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Strategic Foresight for Iran's Oil Refining Industry: Identifying Drivers, Uncertainties, and Development Pathways to 2050

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Highlights

- Application of a mixed-methods futures studies approach integrating PESTEL analysis, Porter's Five Forces, expert interviews, and MICMAC structural analysis to systematically identify the drivers and uncertainties shaping Iran's oil refining industry through 2050.
- Identification of 34 key factors, classified into six domains—political, economic, social, technological, environmental, and legal—as the principal drivers shaping the future design and development of Iran's oil refineries.
- Identification of three uncertainty states for key drivers, including foreign policy scenarios—continued confrontation, eastward alignment, and détente—and energy transition scenarios—accelerated substitution, continuation of current trends, and slowed substitution—which are critical to scenario development.
- Confirmation that domestic governance factors, including state monopoly, administered pricing, and legal uncertainties, constitute the primary barriers to attracting private capital and improving efficiency in Iran's refining sector.

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Abstract

Iran’s oil refining industry, which serves as a backbone of the national economy and supplies more than 95% of the country’s domestic transportation fuel requirements, operates at the intersection of geopolitical challenges, global energy transition dynamics, and growing environmental pressures. Adopting a foresight approach, this study identifies and analyzes the strategic drivers and uncertainties that are expected to influence the design and development of petroleum refineries in Iran through 2050. Using a mixed-methods methodology encompassing a systematic literature review, analysis of international reports from the Organization of the Petroleum Exporting Countries (OPEC), Shell, and the International Energy Agency (IEA), macro-level analysis using PESTEL, micro-level analysis using Porter’s Five Forces, semi-structured expert interviews, and MICMAC structural analysis, 34 key factors were identified and ranked. The findings indicate that the principal drivers shaping the future of Iran’s refining industry include foreign policy, domestic governance, demographic trends, global energy transition dynamics, emerging technologies, environmental regulations, and domestic consumption patterns. Furthermore, the results suggest that environmental pressures, changing demand patterns for petrochemical products, and limited access to advanced technologies collectively underscore the need to transform conventional refineries into integrated petro-refinery complexes. This study provides a dynamic roadmap for policymakers and industry leaders to enhance sectoral resilience, advance decarbonization, and strengthen global competitiveness through the development of integrated petro-refineries, adoption of emerging technologies, and implementation of smart governance, while capitalizing on opportunities arising from the eastward shift in the global energy center of gravity.

Keywords: Futures studies; Iran’s oil refining industry; Strategic drivers; Uncertainties; PESTEL; Porter’s Five Forces; MICMAC; Energy transition

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1. Introduction

Since the advent of petroleum exploration, the oil refining industry has remained one of the world’s largest industrial sectors and a critical component of the global energy supply. The industry emerged in the late nineteenth century, when petroleum began to replace traditional fuels for lighting and power generation. Early refineries were primarily designed to produce kerosene (paraffin); however, the rapid expansion of automobile transportation in the early twentieth century fundamentally transformed the industry’s structure and processes. Technological innovations such as vacuum distillation, thermal cracking, and catalytic cracking enabled the conversion of heavy petroleum fractions into higher-value products. During the latter half of the twentieth century, increasingly stringent environmental regulations compelled refineries to adopt processes such as desulfurization, hydrocracking, and sulfur removal, thereby expanding the industry’s role in supplying feedstocks for the petrochemical and polymer industries.

Given that the petroleum industry, particularly the refining sector, remains a major component of the global energy system, its examination through forward-looking governance and policymaking frameworks is critically important. Reports from international institutions indicate that the refining industry has recently undergone profound and rapid structural transformation driven by several major forces. The first is the expansion of refining capacity in emerging regions. In recent decades, Asia, particularly China and India, and the Middle East have substantially increased their shares of global refining capacity, rising from 18% in 2000 to 33.8% in 2024 (Asia-Pacific Energy Research Centre, 2025). This expansion has generally involved larger-scale facilities equipped with advanced technologies, thereby intensifying competition in global petroleum product markets. At the same time, aging refineries in Europe and North America have faced stagnant demand and high operating costs, compelling many facilities to cease operations or convert into storage facilities or renewable energy hubs. Refining capacity in Organization for Economic Co-operation and Development (OECD) member countries is expected to decline by 2.8 million barrels per day between 2008 and 2024 (OPEC, 2023). The World Oil Outlook 2050 further projects that, by 2030, approximately 90% of global refining capacity additions will occur in Asia, Africa, and the Middle East. This trend is particularly significant given that China and India's combined share of global oil consumption increased from 9% in 2000 to 21% in 2024 (International Energy Agency [IEA], 2024). Collectively, these developments indicate a fundamental eastward shift in the geographical center of gravity of the refining industry, thereby reshaping future competitive dynamics.

The second major trend is the changing pattern of demand for petroleum products. Although demand for conventional transportation fuels, such as gasoline, is declining in developed economies because of increasing electric vehicle penetration, demand for petrochemical products and jet fuel continues to grow. The International Energy Agency (IEA, 2025) projects that, from 2026 onward, the petrochemical sector will become the primary driver of global oil demand growth. This paradigm shift is transforming refineries from conventional fuel producers into integrated energy and petrochemical complexes. The transition is driven by the higher profitability and value-added potential of petrochemical products relative to traditional fuels, underscoring the urgent need to redesign Iran's refining operations toward greater production of petrochemical products.

In Iran, approximately one million barrels per day of crude oil or equivalent energy carriers are currently consumed as feedstock by the petrochemical industry through refinery products, gas-processing outputs, and associated gas recovery (National Petrochemical Company of Iran, 2024). In 2024 (Persian calendar year 1403), Iran's petrochemical production capacity reached 96 million tons; however, actual production amounted to only 75.2 million tons, indicating that approximately one-fifth of installed capacity remained underutilized because of feedstock shortages. Consequently, several measures have been proposed to address this constraint, including modifying refinery product slates, substituting natural gas for fuel oil, participating in upstream field development, recovering flare gas, and optimizing fuel consumption (Ministry of Petroleum, 2024).

Another major transformation affecting the refining industry is the intensification of environmental regulations and decarbonization policies. International agreements and increasingly stringent fuel standards require refineries to reduce emissions, improve energy efficiency, and invest in cleaner technologies. These structural changes, combined with the high capital intensity of refinery projects, have increased investment risks and accelerated the transition toward more integrated, flexible, and resilient refining systems.

Iran, which possesses the world's third-largest proven crude oil reserves, estimated at 157 billion barrels, accounts for 8.5% of refining capacity in the Middle East (OPEC, 2023). With a nominal refining capacity of 2.2 million barrels per day, Iran's refining industry constitutes a cornerstone of national energy security and economic stability, supplying approximately 95% of domestic transportation fuel requirements (Fattouh and Mahadeva, 2013) and generating approximately $18 billion in annual value added (International Energy Agency [IEA], 2023). However, the industry currently faces numerous challenges that make its sustainable development increasingly imperative. One of the most pressing challenges is the relatively low Nelson complexity index (NCI) of Iranian refineries. The NCI is a widely used benchmark for assessing and comparing refinery complexity and reflects a facility's capability to convert lower-value crude oil fractions into lighter, higher-value products such as gasoline, diesel, and petrochemical feedstocks. Higher NCI values indicate greater process sophistication and conversion capability. Iranian refineries have an average NCI of approximately 7.5, with older facilities typically ranging from 5 to 6 and modern complexes such as the Persian Gulf Star Refinery approaching 10. In comparison, advanced integrated petro-refineries in North America, Europe, and East Asia generally achieve NCI values of 10–12, while highly complex facilities in Singapore and South Korea exceed 12. Such high levels of complexity enable the conversion of more than 50% of each barrel of crude oil directly into chemicals and other high-value products (Hydrocarbon Processing, 2023; NIOPDC, 2022).

Iran's geographical advantages, access to abundant crude oil reserves, and existing infrastructure provide substantial potential for the country to become a regional hub for oil and gas refining and distribution. Nevertheless, the sector is expected to face unprecedented challenges and opportunities in the coming decades. These include the global energy transition toward reduced dependence on fossil fuels, which is projected to decrease global demand for petroleum products by 30% by 2040 (IEA, 2023); the expansion of renewable energy; increasingly stringent environmental regulations and climate change commitments, such as those associated with the Paris Agreement; restricted access to advanced technologies and foreign investment (Farzanegan, 2019); volatility in global oil and gas markets; rapid advances in clean energy and digital technologies; persistent international sanctions; and delays in deploying carbon capture, utilization, and storage (CCUS) and green hydrogen technologies (Mohammadi and Ghazinoory, 2021). Collectively, these developments necessitate a fundamental reassessment of refinery design, development, and modernization strategies (Farzin, 2020; OPEC, 2022). The future trajectory of Iran's refining industry will not only have critical implications for national energy security and economic stability but will also play a pivotal role in achieving the country's long-term development goals.

In this context, futures studies represent not merely an optional analytical approach but an important strategic consideration. As Bell (1996) emphasizes, "the future is not the product of an inevitable past; rather, it is a domain of plural possibilities shaped by driving forces and critical uncertainties." The petroleum industry, particularly the refining sector, is no exception to this principle. Given its central role in the global economy and in the development of petroleum-exporting countries, anticipating future changes and preparing appropriate responses have long been major concerns for energy organizations and petroleum companies. Recognizing the challenges facing Iran's refining industry, the accelerating pace of environmental change, and increasing levels of uncertainty, this study applies futures studies methodologies to identify and analyze the strategic drivers and uncertainties influencing the design and development of Iran's oil refineries through 2050 (Persian calendar year 1430). By mapping prospective scenarios, the findings may assist managers and policymakers in selecting appropriate development pathways.

