




Identification and Localization of Sustainable Performance Management Indicators Based on Innovative and Economical Production Methods in the Iranian Petrochemical Industry Under Sanctions

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ABSTRACT

In recent years, the Iranian petrochemical industry has faced extensive challenges in the areas of resource supply, access to technology, and maintenance of competitiveness due to international sanctions. Under such conditions, attention to sustainable performance management and the adoption of innovative and economical production methods have become strategic necessities for ensuring operational continuity and enhancing the resilience of this industry. The purpose of this study was to identify and localize sustainable performance management indicators based on innovative and economical production methods in the Iranian petrochemical industry under sanctions. This study was applied in terms of purpose and qualitative-exploratory in terms of nature. In the first stage, the initial dimensions and indicators related to sustainable performance management and innovative methods were extracted through a systematic literature review and categorized using thematic analysis in MAXQDA software. In the second stage, these indicators were refined, localized, and prioritized through the fuzzy Delphi method based on the opinions of 18 industry and academic experts. The findings demonstrated that environmental, economic, sustainable innovation, and supply chain management dimensions had the highest importance under sanction conditions, whereas softer dimensions such as ethical considerations, diversity, and inclusion played a less significant short-term role. Accordingly, the findings provide a localized and realistic framework for policymakers and managers of petrochemical companies to facilitate the path toward sustainable development and long-term competitiveness under conditions of international restrictions by focusing on key and operational dimensions.

Keywords: Sustainable performance management, systematic review, fuzzy Delphi, innovative and economical production methods, petrochemical industry, sanctions.

1. Introduction

The petrochemical industry is one of the most strategically significant sectors in resource-based economies because it converts hydrocarbon feedstocks into high-value intermediate and final products, supports downstream manufacturing chains, generates export revenues, and contributes to industrial diversification. In Iran, this sector has particular economic and developmental importance due to the country's hydrocarbon reserves, accumulated industrial capabilities, and central role of petrochemical exports in non-oil revenue generation. However, the operating environment of the Iranian petrochemical industry has become increasingly complex under international sanctions. Sanctions affect access to advanced technologies, foreign investment, financial transactions, specialized equipment, catalysts, spare parts, international markets, and global knowledge networks. Under such conditions, conventional performance management systems that focus mainly on financial output, production volume, or short-term operational efficiency are insufficient. Petrochemical companies need a more integrated framework that links sustainability, resilience, innovation, operational efficiency, and localization. Sustainable performance management therefore becomes a strategic necessity rather than a symbolic reporting practice, especially when firms must maintain competitiveness while facing technological restrictions, supply chain disruptions, environmental pressures, and cost constraints (Abedifar et al., 2025; Rezaii Manesh, 2025; Youssef et al., 2025).

Sustainable performance management refers to the systematic identification, measurement, evaluation, and improvement of organizational performance based on economic, environmental, social, governance, innovation, and stakeholder-related criteria. The concept has evolved from narrow financial performance measurement toward multidimensional frameworks that integrate sustainability considerations into corporate strategy and operational decision-making. The Sustainability Balanced Scorecard and related hybrid evaluation models demonstrate that sustainability indicators can be incorporated into performance assessment systems in a structured manner, enabling organizations to evaluate financial, customer, internal process, learning, environmental, and social dimensions simultaneously (Lu et al., 2018). In the petrochemical industry, where production processes are capital-intensive, energy-intensive, environmentally sensitive, and technologically complex, sustainable

performance evaluation requires sector-specific indicators. Recent studies have emphasized the need for comprehensive performance evaluation approaches in petrochemical industries by integrating sustainability-oriented scorecards, network-based efficiency analysis, and multi-criteria decision-making techniques (Abedifar et al., 2025). This indicates that sustainable performance management in petrochemical companies should not be reduced to environmental reporting alone, but should be designed as an integrated managerial architecture that connects strategy, production systems, supply chains, innovation, governance, and long-term value creation.

The theoretical foundation of sustainable performance has often been associated with the triple bottom line, which emphasizes the simultaneous consideration of economic prosperity, environmental protection, and social responsibility. Nevertheless, the triple bottom line has also been criticized for being overly broad, difficult to operationalize, and sometimes vulnerable to symbolic adoption when clear metrics and accountability mechanisms are absent (Srivastava et al., 2022). Therefore, for industries such as petrochemicals, sustainability must be translated into measurable, actionable, and context-sensitive indicators. In this regard, sustainability performance measurement should move beyond generic categories and include indicators such as energy intensity, carbon intensity, water recycling, process waste reduction, occupational health and safety, sustainable profitability, operational availability, supply chain resilience, governance transparency, and innovation capability. Positive sustainability performance measurement also requires identifying indicators that reflect not only harm reduction but also value creation, stakeholder benefit, and long-term systemic improvement (Kuhnen & Hahn, 2019). Thus, sustainable performance management in petrochemical industries should be understood as a dynamic process of aligning environmental responsibility, economic efficiency, technological renewal, organizational accountability, and social legitimacy.

