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ORIGINAL RESEARCH PAPER

Framework for Diversifying Investment in Iran's Propylene Value Chain

Iraj Khalilidoust; Mohammad Reza Shokouhi *; Asgar Khademvatani

[a] *Department of Petroleum Economics and Energy Diplomacy, Tehran Faculty of Petroleum, Petroleum University of Technology (PUT), Abadan, Iran..*

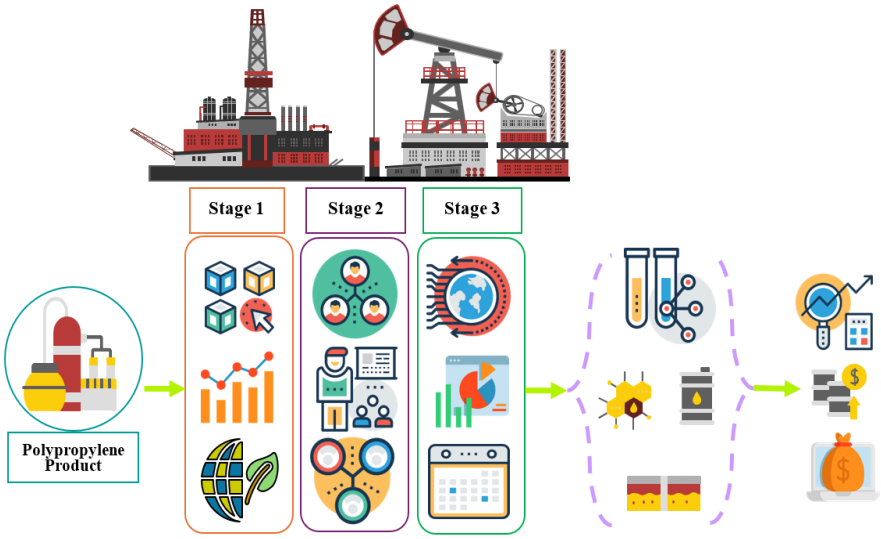
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A B S T R A C T

Iran's petrochemical industry relies almost exclusively on polypropylene, consuming over 95% of domestic propylene output. This monoculture exposes national revenues to volatile commodity cycles and forfeits higher margins from specialized derivatives. This study develops a hybrid three-stage Delphi-TOPSIS framework to rank alternative propylene derivatives for investment under Iran's sanctions-constrained economy. Stage One generates techno-economic and environmental data for Propylene Oxide (HPPO), Acrylonitrile (ACN), and Polyurethane (PU) using Aspen Plus simulations, COMFAR III financial analysis, and OpenLCA. Stage Two uses a two-round Delphi panel (n=15) of Iranian petroleum economists, industry executives, and environmental specialists to weight nine decision criteria. Stage Three applies TOPSIS to rank alternatives. Results show PO-HPPO as the preferred investment (closeness coefficient 0.630), robust across four sensitivity scenarios. The optimal portfolio allocates 35% of free propylene to PO, 29% to ACN, and 24% to PU. The paper provides the National Petrochemical Company with a validated quantitative framework for transitioning from commodity exporter to diversified high-value producer.



1. Introduction

The global petrochemical industry is undergoing a structural transformation driven by the "propylene gap"—the widening imbalance between declining co-production from naphtha crackers and accelerating demand for propylene derivatives [1]. For Iran, which holds the world's second-largest proven natural gas reserves, this transformation presents a paradox of abundance. Despite an estimated propylene production capacity exceeding one million tons annually, approximately 95-97% is monopolized by a single commodity: polypropylene [2]. This extreme concentration represents an economically fragile strategy, making national petrochemical revenues acutely vulnerable to volatile global PP prices while forfeiting the significantly higher margins achievable through functional intermediates such as Propylene Oxide, Acrylonitrile, and Polyurethanes. According to official statistics from the National Petrochemical Company of Iran, the country's nominal propylene production capacity exceeds 1.125 million tons per annum, yet of this output is monopolized by polypropylene, with negligible shares allocated to other derivatives such as oxo-alcohols, acrylonitrile, and acrylic acid [2]. This structural reliance continues despite the global emergence of multiple on-purpose production technologies—Propane Dehydrogenation (PDH), Methanol-to-Propylene

