multiple conflicting criteria.

Another important result of the study was the successful application of fuzzy goal programming for minimizing undesirable deviations and optimizing organizational efficiency levels. The integrated fuzzy goal programming model enabled the simultaneous consideration of multiple operational goals and efficiency targets. The results showed that the proposed model effectively identified deviations from optimal efficiency levels and generated target values for inputs and outputs necessary for achieving maximum organizational efficiency. This finding suggests that integrated fuzzy optimization approaches can serve as highly practical tools for strategic industrial decision-making. The findings are supported by the studies of (Nabizadeh et al., 2021) and (Thu et al., 2021), both of which highlighted the capability of fuzzy goal programming to optimize organizational performance under uncertain and multi-objective conditions. Likewise, (Kao, 2022) found that integrated fuzzy multi-stage goal programming models significantly improve industrial decision-making quality under volatile operational conditions.

The findings related to the significant role of sales and production indicators in organizational efficiency also deserve attention. Production performance directly influences profitability, market responsiveness, customer fulfillment, and operational sustainability in petrochemical industries. Efficient production systems reduce waste, improve resource utilization, and enhance overall organizational competitiveness. These findings are consistent with previous studies emphasizing the relationship between operational productivity and organizational performance in manufacturing and supply-chain systems (Harale et al., 2023; Yao et al., 2024). In addition, the findings align with the research conducted by (Akhtar et al., 2023), which demonstrated that agile and sustainable production systems significantly contribute to improving organizational efficiency under uncertain environments.

Customer satisfaction emerged as another influential efficiency indicator in the present study. Although petrochemical industries are traditionally considered production-oriented sectors, the growing competitiveness of global markets has increased the importance of customer-centered operational strategies. The findings indicate that organizations with higher customer satisfaction levels demonstrate superior operational efficiency and competitive positioning. This finding supports the growing body of literature emphasizing the strategic role of customer satisfaction in industrial sustainability and operational success (Abdallah et al., 2024; Regragui et al., 2023). Similarly, (Hariri et al., 2023) emphasized that integrated quality-function deployment and multi-criteria evaluation systems contribute significantly to improving customer-oriented industrial performance.

The findings concerning personnel and working-hours indicators further indicate that human resources continue to play a meaningful role in determining industrial efficiency. Although technological and financial variables were more influential, the contribution of workforce-related factors demonstrates that organizational productivity cannot be fully optimized without effective human resource management. Employee expertise, technical capability, operational coordination, and labor productivity remain essential components of industrial performance. These findings correspond with previous studies emphasizing the importance of organizational human capital in operational excellence and sustainable industrial management (Duc et al., 2023; Zarte et al., 2021). Moreover, (Berberoğlu et al., 2023) argued that sustainable business performance management requires balanced consideration of operational, technological, environmental, and human-resource-related dimensions.

The successful validation of the proposed integrated model also represents a major contribution of the study. The significant correlations observed between the proposed hybrid model and traditional DEA-based models suggest that the integrated fuzzy quasi-data envelopment analysis and fuzzy goal programming framework possesses acceptable validity and analytical reliability. However, the proposed model demonstrated superior flexibility in addressing uncertainty and multiple objectives simultaneously. This finding confirms the growing argument within operations research literature that hybrid fuzzy optimization models outperform traditional deterministic methods in uncertain industrial environments (Ecer, 2024; Yazdani et al., 2022). Likewise, (Ali et al., 2022) emphasized that integrated fuzzy decision-making frameworks improve the robustness and adaptability of industrial optimization models.

The present study also contributes theoretically to the growing literature on hybrid multi-criteria decision-making systems. By integrating fuzzy quasi-data envelopment analysis with fuzzy goal programming, the study developed a comprehensive framework capable of simultaneously evaluating efficiency, handling uncertainty, and optimizing organizational goals. This integrated perspective extends previous research that often focused on isolated applications of DEA or fuzzy programming separately. The findings therefore support the increasing trend toward methodological integration in industrial management and decision sciences (Hariri et al., 2023; Özdağoğlu et al., 2024). Furthermore, the results align with studies demonstrating the effectiveness of hybrid fuzzy optimization models in sustainable industrial decision-making and organizational performance management (Tırkolaee et al., 2021; Yazdani et al., 2021).