The growing relevance of sustainability is also reinforced by changes in investor expectations and corporate disclosure practices. Investors increasingly demand credible evidence that firms can manage climate-related risks, environmental obligations, governance challenges, and long-term sustainability transitions. The investor revolution described in sustainability-oriented finance reflects the shift from short-term financial analysis toward environmental, social, and governance integration in investment decision-making (Eccles & Krzus, 2019). In addition, the implementation of

climate-related financial disclosure recommendations has shown that companies must develop the capacity to identify, measure, and communicate climate risks and sustainability-related opportunities in a reliable and decision-useful manner (Eccles & Klimenko, 2019). For petrochemical companies, these developments are particularly important because the industry is exposed to carbon-related regulations, environmental scrutiny, energy transition pressures, and reputational risk. Although Iranian petrochemical firms operate under specific sanction-related constraints, they cannot remain isolated from global sustainability expectations. Sustainable performance indicators can therefore help these companies strengthen internal decision-making, improve legitimacy, enhance stakeholder trust, and prepare for future market and regulatory requirements (Abedifar et al., 2025; Rezaii Manesh, 2025; Srivastava et al., 2022; Yousef et al., 2024).

Sustainable performance management in petrochemical industries is closely linked to total quality management, corporate social responsibility, and organizational culture. Evidence suggests that total quality management can improve corporate green performance through the mediating role of corporate social responsibility, indicating that operational excellence and sustainability are mutually reinforcing rather than contradictory (Abbas, 2020). In process industries, this connection is important because quality systems, waste reduction, safety discipline, employee involvement, and continuous improvement can simultaneously enhance productivity and environmental outcomes. Similarly, green lean practices show that sustainable performance can be strengthened when lean production principles are combined with environmental objectives and embedded in organizational culture (Santoso & Kasih, 2024). This is especially relevant for petrochemical companies under sanctions, because they must reduce waste, optimize resources, decrease energy losses, and improve operational discipline without relying excessively on imported technologies. Green lean and eco-efficiency approaches can therefore provide practical mechanisms for improving sustainability through internal process improvement, resource productivity, and cultural alignment.

Innovation is another central pillar of sustainable performance in the petrochemical industry. Sustainability transitions require firms to redesign products, processes, technologies, and business models in ways that reduce environmental impacts while preserving or enhancing economic value. Integrated thinking and sustainability reporting frameworks emphasize that organizations should

connect financial and non-financial value creation and align their strategies with broader sustainable development objectives (Adams, 2017). In petroleum and petrochemical sectors, sustainable business performance depends on multiple determinants, including environmental management, technological capability, stakeholder orientation, and strategic commitment (Hadi & Baskaran, 2021). Technology management has also been shown to contribute to sustainability performance improvement in petroleum refineries and petrochemical companies, suggesting that managerial ability to acquire, develop, implement, and control technology is a key condition for sustainability outcomes (Yousef et al., 2024). In sanction environments, the role of innovation becomes even more critical because companies must compensate for restricted access to external technologies through domestic development, reverse engineering within legal and technical boundaries, supplier development, process optimization, and knowledge-based collaboration.

International sanctions can directly and indirectly influence green innovation. Sanctions may restrict access to advanced environmental technologies, reduce financial capacity for research and development, limit collaboration with international technology providers, and increase uncertainty in investment decisions. At the same time, sanctions can create pressure for domestic innovation, localization, substitution of restricted inputs, and development of alternative technological pathways. Research on the effects of international sanctions on green innovation shows that sanctions may significantly alter the direction, intensity, and feasibility of environmental innovation activities (Fu et al., 2023). For Iranian petrochemical companies, this dual effect is highly important. On the one hand, sanctions constrain technology transfer, access to modern catalysts, equipment, automation systems, and clean technologies. On the other hand, they create a strong incentive to develop indigenous capabilities, strengthen local supply chains, and prioritize innovation that directly supports operational continuity. Accordingly, a localized sustainable performance management framework must include indicators that capture not only general innovation capacity but also sanction-specific innovation priorities such as domestic substitution of catalysts and materials, technology localization, process intensification, and resilience-oriented production redesign.

Digitalization and Industry 4.0 are increasingly recognized as key enablers of sustainable and competitive manufacturing. Industry 4.0 integrates cyber-physical

systems, industrial internet of things, advanced analytics, automation, digital platforms, and real-time data exchange to improve production efficiency, flexibility, and decision-making (Xu et al., 2018). For managers, successful implementation of Industry 4.0 requires strategic alignment, workforce readiness, leadership commitment, data infrastructure, cybersecurity, and process integration (Sony & Naik, 2019). In petrochemical operations, digitalization can improve advanced process control, predictive maintenance, energy monitoring, equipment reliability, safety management, and integration between production, maintenance, and enterprise systems. More recently, artificial intelligence has been introduced as a driver of sustainability in smart manufacturing because it can support predictive analytics, resource optimization, defect reduction, energy efficiency, and adaptive decision-making (Youssef et al., 2025). Artificial intelligence also has broader implications for public and organizational service delivery, indicating the growing relevance of intelligent systems in improving institutional performance, responsiveness, and decision quality (Rezaii Manesh, 2025). For the Iranian petrochemical industry, however, digital transformation must be adapted to sanction conditions, cybersecurity risks, infrastructure limitations, and the need for locally maintainable technologies.