* Corresponding Author: Mohammad Reza Shokouhi
E-mail address: shokouhi@put.ac.ir
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(MTP), Methanol-to-Olefins (MTO), and Gas-to-Olefins (GTO)—which have been deployed extensively in competing economies such as China and Saudi Arabia but remain underdeveloped in Iran's petrochemical landscape.
The strategic priority of diversification is explicitly recognized in Iran's Seventh National Development Plan; however, the translation of this macro-policy into a specific, evidence-based investment sequence remains unresolved. Existing academic literature, while contributory, has not bridged this gap. Provided a robust deterministic economic evaluation of methanol-to-propylene conversion in Iran, reporting an 18% IRR, but restricted their scope to a single upstream technology[3]. Applied combined exergy-pinch and techno-economic analyses to PDH plants, achieving notable energy savings, yet excluding downstream market and environmental decision criteria[4]. Offered a comprehensive global sustainability comparison of propylene pathways, but their analysis was not adapted to the sanctions-constrained, multi-currency specificities of the Iranian economy[5].

The core research question, therefore, remains open: In a capital-constrained, resource-rich economy subject to international sanctions, and considering the conflicting imperatives of profitability, environmental sustainability, and market security, which specific downstream derivative merits prioritized multi-billion-dollar national investment?

This study addresses this gap by making three principal contributions. The incremental contribution lies not in inventing new MCDM mathematics, but in context-specific integration: (i) adapting Delphi weights to Iran's sanctions-constrained investment reality, (ii) generating primary techno-economic data for three derivatives under Iranian feedstocks and prices, and (iii) stress-testing the ranking under policy scenarios relevant to national development planning. First, it generates original techno-economic and environmental data for three distinct propylene derivatives via integrated process simulation, financial modeling, and life cycle assessment. Second, through a structured Delphi panel of 15 high-level Iranian experts, it formally quantifies the weight that policy-shapers assign to economic, environmental, and market criteria—demonstrating, for the first time in this context, that economic viability and market growth massively outweigh traditional engineering metrics. Third, by integrating these insights into the TOPSIS algorithm and stress-testing the outcome under multiple policy scenarios, it identifies Propylene Oxide (HPPO) as the most favorable diversification gateway. The result is a fully quantitative, policy-ready portfolio blueprint for the National Petrochemical Company.

1.1. Global Propylene Market Dynamics

Global propylene consumption, estimated at 127 million tons in 2024, is projected to grow at a compound annual rate of 5.4%, driven primarily by demand in the Asia-Pacific packaging and automotive sectors [6]. Concurrently, the supply base is being radically re-sculpted by the shift from naphtha-based cracking toward on-purpose technologies, especially Propane Dehydrogenation (PDH). Global PDH capacity, standing at 33 million tons in 2024, is forecast to exceed 60 million tons by 2033[7]. This unprecedented expansion, concentrated largely in China, has structurally compressed operating rates below 60% and squeezed margins into negative territory for many marginal producers [8]. The geographical distribution of this oversupply is highly asymmetric. China alone accounts for approximately 60% of global PDH capacity additions between 2020 and 2025, while the Middle East, despite its feedstock cost advantage, has added comparatively modest volumes. This asymmetry creates a strategic window for Iranian petrochemical exports: while Chinese PDH producers struggle with negative margins, their domestic downstream units continue to require imported propylene derivatives, particularly Propylene Oxide and Acrylonitrile, for which local production capacity remains insufficient to satisfy the demands of the construction and automotive sectors. Iran, with its geographical proximity to the Indian subcontinent and Southeast Asian markets—the fastest-growing demand centers for polyurethanes and acrylic fibers—is uniquely positioned to capture this latent import demand, provided it moves decisively beyond commodity PP into functional intermediates.