From a practical perspective, the findings indicate that petrochemical managers can utilize integrated fuzzy DEA and fuzzy goal programming models as strategic decision-support tools for performance monitoring, operational benchmarking, and resource optimization. The proposed model provides organizations with the ability to identify operational inefficiencies, quantify performance gaps, establish realistic improvement targets, and allocate resources more effectively under uncertain conditions. This capability is particularly important in petrochemical industries where operational decisions significantly influence financial performance, energy consumption, environmental sustainability, and international competitiveness. The findings therefore reinforce the growing managerial importance of intelligent mathematical programming approaches in modern industrial systems (Gupta et al., 2024; Wang et al., 2024).

The results additionally highlight the importance of uncertainty management in industrial performance evaluation. Conventional deterministic evaluation systems frequently fail to capture the ambiguous and dynamic nature of real-world industrial operations. By integrating fuzzy concepts into DEA and goal programming structures, the present study developed a more realistic and adaptive performance evaluation framework capable of functioning under uncertain operational conditions. This finding is highly relevant in contemporary industrial environments characterized by fluctuating market conditions, technological transformation, environmental regulations, and geopolitical instability. The findings therefore support the argument that uncertainty-based decision-making models are increasingly necessary for effective industrial management and strategic planning (Keshavarz-Ghorabaee, 2023; Nabizadeh et al., 2021).

Overall, the findings of the present study indicate that the integrated fuzzy quasi-data envelopment analysis model based on fuzzy goal programming represents a robust, flexible, and practical framework for evaluating and optimizing petrochemical industry performance. The model successfully integrated multiple operational indicators, uncertainty management mechanisms, and optimization objectives into a unified analytical structure. The results demonstrate that hybrid fuzzy mathematical programming approaches can significantly improve the quality of industrial efficiency evaluation and strategic decision-making under uncertain environments. Consequently, the study contributes both theoretically and practically to the fields of industrial management, operations research, and performance evaluation systems.

One limitation of the present study concerns the restricted number of petrochemical companies included in the analysis due to confidentiality constraints and limited access to organizational data. Although the selected companies provided valuable operational information, a larger sample size could improve the generalizability of the findings. Another limitation relates to the dependence on expert judgments and questionnaire-based fuzzy data, which may involve subjective bias despite the application of reliability and validity assessments. Furthermore, the study focused primarily on operational and managerial indicators and did not comprehensively incorporate environmental, social, or geopolitical variables that may also influence petrochemical industry performance.

Future research is recommended to apply the proposed integrated model to larger industrial datasets and different industrial sectors in order to examine its broader applicability and comparative effectiveness. Researchers may also integrate additional sustainability indicators, including environmental emissions, energy efficiency, and social responsibility measures, into future evaluation frameworks. Moreover, future studies could combine artificial intelligence techniques, machine learning algorithms, and dynamic simulation methods with fuzzy DEA and fuzzy goal programming models to develop more adaptive and predictive industrial performance evaluation systems. Comparative studies between deterministic and fuzzy optimization frameworks across different industries may also contribute to the advancement of hybrid decision-making methodologies.

From a practical perspective, petrochemical companies are encouraged to adopt integrated intelligent decision-support systems for continuous operational monitoring and strategic resource optimization. Managers should pay particular attention to cost management, production efficiency, customer satisfaction, and workforce productivity as key determinants of organizational competitiveness. Implementing uncertainty-based mathematical evaluation models can improve managerial flexibility and facilitate more effective responses to dynamic industrial conditions. Furthermore, organizations should invest in advanced analytical infrastructures and staff training programs to enhance the utilization of modern optimization and performance evaluation techniques in industrial decision-making processes.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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