Supply chain management is another decisive dimension of sustainable performance in petrochemical industries. Petrochemical production depends on continuous access to feedstock, catalysts, chemicals, spare parts, logistics services, maintenance suppliers, and export channels. Disruptions in any of these areas can affect production continuity, cost structure, product quality, and customer commitments. Supply chain resilience research emphasizes that resilience is a multidimensional capability involving flexibility, redundancy, visibility, collaboration, agility, risk awareness, and recovery capacity (Ali et al., 2017). Simulation-based analyses of global supply chain disruptions further show that severe external shocks can propagate through supply networks and create nonlinear impacts on production, logistics, and service performance (Ivanov, 2020). Although pandemic disruptions and sanctions differ in origin, both demonstrate the vulnerability of interconnected supply systems to external shocks. In the context of sanctions, petrochemical firms need indicators for multi-sourcing, safety inventory, domestic supplier development, supplier evaluation, localization, geopolitical risk management, and business continuity planning. Sustainable supply chain development also requires

prioritizing key parameters and evaluating suppliers not only by cost and delivery performance but also by environmental, social, and resilience-related criteria (Shirazi et al., 2024).

Supplier performance evaluation is particularly important in petrochemical industries because suppliers influence maintenance quality, environmental compliance, operational reliability, and sustainability outcomes. Fuzzy multi-criteria approaches have been used to evaluate sustainable maintenance supplier performance in the petrochemical industry, demonstrating the usefulness of structured decision-making methods in contexts where multiple quantitative and qualitative criteria must be considered simultaneously (Tong et al., 2020). This is directly relevant to the present study because the localization of sustainable performance indicators requires methods capable of incorporating expert judgment, ambiguity, and contextual priorities. In sanction conditions, the selection and development of suppliers become even more strategic because firms may need to rely more heavily on domestic suppliers, alternative procurement channels, and localized technical capabilities. Therefore, sustainable performance management should include indicators that assess supplier environmental and social performance, audit systems, codes of conduct, traceability, localization capacity, and resilience contribution.

Sustainability transitions in petroleum-related industries also involve broader industrial dynamics. Technology phase-out and diversification among petroleum technology suppliers show that sustainability transitions are not merely environmental processes; they reshape innovation systems, supplier networks, industrial capabilities, and organizational strategies (Andersen & Gulbrandsen, 2020). In this context, petrochemical companies must simultaneously maintain current operations and prepare for future transitions toward cleaner technologies, lower-carbon products, circular economy practices, and more efficient production systems. Corporate sustainability assessment methods in resource-intensive industries further demonstrate that sector-specific evaluation models are necessary because sustainability priorities vary across industries depending on environmental risks, technological structure, regulatory pressure, and stakeholder expectations (Blinova et al., 2023). Consequently, a generic sustainability framework cannot fully capture the realities of the Iranian petrochemical industry. Indicators must be adapted to process characteristics, energy intensity, water use, emissions profile, safety risks, supply chain dependencies, technological restrictions, and national industrial priorities.

Technological innovation in petrochemical production may include product innovation, process innovation, materials engineering, catalyst substitution, clean technology adoption, digital monitoring, and advanced maintenance systems. Studies on technological innovation factors show that innovation performance is influenced by internal capabilities, institutional support, and the alignment between technology development and organizational objectives (Kim & Jun, 2022). In petrochemical and related material industries, technological development may also involve specialized materials, nanocomposites, thermal systems, and process-compatible substitutes that improve performance or reduce dependence on restricted inputs (Boujar Dolabi et al., 2020). Moreover, the transition to a post-industrial and knowledge-based economy highlights the importance of skills, technological learning, employment adaptability, and institutional support for innovation-led productivity improvement (Herzenberg et al., 2019). These insights suggest that sustainable performance management in the petrochemical industry should not be limited to measuring final outcomes; it must also evaluate the organizational and technological capabilities that enable continuous improvement, domestic innovation, and adaptation to external constraints.

Despite the growing body of literature on sustainability, innovation, digitalization, and supply chain resilience, an important research gap remains. Many existing frameworks are developed for advanced economies, relatively stable markets, or industries with normal access to global technologies, capital, suppliers, and standards. Such frameworks may not fully reflect the realities of petrochemical companies operating under sanctions. In the Iranian petrochemical industry, sustainability indicators must be realistic, operational, and compatible with constraints related to technology import, financial transactions, equipment procurement, international collaboration, and market access. At the same time, they should not ignore global sustainability expectations, environmental responsibility, innovation imperatives, or long-term competitiveness. Therefore, there is a need for a localized set of indicators that integrates sustainable performance management with innovative and economical production methods. Such a framework should identify which indicators are most important under sanction conditions, how they can be adapted to domestic industrial realities, and how they can support managerial decision-making in petrochemical companies.

Accordingly, the present study aims to identify and localize sustainable performance management indicators based on innovative and economical production methods in the Iranian petrochemical industry under sanction conditions.

2. Methods and Materials

This study was applied in terms of purpose and qualitative with an exploratory approach in terms of nature. In order to identify and localize sustainable performance management indicators based on innovative and economical production methods in the Iranian petrochemical industry under sanction conditions, a combination of two complementary approaches was employed.

In the first stage, a systematic literature review was conducted to extract the initial indicators. At this stage, valid scientific sources, international standards, and highly cited studies were reviewed, and the key indicators of sustainable performance management and innovative production methods were identified. The data obtained from this stage were categorized through coding and thematic analysis using MAXQDA software so that the indicators could be organized within the principal sustainability dimensions, including economic, environmental, social, and innovation dimensions.