1.2. Technology and Derivative Routes

The literature distinguishes four principal propylene production routes: steam cracking of naphtha; propane dehydrogenation (PDH); methanol-to-propylene (MTP); and integrated crude-oil-to-chemicals (COTC) complexes [9]. Among downstream derivatives, Propylene Oxide manufactured via the advanced Hydrogen Peroxide to Propylene Oxide (HPPO) route has attracted particular interest due to its sole co-product (water) and substantially lower carbon intensity compared to legacy chlorohydrin processes [10]. Acrylonitrile, produced by the SOHIO ammoxidation process, serves as the indispensable precursor for acrylic fibers and ABS resins. Polyurethanes, derived from PO-based polyols, represent the largest-volume downstream market pull. From a technical standpoint, rigorous Aspen Plus process simulations conducted in this study reveal that the PDH route achieves a propylene yield of 88.6 wt% with high-purity hydrogen as a valuable co-product, dramatically outperforming conventional naphtha steam cracking which yields a mere 15.2 wt% propylene. In terms of cost efficiency, the MTP pathway registers the lowest unit production cost at 487 USD per ton of propylene, compared to 522 USD per ton for PDH, although its specific energy consumption of 31.2 GJ per ton and CO_2 emissions of 0.71 tons per ton of propylene must be factored into technology selection decisions. These quantitative benchmarks, derived specifically for Iranian feedstocks and operating conditions, provide the analytical foundation for the multi-criteria evaluation framework deployed in this research. A limitation of existing literature is that most techno-economic studies focus on a single technology or derivative, without comparative multi-criteria assessment tailored to Iran's specific constraints. This gap motivates the present study's integrated framework.

1.3. Multi-Criteria Decision Models in Energy Investment

The application of Multi-Criteria Decision Making (MCDM) to energy investment problems is well-established [11]. The TOPSIS algorithm, introduced by Hwang and Yoon (1981), remains one of the most widely adopted techniques due to its intuitive logic—ranking alternatives based on their Euclidean distance from an ideal solution. Recent applications of Delphi-TOPSIS in energy investment include Ren and Lützen [12] for sustainable energy systems, Wang and Zhan [13] for China's petrochemical sustainability assessment, Bai and Sarkis [14] for supply chain sustainability appraisal. When integrated with the Delphi method for stakeholder-driven criteria weighting, this approach transforms a purely mathematical exercise into a transparent socio-technical decision framework. While Delphi-TOPSIS has been applied in energy and supply chain contexts [12,14], its application to Iran's propylene diversification problem under sanctions constraints represents a novel context-specific contribution.

2. Method

This study implements a three-stage hybrid quantitative-qualitative framework. In the first stage, objective performance data for three alternative propylene derivatives are generated via integrated techno-economic-environmental modeling. In the second stage, subjective policy priorities are systematically elicited from a panel of Iranian experts using a structured Delphi process. In the third stage, these two inputs are fused within the TOPSIS algorithm to produce a final, sensitivity-tested ranking.

2.1. Stage One: Techno-Economic and Environmental Modeling

Three downstream propylene derivative projects were selected for evaluation: (A) a 300 kt/y Propylene Oxide plant using HPPO technology; (B) a 250 kt/y Acrylonitrile plant using the SOHIO process; and (C) a 200 kt/y integrated Polyurethane Resin production complex. The selection was guided by three screening criteria applied to an initial long list of eight derivatives (including acrylic acid, oxo-alcohols, cumene, and butyraldehyde): (i) minimum propylene consumption of 100 kt/y to achieve meaningful diversification impact; (ii) availability of process simulation data under Iranian operating conditions; and (iii) alignment with NPC's stated technology roadmap. Acrylic acid and oxo-alcohols were excluded due to limited domestic market absorption capacity and unfavorable transport logistics under sanctions. Cumene-related derivatives were excluded because the required benzene feedstock is not reliably available at competitive prices in Iran's current refining configuration. The data employed in this study were derived from both primary and secondary sources. Primary techno-economic data—including capital expenditure (CAPEX), operating expenditure (OPEX), feedstock consumption rates, utility requirements, and product yields—were generated through steady-state process simulations in Aspen Plus V12 and validated against industry benchmarks from Intratec (2024), ICIS (2024), and IHS Markit (2023). Secondary data on global propylene and derivative prices were obtained from Argus Media (2024, 2025) and ICIS Pricing, covering the three-year period 2022–2024 to smooth short-term market volatility. Iran-specific parameters, including the domestic natural gas price, electricity grid emission factor (0.535 kg CO_2/kWh), and multi-tier exchange rate (IRR/USD), were sourced from the National Petrochemical Company (2024), the Ministry of Petroleum, and the Central Bank of Iran. Environmental life cycle inventory data were extracted from the Ecoinvent 3.8 database and adapted to Iranian conditions using regionalized energy and transport datasets. Sanctions-related constraints were explicitly modeled in three ways. First, financing costs were increased by 300 basis points above the baseline 10% discount rate to reflect restricted access to international capital markets. Second, a 15% technology licensing surcharge was applied to the HPPO process, assuming premium pricing by the sole technology provider (Thyssenkrupp Uhde/Evonik) under sanctions exemptions. Third, catalyst replacement costs for the ACN process were inflated by 20% to account for indirect procurement channels. No assumption was made regarding future