This study contributes to the literature on strategic foresight in the refining industry in three principal dimensions. First, it integrates futures studies methodologies, including PESTEL analysis, Porter's Five Forces, expert interviews, and MICMAC structural analysis, to identify and evaluate the major drivers and uncertainties shaping Iran's refining industry through 2050. Second, it provides a structured analytical framework for examining the transition from conventional fuel-oriented refineries to integrated petro-refinery systems under conditions of energy transition and geopolitical uncertainty. Third, the study offers policy-relevant insights into the governance, technological development, investment conditions, and environmental requirements that may influence the industry's long-term development pathways. By combining qualitative, expert-based assessments with structural analysis, the study provides a comprehensive perspective on the future evolution of refining industries in developing economies.

To identify macro-level trends and ongoing transformations, a systematic review of institutional reports and scholarly literature was conducted to determine the drivers and strategic uncertainties affecting refinery design and development. During this phase, publications from reputable international organizations and relevant academic sources were systematically examined and analyzed. Reports from international institutions indicate a broad consensus regarding the expansion of clean energy deployment and the increasing stringency of environmental regulations affecting the petroleum industry. For example, the International Energy Agency (IEA, 2024) emphasizes that investment in clean energy is accelerating substantially and that its benefits extend beyond climate change mitigation to include lower operating costs and enhanced energy security.

The knowledge contribution of this study can be characterized at five levels: methodological, through the integration of expert intuition with MICMAC structural analysis for scenario planning; content-related, through the transition from a fuel-centric to a product-centric paradigm based on the crude-oil-to-chemicals (COTC) concept and the integration of refining and petrochemical operations; analytical, through the identification of 34 factors and eight key drivers using an integrated PESTEL and Porter's Five Forces framework; practical, through the development of a four-layer gap analysis and a roadmap for future product development; and validation, through the application of Wilson's criteria and Cronbach's alpha. Collectively, these contributions establish a common analytical language between futures studies researchers and process engineers and provide a basis for revising the 2030 vision of Iran's refining industry.

More broadly, the principal knowledge contribution of this research lies in bridging futures studies and process engineering. The findings indicate that the future competitiveness of Iran's refining industry depends not primarily on expanding physical refining capacity, but on increasing refinery complexity and improving the intelligence of product portfolio selection based on scenario-driven decision making. This represents a novel step toward strengthening the scientific and competitive position of Iran's oil industry at the international level. In summary, through methodological innovation involving the integration of expert intuition and structural analysis, content-related innovation involving the development of original scenarios with particular emphasis on a surprising or wild-card scenario, and practical innovation involving gap analysis and the formulation of a development roadmap, this study contributes to both the futures studies literature on Iran's oil industry and the broader literature on sustainable industrial development in developing countries.

2. Literature review

Following the examination of international institutional reports, this study systematically reviewed an extensive body of scholarly literature addressing the future of the oil refining industry and the factors influencing refinery design and development. The review indicates that a substantial share of the existing literature examines the future of refining within the broader context of macro-level energy transitions and the evolving role of refineries in the hydrocarbon value chain. At the same time, many studies identify climate change and increasingly stringent environmental regulations as major drivers of transformation in the refining sector, emphasizing the need to reduce pollutant emissions, improve energy efficiency, and align refinery operations with decarbonization policies.

Several studies have examined alternative strategies for mitigating regulatory and environmental pressures on refineries. For example, Park et al. (2021) investigated the effects of environmental regulations, particularly the mandatory installation of scrubbers on maritime vessels, on refinery product slates and concluded that such regulations could fundamentally alter the refining landscape of the European Union. Scarbrough (2022) demonstrated that decarbonization policies can create both challenges and opportunities for refineries. By examining the short-term biofuel and hydrogen programs of five major European oil companies, the study reported that European refineries are increasingly investing in biofuel pathways as integral components of their decarbonization strategies. The study further noted that decarbonization is fundamentally transforming traditional refinery business models and redirecting investment toward renewable energy, biofuels, and hydrogen.

Another body of research has focused on the role of emerging technologies, including digitalization, process automation, low-carbon technologies, and novel refining processes, identifying them as critical factors in enhancing the flexibility and competitiveness of future refineries. Olaizola et al. (2022) reviewed the challenges and opportunities associated with the Industry 4.0 paradigm, which is characterized by the extensive integration of digital technologies into industrial and manufacturing processes, in the downstream oil and gas sector. Their analysis examined the effects of artificial intelligence (AI) on productivity enhancement, production optimization, maintenance improvement, and the feasibility of intelligent operations. The authors emphasized the substantial potential of digital technologies to optimize refinery operations, improve energy management, and enhance fault detection.

Other studies examining energy market transformations have focused on long-term shifts in demand patterns for refined products, highlighting the gradual decline in demand for conventional fossil fuels and the increasing importance of higher-value-added products. In this context, the transition from fuel-oriented refineries to integrated petro-refinery complexes has emerged as a strategic trend intended to diversify product portfolios, strengthen economic resilience, and mitigate risks associated with fuel market volatility. Murphy and Payn (2019) examined the future of refining from the perspective of refinery–petrochemical integration. By investigating innovative approaches to crude-to-chemicals conversion, they identified this transition as a key driver of future refinery design and introduced technological pathways capable of significantly improving the profitability and flexibility of integrated refining–petrochemical complexes. Similarly, Al Abdullah et al. (2020) focused on direct crude-oil-to-chemicals operations and examined technological developments that enable refineries to shift from fuel production centers toward the manufacture of petrochemical products. They concluded that achieving this transition depends on the development of advanced catalysts and novel integrated processes capable of maximizing the yields of light olefins and other petrochemical products.

Overall, the literature demonstrates that the future of the oil refining industry and refinery development is shaped by a broad range of environmental, technological, economic, and market-related drivers. Understanding these factors and their associated uncertainties is therefore essential for identifying plausible refinery development pathways over long-term horizons.

From a futures studies perspective, extensive research has focused on identifying the key factors shaping the industry's future and developing scenarios for the refining and broader energy sectors in Iran and worldwide. Ghasemian et al. (2024) employed expert judgment and cross-impact analysis to investigate global energy scenarios through 2040 and identify the principal driving forces. The study identified ten critical drivers shaping the global energy system through 2040: population growth rate as a social factor; climate change as an environmental factor; infrastructure investment, financial shocks, consumer behavior, and energy efficiency as economic factors; global governance and geopolitical relations as political factors; and technological development in renewable energy and the upstream oil and gas sector as technological factors. The authors further emphasized that refinery design and development are profoundly influenced by the complex interactions among these driving forces.

Several studies have also examined the future of Iran's oil and energy industry. Ghodusinejad et al. (2022) developed a scenario-based model for Iran's energy future to identify the underlying assumptions, driving forces, and key uncertainties capable of shaping the country's energy landscape. Considering political, technological, and environmental dimensions, the authors proposed four future scenarios, each representing a distinct trajectory for Iran's energy system, including the potential expansion of renewable energy utilization and reduced dependence on fossil fuels. They further projected a decline in fossil fuel-based energy production in Iran from 2019 onward. Ghalambor (2024) specifically developed four scenarios for the future of Iran's petrochemical industry and demonstrated that Iran's foreign policy, characterized by extensive versus limited global engagement, and government economic policies, characterized as intelligent versus unstable, represent the most influential and uncertain drivers shaping the industry's future. Other important factors include financial and technological sanctions, technological advances, the substitution of fossil fuels with renewable energy, and global oil prices. An overview of the principal findings obtained from the peer-reviewed literature and supporting documents is provided in Table 1.

Table 1

Summary of key findings from the reviewed articles and documents

Source	Primary objective and methodology	Key findings	Implications
Organization of the Petroleum Exporting Countries (2025), World Oil Outlook	Provides a long-term outlook for global oil markets and refinery capacity development through 2030 using statistical forecasting and analysis of investment trends.	More than 90% of new refining capacity additions through 2030 are projected to occur in Asia, Africa, and the Middle East. Global refining capacity is expected to increase by approximately 5.8 million barrels per day by 2030.	The concentration of refining capacity expansion in emerging regions is expected to intensify competition in global petroleum product markets and exert increasing pressure on the profitability of legacy refineries.
International Energy Agency (2023), World Energy Outlook	Examines global energy trends and the transition toward cleaner energy systems through scenario development and policy analysis.	he transition toward clean energy is accelerating at an unprecedented pace, driven by the rapid expansion of electric vehicles and renewable energy technologies. Renewable energy sources are projected to account for nearly 50% of global electricity generation.	The accelerating energy transition is expected to slow the growth of fossil fuel demand in the transportation and power sectors, thereby influencing long-term refinery investment strategies.
International Energy Agency (2025), Oil 2025	Evaluates the current status of the global oil market and its outlook through the end of the decade using comprehensive supply–demand analysis, with particular emphasis on the energy transition and refining trends.	Global oil demand is expected to plateau by 2030. While demand growth for traditional transportation fuels is projected to decline, petrochemicals are expected to become the primary source of incremental oil demand growth.	Excess growth in refining capacity relative to demand in Asia is likely to accelerate the closure of high-cost refineries in Europe and North America, thereby intensifying competition in global petroleum product markets.
International Energy Agency (2025), Economic Pathway Report on Petrochemical Transition	Investigates the structural shift in global oil demand from transportation fuels toward petrochemicals based on International	By 2023, petrochemicals accounted for nearly one-quarter of global oil demand growth, while growth in gasoline and diesel demand remained constrained by	The increasing role of petrochemicals presents a strategic challenge for conventional refineries, particularly as a growing share of petrochemical

