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Prioritizing Investment in High-Tech Industries within the Iranian Oil and Gas Sector

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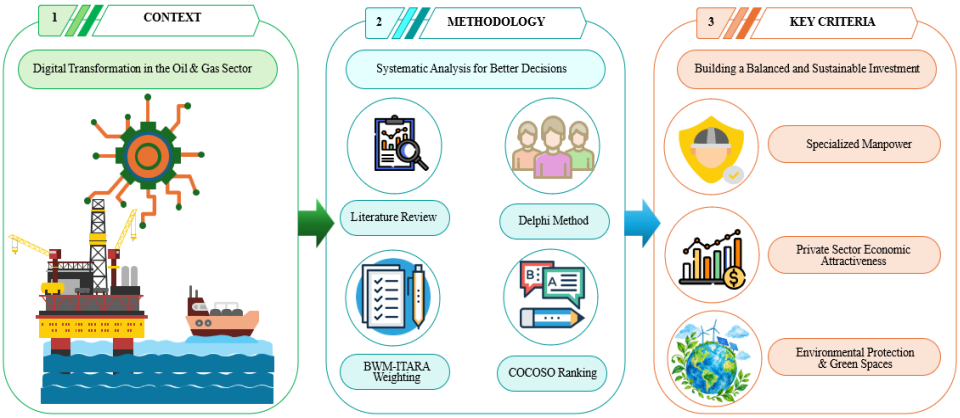
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A B S T R A C T

The oil and gas industry in a developing country like Iran serves as a key economic driver, necessitating smart and targeted investments in advanced technologies. Given capital constraints and the importance of selecting optimal technologies, this study was conducted to prioritize investment in high-tech sectors. Initially, through a literature review and expert interviews, a preliminary list of 14 technologies and 21 criteria was extracted; subsequently, following the Delphi method with 14 experts for refinement, this list was finalized to 11 technologies and 19 criteria. To weigh these criteria, a combination of the Best-Worst Method (BWM) and the ITARA method was employed, revealing that "availability of specialized manpower," "economic attractiveness for the private sector," and "destruction of green spaces and natural resources" are the most critical criteria according to experts. Finally, the Comparative Coefficient of Similarity Optimization (COCOSO) method was used to prioritize the research alternatives. Based on expert opinions and the established criteria, Enhanced Oil Recovery (EOR), biotechnology, and nanotechnology were identified as the top three high-tech technologies requiring special investment priority within the Iranian oil and gas industry.



1. Introduction

Technology, from its inception as rudimentary survival tools to its current role as a driving force for economic and social development, has always played a fundamental role in human progress. Today, considering global trends, economic growth, and increasing competition for limited resources, innovation and the application of advanced technologies are vital for creating sustainable competitive advantages and ensuring survival in the market [1]. In global trade, high-tech industries hold a special position in manufacturing and exports and are considered the primary factor for countries to surpass one another [2]. Since advanced technologies lead to high value-added creation and increased productivity in other economic sectors, securing sufficient capital for infrastructure projects to achieve macroeconomic goals is an undeniable necessity [3].

Examining the investment-to-GDP ratio reveals that this ratio exceeds 20% in the Philippines and is above 30% in South Korea; however, in Iran, due to capital inefficiency, the use of outdated equipment, and population growth, this figure is less than 16% [4]. Given investors' risk aversion, focusing on high-yield areas is mandatory [5], especially in Iran's oil and gas industry, which holds 650 billion barrels of oil in place and 156 billion barrels of recoverable oil (considering the recovery factor), providing a 60-year operational potential.

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Consequently, to prevent the waste of resources and specialized manpower, determining technology development priorities is essential [1]. Ultimately, considering the investment gap in research and development compared to developed countries, leveraging successful global experiences is the only way to combat backwardness and bridge the technological gap.

Selecting investment projects is among the strategic decisions of managers that determine the long-term value and profitability of an enterprise [1]. Given the technological nature of the oil industry and the necessity of utilizing advanced equipment for optimal reservoir management [6], the failure to adopt modern technologies has caused the country's production capacity to decline by an average of 10% annually [7]. Furthermore, to maintain current production levels, Iran's oil industry requires a minimum investment of $200 billion; otherwise, given increasing domestic demand and a negative gas balance, the country will face serious future crises.

During the 13th administration, shifting the approach from the crude sale of oil to completing the value chain led to the definition of six Petro-refineries with a 46 billion investment, among which projects like "Morvarid Makran", with an 8 billion capital, show tangible physical progress. In the gas sector, to achieve macroeconomic goals, an investment of over 80 billion is required, of which 23.6 billion is allocated to pressure-boosting and production stabilization, and $36.4 billion is dedicated to the development of new fields. Securing these financial resources for optimal reservoir management and increasing the recovery factor is an unavoidable necessity to prevent a negative energy balance and a return to the era of gasoline imports.

This study seeks to develop an optimal decision-making framework by addressing the following fundamental questions: Which sectors constitute the high-tech industries within Iran's oil and gas industry, and which criteria exert the greatest influence on investment decisions in these sectors? Furthermore, the study aims to prioritize the various investment areas within Iran's high-tech oil and gas industries and to examine the relative importance and priority of investment criteria in light of Iran's existing capabilities, resources, and operational potential.

It is expected that upon the completion of this research, its findings, along with the identified priorities and criteria for investment in high-tech industries within the oil and gas sector, will be utilized by the policy-making and investment institutions of the oil industry. It is also anticipated that the priorities obtained in this study will help higher-level decision-making bodies allocate capital more efficiently and effectively toward the development of high-tech industries.

1.1. Investment

In its simplest form, investment entails committing capital with the expectation of generating profit, while technically, it involves allocating money toward financial or other assets to secure returns via interest, dividends, or capital appreciation. As a fundamental prerequisite for transitioning from an underdeveloped to a developed economy, investment necessitates fostering public trust to effectively channel the resources of interested stakeholders [8]. Investment can be classified into various types depending on the perspective adopted, the most important of which are presented in Table 1 [10-13].