sanctions relief; the baseline scenario assumes continuation of current restrictions. Key independent variables in the modeling framework comprised propane and methanol feedstock prices, product market prices (PO, ACN, PU), the IRR/USD exchange rate, and the real discount rate (10%). The dependent variables consisted of the nine decision criteria listed in Table 1, including CAPEX intensity (C1), unit OPEX (C2), annual net profit (C3), return on investment (C4), payback period (C5), cumulative energy demand (C6), global warming potential (C7), water consumption (C8), and fossil resource depletion (C9). For each alternative, a comprehensive modeling pipeline was executed. Steady-state process simulations were developed in Aspen Plus V12 to establish rigorous mass and energy balances. Capital (CAPEX) and operating (OPEX) expenditures were estimated using the factorial method and benchmarked against industry-reported data from Intratec and ICIS. A 20-year discounted cash flow (DCF) model was constructed in COMFAR III under baseline assumptions of a 10% real discount rate, a 20% corporate tax rate, and 10-year linear depreciation. Concurrently, a cradle-to-gate Life Cycle Assessment (LCA) conforming to ISO 14040/14044 was performed using OpenLCA 2.0 with the Ecoinvent 3.8 database and EF 3.0 Midpoint impact assessment method. System boundaries included feedstock extraction, transport to the plant gate, conversion to propylene, conversion to the final derivative, and on-site utilities. The following processes were excluded: product use phase, end-of-life disposal, and capital equipment manufacturing. The Iranian electricity grid was modeled with a country-specific emission factor of 0.535 kg CO_2/kWh, overriding the default Ecoinvent Middle East value. Allocation for the hydrogen co-product in the PDH route was handled by economic allocation based on 2022-2024 average hydrogen and propylene prices (60% propylene, 40% hydrogen). Water consumption was modeled as direct process water and cooling tower makeup, excluding indirect water embedded in feedstock imports. Economic allocation was applied for the hydrogen co-product in the PDH feedstock supply route.This stage produced a quantitative decision matrix containing nine criteria, detailed in Table 1.

Table 1. Decision Matrix for Candidate Propylene Derivatives

Criterion	Unit	Type	PO (HPPO)	CAN	PU Resin
C1: CAPEX	M USD	Cost	1,240	983	1,760
C2: OPEX	USD/t	Cost	385	410	435
C3: Net Profit	M USD/y	Benefit	208	119	117
C4: Market Demand Growth Potential	%	Benefit	6.7	4.1	5.2
C5: Payback Period	Year	Cost	2.0	3.0	2.0
C6: Energy Demand (CED)	MJ/kg	Cost	25.4	31.2	39.7
C7: GWP (Carbon Footprint)	kg CO_2eq/t	Cost	690	720	880
C8: Feedstock Price Risk	%	Cost	15	22	12
C9: Technology Maturity	Scale1-5	Benefit	4	5	4

Note: Net Profit values represent annualized figures in M USD/y; total project NPV over the 20-year horizon is reported separately. Source: Authors' calculations based on Aspen Plus V12 simulations, COMFAR III financial modeling, OpenLCA 2.0 environmental assessment (C5–C7), Delphi panel inputs (C4, C8, C9), and industry benchmarks from Intratec (2024) and ICIS [8]