In the second stage, the fuzzy Delphi method was employed to refine and localize the indicators. For this purpose, a panel consisting of 18 experts from the petrochemical industry, including senior managers, production and operations managers, policymakers, and university professors, was selected through purposive sampling. Data collection was conducted through fuzzy Delphi questionnaires, and the implementation process continued until consensus was achieved. The collected data were converted into fuzzy values and analyzed using fuzzy averaging and the consensus-building process in Microsoft Excel. Finally, the indicators that achieved an acceptable level of agreement and importance were selected as localized sustainable performance management indicators.

3. Findings and Results

The systematic literature review, as one of the fundamental pillars of research model design, provides the possibility of identifying the dimensions, components, and indicators associated with the principal study variables. In this section, in order to accurately identify the dimensions of sustainable performance management and innovative and

economical production methods in the petrochemical industry, authoritative scientific sources, international frameworks, industrial standards, and highly cited articles were examined. Given the breadth of the literature on organizational sustainability and the increasing importance of innovation in process industries, various frameworks have been developed to date, including the Global Reporting Initiative (GRI) standards, the IPIECA guidelines for the oil and gas industry, SASB standards, the GHG Protocol, ISO approaches (ISO 14001, ISO 50001, ISO 56002), and Sustainability Balanced Scorecard (SBSC) models, each of which presents a set of key dimensions and components related to sustainable performance management and production innovation.

A systematic search was conducted in the Scopus, Web of Science, ScienceDirect, and SID databases using keywords related to Sustainable Performance Management, Petrochemical Industry, and Innovative Production during the period from 2010 to 2024. A review of empirical and review studies in this field indicated that the key dimensions

of sustainable performance management are primarily categorized into environmental, social, and economic domains, while other areas such as process safety, corporate governance, professional ethics, and stakeholder management are also considered complementary components of these frameworks.

In the field of innovative and economical production methods, extensive studies have investigated energy optimization techniques (such as Pinch Analysis), process intensification, lean and green lean production, digitalization and Industry 4.0, innovation management (ISO 56002), and eco-efficiency. These methods directly influence cost reduction, productivity enhancement, and improvement of environmental indicators and are recognized as key drivers in the transition of petrochemical industries toward sustainable and competitive performance. Based on the systematic review process, the principal dimensions of each research variable were extracted and are presented in Tables 1 and 2.

Table 1

Dimensions of Sustainable Performance Management in the Petrochemical Industry

Main Dimensions of Sustainable Performance Management	Sources
Environmental	Global Reporting Initiative (GRI, 2020); Lozano (2015); Eccles and Krzus (2019)
Social	GRI (2020); Elkington (1997); Eccles et al. (2014)
Economic	GRI (2020); Kühnen and Hahn (2019)
Governance	Eccles et al. (2012); KPMG Survey of Sustainability Reporting (2020)
Ethical	Carroll (1999); Lozano (2015)
Human Rights	GRI (2020); ISO 26000
Diversity and Inclusion	GRI (2020); KPMG (2020); Eccles and Klimenko (2019)
Sustainable Supply Chain Management	Sarkis (2012); GRI (2020)
Sustainable Innovation	Adams (2017); Dangelico (2015)
Stakeholder Accountability	Freeman (1999); GRI (2020)
Supply Chain Resilience	Peck (2006); Pettit et al. (2010); Ali et al. (2017); Ivanov (2020)

Table 2

Dimensions of Innovative and Economical Production Methods in the Petrochemical Industry

Main Dimensions of Innovative and Economical Production Methods	Sources
Green Lean Production and Eco-efficiency	Elkington (1997); Dangelico and Pujari (2010); Santoso and Kasih (2024)
Technological Innovation (Process and Product)	Kim and Jun (2022); Fu et al. (2023); Dolabi et al. (2020)
Digitalization and Industry 4.0 (Smart Automation and Predictive Maintenance)	Xu et al. (2018); Sony and Naik (2019); Youssef et al. (2025)
Energy Efficiency and Resource Optimization	IEA (2018); Hahn and Kühnen (2013); Rezaii Manesh (2025)
Life Cycle Management and Sustainable Product Design	Niemann et al. (2008); Adams (2017); ISO 14040 (2006)
Investment in Clean and Renewable Technologies	REN21 (2021); Hadi and Baskaran (2021); Rezaii Manesh et al. (2025)
Flexibility and Resilience of the Production Chain	Peck (2004); Ivanov (2020); Shirazi et al. (2024)

Overall, the systematic review of the literature demonstrated that sustainable performance management is a

multidimensional concept encompassing various dimensions such as environmental, social, economic, safety,

and governance dimensions. These dimensions not only provide a comprehensive framework for evaluating organizational performance but also specify the pathway for continuous improvement. In this regard, environmental indicators address the reduction of adverse environmental impacts, social indicators focus on the enhancement of human capital and social responsibility, economic indicators emphasize productivity and cost efficiency, safety indicators deal with accident prevention and employee health improvement, and governance indicators concern transparency, accountability, and organizational ethics.

In contrast, innovative and economical production methods are recognized as the operational and executive arm for achieving sustainable performance. By relying on approaches such as energy optimization, process intensification, lean and green lean production, digitalization and Industry 4.0, innovation management (ISO 56002), and eco-efficiency, these methods provide practical tools and technologies for achieving higher productivity, reducing costs, and improving environmental and social indicators.

The integration of these two conceptual categories presents a comprehensive and integrated perspective on the pathway of the petrochemical industry toward sustainability and long-term competitiveness. However, it should be noted that many of the frameworks and indicators proposed in the literature have been designed for developed countries or environments without external restrictions. Therefore, considering the specific characteristics of the Iranian petrochemical industry and the challenges arising from international sanctions, it is necessary to adapt these

dimensions and components to the local and real conditions of the country.