Source	Primary objective and methodology	Key findings	Implications
	Energy Agency (IEA) projections using statistical and trend analyses.	improvements in fuel efficiency.	feedstocks may be derived from natural gas rather than crude oil.
Meeno et al. (2017), A Process Framework for Identifying Uncertainties and Drivers (Case Study: Oil and Energy)	Develops a systematic framework for the rapid identification of uncertainties and driving forces through literature review, content analysis, and expert consultation.	Three major uncertainties were identified in the energy sector: the relationship between economic growth and energy dependence, the technological competitiveness of renewable energy, and the future configuration of global energy markets.	Systematic identification of strategic uncertainties and driving forces provides a robust foundation for scenario planning and enhances organizational preparedness for alternative futures.
Rezayan Ghayehbashi et al. (2024), Identifying and Managing Strategic Drivers for Crude Oil Export Cessation in Iran to Horizon 2035	Identifies the key drivers and uncertainties affecting Iran's strategy for terminating crude oil exports over a 15-year horizon through literature review and expert assessment.	Seven strategic drivers were identified from an initial set of 64 key factors.	Expansion of investment in the refining and petrochemical industries was identified as a critical enabler for reducing dependence on crude oil exports.
Murphy, J. J. and Payn, C. F. (2019)	Examines innovative approaches to integrating refineries with petrochemical complexes, particularly crude-to-chemicals technologies, through technological and process analysis.	Crude-to-chemicals conversion technologies were identified as a major driver shaping the future design of refineries.	Technological integration can significantly enhance refinery profitability and operational flexibility by shifting production toward higher-value chemical products rather than conventional fuels.
Ghasemian et al. (2024)	Conducts a comparative analysis of global energy scenarios through 2040 and identifies key driving forces using cross-impact analysis.	Ten major driving forces shaping the future global energy system were identified.	Refinery development strategies will increasingly depend on the dynamic interactions among climate change, technological innovation, geopolitical relations, and advances in renewable and upstream energy technologies.
Ghalambor (2024)	Develops future-oriented scenarios for Iran's petrochemical industry to identify key drivers, uncertainties, and alternative development pathways.	Iran's foreign policy orientation and the stability of government economic policies emerged as the most influential and uncertain drivers affecting the petrochemical sector. Other influential factors included sanctions, technological	The findings underscore the critical role of geopolitical and macroeconomic stability in shaping the long-term trajectory of Iran's petrochemical industry.

Source	Primary objective and methodology	Key findings	Implications
		advances, fossil fuel substitution, and global oil prices.	
Amiri, H. and Nilipour Tabatabaei, S. A. (2021)	Investigates uncertainties influencing the future role of crude oil in Iran's economy using futures studies approaches, environmental scanning, and cross-impact analysis.	Thirty-five drivers were identified, among which international engagement patterns, renewable energy penetration, and oil prices emerged as critical uncertainties.	Four alternative scenarios for the future of Iran's crude oil sector through 2035 (Persian calendar year 1414) were developed based on these strategic uncertainties.
Status of Iranian Refineries and Nelson Index (Hydrocarbon Processing, 2023; NIOPDC, 2022)	Assesses the operational status of Iranian refineries and compares their Nelson complexity index (NCI) values with global benchmarks through expert interviews and industry analysis.	Iranian refineries remain substantially below international complexity standards, with an average Nelson complexity index of approximately 6, compared with nearly 14 for advanced refineries.	Even under favorable financing conditions, substantial refinery modernization would remain unattainable without access to advanced technologies, representing a fundamental structural challenge for the sector.

3. Methodology

3.1. Research design

This study employed a mixed-methods research design that combined qualitative, expert-based assessments with quantitative cross-impact analysis using MICMAC software (Amer et al., 2020). Qualitative data were obtained from the literature review, expert interviews, and panel discussions, whereas the quantitative component involved assessing the influence and interdependence of key factors through structural analysis. This integrated approach enabled the identification and evaluation of the major drivers and uncertainties shaping the future of Iran's oil refining industry. Furthermore, the theoretical framework of this study is grounded in the futures studies literature and the prevailing assumptions within this field.

The MICMAC method (Matrice d'Impacts Croisés Multiplication Appliquée à un Classement, or cross-impact matrix multiplication applied to classification), developed by Godet in the 1980s, is a foundational structural analysis method in futures studies and strategic foresight (Arcade et al., 1999). This method examines the complex relationships among system variables through cross-impact analysis and matrix algebra. It evaluates the influence and dependence of each variable and classifies the variables into four distinct groups: bipolar variables (strategic goals), influential variables (drivers), linkage variables (relay variables), and output variables (dependent variables). In scenario development and strategic foresight, MICMAC helps reduce systemic complexity and identify key drivers, defined as variables exerting the strongest direct and indirect influences on the system's future evolution. These drivers subsequently serve as the foundation for scenario planning (Zinati and Maleki, 2024).

3.2. Data collection and analysis methods

This study employed a combination of data collection and analytical methods, including a systematic literature review, semi-structured interviews, questionnaires, expert panels, cross-impact analysis, and MICMAC software to identify and analyze key factors and drivers. Analytical frameworks such as PESTEL analysis and Porter's Five Forces were also applied.

3.3. Research Procedure

The research was conducted in three stages:

1. Environmental scanning
2. Key factor analysis and driver identification
3. Evaluation of drivers and associated uncertainties

Stage One: Environmental scanning. This stage aimed to identify and clearly define the research problem and extract the key factors affecting the future of the refining industry. A literature review and the identification of authoritative sources constituted the primary information sources for the environmental scanning process, the results of which served as the main input for the futures studies exercise. During this stage, reports published by reputable international organizations, including the International Energy Agency (IEA), OPEC, and other relevant institutions, were examined and analyzed to identify trends and weak signals of change in the refining industry. The findings led to the incorporation of keywords such as "decarbonization," "petro-refinery," and "environmental requirements" into the search strategy, followed by a review of relevant scholarly research. The principal output of this phase was the identification and extraction of influential key factors. However, the identification of driving forces was not considered complete at this stage. To identify potentially overlooked factors, several semi-structured interviews were conducted with selected experts using structured questionnaires. The participants included managers and university professors active in the fields of oil, refining, and economics. Given the specialized and complex nature of the research topic, experts were selected through purposive sampling from among specialists in Iran's energy, refining, and petrochemical industries who had at least ten years of relevant executive or research experience. Interviews continued until theoretical saturation was achieved. These interviews resulted in the identification of several additional key factors, which were incorporated into the existing set.

Stage Two: Driver identification. Schwartz's (1991) scenario model was used to identify the principal drivers. At this stage, the extracted driving forces were reviewed and evaluated by an expert panel comprising the authors. Subsequently, a questionnaire was developed in which experts were asked to assess the degree of influence and uncertainty associated with each factor using a Likert scale. Based on the average scores, the most important key factors, defined as those exhibiting the highest levels of influence and uncertainty, were identified as principal factors. These factors were then reviewed by the expert panel and grouped thematically to identify and formulate the drivers shaping the future of the refining industry. In addition, cross-impact analysis using MICMAC software was conducted to examine the relationships among the key factors and further assess the robustness of the identified drivers.

Stage Three: Driver evaluation. The identified drivers were reviewed and evaluated, and the uncertainties associated with each driver over the study horizon were determined. The principal outcome of this stage was the identification of the most important drivers and strategic uncertainties influencing the design and development of Iran's oil refineries through 2050.

3.4. Justification for the 2050-time horizon

Following the formulation of Iran's first 20-year vision document, Vision 2025, in 2004 and its implementation beginning in 2005, a formal framework for long-term planning and futures studies became established within Iran's governance system. With the conclusion of this first 20-year vision in 2025, policymakers and planners have begun efforts to formulate the country's next long-term vision toward 2050 (Islamic Parliament Research Center, 2021). In developing this vision, strategic sectors such as oil, gas, petrochemicals, and energy, which constitute key components of Iran's industrial infrastructure, should receive priority commensurate with national conditions and evolving global trends.

Given the inherently global nature of the energy industry, long-term policymaking and strategic planning must account for international trends and regional market developments. A review of reports and strategic documents published by major international institutions and energy companies, including Shell (2023), BP (2024), ExxonMobil (2023), the International Energy Agency (IEA, 2023), Saudi Aramco (2023), and TotalEnergies (2023), indicates that the 2050 horizon receives substantial attention in long-term energy planning. Accordingly, 2050 was selected as the time horizon for this study. Moreover, the energy, oil, gas, and petrochemical industries are characterized by substantial structural inertia because of their phased and complex development processes, high capital requirements, and lengthy project implementation periods. Consequently, the implementation of major strategic changes and corrective measures requires a long-term planning horizon.

4. Findings

This research commenced with environmental scanning as the first stage. The primary objective of this stage was to identify the driving forces or key factors influencing Iran's oil and refining industry. According to Marzban et al. (2018), key factors are important variables in the surrounding environment that can significantly shape future options. Their systematic and rigorous identification therefore requires a structured analytical process. To this end, a comprehensive literature review was conducted. Reports published by reputable international organizations, including the International Energy Agency (IEA) and OPEC, were examined and analyzed to identify trends and weak signals of change in the refining industry. During this phase, the reviewed reports and related scholarly articles placed considerable emphasis on factors such as the energy transition toward renewable sources, decarbonization, the shift of refineries toward the joint production of petrochemical materials and refined products through petro-refinery configurations, and increasingly stringent environmental requirements related to fuel quality standards. Accordingly, the search strategy was expanded to include these keywords.