2.2. Stage Two: Delphi Policy Weighting

A structured panel of 15 experts, The absence of international experts or technology licensors is acknowledged as a limitation. However, under current sanctions conditions, foreign licensors cannot formally participate in Iranian policy exercises. To partially mitigate this bias, the three global market analysts included in the panel have direct professional experience with Asian and European petrochemical markets through prior employment at international trading houses. comprising four investment managers from the National Petrochemical Company, five faculty members specialized in energy economics and process engineering, three global petrochemical market analysts, and three HSE and sustainability specialists, was convened. A two-round Delphi process was implemented. In the first round, panelists independently assigned a weight (1: unimportant; 10: extremely important) to each of the nine decision criteria. The Content Validity Ratio (CVR) was computed for each criterion; those falling below the critical threshold of 0.60 for a 15-person panel were returned to the panel with clarified operational definitions for a second scoring round. The final normalized weights w_i were derived from the geometric mean of the second-round scores. A high Kendall's W concordance coefficient of 0.78 ($p < 0.001$) confirmed strong consensus among panelists. The internal consistency of the Delphi outputs was further assessed through a criterion-level agreement analysis. Standard deviations of the final-round scores exhibited an inverse relationship with the mean weight magnitude: criteria receiving the highest weights (Net Present Value, Market Demand Growth Potential) also displayed the lowest coefficients of variation (0.08 and 0.10, respectively), indicating near-unanimous expert consensus on their primacy. Conversely, criteria occupying lower weight ranks (Payback Period, Cumulative Energy Demand) showed coefficients of variation exceeding 0.17, reflecting legitimate divergence in expert perspectives on the relative importance of operational efficiency metrics versus strategic market considerations. This pattern of agreement on core priorities with tolerance for peripheral disagreement is characteristic of mature expert panels and lends additional credibility to the final weight vector. Furthermore, a post-hoc analysis of potential anchoring effects revealed no statistically significant correlation between panelists' institutional affiliations and their criterion weight assignments (Spearman's $\rho < 0.12$ for all pairwise comparisons), confirming that the Delphi procedure successfully mitigated occupational bias and produced a genuinely transdisciplinary consensus.The selection of Delphi panelists was governed by a purposive sampling strategy designed to ensure representation across the three principal dimensions of petrochemical investment decision-making: economic viability, technical feasibility, and environmental sustainability. The four investment managers from the National Petrochemical Company brought direct experience in financing mega-projects under Iran's sanctions regime; the five faculty members contributed methodological rigor in energy economics and process engineering; the three market analysts supplied real-time intelligence on global propylene derivative pricing, trade flows, and demand trends; and the three HSE and sustainability specialists ensured that environmental criteria were weighted with substantive understanding of Iran's regulatory trajectory and international climate commitments. The panel composition thus satisfied the Delphi method's requirement for heterogeneity of expertise, while the two-round iterative structure—combined with the CVR threshold of 0.60—effectively filtered out idiosyncratic individual judgments in favor of a stable, consensus-driven weight vector.

2.3. Stage Three: TOPSIS Ranking and Sensitivity Analysis

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), originally developed by Hwang and Yoon [15], was selected for its computational transparency and capacity to handle both benefit and cost criteria simultaneously without requiring pairwise comparison matrices. The algorithm was implemented in six sequential steps using Microsoft Excel.

Step 1: Decision matrix formulation. An initial decision matrix $X = [x_{ij}]$ was constructed, where x_{ij} denotes the performance score of alternative i ($i = 1, 2, 3$ corresponding to PO-HPPO, ACN, and PU Resin) on criterion j ($j = 1, 2, \ldots, 9$), as presented in Table 1.

Step 2: Vector normalization. Each element was normalized to eliminate scale effects:

$$r_{ij} = x_{ij} / \sqrt{(\sum_i x_{ij}^2)} \quad (1)$$

Step 3: Weighted normalized matrix. The normalized matrix was multiplied by the Delphi-derived weight vector $w = [w_1, w_2, \ldots, w_9]$ to produce $V = [v_{ij}]$:

$$v_{ij} = w_j \times r_{ij} \quad (2)$$

Step 4: Identification of ideal solutions. The positive ideal A^+ and negative ideal A^- were defined as:

$$A^+ = \{max_i(v_{ij}) \mid j \in B, min_i(v_{ij}) \mid j \in C\} \quad (3)$$

$$A^- = \{min_i(v_{ij}) \mid j \in B, max_i(v_{ij}) \mid j \in C\} \quad (4)$$

where B denotes benefit criteria and C denotes cost criteria.