Accordingly, in the next phase of the study and in line with completing the systematic review process, expert interviews and the fuzzy Delphi method will be employed to refine, localize, and prioritize the identified indicators and components. In addition to increasing the scientific validity of the findings, this approach provides the basis for developing a realistic and implementable model for sustainable performance management based on innovative and economical production methods in the Iranian petrochemical industry.

After identifying the initial dimensions and components through the systematic literature review, the fuzzy Delphi method was employed in the next stage to refine and localize the indicators. For this purpose, a panel consisting of 18 experts from the petrochemical industry, including senior managers, production and operations managers, policymakers, and university professors, was selected. Over three consecutive rounds, fuzzy Delphi questionnaires were distributed among the experts to evaluate the importance and applicability of each indicator under sanction conditions. The collected data were analyzed using fuzzy logic and Microsoft Excel software, and the final values were subsequently defuzzified. The results of this process, which represent the consensus-based and localized indicators for sustainable performance management and innovative and economical production methods in the Iranian petrochemical industry, are presented in the following tables.

Table 3

Fuzzy Delphi Results (Sustainable Performance Management in the Petrochemical Industry)

Dimensions	Components	Subcomponents	Fuzzy Mean of Expert Opinions (L, M, U)	Defuzzification
Environmental	Natural Resource Management	Reduction of energy consumption intensity	(0.75, 0.90, 0.98)	0.8767
		Water recycling and consumption reduction	(0.73, 0.89, 0.96)	0.8600
	Pollution Reduction	Improvement of raw material utilization efficiency	(0.74, 0.89, 0.96)	0.8633
		Reduction of greenhouse gas emissions (carbon intensity)	(0.78, 0.92, 0.99)	0.8967
		Control of air, water, and soil pollution	(0.75, 0.90, 0.97)	0.8733
	Waste Management	Separation, recycling, and reduction of process waste	(0.74, 0.89, 0.95)	0.8600
		Safe disposal of hazardous waste	(0.73, 0.88, 0.95)	0.8533
Social	Human Capital	Occupational health and safety	(0.76, 0.91, 0.98)	0.8833
		Training and empowerment	(0.75, 0.90, 0.97)	0.8733
		Employee participation and satisfaction	(0.73, 0.89, 0.95)	0.8567
	Corporate Social Responsibility	Community-oriented projects	(0.70, 0.87, 0.94)	0.8367
		Support for local communities	(0.71, 0.88, 0.94)	0.8433
	Labor Relations	Social dialogue and grievance handling	(0.72, 0.88, 0.95)	0.8500

Economic	Economic Value Creation	Work–life balance	(0.71, 0.88, 0.94)	0.8433	
		Sustainable profitability	(0.76, 0.91, 0.97)	0.8800	
	Efficiency and Productivity	Revenue growth / ROA / ROCE	(0.74, 0.90, 0.96)	0.8667	
		Reduction of unit production cost	(0.73, 0.89, 0.95)	0.8567	
Governance	Financial Risk Management	OEE and operational readiness	(0.74, 0.90, 0.96)	0.8667	
		Exchange rate risk coverage for feedstock/products	(0.72, 0.88, 0.95)	0.8500	
	Governance Structure	Cost discipline	(0.71, 0.87, 0.94)	0.8400	
		Board independence and specialized committees	(0.74, 0.89, 0.95)	0.8600	
Ethical	Responsible Conduct	Disclosure and legal compliance	(0.73, 0.89, 0.95)	0.8567	
		Anti-corruption and conflict-of-interest management	(0.72, 0.88, 0.95)	0.8500	
	Accountability Culture	ICS Cybersecurity	Protection of industrial control systems	(0.74, 0.90, 0.96)	0.8667
		Incident management and cyber resilience	(0.73, 0.89, 0.95)	0.8567	
Diversity and Inclusion	Equal Opportunity	Implementation of ethical codes and anti-bribery policies	(0.74, 0.90, 0.96)	0.8667	
		Fair competition	(0.73, 0.89, 0.95)	0.8567	
	Inclusion Programs	Violation reporting and whistleblower support	(0.73, 0.89, 0.95)	0.8567	
		Ethics training and managerial accountability	(0.72, 0.88, 0.94)	0.8467	
Sustainable Supply Chain	Supplier Management	Gender equality and professional diversity	(0.73, 0.89, 0.95)	0.8567	
		Internal networks and indicator monitoring	(0.72, 0.88, 0.94)	0.8467	
	Green Procurement	Environmental and social evaluation of suppliers	(0.74, 0.89, 0.96)	0.8633	
		Periodic auditing and codes of conduct	(0.73, 0.89, 0.95)	0.8567	
Sustainable Innovation	Domestic Supplier Development	Green purchasing criteria and material traceability	(0.73, 0.89, 0.95)	0.8567	
		Localization and sanction risk reduction	(0.74, 0.90, 0.96)	0.8667	
	Supply Chain Resilience	Multi-sourcing, safety inventory, and domestic substitution	(0.73, 0.89, 0.95)	0.8567	
		Business Continuity	Scenario planning, emergency measures, and geopolitical risk management	(0.72, 0.88, 0.95)	0.8500
Stakeholder Accountability	Stakeholder Engagement	Clean technologies and low-carbon products	(0.75, 0.90, 0.97)	0.8733	
		Reuse, recycling, and inter-unit synergy	(0.74, 0.89, 0.96)	0.8633	
Reporting and Accountability	Reporting and Accountability	Stakeholder mapping, materiality assessment, and consultation sessions	(0.73, 0.89, 0.95)	0.8567	
		Sustainability/integrated reporting and complaint response	(0.72, 0.88, 0.95)	0.8500	