Table 1. Classification of Investment Types Based on Different Dimensions and Criteria

Classification Criteria	Investment Type	Structural Description and Characteristics
Subject	Real	Acquiring non-movable and tangible assets by sacrificing value in the present.
	Financial	Acquiring financial assets by sacrificing present value, which typically generates cash flows.
Time	Short-term	Investment with a time horizon of up to one year.
	Long-term	Investment with a time horizon exceeding one year.
Risk	Commensurate with Return	Investment where the level of risk is proportional to the expected rate of return.
	High Relative Risk (Speculation)	Accepting higher risks by the investor in anticipation of earning above-average returns.
	Extremely High Risk (Gambling)	Accepting extremely high and irrational risks, even when the potential return is very low.
Origin	Domestic (Public/Governmental)	A policy instrument in developing countries that acts as a strong catalyst for economic growth, stability, and stimulating private sector investment.
	Domestic (Private)	Investment activities in the non-governmental sector, which are reinforced and stimulated by public sector policies and investments.
	Foreign Direct (Micro Perspective)	Rooted in industrial organization theory; directly enhances financing, technological transfer, host-country competition, value chain productivity, production growth, employment, exports, and price reduction.
	Foreign Direct (Macro Perspective)	Rooted in international finance; refers to the cross-border flow of capital from the home country to the host country, recorded in the balance of payments.

Source: Refs [11-13]

Investors are generally divided into two categories: natural persons and legal entities, which are discussed in Table 2 [14].

Table 2. Types of Investors

Type	Definition
Natural Persons	These are individuals who generally buy or sell securities with the expectation of earning a profit. In some cases, when their capital is substantial, they may pursue other objectives as well, such as gaining control of a company by acquiring a large percentage of its shares.
Legal Entities	These entities, due to the scale of their operations and the large volume of financial resources at their disposal, exert a significant influence on the capital market.

Source: Ref [14]

1.2. Technology

Technology is defined as the systematic application of knowledge, tools, and processes to create products and provide services [15], a concept fundamentally rooted in the Greek terms Technes and logia. According to the Technology Atlas, this concept represents a complex synergy of four elements, comprising hardware as physical equipment, infoware as technical knowledge and software, humanware as skills and ingenuity, and orgaware as managerial and organizational systems [16]. This multidimensional nature is further supported by various scholars, ranging from Porter's (1991) value-added systems and WIPO's (2010) systematic industrial knowledge to Khalil's [15] broader view of technology as the way of doing things, ultimately characterizing it as an integrated capability that transforms raw resources into human needs [3,17]. In this regard, some of the most key classifications of technology are presented in Table 3.

Table 3. Classification of Technology Types

Basis of Classification	Category	Description
Based on capabilities	Technology of use and operation	The level of technology used for operating and utilizing equipment and systems.
	Maintenance and repair technology	Technology related to the maintenance, servicing, and repair of equipment and systems.
	Assembly technology	Technology used for assembling components and systems.
	Copying and adaptation technology	Technology for replicating and adapting existing technologies.
	Design and manufacturing technology	Technology involved in designing and producing products and systems.
	Capability to produce new technologies	The ability to generate new technologies.
	Basic research capability	The ability to conduct fundamental research.
Countries classified by technological capability	Brain-based countries	Advanced industrial countries such as Japan, the United States, and Western Europe.
	Technology-based countries	Newly industrialized countries such as Brazil, South Korea, and others.
	Skill-based countries	Countries such as Iran, North Korea, Syria, and others.
	Labor-based countries	Highly underdeveloped countries, especially those in Central Africa.
Based on the origin of technology	Imported technology	Technology originating outside national borders, usually at lower knowledge levels than assembly. Its main purpose is to support faster economic growth and national development goals in developing countries.
	Indigenous and traditional technology	Traditional technologies that have existed in Third World countries for a long time but are often rapidly replaced by imported technologies due to lower productivity.
	Hybrid technology	A combination of imported and traditional technologies, meaning imported technologies are absorbed and integrated with national technological conditions. It does not imply the simultaneous use of primitive and advanced imported technologies, but rather the development of traditional technology by combining the advantages of advanced imported knowledge and local experiential knowledge accumulated over generations for local conditions.
Based on complexity	Absorbable technology	Technology with a level of complexity that can be used at the national level of a country. Its technical attractiveness depends on the capability of human resources or R&D institutions, and it becomes attractive when it can play a role in the country's technological system.

Source: Refs [3,15-17]

1-3. Difference between Technology and High Technology

Current definitions of high technology often lack practical utility, as they frequently rely on generic classifications rather than focusing on the dominance of the human element over hardware. High technology fundamentally transforms organizational structures, management procedures, and cultural dynamics, thereby necessitating more complex coordination and refined interpersonal relations, as illustrated in the comparative analysis provided in Table 4 [18].

Table 4. The difference between Technology and High Technology

Technology	High Technology
Efficiency	Effectiveness
Economic indicator	Economic perspective
Know-how	Know-what and know-why
Information	Knowledge and wisdom
Standards and goals	Continuous development
System provision	Innovation, creativity, and change
Specialization	Systemic view and integration
Systemic view and integration	Optimal system design
Same way, same thing, but better	Same thing, differently and better
Working harder	Working smarter

Source: Ref [18]

1.4. High-tech

High-tech industries are characterized by substantial R&D intensity—which often exceeds 4% according to OECD standards—and a high concentration of STEM personnel, such that the U.S. Office of Technology Assessment defines such firms by their systematic application of scientific knowledge and significant investment in human capital. Furthermore, these industries are distinguished by rapid evolution, shorter product life cycles—which are often around one year compared to over ten years for traditional sectors—and a shift from experience-based production to science-driven production that leads to the creation of significant value-added results [19]. Accordingly, Table 5 presents some of the most key types of high-tech industries.

Table 5. Types of High-Tech Industries

Industry Type	Description / Examples
Electronic Industry	Computer hardware & components, Integrated Circuits (ICs), advanced electronic and communication equipment (excluding SKD assembly)
New Materials	Advanced ceramics, composites, advanced polymers, superconductors
Biotechnology	Advanced pharmaceuticals, diagnostic kits, food supplements, biopolymers, bioreactors, biotech chips, bio-fertilizers, enzymes
Optics and Laser	Lenses, laser application equipment, fiber optics, crystals, optical and optomechanical thin films
Industrial Automation & Intelligent Systems	Process control systems/equipment, instrumentation, thermal control, sensors, robots
Nanotechnology	Applications in electricity, computing, medicine, environment, energy, etc.
Information Technology (IT)	Software packages, information transmission, network services, information systems
Aerospace	Air navigation equipment, aerodynamics, civil aircraft flight mechanics, satellite technologies
New Energies	Fuel cells, solar converters
Micro-Electro-Mechanical Medical Systems	High-tech category classification
Nanotechnology	High-tech category classification
Biotechnology	High-tech category classification
Biomedical Engineering	High-tech category classification

Source: Refs [20,21]

1.5. Investment in Oil and Gas Industry

The oil and gas industry stands as a cornerstone of investment with a comparative advantage driven by Iran's massive hydrocarbon reserves, strategic geographical position, and long-standing operational history of over 100 years. With total in-place oil reserves estimated at 650 billion barrels and a recovery factor of 24%, Iran holds over 156 billion barrels of recoverable reserves, leaving approximately 494 billion barrels underground and ensuring at least 60 years of future activity. Furthermore, recent assessments by the National Iranian Oil Company indicate that the nation holds a total of over 1,200 billion barrels of oil equivalent in hydrocarbon reserves, including approximately 157 billion barrels of recoverable oil and 33 trillion cubic meters of gas, reinforcing Iran's position as a global leader in energy resources. To address investment potential, industry activities are traditionally categorized into upstream operations—comprising exploration, drilling, extraction, transport, and storage—and downstream operations, which encompass refining and distribution [20].