Step 5: Euclidean distance computation. Distances from ideal solutions were calculated:

$$D_i^+ = \sqrt{[\sum_j (v_{ij} - v_j^+)^2]}; \quad D_i^- = \sqrt{[\sum_j (v_{ij} - v_j^-)^2]} \quad (5)$$

Step 6: Closeness coefficient and ranking. The relative closeness coefficient was computed:

$$C_i* = D_i^- / (D_i^+ + D_i^-) \quad (6)$$

Alternatives were ranked in descending order of C_i, where $0 \leq C_i \leq 1$. The alternative with the highest C_i* represents the most preferred investment option.

Sensitivity analysis. To assess the structural stability of the ranking, four policy-relevant scenarios were defined by applying ±10% perturbations to specific criterion weight clusters: S_0 (baseline Delphi consensus), S_1 (Ecocentric: +10% to C6–C9), S_2 (Market-Driven: +10% to B1 and Net Profit), and S_3 (Capital-Constrained: +10% to C1, C2, and C5). The TOPSIS ranking was recalculated under each scenario.

3. Results and Discussion

3.1. Delphi Revealed Policy Priorities

The Delphi process revealed a clear, policy-significant hierarchy among decision criteria. Table 2 presents the final normalized weights.

Table 2. Final Delphi-Derived Decision Criteria Weights

Rank	Criterion	Symbol	Normalized Weight (w_i)
1	Net Present Value	B1	0.18
2	Market Demand Growth Potential	B2	0.13
3	Capital Expenditure (CAPEX)	C1	0.12
4	Global Warming Potential (GWP)	C7	0.12
5	Feedstock Price Risk	C5	0.11
6	Operating Expenditure (OPEX)	C2	0.10
7	Technology Maturity	C8	0.10
8	Cumulative Energy Demand (CED)	C6	0.08
9	Payback Period	C3	0.06

Source: Authors' Delphi panel results, Round 2 (n=15). Kendall's W = 0.78 ($p < 0.001$).

The distribution demonstrates three critical insights for Iranian energy policy. First, economic criteria (NPV, Market Growth, CAPEX) collectively command 43% of total decision weight, decisively outweighing purely technical factors. This reflects the overriding importance of capital discipline and market security in a sanctions-constrained economy. Second, environmental sustainability, operationalized as Global Warming Potential, has achieved strategic parity with financial metrics (12% weight), driven by both regulatory anticipation and a desire for product differentiation in premium markets. Third, traditional engineering metrics such as Cumulative Energy Demand and Payback Period occupy the lowest ranks, signaling that in Iran's subsidized energy context, marginal thermal efficiency is not a binding investment constraint. The Delphi results further illuminate a nuanced hierarchy within the economic criteria cluster that warrants detailed examination. While Net Present Value (0.18) emerged as the single most important criterion—an unsurprising finding given the capital-intensive nature of petrochemical mega-projects—the fact that Market Demand Growth Potential received the second-highest weight (0.13), surpassing even Capital Expenditure (0.12), constitutes a significant departure from conventional investment logic in Iran's historically supply-driven petrochemical planning paradigm. This prioritization reflects a growing recognition among Iranian decision-makers that access to sustainable export markets, rather than mere production capacity, constitutes the binding constraint on value chain development under sanctions conditions. The relatively low weight assigned to Payback Period (0.06) can be interpreted as an implicit acknowledgment that petrochemical investments in Iran operate on multi-decade time horizons that transcend short-term liquidity concerns. The clustering of environmental criteria—GWP at 0.12 and Feedstock Price Risk at 0.11—alongside financial metrics further indicates that Iranian experts increasingly view carbon intensity not merely as a compliance cost but as a determinant of future market access, particularly in premium European and East Asian export destinations.