Concurrently with the literature search, key factors were identified using two analytical frameworks: PESTEL analysis for macro-environmental factors and Porter's Five Forces for factors related to the internal competitive environment of the refining industry. In the subsequent step, expert interviews were conducted to identify potentially overlooked factors. Semi-structured interviews were carried out with experts from the oil refining, petrochemical, and economic sectors. The factors identified through these procedures were then categorized according to the PESTEL and Porter frameworks. This process initially yielded 88 factors from the PESTEL analysis and 29 factors from Porter's Five Forces analysis. These factors were subsequently reviewed by an expert panel. After duplicate items were removed and factors with overlapping content were consolidated, a final list of 95 key factors was prepared. In futures studies that rely on collective intelligence and expert judgment, the expertise and diversity of participants are important determinants of the quality and robustness of the resulting scenarios.

To ensure comprehensiveness and minimize narrow disciplinary bias, explicit criteria were established for expert selection. The first criterion was recognized scientific or practical expertise in at least one of the principal disciplines relevant to the study. These disciplines comprised six specialized fields: futures studies, energy economics, chemical engineering with specialization in oil, refining, petrochemicals, or gas, strategic management, industrial sociology, and energy law. The second criterion was sufficient familiarity with the research topic, particularly governance and the future of the refining industry. Based on these criteria, an initial pool of experts was identified and subsequently expanded and refined using snowball sampling, beginning with a group of knowledgeable informants.

In total, 36 individuals, including university professors, senior managers from the oil and petrochemical industries, directors of major refining projects, and distinguished researchers, were selected to form the study's expert pool. Of these, 34 actively participated in various stages of questionnaire completion, including assessments of the importance and uncertainty of key factors and cross-impact analysis. The participant composition was designed to achieve a balanced representation of inside-industry experts, including senior managers and specialists from the Ministry of Petroleum, the National Iranian Oil Refining and Distribution Company (NIORDC), and the National Petrochemical Company (NPC), and outside-industry experts, including university professors, academic researchers, and independent consultants. This diversity facilitated the integration of complementary perspectives and reduced the potential for organizational bias.

For the more demanding phases of the research, including specialized expert panels, participants were selected from the 36-member expert pool based on their level of engagement with the subject and their combined managerial and analytical expertise. These groups included a 20-member panel tasked with identifying the principal driving forces and a 12-member panel responsible for scenario validation. Panel sessions were conducted in person and lasted approximately three hours on average. During these sessions, the findings derived from the questionnaires and MICMAC analyses were discussed, reviewed, and finalized. Based on our interpretation of the data, Figure 1 provides a categorized outline of the principal factors.

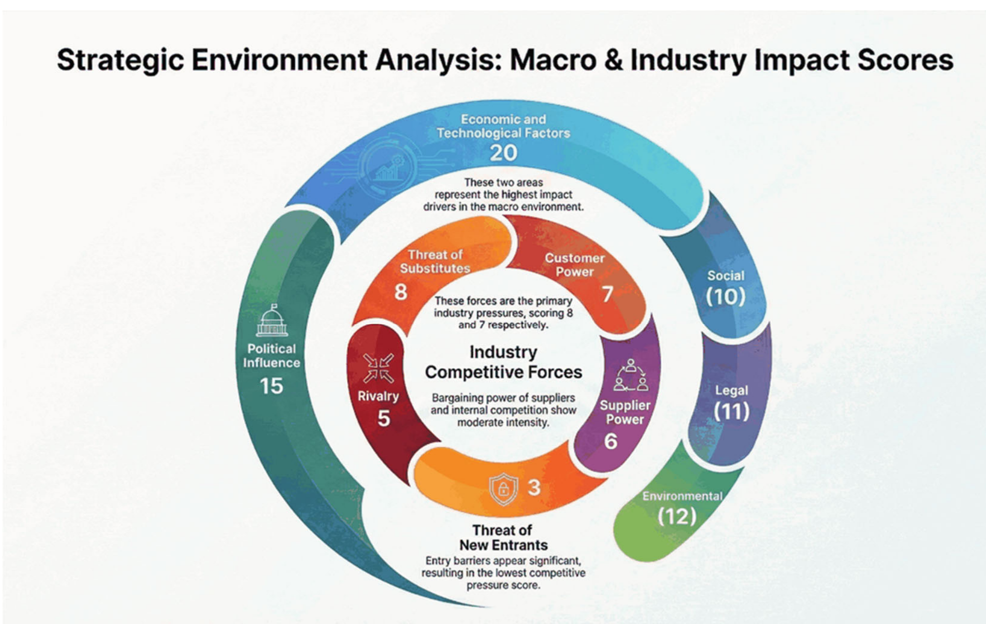

Figure 1

Categorization of key factors (Authors' elaboration based on research findings)

The second stage of this research focused on identifying the strategic drivers influencing the design and development of Iran's oil refineries through 2050. Drivers are primary forces of change that can play both constructive and disruptive roles in futures analysis. Their constructive role lies in providing insights into plausible futures, whereas their disruptive role involves challenging prevailing assumptions about current conditions (Hines and Bishop, 2006).

To this end, a questionnaire based on a five-point Likert scale was designed to evaluate and rank the 95 key factors identified during the environmental scanning phase. The questionnaire assessed each factor according to two criteria: importance, defined as the degree of its potential impact on the industry, and uncertainty, defined as the degree of ambiguity associated with its future occurrence or development. The results therefore enabled the identification of factors characterized by both a high potential impact on the future of the refining industry and a high level of uncertainty.

To evaluate the questionnaire results, the mean importance and uncertainty scores were plotted on a coordinate plane, with importance represented on the x-axis and uncertainty on the y-axis. Factors with mean scores above 4.5 for both importance and uncertainty were selected as the final key factors. Accordingly, 34 of the initial 95 factors were identified as the principal factors shaping the future of Iran's oil refining industry. These factors were classified into six categories: political, economic, social, technological, environmental, and legal, as presented in Table 2.

Subsequently, the 34 key factors were re-examined by an expert panel to identify the underlying strategic drivers. Based on their thematic content and shared conceptual foundations, factors with similar characteristics were grouped together. This process resulted in the classification of the 34 factors into 8 principal driver categories.

Table 2

Key factors identified as principal drivers shaping the future of Iran's oil refining industry

Row	Factor description	Code
1	International sanctions and foreign policy: Restrictions on oil exports, technology transfer, and access to international capital markets.	P1
2	National macro-energy policies: Strategic prioritization of exports, refinery development, and fuel self-sufficiency.	P2
3	Government monopoly in the oil industry: Centralized ownership and decision-making structures within the National Oil Company.	P3
4	Global energy transition: The worldwide structural transition from fossil fuels toward renewable and low-carbon energy systems.	P4
5	Attraction of major international companies: Access to foreign investment, advanced technologies, and international expertise.	P5
6	Development of relations with allied countries: Access to secure export destinations and alternative channels for technology acquisition.	P6
7	Economic stability: Inflation and exchange-rate volatility affecting investment costs and project profitability.	EC1
8	Domestic demand for transportation fuels: Consumption of gasoline and diesel in the transportation sector.	EC2
9	Development pattern of the refining and petrochemical industries: Expansion of integrated refinery–petrochemical complexes and enhancement of the hydrocarbon value chain.	EC3
10	Product profitability: Refining margins and value added per barrel relative to crude oil input.	EC4

Row	Factor description	Code
11	Global energy demand patterns: Structural shifts toward natural gas, renewable electricity, and low-carbon fuels.	EC5
12	Administrative pricing of energy carriers: Government regulation and control of fuel and petrochemical feedstock prices.	EC6
13	Global crude oil prices: Effects of crude oil prices on project economics, revenues, and the feasibility of refinery investments.	EC7
14	Investment in the refining and petrochemical industries: Mobilization of financial resources for modernization and capacity expansion.	EC8
15	Availability of fossil fuel resources: Access to low-cost crude oil and natural gas feedstocks.	EC9
16	Investment security index in Iran: Exposure of domestic and foreign investors to political and economic risks.	EC10
17	Social pressure for fuel quality improvement: Public demand for cleaner fuels and reduced air pollution.	S1
18	Expansion of demand management and an energy conservation culture: Reduction of energy losses and improvement of consumption efficiency.	S2
19	Population growth: Increasing domestic demand for petroleum products and overall energy consumption.	S3
20	National refining capacity: Total national refining and processing capacity, measured in barrels per day.	T1
21	National energy consumption patterns: Energy intensity and the sectoral distribution of energy demand.	T2
22	Recycling industry and circular economy: Conversion of plastic and industrial waste into petrochemical feedstocks.	T3
23	Optimization of national energy systems: Improvement of energy conversion efficiency and supply-chain performance.	T4
24	Expansion of alternative energy consumption: Declining dependence on petroleum products across economic sectors.	T5
25	Digitalization (Refinery 4.0): Integration of the Internet of Things (IoT), artificial intelligence (AI), and smart technologies into refinery operations.	T6
26	Complexity index of Iran's refineries: The Nelson complexity index (NCI), crude oil conversion depth, and product diversification capability of Iranian refineries.	T7
27	Emerging refining technologies: Advanced conversion technologies, including methane-to-olefins and crude-to-chemicals processes.	T8
28	Demand for petrochemical products driven by emerging technologies: Growing demand for petrochemical feedstocks in the electronics and advanced materials industries.	T9
29	Emergence of energy-intensive technologies: Increasing electricity demand and the continued need for liquid fuels in advanced industries.	T10
30	Global climate change: Increasing international pressure to reduce greenhouse gas emissions and environmental impacts.	EN1
31	Global decarbonization requirements: Implementation of increasingly stringent carbon emission standards and low-carbon regulations.	EN2
32	Dependence on fossil fuels: The share of fossil fuels in the national energy portfolio.	EN3
33	National development requirements: Strategic national plans, five-year development programs, and long-term energy visions.	L1
34	Environmental requirements and regulations: Regulatory limits on refinery emissions, including SO_x and NO_x.	L2

4.1. Stage three: driver mechanism evaluation and uncertainty identification

The third stage involved evaluating the operational mechanisms of the identified drivers and determining their associated uncertainties over the research horizon. At this stage, the mechanism through which each driver influences the refining industry was first specified based on the environmental scanning results, after which the uncertainties associated with each driver were identified based on expert judgments.