Table 4. Top 10 Countries in the World by Oil Reserves

Country	Share of Total Global Reserves
Venezuela	17.5%
Saudi Arabia	17.2%
Canada	9.7%
Iran	9.1%
Iraq	8.4%
Russia	6.2%
Kuwait	5.9%
United Arab Emirates	5.6%
America	4%
Libya	2.8%

Source: Research Findings

Table 5. Top 10 Countries in the World by Gas Reserves

Country	Share of Total Global Reserves
Russia	19.9%
Iran	17.1%
Qatar	13.1%
Turkmenistan	7.2%
America	6.7%
China	4.5%
Venezuela	3.3%
Uzbekistan	3.2%
United Arab Emirates	3.2%
Nigeria	2.9%

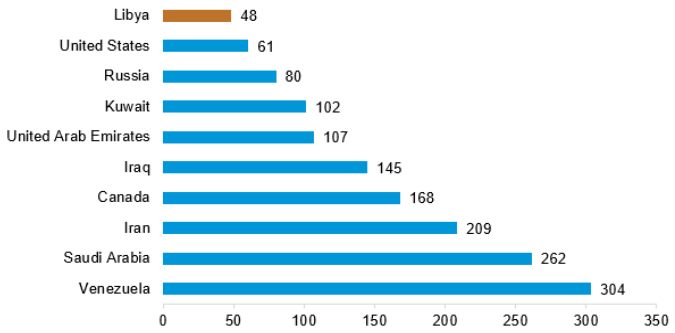


Figure 1. Largest proved reserve holders of total oil, 2021
Note: Oil reserves include crude oil, condensates, natural gas liquids, and oil sands.

Investment in Iran's upstream oil sector remains largely concentrated under the National Iranian Oil Company across its five core areas of exploration, drilling, extraction, transport, and storage, while the downstream sector currently operates nine refineries with a nominal capacity of 1,917 thousand barrels per day (bpd). Ongoing projects, including the Persian Gulf Star refinery (360,000 bpd) and the Pars refinery (120,000 bpd), alongside the planned construction of seven additional facilities, are set to increase the country's total refining capacity to 3,397 thousand bpd by processing an additional one million bpd of crude and 480,000 bpd of gas condensates [22]. Building on this, current capacity stands at 2.2 million bpd, with strategic planning aimed at surpassing 3.5 million bpd within the next four to five years to further enhance national energy processing capabilities.

Table 6. Ownership Status of Iran's Oil Refineries

Oil Refining Companies	Current Capacity (thousand barrels per day)	Shareholders
Abadan Oil Refining Company	430	National Iranian Oil Refining and Distribution Company (NIORDC) - Oil Industry Pension and Welfare Fund
Persian Gulf Star Oil Company	420	- Taipico (Tamin Petroleum & Petrochemical Investment Co.) - National Iranian Oil Refining and Distribution Company (NIORDC) - Taban Farda Research Group - Ahdaf Investment Company Bank - Mellat - Siahan Oil Company - Palayeshi Yekom Investment Fund - Bank Tejarat
Isfahan Oil Refining Company	370	- Civil Servants Pension Fund Investment Company - Bank Saderat Iran - Jey Oil Refining Company Refah Capital Development Company - Justice Shares Investment Companies (30 Provinces) - Avaye Pardis Salamat Company

Source: Research Findings

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Isfahan Oil Refining Company	370	- Civil Servants Pension Fund Investment Company - Bank Saderat Iran - Jey Oil Refining Company Refah Capital Development Company - Justice Shares Investment Companies (30 Provinces) - Avaye Pardis Salamat Company

Source: Research Findings

The growing need for gas to supply energy and fuel, together with the foreign-exchange revenues generated through its sale and export for investing in and establishing basic and infrastructural industries in the country, strengthened the idea of concentrating activities related to the gas industry; accordingly, based on its legal charter, the National Iranian Gas Company was established in 1344 AH as one of the four major companies affiliated with the Ministry of Petroleum of the Islamic Republic of Iran, with an initial capital of 25 billion rials. Today, with more than 45 years of experience, the National Iranian Gas Company is one of the ten largest companies operating in the gas sector in the Middle East and one of the four major companies of the Ministry of Petroleum, responsible for supplying more than 61 percent of the country's required fuel. In this regard, the company occupies an important position both inside and outside the country and has modified its organizational structure in line with its needs and the expansion of its domestic and international activities. While maintaining and strengthening its hardware and software capacities, the company has recruited specialized personnel and provided training and updated the capabilities of its experienced workforce [20].

2. Materials and Methods

The present study is applied in terms of its purpose and descriptive-analytical in terms of data collection. The research was carried out through the following steps: reviewing the literature and collecting previous studies; examining high-tech industries and identifying those used in the oil and gas industry; determining investment criteria in high-tech industries based on the literature and expert opinions; collecting expert opinions; selecting an appropriate tool for analyzing expert judgments; performing the required calculations and analyses; prioritizing the industries for investment; and finally consolidating, summarizing, and presenting the research findings.

2.1. Data Collection Method

Data collection in this study is conducted at both the field and library levels. At the library level, the research gap is identified and the theoretical foundations and previous studies are reviewed and compiled. At the field level, expert opinions are used to identify advanced technologies and the investment criteria relevant to these technologies, after which these criteria are prioritized.

2.2. Data Collection Instrument

The data collection instruments include expert interviews and a pairwise comparison questionnaire, which are completed based on the snowball technique [23].