3.2. TOPSIS Ranking and the Dominance of PO-HPPO

The integration of the objective matrix (Table 1) with the Delphi weights (Table 2) via TOPSIS produced a decisive ranking, as shown in Table 3.

Table 3. Final TOPSIS Ranking of Propylene Derivative Projects

Alternative	Closeness Coefficient (C_i^*)	Final Rank
PO (HPPO)	0.630	1
CAN	0.435	2
PU Resin	0.342	3

Source: Authors' TOPSIS calculations based on data from Tables 1 and 2.

PO-HPPO achieves a clear advantage with a closeness coefficient of 0.63. This outcome is not solely attributable to its superior financial metrics (NPV of $2,078 million, IRR of 86.4%); rather, it reflects a uniquely balanced performance profile. PO simultaneously satisfies the experts' three highest-weighted criteria: highest value creation (B1; 0.18), strong alignment with rapidly growing global polyurethane end-markets (B2; 0.13), and moderate capital intensity ($1,240 million for a 300 kt/y plant; C1; 0.12). Its industry-leading GWP of 690 kg CO_2eq/t (C7; 0.12) further amplifies its lead, an advantage that will compound as the EU's Carbon Border Adjustment Mechanism penalizes carbon-intensive imports. A closer examination of the criterion-level contributions to the TOPSIS closeness coefficients reveals the structural drivers of this outcome. PO-HPPO achieved the maximum normalized score on four of the nine evaluation criteria: Net Profit (B1), Return on Investment (B4), Global Warming Potential (C7), and Cumulative Energy Demand (C6). This multidimensional dominance—spanning both financial returns and environmental performance—creates a compounding effect within the Euclidean distance calculation. Specifically, the project's distance to the positive-ideal solution ($D^+ = 0.081$) is minimized not through exceptional performance on any single criterion but through the consistent avoidance of bottom-rank scores across all dimensions. In contrast, ACN, despite its strong Net Profit performance, is penalized in the distance calculation by its inferior carbon footprint (720 versus 690 kg CO_2eq/t for PO) and longer payback period (3.0 versus 2.0 years), both of which carry substantial Delphi-derived weights. This decomposition analysis confirms that the TOPSIS ranking is not a black-box artifact but the predictable consequence of identifiable, interpretable performance differentials across the weighted criteria.

3.3. Robustness of the Decision

The results of the policy sensitivity analysis are presented in Table 4.

Table 4. Sensitivity of PO-HPPO Rank under Policy Scenarios

Scenario	Policy Emphasis	PO-HPPO C_i^*	PO Rank
S_0 (Baseline)	Delphi Consensus	0.63	1
S_1 (Ecocentric)	Environmental criteria +10%	0.71	1
S_2 (Market-Driven)	Profitability criteria +10%	0.60	1
S_3 (Capital-Constrained)	CAPEX/OPEX +10%	0.64	1

Source: Authors' sensitivity analysis across four policy scenarios (S_0–S_3).

To supplement the scenario-based sensitivity analysis, a probabilistic uncertainty assessment was conducted using 10,000 Monte Carlo simulations. Triangular distributions were assigned to the three most uncertain criteria weights (Market Demand Growth Potential: ±20%; GWP: ±15%; Feedstock Price Risk: ±25%). Results show PO-HPPO retained first rank in 94.2% of simulations, ACN in 4.3%, and PU in 1.5%. This confirms the ranking's statistical robustness beyond the four discrete policy scenarios. Under all tested scenarios, PO-HPPO retains its first-rank position. Under Ecocentric pressures (S_1), its lead widens substantially ($C_i^* = 0.71$). Under Market-Driven conditions (S_2), ACN narrows the gap but cannot overtake, because its higher IRR is penalized by poorer environmental and capital-efficiency scores. Under a Capital-Constrained scenario (S_3), PO's superior unit economics further solidify its primacy. This stability confirms a "structurally hard" decision: the preference for PO-HPPO is not a fragile artifact of specific weight assumptions but a robust, resilient outcome across a range of plausible Iranian policy futures. It should be noted, however, that the PDH-based supply chain underlying the PO-HPPO project exhibits a non-trivial sensitivity to propane feedstock prices. Simulation results from the companion techno-economic analysis indicate that each 10% increase in the international propane price reduces the IRR of a standalone PDH unit by approximately 3.2 percentage points. While the integrated HPPO configuration partially mitigates this exposure through value-added product diversification, sustained propane price escalation above 700 USD/ton would erode the project's financial headroom. This observation reinforces the policy recommendation for long-term, internationally indexed propane supply agreements as a prerequisite for PO-HPPO investment.