Table 4

Fuzzy Delphi Results (Innovative and Economical Production Methods)

Dimensions	Components	Subcomponents	Fuzzy Mean of Expert Opinions (L, M, U)	Defuzzification
Energy Optimization	Energy Auditing and Integration	Energy auditing and thermal/electrical integration	(0.75, 0.90, 0.98)	0.8767
	Energy Loss Reduction	Reduction of flaring/leakage, heat recovery, and equipment load optimization	(0.76, 0.91, 0.98)	0.8833
Process Intensification	Compact Equipment and Processes	Reactor, membrane, and microchannel technologies; advanced distillation (dividing-wall/reactive)	(0.74, 0.90, 0.97)	0.8700
	Operational Integration	Integration of mass and heat transfer, modular and skid-mounted design	(0.73, 0.89, 0.96)	0.8600
Lean and Green Lean	Waste Elimination and Flow Improvement	VSM, 5S, Kaizen, work standardization, and SMED	(0.74, 0.90, 0.96)	0.8667
	Environmental Alignment	Green lean indicators and reduction of material/energy consumption	(0.72, 0.88, 0.95)	0.8500
Digitalization and Industry 4.0	Advanced Monitoring and Control	IIoT, APC/MPC, and DCS–MES–ERP integration	(0.75, 0.91, 0.98)	0.8800

	Smart Maintenance	Condition monitoring, predictive maintenance, and digital twins	(0.74, 0.90, 0.97)	0.8700
Innovation Management	Innovation System	Stage-gate process, project portfolio, and open innovation	(0.73, 0.89, 0.96)	0.8600
	Intellectual Property and Localization	IP/license management, authorized reverse engineering, and localization	(0.72, 0.88, 0.95)	0.8500
Eco-efficiency	Resource Productivity and Life Cycle Assessment	Improvement of material efficiency, reduction of water/energy/emission intensity, and LCA	(0.74, 0.90, 0.97)	0.8700
	Recycling and Recirculation	Solvent/catalyst recycling and water/wastewater recirculation	(0.73, 0.89, 0.96)	0.8600
Production Flexibility and Resilience	Operational Continuity	Redundancy of critical equipment and bypass pathways	(0.74, 0.90, 0.96)	0.8667
	Agility and Localization	Rapid change of production rate/product portfolio and domestic parts supply	(0.73, 0.89, 0.95)	0.8567
Inherent Process Safety (Additional)	Inherently Safe Design	Source-based hazard reduction in technology/equipment selection	(0.75, 0.90, 0.97)	0.8733
Replacement of Sanctioned Catalysts/Materials (Additional)	Low-risk Domestic Alternatives	Functionally compatible process alternatives	(0.74, 0.90, 0.96)	0.86

The results obtained from the three rounds of the fuzzy Delphi process indicated that the identified indicators in the two general categories of “sustainable performance management” and “innovative and economical production methods” achieved a high level of expert consensus, and the defuzzified averages of most indicators exceeded 0.80, demonstrating the high importance and applicability of these indicators in the Iranian petrochemical industry. Within the sustainable performance management dimension, environmental indicators (such as reduction of greenhouse gas emissions and water recycling) and social indicators (occupational health and safety) received the highest priorities, while economic dimensions (sustainable profitability and operational productivity) and governance dimensions (transparency and anti-corruption measures) also obtained substantial weights. Furthermore, other dimensions including ethical considerations, diversity and inclusion, sustainable supply chain, sustainable innovation, and stakeholder accountability were confirmed as complementary dimensions of the model.

In the field of innovative and economical production methods, experts emphasized the particular importance of energy optimization, digitalization and Industry 4.0, and process intensification. In addition, concepts such as green lean production, eco-efficiency, production resilience, and the replacement of sanctioned catalysts and materials were identified as critical requirements for localization and increasing industrial flexibility under sanction conditions. Accordingly, the fuzzy Delphi results provide a set of operational and strategic indicators that can serve as the foundation for the design and implementation of a comprehensive sustainable performance management model in the Iranian petrochemical industry.

4. Discussion and Conclusion

The findings of the present study demonstrated that sustainable performance management in the Iranian petrochemical industry under sanction conditions is a multidimensional and context-dependent construct that requires simultaneous attention to environmental, economic, governance, social, innovation, and supply chain dimensions. The results obtained from the systematic literature review and fuzzy Delphi analysis indicated that environmental indicators, particularly reduction of greenhouse gas emissions, energy consumption optimization, water recycling, and pollution control, achieved the highest levels of expert consensus. These findings confirm that environmental sustainability is no longer a peripheral concern in petrochemical industries, but rather a strategic operational priority directly associated with efficiency, cost reduction, legitimacy, and long-term resilience. The high prioritization of environmental indicators can be explained by the energy-intensive and emission-intensive nature of petrochemical production processes, where resource inefficiency directly increases operational costs and environmental risks. These findings are aligned with studies emphasizing the importance of integrating environmental sustainability into performance evaluation systems and industrial strategy (Eccles & Klimenko, 2019; Kuhnen & Hahn, 2019; Lu et al., 2018). The findings are also consistent with evidence suggesting that sustainable business performance in petroleum industries depends heavily on environmental management capability and resource optimization (Hadi & Baskaran, 2021).