2.3. Statistical Population, Sample, and Sampling Method

The statistical population of this study consists of all specialists and experts in the oil and gas industry, preferably those familiar with high-tech industries as well as investment and financial issues in these sectors. The sampling method is purposive, meaning that only individuals willing and able to respond to the research questions are selected. It should be noted that, given the limited scope of the selection, the sample may cover the entire country and is not restricted to a specific region or area.

2.4. Data Analysis Methods

Multi-criteria decision-making (MCDM) methods were used to analyze the data. After identifying and finalising the criteria through the Delphi method, their relative importance was determined using two methods: the Best-Worst Method (BWM) and ITARA. BWM was used to extract subjective weights based on expert judgments, while ITARA was used to extract objective weights based on data dispersion. Subsequently, the weights from both methods were combined to determine the final weights of the criteria. Finally, the investment alternatives were ranked using the CoCoSo method.

2.4.1. Combining BWM and ITARA Weights

The weight of each criterion represents its relative importance compared to other criteria. In this study, a hybrid weighting approach is used to reduce the subjectivity of experts and simultaneously utilize both judgmental and objective data.

First, the subjective weights of the criteria are calculated using the Best-Worst Method. Then, the objective weights of the criteria are obtained using the ITARA method based on the dispersion of alternative scores for each criterion. In the final step, the subjective and objective weights of each criterion are multiplied, and the results are normalized. The hybrid weight of criterion j is calculated as follows.

$$w_j^c = \frac{w_j^{BWM} w_j^{ITARA}}{\sum_{i=1}^{n} w_i^{BWM} w_i^{ITARA}} \quad (1)$$

Where w_j^{BWM} is the subjective weight, w_j^{ITARA} is the objective weight, and w_j^c is the hybrid weight of criterion j.

2.4.1.1 The Best-Worst Method (BWM)

The Best-Worst Method (BWM) is a relatively new weighting method in MCDM, introduced by Jafar Rezaei in 2015. The key feature of this method is the reduction of pairwise comparisons and the improvement of comparison consistency. In this method, the decision-maker first identifies the best and worst criteria. Then, the best criterion is compared with all other criteria, and all other criteria are compared with the worst criterion.

Step 1. Determine the set of criteria

In the first step, the set of research criteria is determined based on the literature, interview results, and Delphi findings. The criteria are defined as follows:

$$C = \{c_1, c_2, \dots, c_3\}$$

Step 2. Select the best and worst criteria

Each expert identifies the most important criterion as the best criterion B and the least important criterion as the worst criterion W from the set of criteria.

Step 3. Conduct pairwise comparisons

In this step, the best criterion is compared with all other criteria to form the Best-to-Others comparison vector

$$A_B = (a_{B1}. a_{B2}. \dots . a_{Bn})$$

Similarly, all other criteria are compared with the worst criterion to form the Others-to-Worst comparison vector

$$A_w = (a_{1w}. a_{2w}. \dots . a_{nw})^T$$

A 9-point scale is used to perform the comparisons. The odd values of this scale are interpreted as follows

Table 7. Nine-Point Linguistic Scale and Corresponding Numerical Scores for Pairwise Comparisons

Linguistic Terms	Very Low	Low	Medium	High	Very High
Corresponding Score	1	3	5	7	9

Source: Research Findings

The values 2, 4, 6, and 8 represent intermediate intensities between the adjacent scale values.

Step 4. Calculate the weights of the criteria

The weights of the criteria are determined by solving the following optimization model

$$\min \varepsilon$$

subject to

$$\left|\frac{w_B}{w_i} - a_{Bj}\right| \le \varepsilon \qquad j = 1, 2, \dots, n$$

$$\left|\frac{w_j}{w_w} - a_{jW}\right| \le \varepsilon \qquad j = 1, 2, \dots, n$$

$$\sum_{i=1}^{n} w_j = 1$$

$$w_j \geq 0 \qquad j = 1, 2, \dots, n$$

To improve calculation accuracy, the linear formulation of the BWM model is used

$$\min \varepsilon^L$$

subject to

$$\left|w_B - a_{Bj} w_j\right| \leq \varepsilon^L \qquad j = 1, 2, \dots, n$$

$$\left|w_j - a_{jW} w_W\right| \leq \varepsilon^L \qquad j = 1, 2, \dots, n$$

$$\sum_{i=1}^{n} w_j = 1$$

$$w_j \geq 0 \qquad j = 1, 2, \dots, n$$

Solving this model yields the final weight of each criterion and the value of ε^L The value ε^{L*}.represents the inconsistency of the comparisons; the closer this value is to zero, the higher the consistency of the expert's judgments.

Complete consistency is achieved when the following relationship holds

$$a_{BW} = a_{Bj} \times a_{jW}$$

Where a_{BW} is the preference of the best criterion over the worst, a_{Bj} is the preference of the best criterion over criterion j and a_{jW} is the preference of criterion j over the worst.

If multiple experts participate in the BWM questionnaire, the weights obtained for each expert are calculated individually. The weights of each criterion are then aggregated across experts and normalized to obtain the group weights.

2.4.1.2. The ITARA Weighting Method

The ITARA method is an objective weighting method that determines the weights of criteria based on the information in the decision matrix. The main logic of this method is that criteria with higher dispersion among alternatives have a higher power to differentiate between alternatives and should receive higher weights. Conversely, if the scores of alternatives under a criterion are nearly similar, that criterion has less power to differentiate.

This method also utilizes the concept of the indifference threshold (IT). Based on this concept, if the difference between the scores of two alternatives under a criterion is less than or equal to the indifference threshold, this difference is considered negligible for decision-making

$$\left|a_{rj} - a_{sj}\right| \leq IT_j$$

Where a_{rj} and a_{sj} are the scores of alternatives r and s under criterion j, and IT_j is the indifference threshold of criterion j.

Step 1. Construct the decision matrix and determine the indifference threshold

The decision matrix of the research consists of m alternatives and n criteria

$$A = \left[a_{ij}\right]_{m \times n}$$

Where a_{ij} represents the performance of alternative j. An indifference threshold is also determined for each criterion

$$IT_j \qquad j = 1, 2, \dots, n$$

Step 2. Normalize the data

The decision matrix scores and the indifference thresholds are normalized as follows

$$\alpha_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}}$$

$$NIT_j = \frac{IT_j}{\sum_{i=1}^{m} a_{ij}}$$

Step 3. Sort the normalized scores

In this step, the values of α_{ij} for each criterion are sorted in ascending order. The sorted values are denoted by β_{ij} . The differences between consecutive values are then calculated as follows

$$\gamma_{ij} = \beta_{(i+1)j} - \beta_{ij} \qquad i = 1, 2, \dots, M-1$$

Step 4. Calculate meaningful differences

In this step, differences greater than the normalized indifference threshold are extracted

$$\delta = \begin{cases} \gamma_{ij} - NIT_j & \gamma_{ij} > NIT_j \\ 0 & \gamma_{ij} > NIT_j \end{cases}$$

Therefore, only differences exceeding the indifference threshold are considered in determining the criterion weights.