4.1.1. Foreign policy

As the country's largest source of foreign exchange revenue, Iran's oil industry has long been situated at the intersection of economic policy and foreign policy. Decisions made by external actors, sanctions mechanisms, policies governing foreign investment, and energy diplomacy can significantly affect production capacity, technology transfer, and long-term investment in both the upstream and downstream oil sectors. The available evidence indicates that foreign policy and international relations are not merely external environmental variables but rather fundamental determinants of the industry's development trajectory, operating through multiple channels.

The primary channel through which foreign policy affects the oil industry is international sanctions. Sanctions, particularly those targeting oil exports and financial transactions, have restricted Iran's access to international markets, multinational investment, and supply chains for advanced equipment and technologies. As a result, development projects may experience delays, increased costs, and reduced technical quality. In addition, stability and predictability in foreign policy are essential prerequisites for long-term investment. Uncertainty in international relations, such as the possibility of intensified sanctions, increases the cost of capital and discourages multinational companies from entering the Iranian market. At the national level, these conditions can reduce potential production capacity and contribute to technological lag. Based on the expert panel assessments, three possible states were identified for this driver.

4.1.2. Continued confrontation and sanctions

If the current pattern of confrontation persists without the emergence of alternative pathways, intensified sanctions are expected to create substantial challenges for the refining industry, particularly in terms of access to advanced technologies, equipment, and investment. Over time, these constraints could contribute to the gradual technological obsolescence of the refining sector. Under this scenario, the domestic development and localization of critical equipment and technologies would become essential to maintaining the industry's operational continuity and long-term viability.

4.1.3. Expansion of relations with the east

The expansion and deepening of relations with countries less constrained by sanctions, particularly China and Russia, through mechanisms such as the 25-Year Comprehensive Cooperation Agreement with China, the Comprehensive Strategic Partnership with Russia, and cooperation with other aligned countries, could help sustain investment flows and exports, although these would likely remain limited and conditional. Through energy diplomacy and bilateral agreements, this approach could facilitate access to technology and export markets through non-Western channels, while also introducing distinct geopolitical costs and risks. Under this scenario, the production and export of refined fuel products, particularly to neighboring countries, together with the supply of feedstock to domestic petrochemical complexes, could provide important sources of revenue for the refining industry.

4.1.4. Détente

In this state, a shift in foreign policy would place Iran's relations with Western countries and neighboring states on a trajectory toward reduced tensions. This development could gradually facilitate the easing or removal of sanctions, confidence building, and greater stability in relations with Western countries, thereby enabling the entry of foreign companies and investors and improving access to required technologies. Under this scenario, Iran's oil refining industry would need to formulate its development strategies based on anticipated global demand over the research horizon, extending its focus beyond the domestic market to international markets.

4.1.5. Key factors

International sanctions and foreign policy, attraction of major international companies, development of relations with aligned countries, and investment security index in Iran.

4.2. Domestic Governance

Oil and energy issues have historically been strongly influenced by political decision-making. In Iran, the nationalization of the oil industry has placed the government in the position of owner and supplier of crude oil and natural gas to refineries and petrochemical complexes. Moreover, according to Gharakhanlu (2023), approximately 99% of refinery ownership in the country is held by the government or quasi-governmental public institutions. These conditions have contributed to the formation of monopolistic structures in other segments of the oil industry. At present, in addition to controlling production, the government maintains substantial control over the distribution, pricing, and export of oil and petroleum products. This structure has limited the development of a competitive market and reduced the incentives for private-sector and foreign-company participation in petroleum product manufacturing and the refining industry (Ghayehbashi et al., 2024).

Under these conditions, the scale and direction of refining industry development are effectively determined by the government and parliament through policymaking and legislation. For example, the Sixth Development Plan established a target refining capacity of 2.7 million barrels per day. These conditions have led to the identification of the country's political and managerial governance approach as an influential driver of refinery design and development. Based on the collected data, two uncertainty states were identified for this driver.

4.2.1. Continuation of state-centered governance

If the current trajectory continues, the government is expected to maintain substantial control over oil production and the refining industry, including production, distribution, and pricing, partly because of the significant social and economic implications of energy carrier prices. Under these conditions, investment would continue to be dominated by the government and affiliated entities, with development primarily aimed at meeting domestic demand for gasoline and diesel. Product diversification and quality improvement would remain secondary priorities.

4.2.2. Movement toward participatory governance

Under this state, the government would gradually reduce its monopoly over the refining sector, including its control over product manufacturing, pricing, and exports. Progress in this direction could encourage private-sector investment and create conditions for refinery development in accordance with contemporary technological standards and global market requirements.

4.2.3. Key factors

National macro-energy policies, government monopoly in the oil industry, economic stability (inflation and exchange rates), administrative pricing of energy carriers, investment in the refining and petrochemical industries, national development requirements (five-year development plans and long-term visions), and optimization of the national energy system.

4.3. Demographics

Population is widely recognized as a major aggregate driver of energy consumption growth. In countries experiencing rapid population growth, demographic change can significantly affect the consumption of crude oil-derived fuels, petrochemical products, and energy more broadly. These effects operate through multiple pathways, including increased transportation demand, higher household and industrial consumption, and the expansion of consumer markets. In Iran, with a population of approximately 92 million and an economy that remains highly dependent on energy, these demographic effects are particularly important.

For this driver, three alternative states were considered based on a study conducted by the National Population Research Institute, which projected Iran's population through 2050 using estimated 2024 population data disaggregated by age and sex. The projections were developed under three scenarios based on different assumptions regarding future fertility trends, including increases in or stabilization of the current fertility rate of 1.61 children per woman. These assumptions extend from the implementation period of the Seventh Five-Year Development Plan through 2028 and continue to the 2050 horizon (National Population Research Institute Report, 2023).

4.3.1. Key factors

Population growth.

4.4. Global energy transition

Many of the identified key factors reflect macro-level trends associated with the emergence of alternative energy sources and changes in both the magnitude and composition of demand for petroleum products. Although most published reports project continued growth in global energy consumption and oil demand through the study horizon of 2050, the projected shares of individual energy sources, including oil, vary considerably across scenarios. Another important source of uncertainty concerns future consumption patterns for specific petroleum products over the study period. Because refinery profitability currently depends largely on product sales, changes in the composition and volume of product demand will play a critical role in shaping the development of future refineries.

OPEC (2025) presents three scenarios for the future of oil over the 2024–2050 period. In the Reference Scenario, OPEC projects a 23% increase in global energy consumption and an increase in oil demand of approximately 19 million barrels per day, reaching 123 million barrels per day by 2050. Oil demand in non-OECD countries is projected to increase by approximately 28 million barrels per day over this period, whereas demand in OECD countries is expected to decline by 8.5 million barrels per day. These projections also indicate a geographical shift in the potential customer base of the refining industry.

In the second scenario, termed the "Technology-Driven Scenario," OPEC assumes that greater investment in advanced technologies will alter the assumptions underlying the Reference Scenario. Such investments are expected to accelerate fuel substitution and improve energy efficiency, resulting in lower primary energy demand and a substantially different energy mix. In the third scenario, the "Equity-Focused Growth Scenario," OPEC envisions a more equitable and prosperous economic future for developing countries, accompanied by a different trajectory for achieving greenhouse gas emission reduction targets. Under this scenario, long-term energy demand, particularly oil demand, is higher.

Similarly, the International Energy Agency (IEA, 2025b) presents two exploratory scenarios and two normative scenarios. The first exploratory scenario, referred to as "Current Policies," projects that global oil demand will increase to 113 million barrels per day by 2050, primarily because of greater consumption in emerging-market and developing economies for road transportation, petrochemical feedstocks, and aviation. The second exploratory scenario reflects the prevailing trajectory of the energy system based on a detailed assessment of energy, climate, and industrial policies that have been adopted or announced by individual countries, even when they have not yet been codified into law. This scenario incorporates prevailing technological and market conditions but excludes purely aspirational targets. Under this scenario, oil demand peaks at approximately 102 million barrels per day around 2030 and subsequently declines gradually. By 2035, more than 840 million electric vehicles are projected to displace approximately 10 million barrels per day of oil demand, primarily in Asia and Europe. However, oil consumption for petrochemical production and aviation continues to increase through 2050. From the 2030s onward, renewable energy is projected to satisfy all incremental global energy demand, while the share of renewables in electricity generation rises to approximately two-thirds by 2050.

Based on these projections, three uncertainty states were defined for this driver (International Energy Agency [IEA], 2023).

4.4.1. Continuation of current trends

Under this state, the timing of peak demand for transportation fuels follows the trajectories projected by major international institutions. Accordingly, decisions regarding refinery development models and technology requirements should account for these demand trajectories, particularly given the long lead times associated with refinery construction, modernization, and operation.

4.4.2. Accelerated energy substitution

Under this state, rapid substitution of petroleum-based fuels by alternative energy sources would cause demand for conventional fuel products to decline. Traditional refineries could therefore face substantial economic pressure and, in some cases, closure. This scenario would increase the strategic importance of transitioning toward integrated petro-refineries and expanding the production of petrochemical products (International Energy Agency [IEA], 2023).

4.4.3. Slowed energy substitution

Under this state, demand for conventional fuel products would continue to grow or remain robust for a longer period. Consequently, the production of gasoline, diesel, and other transportation fuels could remain economically attractive because of sustained market demand.