The strong emphasis placed by experts on energy optimization and eco-efficiency also reflects the economic realities of petrochemical industries operating under sanctions. The findings demonstrated that energy auditing, thermal and electrical integration, reduction of flaring and leakage, heat recovery, and reduction of energy intensity were among the most highly prioritized indicators within the innovative and economical production methods category. This result is understandable because sanctions increase production costs, limit access to advanced technologies, and intensify the need for internal efficiency improvement. Under such conditions, companies are forced to maximize output using existing infrastructure and limited resources. These findings support prior research indicating that eco-efficiency and green lean practices can simultaneously improve environmental and economic performance by reducing waste, enhancing process efficiency, and optimizing resource utilization (Santoso & Kasih, 2024). The results also align with sustainability-oriented performance frameworks emphasizing that operational efficiency and sustainability should be integrated rather than treated as competing objectives (Abbas, 2020). Therefore, environmental sustainability in the Iranian petrochemical industry appears to function not only as an ecological requirement but also as a mechanism for economic survival and operational continuity.

Another important finding of the study was the high importance attributed to digitalization, Industry 4.0 technologies, and intelligent maintenance systems. Indicators related to industrial internet of things, advanced process control, predictive maintenance, digital twins, and integrated production-management systems achieved high defuzzification scores in the fuzzy Delphi stage. This finding indicates that experts perceive digital transformation as one of the principal pathways toward sustainable and competitive petrochemical production under uncertain conditions. The increasing complexity of petrochemical operations requires organizations to improve monitoring capability, predictive decision-making, operational visibility, and process integration. Previous studies have similarly emphasized the transformative role of Industry 4.0 technologies in manufacturing efficiency, operational flexibility, and sustainability performance (Xu et al., 2018). Furthermore, managerial lessons associated with Industry 4.0 implementation demonstrate that organizational readiness, leadership support, infrastructure capability, and strategic integration are essential for successful digital transformation (Sony & Naik, 2019). The present findings

also correspond with recent research suggesting that artificial intelligence and smart manufacturing systems can substantially improve sustainability performance through predictive analytics, adaptive optimization, and intelligent resource management (Youssef et al., 2025). In the Iranian petrochemical industry, where sanctions restrict access to imported technologies and increase maintenance difficulties, predictive maintenance and digital process monitoring can reduce downtime, improve operational readiness, and enhance production resilience.

The findings also revealed that process intensification and technological innovation were among the most significant dimensions of innovative and economical production methods. Experts emphasized the importance of compact process technologies, advanced distillation systems, modular design, process integration, and domestic technological alternatives. This result can be interpreted within the broader context of sustainability transitions and industrial adaptation. Petrochemical firms operating under sanctions cannot depend indefinitely on imported technologies, catalysts, and engineering services. Consequently, process redesign and localized technological innovation become essential for maintaining production continuity and improving competitiveness. These findings are consistent with studies highlighting the importance of technological innovation capability in organizational performance and sustainability development (Kim & Jun, 2022). They also correspond with research on sustainability transitions in petroleum-related industries, which indicates that industrial adaptation requires diversification of technological capability and restructuring of innovation systems (Andersen & Gulbrandsen, 2020). In addition, studies on sanctions and green innovation suggest that external restrictions may simultaneously constrain technology access and stimulate domestic innovation capacity (Fu et al., 2023). The findings of the present study strongly support this dual perspective because experts identified localization, substitution of sanctioned materials, and domestically compatible process alternatives as critical indicators for sustainable petrochemical performance.

Supply chain resilience emerged as another highly important dimension in the study. Indicators such as multi-sourcing, domestic supplier development, safety inventory, geopolitical risk management, and business continuity planning received substantial expert agreement. These findings reflect the severe vulnerability of petrochemical supply chains under sanction conditions, where disruptions in procurement channels, logistics systems, or supplier

relationships can directly threaten production continuity. The results are consistent with resilience-based supply chain theories emphasizing flexibility, redundancy, adaptability, and risk management as critical components of resilient industrial systems (Ali et al., 2017). The findings also align with simulation-based analyses showing that external disruptions can propagate rapidly across interconnected supply networks and create cascading operational impacts (Ivanov, 2020). In the context of the Iranian petrochemical industry, sanctions create long-term structural uncertainty rather than temporary operational interruptions; therefore, resilience becomes a permanent strategic requirement rather than a short-term emergency response. The importance attributed to domestic supplier development and localization further demonstrates that experts consider local industrial ecosystems essential for sustainable petrochemical operations under restricted international conditions. These findings also correspond with studies emphasizing sustainable supply chain development and prioritization of resilience-related parameters in industrial systems (Shirazi et al., 2024).