Step 5. Calculate criterion weights

First, the value V_j is calculated for each criterion

$$V_j = \left(\sum_{i=1}^{m-1} \delta_{ij}^{p}\right)^{1/p}$$

Then, the objective weights of the criteria are obtained from the following relationship

$$w_j^{ITARA} = \frac{V_j}{\sum_{i=1}^{n} V_j}$$

The parameter p is the model parameter, and values of 1, 2, or infinity are typically considered for it. In this study, the value of p will be determined based on the common practice in related studies.

2.4.1.3. The CoCoSo Ranking Method

The Combined Compromise Solution (CoCoSo) method is used to rank the investment alternatives. This method is a modern MCDM technique that combines the weighted sum and weighted product approaches to provide a compromise solution for ranking alternatives.

Step 1. Construct the decision matrix

The initial decision matrix is defined as follows

$$X = \left[x_{ij}\right]_{m \times n}$$

Where x_{ij} represents the performance of alternative i under criterion j.

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}$$

Step 2. Normalize the decision matrix

For benefit criteria (where higher values are preferred), the normalization formula is

$$r_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}$$

For cost criteria (where lower values are preferred), the normalization formula is

Step 3. Calculate the S_i and P_i measures

The measure S_i is calculated based on the weighted sum approach

$$S_i = \sum_{i=1}^{n} r_{ij}^{w_j}$$

The measure P_i is calculated based on the weighted product approach

$$P_i = \sum_{i=1}^{n} r_{ij}^{w_j}$$

Where w_j is the final weight of criterion j and r_{ij} is the normalized score of alternative i under criterion j.

Step 4. Calculate relative compromise scores

In this step, three compromise indicators are calculated for each alternative

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m}(P_i + S_i)}$$

$$k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i}$$

$$k_{ic} = \frac{\lambda S_i + (1-\lambda) P_i}{\lambda \max_i S_i + (1-\lambda) \max_i P_i}$$

Step 5. Calculate the final score of the alternatives

The final score for each alternative is calculated as follows

$$k_i = (k_{ia} k_{ib} k_{ic})^{1/3} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic})$$

Finally, the alternatives are ranked based on the value of k_i. A higher value of the final index indicates a higher priority for investment.

2.13. Summary of the Research Process

The research process is executed in five main stages:

1. Reviewing literature and identifying the initial investment criteria in high-tech industries within the Iranian oil and gas sector;
2. Conducting semi-structured interviews with experts to finalize the list of criteria;
3. Using the Delphi method to refine the criteria and achieve expert consensus;
4. Calculating subjective weights using BWM, objective weights using ITARA, and combining them to determine the final weights of the criteria;
5. Constructing the decision matrix, calculating CoCoSo parameters, and ranking the investment alternatives.

Accordingly, the research methodology allows for a comprehensive identification of criteria, utilization of expert knowledge, minimization of subjectivity in weighting, and final prioritization of investment alternatives in the high-tech oil and gas sector.

3. Results and Discussion

3.1. Identification and Extraction of Components

In this study, since the objective is to prioritize investments in high-tech oil and gas industries, two primary components were required: identifying the relevant high-tech industries and establishing the criteria for prioritizing these investments. During the initial phase, a comprehensive review of the literature and scientific resources was conducted, resulting in an initial list of high-tech industries and decision-making criteria, as presented in Table 8.

Table 8. Technologies Extracted

No.	Technology Name
1	Nanotechnology
2	Information Technology (IT)
3	New Energies
4	Digital Oil Fields
5	3D Seismic
6	Carbon Fiber
7	Big Data
8	Virtual Reality (VR)
9	Enhanced Oil Recovery (EOR)
10	Robotics
11	Internet of Things (IoT)
12	Fiber Optic Sensors
13	Blockchain

Source: Research Findings

3.2. Delphi Method

In this study, the Delphi panel consists of 14 experts who ultimately reached a general consensus over two rounds of the Delphi method.

In the first round of the Delphi method, the initial questionnaire was distributed among 20 experts; with a 70% return rate, the panel size was reduced to 14 experts, which is considered suitable for specialized topics (typically 8–16 members). The consensus criterion for confirming a technology in the first round (determining high-tech status) was that at least 70% of experts must vote for it being high-tech and applicable to Iran's oil and gas industry, while a 70% negative vote leads to its removal; otherwise, the questionnaire is redistributed to reach consensus. In the second round, a criterion is rejected if over 70% of experts rate its importance as low or very low, and accepted if 70% rate it as high or very high; otherwise, decision-making is deferred. The results of the first Delphi round are presented in Table 8 for the first question and Table 9 for the second.

Table 9. Results of the First Round of the Delphi Questionnaire (First Question)

No.	Technology Name	Percentage of Expert Opinions				Result
		It is High-Tech and applicable in Iran	It is High-Tech but not applicable in Iran	No Opinion	It is not High-Tech	
1	Nanotechnology	92.9	00.0	07.1	00.0	Accepted
2	Information Technology	85.7	00.0	14.3	00.0	Accepted
3	New Energies	50.0	35.7	14.3	00.0	Round 2
4	Digital Oil Fields	71.4	00.0	28.6	00.0	Accepted
5	3D Seismic	85.7	00.0	14.3	00.0	Accepted
6	Carbon Fiber	71.4	14.3	14.3	00.0	Accepted
7	Big Data	71.4	28.6	00.0	00.0	Accepted
8	Virtual Reality	14.3	71.4	14.3	00.0	Rejected
9	Enhanced Oil Recovery (EOR)	100	00.0	00.0	00.0	Accepted
10	Robotics	78.5	00.0	21.5	00.0	Accepted
11	Internet of Things (IoT)	28.6	71.4	00.0	00.0	Rejected
12	Fiber Optic Sensors	42.8	35.7	21.5	00.0	Round 2
13	Blockchain	35.7	14.3	50.0	00.0	Round 2
14	Biotechnology	Added by experts -				