4.4.4. Key factors

Global energy transition, global energy demand patterns, global crude oil prices, and dependence on fossil fuels.

4.5. Emerging technologies in oil, gas, and petrochemicals

Technology is a major driver of refining industry development, both globally and in Iran. The growing importance of environmental concerns, increasingly stringent regulatory requirements, and rising demand for new products have heightened the importance of advanced technologies, including modern process technologies and catalysts, in enabling product diversification and facilitating the transition from conventional refineries to integrated petro-refinery complexes. In this context, the use of crude oil as a petrochemical feedstock is likely to become an increasingly important source of profitability for the refining industry. Petrochemical products encompass a broad range of materials, including polymers, advanced lightweight materials, pharmaceuticals, solvents, and numerous other products that have become integral to modern life. Given the substantial price differential between conventional fuel products (approximately $600/ton) and petrochemical products (approximately $1,200/ton), refineries capable of producing higher-value petrochemical products are likely to achieve significantly greater profitability. In addition, the application of artificial intelligence (AI) and advanced process control systems has considerable potential to optimize refinery operations, improve energy management, and enhance fault detection (Olaizola et al., 2022).

Based on expert judgment, three uncertainty states were defined for this driver, with the scenario titles adapted from Rezayan Ghayehbashi et al. (2024).

4.5.1. Advanced technology access

Under this state, the country has access to cutting-edge global technologies, enabling investors to design and construct new refining facilities in accordance with evolving global market requirements.

4.5.2. Restricted technology access

Under this state, access to advanced technologies remains possible through indirect channels, including sanctions circumvention and informal markets. Because such access entails additional costs, further development of the industry would likely require government support, including the provision of low-cost feedstock to offset higher production costs and reduce final product prices, thereby maintaining competitiveness in international markets.

4.5.3. Limited technology access

Under this state, access to advanced technologies is severely constrained or unavailable, creating a major barrier to the development of modern refineries. Consequently, refinery development would likely remain largely conventional and focused on meeting domestic market requirements, particularly the production of transportation fuels.

4.5.4. Key factors

Digitalization (Refinery 4.0), Nelson complexity index (NCI) of Iranian refineries, emerging refining technologies, demand for petrochemical products driven by emerging technologies, and emergence of energy-intensive technologies.

4.6. Environmental policies and requirements

In recent decades, climate change and global warming have emerged as major international concerns. These developments have contributed to the formulation of new environmental policies and regulations, including decarbonization measures and increasingly stringent standards for petroleum products. Such measures can significantly affect demand levels, production costs, and technology requirements and may reduce the competitiveness of conventional refineries. In recent years, these pressures have contributed to the closure of several refineries, particularly in Europe and North America. In Iran, social pressure to improve fuel quality and reduce the use of mazut has also increased. If this trend continues, the government may be compelled to formulate and enforce more stringent environmental and fuel-quality standards.

4.6.1. Uncertainty states

Two uncertainty states were identified for this driver.

Stricter environmental requirements

In recent years, international and regional policies addressing climate change and environmental pollution have become increasingly important challenges for the refining industry. Carbon taxes, the reduction or elimination of fossil fuel subsidies, stricter pollution standards, vehicle fuel-efficiency requirements, restrictions on the sale of new gasoline- and diesel-powered vehicles, including measures planned for implementation from 2035 in Europe, and international agreements such as the Paris Agreement are among the major ongoing policy trends. These measures, which fall under the driver of environmental policies and requirements, can influence the future of the refining industry by increasing production costs and constraining demand for conventional petroleum products (International Energy Agency [IEA], 2021).

Moderation or delay of environmental policies

The environmental scanning results indicate that, despite substantial social and political pressure, achieving global environmental objectives continues to face significant challenges. At the 30th Conference of the Parties (COP30) to the United Nations Framework Convention on Climate Change in Brazil, the final agreement did not establish a binding and definitive pathway for phasing out fossil fuels (COP30, 2025). In addition, continued technological advances, including the deployment of scrubbers and carbon capture technologies, could moderate the stringency or timing of policies related to fuel quality and carbon emissions. Under this state, lower regulatory pressure could reduce production costs and allow demand for petroleum products to remain robust for a longer period.

4.6.2. Key factors

Social pressure for fuel quality improvement, recycling industry and circular economy, global climate change, global decarbonization requirements, and environmental requirements and regulations.

4.7. Domestic consumption pattern

In Iran, domestic oil consumption patterns have consistently been among the most influential factors shaping the development of the refining industry. Although overall consumption has continued to increase, the composition and structure of energy demand have undergone significant changes. Moreover, in modern petro-refineries, crude oil can be converted directly into basic chemical products, primarily olefins and aromatics, using crude-oil-to-chemicals (COTC) technologies rather than passing through the multiple distillation and conversion stages employed in conventional refineries. Consequently, the share of fuel products in the overall product slate can be reduced (Zhang et al., 2022). Persistent pressure to satisfy domestic demand for transportation fuels may therefore constrain the production of higher-value petrochemical products in refineries.

At the same time, the aging of Iran's oil reservoirs and insufficient investment in the upstream sector, partly because of international sanctions, have constrained the development of crude oil production capacity in recent decades. Given the 25-year research horizon, continuation of these trends could create significant challenges for crude oil production and the reliable supply of refinery feedstock. Two uncertainty states were identified for this driver.

4.7.1. Continuation of the status quo

Under this state, sustained high demand from the road transportation sector would compel the government to prioritize the supply of transportation fuels. Such a policy could constrain the sustainable development of the refining industry by limiting opportunities for product diversification and the production of higher-value petrochemicals. Given the administrative pricing of energy carriers, these conditions could also adversely affect refinery profitability and discourage new capital investment. However, based on expert assessments and global trends over the research horizon, this driver is expected to begin shifting after approximately 2035 toward greater alignment with international trends, particularly through increased adoption of electric vehicles.

4.7.2. Consumption pattern reform and balanced development of the oil industry

Under this state, the government would succeed in reforming both the level and structure of domestic oil consumption through measures such as regulatory reform, expansion of public transportation, changes in consumption behavior, and increased adoption of electric vehicles. Alternatively, balanced development of the upstream oil sector could increase crude oil production in line with rising domestic demand. Under either pathway, pressure on the refining industry would decrease, thereby improving sector profitability and making refinery investment more attractive to the private sector.

4.7.3. Key factors

Domestic demand for transportation fuels, availability of fossil fuel resources (oil and natural gas), expansion of demand management and energy conservation culture, national refining capacity, national energy consumption patterns, and expansion of alternative energy consumption.

4.8. Petrochemical industry development trajectory in the country

As previously noted, the primary objective of first-generation refineries was to maximize the production of transportation and heating fuels. Their principal processes were largely limited to atmospheric and vacuum distillation, together with relatively simple thermal cracking operations, resulting in a relatively fixed slate of fuel products with defined yields from each barrel of crude oil. However, beginning in the mid-twentieth century, the rapid expansion of downstream industries, particularly petrochemicals, created growing demand for feedstocks such as naphtha and light gases, including ethane, propane, and butane (Letcher, 2020). Consequently, a portion of refinery output began to be directed not to final fuel markets but to downstream industrial processes as feedstock. This transformation was driven by the rapid expansion of the polymer, chemical, and plastics industries, which substantially increased demand for petrochemical feedstocks. In response, refineries were required to upgrade their technologies and modify their process configurations to increase the share of petrochemical feedstocks produced from each barrel of crude oil. Petrochemical feedstocks are generally supplied in two forms: gaseous feedstocks, such as associated petroleum gases, refinery gases, and natural gas, and liquid feedstocks, primarily naphtha and other intermediate fractions. This convergence between refining and petrochemical production represented an important step toward the emergence of petro-refineries, or integrated refining–petrochemical complexes.

In Iran, the feedstock consumption of petrochemical complexes has increased substantially over the past five years, although this growth has been accompanied by significant supply constraints. According to data from the Iran Petrochemical Industry Yearbook, the industry's combined feedstock and fuel consumption increased from 34.5 million tons in 2020 to 72 million tons in 2022 and is projected to reach 85 million tons by 2025. This increase has been driven primarily by the commissioning of new projects and the expansion of existing production capacity. In practice, however, feedstock shortages have emerged as one of the principal constraints on production, particularly in recent years. Reports indicate that capacity utilization reached only 70% in 2022, 76% in 2023, and 79% in 2024, partly because of unstable feedstock supply. Thus, although the petrochemical industry's share of available hydrocarbon resources has increased, imbalances in the reliable and efficient supply of feedstock have constrained actual production levels (National Petrochemical Company of Iran, 2023).

Based on these considerations, the development trajectory and structural pattern of the petrochemical industry, as a major consumer of refinery products, are expected to significantly influence the future development of the country's refining sector. By producing higher-value-added and more profitable products than conventional fuels, the petrochemical industry can provide a stable market for the output of modern refineries and thereby strengthen incentives for investment in integrated refining and petrochemical projects. Based on expert judgment, two uncertainty states were identified for this driver.

4.8.1. Advancement of petrochemical industry development programs

According to official plans, Iran's petrochemical production capacity is expected to increase substantially over the coming decade. Based on the Seventh and Eighth Development Plans and announcements by the National Petrochemical Company, installed capacity is projected to increase from approximately 96 million tons in 2025 to 132 million tons by the end of the Seventh Development Plan in 2028 through the commissioning of 66 new projects. Capacity is subsequently projected to reach approximately 186 million tons over the ten-year horizon through projects associated with the Eighth Development Plan. This increase of approximately 90 million tons would nearly double current capacity and corresponds to an average annual growth rate of approximately 8%. An important feature of this development pathway is the anticipated qualitative transformation of the product structure and further integration of the value chain. Methanol production capacity is projected to increase from 16 to 34 million tons, polymer capacity from 9 to 30 million tons, and ammonia capacity from 7 to 10 million tons, with greater emphasis on higher-value-added products such as polypropylene. If this state materializes, the simultaneous development of the petrochemical industry and modern refining facilities could create a positive feedback mechanism that supports sustained growth in both sectors (Rezaei and Hosseini, 2022).