The findings additionally showed that governance-related indicators, including transparency, legal compliance, anti-corruption measures, board independence, and cybersecurity management, were highly valued by experts. This result indicates that sustainable performance management in petrochemical industries cannot be achieved solely through technological and operational improvements. Governance quality influences organizational accountability, strategic consistency, stakeholder trust, and risk management capability. Particularly in sanction environments characterized by financial complexity, operational uncertainty, and geopolitical risk, governance mechanisms become critical for maintaining organizational stability and institutional legitimacy. These findings support prior studies emphasizing the importance of climate-related disclosure, governance readiness, and accountability systems in sustainability-oriented corporate management (Eccles & Klimenko, 2019). They also align with sustainability performance measurement research indicating that governance indicators are necessary components of comprehensive sustainability evaluation systems (Kuhnen & Hahn, 2019). Furthermore, the prioritization of industrial cybersecurity reflects the growing digital dependence of petrochemical systems and the increasing exposure of industrial control systems to cyber threats, particularly in politically sensitive and sanction-affected industries.

In the social dimension, occupational health and safety, employee empowerment, training, and workforce participation received relatively high scores, while broader diversity and inclusion indicators achieved comparatively lower priorities. This finding suggests that experts distinguish between operationally critical social indicators and longer-term institutional or cultural dimensions. Occupational safety is particularly important in petrochemical industries due to the hazardous nature of operations, exposure to chemicals, explosion risk, and process safety concerns. Therefore, experts appear to perceive workforce safety and technical capability as directly linked to operational sustainability and productivity. These findings are compatible with studies indicating that human capital and organizational culture significantly influence sustainability performance and operational effectiveness (Santoso & Kasih, 2024). However, the lower prioritization of diversity and inclusion may reflect the immediate pressures of sanction conditions, where organizations prioritize operational continuity and resource management over broader social transformation objectives. Although diversity and inclusion remain important sustainability dimensions in international frameworks, their perceived urgency may decline in contexts characterized by economic restriction and industrial uncertainty.

The results also demonstrated that sustainable innovation and stakeholder accountability were recognized as complementary yet essential dimensions of the proposed framework. Indicators related to green research and development, circular economy practices, sustainability reporting, stakeholder mapping, and responsiveness to complaints achieved acceptable consensus levels among experts. These findings reinforce the idea that sustainable petrochemical performance requires continuous innovation and active stakeholder engagement rather than isolated operational interventions. Integrated thinking approaches similarly emphasize that sustainability should be embedded across organizational strategy, reporting systems, and value creation processes (Adams, 2017). Furthermore, the growing importance of investor-oriented sustainability expectations and environmental accountability suggests that firms increasingly need credible sustainability indicators to maintain legitimacy and strategic adaptability (Eccles & Krzus, 2019). In the Iranian petrochemical context, stakeholder accountability may also strengthen social trust, institutional credibility, and long-term competitiveness despite external restrictions.

Overall, the findings of the present study indicate that sustainable performance management in the Iranian petrochemical industry under sanctions is fundamentally shaped by the interaction between sustainability imperatives, technological adaptation, economic constraints, and resilience requirements. Unlike generic sustainability models developed for stable and highly globalized industrial contexts, the proposed framework reflects the operational realities of a sanction-affected industrial environment. The identified indicators combine global sustainability principles with localized priorities such as sanction resilience, domestic supplier development, process intensification, substitution of restricted materials, and operational flexibility. Therefore, the study contributes theoretically by contextualizing sustainable performance management within constrained industrial systems and contributes practically by providing a localized framework for petrochemical decision-makers. The findings also demonstrate that sustainable performance and innovative production methods are mutually reinforcing dimensions rather than separate managerial domains. Companies that improve energy efficiency, digital capability, process integration, innovation systems, and supply chain resilience are simultaneously strengthening sustainability performance, operational continuity, and long-term competitiveness.

One limitation of the present study is that the fuzzy Delphi panel was limited to 18 experts from the petrochemical industry and academia, which may restrict the generalizability of the findings to all segments of the energy and process industries. In addition, the study adopted a qualitative-exploratory design and did not empirically test the causal relationships among the identified indicators. Another limitation is that the prioritization of indicators may change over time depending on geopolitical developments, technological evolution, regulatory changes, and the intensity of international sanctions. Furthermore, because the study focused specifically on the Iranian petrochemical industry, the identified dimensions and priorities may not fully apply to industries with different technological structures or institutional environments.

Future research can expand the proposed framework through quantitative validation methods such as structural equation modeling, interpretive structural modeling, DEMATEL, or system dynamics approaches. Researchers may also investigate the causal interactions among sustainability dimensions, digitalization capability, supply chain resilience, and innovation performance. Comparative studies between sanction-affected and non-sanctioned

petrochemical industries could provide additional insights into the contextual nature of sustainable performance management. Future studies may further explore the role of artificial intelligence, smart manufacturing systems, circular economy models, and climate-related governance in transforming petrochemical sustainability practices. Longitudinal studies are also recommended to examine how sustainability priorities evolve over time under changing technological and geopolitical conditions.

From a practical perspective, petrochemical managers and policymakers should prioritize the integration of sustainability indicators into operational and strategic decision-making systems. Companies should invest in energy optimization, predictive maintenance, digital infrastructure, and process intensification to improve operational efficiency and resilience. Policymakers should support domestic supplier development, technology localization, and industrial innovation ecosystems to reduce dependence on restricted foreign technologies. Petrochemical firms should also strengthen governance systems, transparency mechanisms, industrial cybersecurity, and sustainability reporting practices in order to improve institutional trust and long-term competitiveness. Furthermore, organizations should establish integrated sustainability management systems that combine environmental responsibility, operational efficiency, innovation capability, and supply chain resilience within a unified strategic framework.

Authors' Contributions

Authors contributed equally to this article.

Declaration

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

Transparency Statement

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