Source: Research Findings

Table 10. Delphi Questionnaire Round 1 Results (Question 2)

No.	Criterion	Very High	High	Neutral	Low	Very Low	Result
1	Capital Expenditures	14.3	21.4	35.7	28.6	00.0	Round 2
2	Economic Attractiveness for the Private Sector	78.6	21.4	00.0	00.0	00.0	Accepted
3	Technology Dependency on Exchange Rates and Other Volatile/Unpredictable Variables	21.4	35.7	21.4	21.4	00.0	Round 2
4	Amount of Required Fixed Capital	07.1	50.0	21.4	21.4	00.0	Round 2
5	Return on Investment (ROI) Period	28.6	21.4	14.3	21.4	00.0	Round 2
6	Access to Appropriate Equipment	71.4	14.3	07.1	07.1	00.0	Accepted
7	Ease of Technology Acquisition and Access	92.9	07.1	00.0	00.0	00.0	Accepted
8	Logistics and Supply Chain for Required Materials	71.4	07.1	21.4	00.0	-	Accepted
9	Availability of Specialized Human Resources	21.4	42.9	07.1	28.6	00.0	Round 2
10	Technology Location and Site Selection	21.4	35.7	35.7	07.1	00.0	Round 2
11	Reduction of Dependency on Other Foreign Technologies	85.7	14.3	00.0	00.0	00.0	Accepted
12	Government Regulations	92.9	00.0	07.1	00.0	00.0	Accepted
13	Government Support for Investment in this Industry	71.4	07.1	21.4	00.0	00.0	Accepted
14	Industry Susceptibility to Sanctions	78.6	07.1	00.0	14.3	00.0	Accepted
15	Job Creation	21.4	28.6	28.6	21.4	00.0	Round 2
16	Contribution to Sustainable Energy Supply	21.4	35.7	35.7	07.1	00.0	Round 2
17	Creating New Capacity in the Country's Production and Refining	85.7	07.1	07.1	00.0	00.0	Accepted
18	Contribution to Diversification of the Country's Energy Portfolio	28.6	21.4	14.3	21.4	00.0	Round 2
19	Destruction of Green Spaces and Natural Resources	21.4	42.9	07.1	28.6	00.0	Round 2
20	Impact of Technology on Environmental Pollution	21.4	35.7	35.7	07.1	00.0	Round 2
21	Industry Energy Intensity	28.6	28.6	35.7	00.0	00.0	Round 2

Source: Research Findings

Table 11. Delphi Questionnaire Round 2 Results (Question 1)

No.	Technology Name	High-Tech & Applicable in Iran	High-Tech but Not Applicable in Iran	No Opinion	Not High-Tech	Result
1	Nanotechnology	92.9	00.0	07.1	00.0	Accepted
2	Information Technology	85.7	00.0	14.3	00.0	Accepted
3	New Energies	28.6	71.4	00.0	00.0	Rejected
4	Digital Oil Fields	71.4	00.0	28.6	00.0	Accepted
5	3D Seismic	71.4	14.3	14.3	00.0	Accepted
6	Carbon Fiber	71.4	07.1	21.5	00.0	Accepted
7	Big Data	85.7	00.0	14.3	00.0	Accepted
8	Virtual Reality	07.1	71.4	21.5	00.0	Rejected
9	Enhanced Oil Recovery (EOR)	100	00.0	00.0	00.0	Accepted
10	Robotics	78.5	00.0	21.5	00.0	Accepted
11	Internet of Things (IoT)	28.6	71.4	00.0	00.0	Rejected
12	Fiber Optic Sensors	78.5	00.0	21.5	00.0	Accepted
13	Blockchain	71.4	00.0	28.6	00.0	Accepted
14	Biotechnology	92.9	00.0	07.1	00.0	Accepted

Source: Research Findings

Due to the lack of a general consensus in the first questionnaire, the second questionnaire was also distributed among the experts; Tables 11 and 12 present the results of this round of the second questionnaire.

Table 12. Delphi Questionnaire Round 2 Results (Question 2)

No.	Criterion	Very High	High	Neutral	Low	Very Low	Result
1	Capital Expenditures	85.7	00.0	14.3	00.0	00.0	Accepted
2	Economic Attractiveness for the Private Sector	78.6	14.3	00.0	07.1	00.0	Accepted
3	Technology Dependency on Exchange Rates and Other Volatile Variables in Iran	71.4	14.3	07.1	07.1	00.0	Accepted
4	Amount of Required Fixed Capital	85.7	00.0	14.3	00.0	00.0	Accepted
5	Return on Investment (ROI) Period	71.4	14.3	14.3	00.0	00.0	Accepted
6	Access to Appropriate Equipment	71.4	28.6	00.0	00.0	00.0	Accepted
7	Ease of Technology Acquisition and Access	92.9	07.1	00.0	00.0	00.0	Accepted
8	Logistics and Supply Chain for Required Materials	71.4	14.3	14.3	00.0	00.0	Accepted
9	Availability of Specialized Human Resources	85.7	07.1	07.1	00.0	00.0	Accepted
10	Technology Location and Site Selection	00.0	28.6	00.0	57.1	14.28	Rejected
11	Reduction of Dependency on Other Foreign Technologies	85.7	14.3	00.0	00.0	00.0	Accepted
12	Government Regulations	92.9	00.0	00.0	07.1	00.0	Accepted
13	Government Support for Investment in this Industry	71.4	00.0	14.3	14.3	00.0	Accepted
14	Industry Susceptibility to Sanctions	78.6	00.0	14.3	07.1	00.0	Accepted
15	Job Creation	85.7	00.0	14.3	00.0	00.0	Accepted
16	Contribution to Sustainable Energy Supply	71.4	14.3	14.3	00.0	00.0	Accepted
17	Creating New Capacity in the Country's Production and Refining	85.7	00.0	14.3	00.0	00.0	Accepted
18	Contribution to Diversification of the Country's Energy Portfolio	14.3	71.4	14.3	00.0	00.0	Rejected
19	Destruction of Green Spaces and Natural Resources	71.4	14.3	14.3	00.0	00.0	Accepted
20	Impact of Technology on Environmental Pollution	85.7	07.1	07.1	00.0	00.0	Accepted
21	Industry Energy Intensity	28.6	71.4	00.0	00.0	00.0	Rejected

Source: Research Findings

At the end of the second round and based on the calculations performed, all experts reached a consensus on the removal or acceptance of each criterion, and the Delphi method concluded. Tables 13 and 14, which contain the final list of high-tech industries and the prioritization criteria, are the outputs of the Delphi method.