4.8.2. Imbalanced and superficial development of the petrochemical industry

Constraints such as insufficient investment and limited access to required technologies could impede the development or balanced expansion of the petrochemical industry. Nevertheless, the existing gap between petrochemical production capacity and refining capacity could continue to create some incentive for investment in the construction and modernization of advanced refineries.

4.8.3. Key factors

Development pattern of the refining and petrochemical industries (value-chain enhancement) and product profitability.

4.9. MICMAC cross-impact analysis results

Concurrent with the driver identification stage, a new matrix-based questionnaire was developed to conduct a cross-impact analysis of the 34 identified key factors and was distributed to the experts. The objective was to assess the degree of influence and dependence associated with each key factor. In the questionnaire, a score of 0 indicated no influence, 1 indicated low influence, 2 indicated moderate influence, and 3 indicated strong influence. After the completed questionnaires were collected, the mean scores were entered into MICMAC software, and the resulting analyses were subsequently presented to the experts for evaluation. Based on the MICMAC analysis, Figure 2 presents the direct influence graph among the key factors. The resulting influence–dependence map generated by the MICMAC software is presented in Figure 3. In this map, factors located in the upper-right quadrant are classified as linkage variables, whereas those in the lower-left quadrant are classified as autonomous variables. This classification provides a basis for identifying and prioritizing the key driving factors to support strategic decision-making.

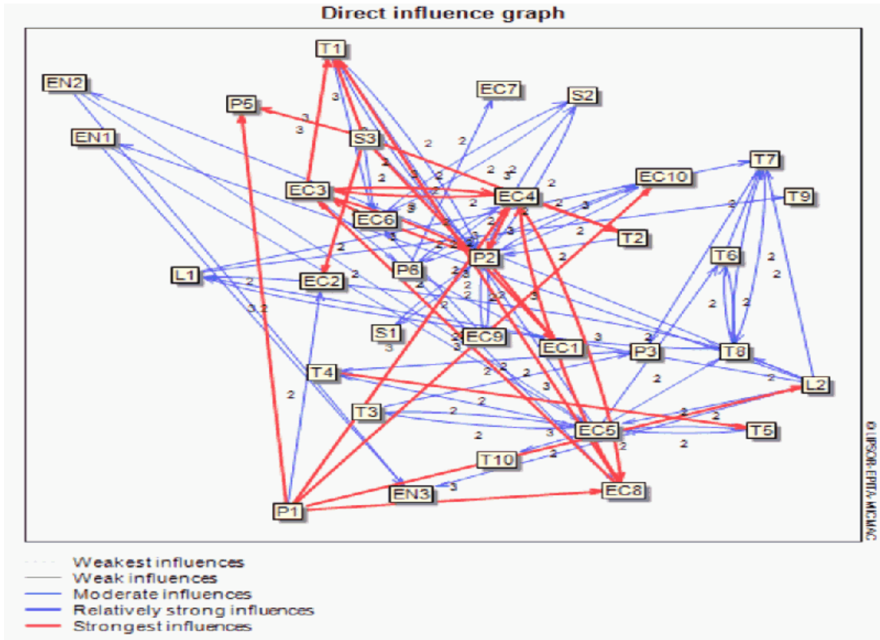

Figure 2

Direct influence graph (MICMAC software output)

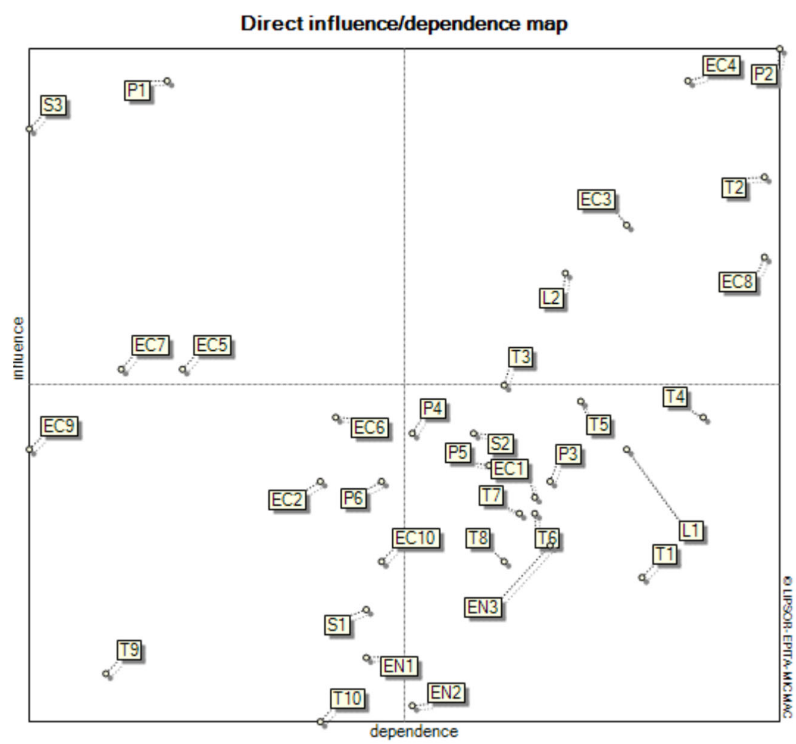

Figure 3

Influence/dependence map (MICMAC software output)

By entering the mutual direct influence (MDI) matrix data into MICMAC software, the 34 key factors were classified into four quadrants based on their driver power (DP) and dependence (D) scores, using the mean threshold value of 34.53.

4.9.1. Quadrant I: driver factors

Factors with high influence (DP > 34.53) and low dependence (D < 34.53) were classified as driver factors. These variables exert strong influence on the system while remaining relatively independent of other factors and therefore play a major role in shaping its future trajectory.

- P1: International sanctions and foreign policy (DP: 56, D: 16)
- EC5: Global energy demand patterns (DP: 38, D: 17)
- EC6: Administrative pricing of energy carriers (DP: 35, D: 27)
- EC7: Global crude oil prices (DP: 38, D: 13)
- S3: Population growth (DP: 53, D: 7)

4.9.2. Quadrant II: linkage factors

Factors with high influence (DP > 34.53) and high dependence (D > 34.53) were classified as linkage factors. These variables are highly interactive and potentially unstable because changes in them can strongly affect other factors while simultaneously being influenced by changes elsewhere in the system.

- P2: National macro-energy policies (domestic policy) (DP: 58, D: 56)
- EC3: Development pattern of the refining and petrochemical industries (DP: 47, D: 46)
- EC4: Product profitability (DP: 56, D: 50)
- EC8: Investment in the refining and petrochemical industries (DP: 45, D: 55)
- T2: National energy consumption patterns (DP: 50, D: 55)
- T3: Recycling industry and circular economy (DP: 37, D: 38)
- T4: Optimization of national energy systems (DP: 35, D: 51)
- T5: Expansion trend of alternative energy consumption (DP: 36, D: 43)
- L2: National standards for pollutant reduction (DP: 44, D: 42)

4.9.3. Quadrant III: dependent factors

Factors with low influence (DP < 34.53) and high dependence (D > 34.53) were classified as dependent factors. These variables are primarily influenced by other components of the system and are less likely to act as independent drivers of change.

- P3: Government monopoly in the oil industry (DP: 31, D: 41)
- P5: Attraction of major international companies (DP: 32, D: 37)
- EC1: Economic stability (inflation and exchange rates) (DP: 30, D: 40)
- S2: Expansion of demand management and energy conservation culture (DP: 34, D: 36)
- T1: National refining capacity (DP: 25, D: 47)
- T6: Digitalization (Refinery 4.0) (DP: 29, D: 40)

- T7: Nelson complexity index (NCI) (DP: 29, D: 39)
- T8: Emerging refining technologies (DP: 26, D: 38)
- EN3: Dependence on fossil fuels (DP: 27, D: 41)
- L1: National development requirements (five-year development plans and long-term vision) (DP: 33, D: 46)

4.9.4. Quadrant IV: autonomous factors

Factors with low influence (DP < 34.53) and low dependence (D < 34.53) were classified as autonomous factors. These variables have relatively weak interactions with the overall system and exert comparatively limited direct influence on its dynamics.

- P4: Global energy transition (DP: 34, D: 32)
- P6: Development of relations with aligned countries (DP: 31, D: 30)
- EC2: Domestic demand for transportation fuels (DP: 31, D: 26)
- EC9: Availability of fossil fuel resources (DP: 33, D: 7)
- EC10: Investment security index in Iran (DP: 26, D: 30)
- S1: Social pressure for fuel quality improvement (DP: 23, D: 29)
- T9: Demand for petrochemical products driven by emerging technologies (DP: 19, D: 12)
- T10: Emergence of energy-intensive technologies (DP: 16, D: 26)
- EN1: Global climate change (DP: 20, D: 29)
- EN2: Global decarbonization requirements (DP: 17, D: 32)

4.9.5. Identification of the eight key drivers

Important drivers are generally selected from the driver and linkage quadrants because factors in these categories exert the strongest influence on the system. Based on the highest driver power (DP) values, eight key drivers were identified as follows:

1. P2: National macro-energy policies (domestic policy) (DP: 58)
2. P1: International sanctions and foreign policy (DP: 56)
3. EC4: Product profitability (DP: 56)
4. S3: Population growth (DP: 53)
5. T2: National energy consumption patterns (DP: 50)
6. EC3: Development pattern of the refining and petrochemical industries (DP: 47)
7. EC8: Investment in the refining and petrochemical industries (DP: 45)
8. L2: National standards for pollutant reduction (DP: 44)

The results obtained from the MICMAC calculations and subsequent analytical evaluation were consistent with the earlier driver identification assessments. The analysis indicates that the combination of low dependence and very high influence associated with international sanctions and foreign policy makes this factor particularly significant. Changes in foreign relations or the easing or intensification of sanctions can rapidly alter the trajectories of investment, technology transfer, and international participation. Accordingly, industry strategies should be designed to remain viable under both international isolation and reintegration into global markets.