Table 13. Final List of Selected Technologies

No.	Technology Name
1	Nanotechnology
2	Information Technology
3	Digital Oil Fields
4	3D Seismic
5	Carbon Fiber
6	Big Data
7	Enhanced Oil Recovery (EOR) Methods
8	Robotics
9	Fiber Optic Sensors
10	Blockchain
11	Biotechnology

Source: Research Findings

Table 14. Final List of Selected Technologies

Main Criterion	Sub-criterion
Economic Criteria (1 to 5)	Capital Expenditures
	Economic Attractiveness for the Private Sector
	Technology Dependency on Exchange Rates and Other Volatile and Unpredictable Variables in Iran
	Amount of Required Fixed Capital
	Return on Investment (ROI) Period
Technological Criteria (6 to 11)	Access to Appropriate Equipment
	Ease of Technology Acquisition and Access
	Domestic Demand for Technology
	Logistics and Supply Chain for Required Materials
	Availability of Specialized Human Resources
	Reduction of Dependency on Other Foreign Technologies
Political and Legal Criteria (12 to 14)	Government Regulations
	Government Support for Investment in This Industry
	Industry Susceptibility to Sanctions
Social Criteria (15 to 17)	Job Creation
	Creation of New Capacity in the Country's Production and Refining
	Contribution to Sustainable Energy Supply
Environmental Criteria (18 and 19)	Destruction of Green Spaces and Natural Resources
	Impact of Technology on Environmental Pollution

Source: Research Findings

3.3. Best-Worst Weighting Method

In this method, the Best-Worst weighting is performed by distributing questionnaires to 6 experts and utilizing their opinions. To obtain the optimal weights, the experts' opinions are first collected, and then the weight of each criterion for each expert is calculated by solving the Best-Worst non-linear model using LINGO software. Tables 15 and 16 summarize the results and the analysis of the experts' opinions in this method.

Table15. BWM Weighting Calculations (1)

Expert	B	W	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8	Criterion 9	Criterion 10
1	10	15	0.046	0.090	0.036	0.075	0.035	0.036	0.031	0.056	0.040	0.150
2	4	11	0.055	0.077	0.036	0.073	0.055	0.036	0.044	0.055	0.031	0.132
3	2	16	0.050	0.018	0.043	0.067	0.049	0.043	0.061	0.061	0.040	0.109
4	2	19	0.053	0.110	0.035	0.058	0.049	0.035	0.051	0.056	0.035	0.102
5	8	11	0.054	0.101	0.039	0.045	0.052	0.036	0.056	0.052	0.039	0.102
6	10	17	0.050	0.088	0.040	0.050	0.055	0.040	0.050	0.060	0.040	0.099

Source: Research Findings

Table 16. BWM Weighting Calculations (2)

Expert	B	W	Criterion 11	Criterion 12	Criterion 13	Criterion 14	Criterion 15	Criterion 16	Criterion 17	Criterion 18	Criterion 19	ε^{L^*}
1	2	16	0.033	0.060	0.047	0.050	0.040	0.044	0.046	0.045	0.040	0.21
2	4	11	0.027	0.055	0.055	0.044	0.073	0.036	0.036	0.036	0.044	0.13
3	10	15	0.024	0.047	0.074	0.047	0.070	0.047	0.052	0.049	0.049	0.19
4	2	19	0.017	0.052	0.064	0.050	0.064	0.035	0.049	0.044	0.041	0.20
5	8	11	0.034	0.048	0.058	0.051	0.052	0.039	0.039	0.052	0.051	0.30
6	10	17	0.036	0.049	0.046	0.047	0.061	0.044	0.033	0.052	0.060	0.16

Source: Research Findings

After calculating the weights using each expert's data input, the final weight is obtained by computing the geometric mean of each criterion and subsequently normalizing them. In this stage, to achieve normalization, we divide the weight of each criterion by the sum of all criterion weights. Table 17 presents the final weights derived from the Best-Worst method.

Table 17. Final Weights from the Best-Worst Method

Criterion Number	Criterion Weight	Criterion Number	Criterion Weight	Criterion Number	Criterion Weight
1	0.0522	8	0.0577	15	0.0600
2	0.0718	9	0.0381	16	0.0414
3	0.0388	10	0.1165	17	0.0428
4	0.0615	11	0.0282	18	0.0469
5	0.0496	12	0.0527	19	0.0480
6	0.0383	13	0.0577	-	-
7	0.0487	14	0.0491	-	-

Source: Research Findings

3.3. ITARA Weighting Method

The input for this method is the same as the input for the COCOSO decision-making method, which is utilized in this study. The decision matrix in this research has been completed by 6 experts. It should be noted that the parameter p in the present study is 1, and the indifference threshold for all criteria is considered to be 0. The input for this method is the arithmetic mean of all experts' decision matrices. The final weight of each criterion is calculated using the ITARA method. Thus, the final weights of the ITARA method are calculated as shown in Table 18.

Table 18. Final Weights from the ITARA Method

Criterion Number	Criterion Weight	Criterion Number	Criterion Weight	Criterion Number	Criterion Weight
1	0.0624	8	0.0499	15	0.0499
2	0.0499	9	0.0298	16	0.0624
3	0.0425	10	0.0549	17	0.0624
4	0.0499	11	0.0374	18	0.0748
5	0.0625	12	0.0374	19	0.0624
6	0.0499	13	0.0499	-	-
7	0.0487	14	0.0621	-	-

Source: Research Findings

3.4. Decision Making

In this research, the COCOSO method has been employed for decision-making and ranking the options. The input for this method consists of the decision matrix and the criteria weights. The criteria weights were obtained in Table 17, and the elements of the decision matrix, reflecting the opinions of multiple experts, are the average of the decision matrices from all experts. Table 18 presents the average expert opinions and the decision matrix used in the COCOSO method. Furthermore, Tables 19 and 20 show the parameters required for the decision-making process using the COCOSO method.

Table 19 Average Experts' Decision Matrix

Option/Criterion	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	6.50	6.00	5.33	5.83	7.00	5.33	5.33	7.67	5.83	8.00	7.33	5.83	7.17	8.17	6.17	8.00	6.83	5.33	5.00
2	3.50	6.17	5.33	5.33	7.67	7.50	6.00	5.83	4.83	7.50	7.00	4.00	6.33	5.50	8.00	5.50	6.67	8.50	8.50
3	6.00	6.17	5.67	3.00	8.00	5.50	5.33	8.17	6.33	6.50	8.50	6.50	6.50	4.83	5.67	7.50	7.17	8.17	6.50
4	5.50	5.50	5.33	3.00	8.00	8.00	5.83	8.00	5.5	6.83	7.33	7.33	7.17	5.00	6.33	8.50	8.00	4.50	4.50
5	6.67	6.33	4.33	3.00	8.17	6.83	5.50	8.00	7.00	4.50	5.00	6.50	4.50	6.17	4.50	6.83	5.00	5.50	5.50
6	6.83	5.67	6.33	6.17	5.50	5.00	6.83	6.17	5.00	6.17	6.83	5.00	5.33	7.33	6.33	5.50	6.83	5.33	5.83
7	7.17	7.17	8.00	7.17	8.00	6.17	8.17	6.83	6.33	7.67	6.17	8.00	6.83	7.00	8.00	8.50	8.50	5.50	4.50
8	4.50	6.83	5.33	6.83	6.33	6.83	6.33	5.33	7.33	7.33	7.17	8.00	7.33	5.50	7.33	5.00	5.33	7.17	5.50
9	5.50	5.50	4.17	5.83	7.00	5.33	5.50	7.17	7.00	5.50	7.17	6.33	5.00	5.50	7.17	5.50	6.33	6.50	6.17
10	8.00	8.17	6.17	3.00	5.00	8.00	5.00	6.17	7.33	5.83	4.33	7.00	6.17	8.00	7.33	4.50	4.50	8.50	8.17
11	6.17	6.50	5.83	7.00	5.33	7.00	7.67	8.00	6.83	6.17	7.33	5.33	5.33	6.50	7.33	5.50	5.00	7.67	8.00

Source: Research Findings

Table 20. COCOSO Method Parameter Calculations (1)

Parameter/ Criterion	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Criterion Aspect	Negative	Positive	Negative	Negative	Negative	Positive	Positive	Positive	Positive	Positive	Positive	Negative	Positive	Negative	Positive	Positive	Positive	Negative	Negative
Max_{ij}	8.000	8.16	8.00	7.16	8.16	8.00	8.16	8.16	7.33	8.00	8.50	8.00	7.33	8.16	8.00	8.50	8.50	8.50	8.50
Min_{ij}	3.500	5.50	4.16	3.00	5.00	5.00	5.00	5.33	4.83	4.50	4.33	4.00	4.50	4.83	4.50	4.50	4.50	4.50	4.50
$Max_{ij}-Min_{ij}$	4.500	2.66	3.83	4.16	3.16	3.00	3.16	2.83	2.5	3.50	4.16	4.00	2.83	3.33	3.50	4.00	4.00	4.00	4.00
R_{ij}	0.330	0.18	0.69	0.32	0.36	0.11	0.10	0.82	0.4	1.00	0.72	0.54	0.94	0.00	0.47	0.87	0.58	0.79	0.87
W_{ij}	0.057 9.000	0.06 08.0	0.04 13.0	0.05 62.0	0.05 65.0	0.04 44.0	0.04 94.0	0.05 45.0	0.03 42.0	0.08 12.0	0.03 30.0	0.04 51.0	0.05 44.0	0.05 61.0	0.05 55.0	0.05 16.0	0.05 24.0	0.06 01.0	0.05 55.0

Source: Research Findings

Based on the data in Tables 18 and 19, the required parameters for each option are calculated in Table 21, and the ranking of the criteria is determined.

Table 21. COCOSO Method Parameter Calculations (2)

Option/Parameter	k_{ia}	k_{ib}	k_{ic}	Arithmetic Mean	Geometric Mean	k_i	Rank
1	0.092	2.142	0.973	1.475	1.077	1.069	2
2	0.091	2.116	0.967	1.470	1.068	1.058	4
3	0.091	2.120	0.968	1.470	1.062	1.060	7
4	0.091	2.099	0.963	1.466	1.051	1.051	8
5	0.089	2.000	0.941	1.447	1.009	1.010	11
6	0.090	2.051	0.953	1.457	1.035	1.031	9
7	0.094	2.259	1.000	1.497	1.122	1.118	1
8	0.091	2.116	0.968	1.470	1.063	1.058	6
9	0.090	2.044	0.951	1.456	1.029	1.028	10
10	0.091	2.121	0.968	1.471	1.066	1.060	5
11	0.092	2.147	0.975	1.476	1.074	1.071	3

Source: Research Findings

5. Conclusions

This research provides a comprehensive framework for prioritizing investment in high-tech industries within Iran's oil and gas sector. By integrating Delphi, Best-Worst, ITARA, and COCOSO methods, the study identified 11 key technologies and 19 evaluation criteria. The findings highlight that Enhanced Oil Recovery (EOR) methods, biotechnology, and nanotechnology are the top-ranked priorities for strategic investment, offering the highest potential value based on expert consensus.

The evaluation criteria were rigorously weighted to reflect industry realities, with "Availability of Specialized Human Resources" of weight 0.08117, "Economic Attractiveness for the Private Sector" of 0.06075, and "Destruction of Green Spaces and Natural Resources" of 0.06011 emerging as the most critical factors. These metrics serve as the primary decision-making levers for policymakers, emphasizing the necessity of balancing high-tech economic benefits with environmental and human capital sustainability in the domestic oil and gas infrastructure.

The final prioritization, validated by the COCOSO analysis, establishes a clear roadmap for stakeholders. Technologies such as Blockchain of rank 4 and Digital Oil Fields of rank 5 were also identified as significant areas for development. These results directly answer the research questions, confirming that investment should be directed toward sectors that maximize operational efficiency, economic return, and national energy security, while mitigating the susceptibility of the industry to volatile variables and external sanctions.

For future research, this study suggests narrowing the scope to specific sub-sectors like petrochemicals or refining to achieve greater granularity. Furthermore, investigating emerging technologies beyond current classifications or conducting comparative studies with advanced oil-producing nations could provide valuable models for localization. Finally, exploring alternative mathematical methodologies that reduce the complexity of the expert consensus process while maintaining high analytical rigor remains a promising avenue for subsequent academic and industrial exploration.

Author Contributions

All Authors contributed equally to the conception, preparation, and writing of this manuscript.

Conflict of Interest

M.A. Hatefi, in the capacity of Editor-in-Chief, had no involvement in the selection of reviewers or the management of the peer-review process, and the other authors, while observing publication ethics in referencing, declare the absence of any conflict of interest.

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AI Used Statment

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