National macro-energy policies and product profitability can be regarded as key points of interaction between policy and market forces. Both variables are positioned within the linkage category, indicating strong reciprocal relationships with other system variables. Changes in energy policy, such as adjustments to pricing mechanisms or the reduction or elimination of subsidies, can immediately affect profitability and investment incentives, thereby generating strong feedback effects across the refining sector.

Domestic demand-related factors also play an important role in shaping long-term industry dynamics. Population growth and national energy consumption patterns are major long-term determinants of demand for transportation fuels and petrochemical products. Even with the continued expansion of alternative energy sources, the strong influence of these variables suggests that a substantial domestic market for petroleum-based fuels and petrochemical products is likely to persist over the study horizon.

With respect to environmental requirements and global decarbonization mandates, the analysis indicates that these factors occupy relatively dependent or intermediate positions within the system. Nevertheless, changes in international environmental policies and regulatory requirements can rapidly create the need for new technologies, additional investment, and modifications to refinery configurations and operating practices.

5. Discussion

5.1. Synthesis of findings and core discussion

Using a futures studies approach and a scenario-planning methodology rooted in *la prospective*, this study systematically analyzes the challenges and opportunities confronting Iran's refining industry through 2050. The findings indicate that the industry is at a critical historical juncture, simultaneously shaped by four macro-level forces: (1) international sanctions and restricted access to markets and technologies, (2) the global energy transition toward a low-carbon economy, (3) increasingly stringent environmental regulations and compliance requirements, and (4) the accelerating pace of technological transformation across the oil and gas value chain. The interaction of these forces has created a highly uncertain environment in which linear and short-term decision-making approaches may no longer be sufficient.

The structural analysis conducted in this study confirms that the traditional fuel-oriented structure of Iran's refining industry is facing growing economic and structural challenges. The projected decline in global demand for fossil-based transportation fuels, driven by the increasing adoption of electric and hydrogen vehicles and increasingly stringent decarbonization policies, is expected to progressively weaken the economic viability of refineries heavily dependent on gasoline and diesel production. Conversely, this global transition presents a significant strategic opportunity to transform Iran's refining industry into a center for high-value chemical production. The transition toward integrated petro-refineries capable of co-producing cleaner fuels and high-margin petrochemical feedstocks could reduce long-term economic risks and substantially increase the economic return generated from each barrel of crude oil.

5.2. Strategic imperatives for industry transformation

Realizing this vision requires the adoption of an integrated portfolio of strategies accompanied by substantial institutional reforms. From a technological perspective, increasing the Nelson complexity index (NCI) of Iranian refineries and investing in advanced technologies such as crude-oil-to-chemicals (COTC) processes are essential. These transformations require substantial capital investment and access to advanced technologies, both of which currently face significant constraints (Zhang et al., 2023).

At the institutional and governance levels, the findings indicate that state monopoly, administrative pricing, and legal uncertainty constitute major barriers to attracting private capital and improving operational efficiency. Accordingly, structural reforms in petroleum industry governance, including regulatory clarification, stronger investment security, and the establishment of effective mechanisms for private-sector participation, are essential prerequisites for the sustainable development of the refining sector.

At the international level, diversification of trade partners and the strengthening of energy diplomacy could reduce the industry's vulnerability to geopolitical disruptions. Technological cooperation with aligned countries and the expansion of relations with emerging actors in global energy markets could facilitate access to advanced technologies and new export markets, particularly in the Middle East and other rapidly growing regional markets.

5.3. Alignment with sustainability and energy transition requirements

Iran's refining industry cannot remain insulated from the powerful forces driving the global energy transition. The industry must respond to increasingly stringent environmental requirements while simultaneously maintaining economic competitiveness. The production of low-carbon and alternative fuels, such as sustainable aviation fuel (SAF) and green hydrogen, could create new competitive opportunities for the industry, particularly given Iran's substantial potential for renewable energy development. Furthermore, optimizing energy consumption and reducing greenhouse gas emissions from refining processes will serve not only as regulatory requirements but also as effective means of lowering operating costs and strengthening the industry's social license to operate.

5.4. Role of scenario planning in managing uncertainty

The scenario planning methodology employed in this study, based on the intuitive school, demonstrates that under conditions of high complexity and uncertainty, constructing a single deterministic vision of the future is neither feasible nor desirable. Instead, developing several coherent and plausible scenarios, each shaped by different combinations of key driving forces, enables decision-makers to enhance strategic flexibility. Rather than attempting to predict a single future, this approach emphasizes preparedness for multiple plausible futures, thereby enabling organizations to identify early warning signals of change and adapt their strategies accordingly.

5.5. Policy implications and recommendations for action

The findings of this study have important implications for policymakers, industry managers, and researchers. Figure 4 presents the authors' proposed roadmap for Iran's oil refining industry toward 2050, considering the sector's current position at a critical historical juncture. This strategic framework identifies the key pathways, challenges, and opportunities that are expected to shape the industry's long-term development over the coming decades.

1. **Development of a refining industry transformation roadmap:** A comprehensive roadmap should be developed based on the findings of this study to guide the gradual transformation of existing refineries into integrated petro-refineries. The roadmap should specify implementation timelines, capital requirements, and technological needs.

2. **Reform of the governance framework and attraction of capital:** The establishment of a refining technology development fund through public–private partnerships, reform of energy carrier pricing regulations, and enactment of transparent legislation to strengthen investment security and facilitate foreign investment should be considered urgent priorities.

3. **Human capital development and innovation ecosystem:** Investment in specialized training for emerging refining technologies and the establishment of joint research and development (R&D) centers with reputable international institutions should be prioritized.

4. **Continued futures studies research:** The scenario planning process should be further developed by assigning quantitative and qualitative indicators to each 2050 scenario and establishing mechanisms for the continuous monitoring of these indicators. This approach would enable decision-makers to assess the country's evolving trajectory and determine which plausible future is becoming increasingly likely.

Figure 4

Iran's oil refining industry at a historical crossroads: roadmap to the 2050 horizon (Authors' elaboration based on research findings)

6. Conclusions

Ultimately, this research emphasizes that the future of Iran's refining industry is not predetermined but will be shaped, to a considerable extent, by the strategic choices made today. Although the challenges ahead, ranging from international sanctions to the global energy transition, are substantial and multidimensional, they also create a historic opportunity to redefine the role and position of the refining industry within the national and regional economies. Realizing these opportunities will require a transition from a reactive and defensive posture to a proactive and future-oriented approach that integrates economic efficiency, technological advancement, and environmental responsibility.

Iran's refining industry may need to gradually evolve from its traditional role as a fuel supplier toward that of an integrated producer of higher-value-added energy and petrochemical products. Such a transformation would not only strengthen the industry's long-term economic viability in the twenty-first century but also contribute to sustainable development, energy security, and the welfare of future generations. Achieving this preferred future will require collective commitment, effective governance, and substantial investment in knowledge, innovation, and advanced technologies. The findings of this study may therefore contribute to future policy discussions and strategic planning efforts concerning the long-term development of Iran's refining industry.

Iran's oil refining industry is entering a period of significant structural transformation. The traditional business model based on the large-scale production of low-value-added fuel products, supported by implicit energy subsidies and relatively static domestic and export markets, is unlikely to remain economically viable in a rapidly changing global energy system. The simultaneous pressures of three major forces—the global transition toward decarbonization, intensified technological and financial sanctions, and increasingly stringent environmental and social requirements—have heightened the need to reassess the industry's long-term business model. The emerging model should shift from a reactive, resource-based orientation toward a proactive, value-based approach. This transition implies that the principal sources of revenue should progressively expand beyond conventional fuel sales to include the production of high-value-added chemicals, such as engineering polymers and specialty intermediates; the provision of energy-related services, including clean hydrogen production and carbon management; and the utilization of physical, technological, and knowledge assets through new collaborative business models. Without such structural adjustments, parts of the refining industry may face increasing economic and operational pressures over the coming decades and could ultimately become stranded assets within a two- to three-decade horizon. The development of this new business model is therefore an important strategic consideration for national energy security, economic development, and the preservation of Iran's position in the evolving global energy market.

Nomenclature

CCUS	Carbon capture, utilization, and storage
COP30	30th Conference of the Parties (UNFCCC)
COTC	Crude oil-to-chemicals
D	Dependence (in MICMAC analysis)
DP	Driver power (in MICMAC analysis)
IEA	International Energy Agency
IoT	Internet of things
MDI	Mutual direct influence (matrix)
MICMAC	*Matrice d'Impacts Croisés Multiplication Appliquée à un Classement* (Cross-impact matrix multiplication applied to classification)
NCI	Nelson complexity index
NIOC	National Iranian Oil Company
NIORDC	National Iranian Oil Refining and Distribution Company
NPC	National Petrochemical Company (of Iran)

OECD	Organization for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PESTEL	Political, economic, social, technological, environmental, legal (analysis framework)
SAF	Sustainable aviation fuel

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