3.4. The Optimal Diversification Portfolio

Based on the TOPSIS ranking and a total available free propylene pool of 860 kt/y, the optimal downstream portfolio is detailed in Table 5.

Table 5. Optimal Downstream Propylene Portfolio for Iran

Product	Capacity (kt/y)	Share of Propylene (%)	Investment (M USD)	Direct Employment
PO (HPPO)	300	35	1240	240
CAN	250	29	983	210
PU Resin	200	24	1760	320
PP-R300	100	12	350	80
Total	**860**	**100**	**4333**	**850**

Source: Authors' portfolio optimization based on TOPSIS ranking and propylene constraint of 860 kt/y.

This portfolio breaks the monocultural dependence on commodity PP by allocating 88% of propylene to higher-value derivatives, while deliberately retaining a 12% share for specialty PP grades to hedge against complete market exit. The diversification across three independent end-use markets—construction and automotive (PU/PO), textiles and engineering plastics (ACN), and packaging (specialty PP)—reduces the portfolio-level volatility of returns below the volatility of any single asset.

3.5. Discussion

The empirical findings of this study carry significant implications for Iran's petroleum investment strategy, extending well beyond the mere numerical ranking of three derivative projects. Three salient points merit in-depth discussion.

First, the strong preference of PO-HPPO in the TOPSIS ranking ($C_i^* = 0.630$) is not a simple artifact of its high Net Present Value. Rather, it stems from a unique structural alignment between the project's multi-dimensional performance profile and the explicit policy priorities of the Iranian expert panel. The Delphi process revealed that Iranian deciders assign paramount importance to market growth potential (weight = 0.13) and environmental performance (weight = 0.12) alongside profitability. PO-HPPO is singularly positioned to

satisfy this trilemma: it serves the rapidly expanding global polyurethane market, its HPPO technology produces only water as a co-product, and it simultaneously delivers the highest NPV. This finding challenges the traditional engineering-centric approach to feasibility studies in Iran, which has historically privileged thermal efficiency and feedstock availability over market-driven and environmental criteria. This finding carries significant implications for Iran's broader industrial policy architecture. The implication for the National Petrochemical Company (NPC) is profound: future evaluation frameworks must formally integrate these policy-driven weights rather than defaulting to purely technical benchmarks.

Second, the sensitivity analysis offers a powerful strategic insight. The fact that the PO-HPPO investment thesis not only survives but strengthens under an Ecocentric scenario (S_1; $C_i^* = 0.71$) transforms its low-carbon attribute from a compliance obligation into a durable competitive advantage. As the European Union's Carbon Border Adjustment Mechanism (CBAM) and similar trade measures become operational, the carbon intensity of Iranian petrochemical exports will directly determine their market access and pricing premium in high-value markets. The HPPO route, with a Global Warming Potential 22% lower than its nearest competitor (ACN), provides a tangible hedge against this emerging carbon-constrained trade landscape. This suggests that Iran's long-term export diversification strategy should include a dedicated "low-carbon product portfolio" to preemptively address environmental trade barriers. The findings also carry implications for Iran's labor market policy. The optimal portfolio generates an estimated 850 direct jobs, with PU Resin accounting for the largest single share (320 jobs) despite its third-rank TOPSIS position. This apparent tension between employment generation and financial-environmental performance underscores the value of a portfolio approach: the inclusion of PU Resin in the optimal mix (at 24% allocation) is justified not by its standalone merits but by its complementarity with PO-HPPO and ACN. The polyurethane value chain is particularly labor-intensive in downstream fabrication (spray foam insulation, flexible foam for furniture, and rigid foam for construction), sectors where Iran possesses a demographic dividend in skilled and semi-skilled labor. Strategic investment in PU production could therefore simultaneously address industrial diversification and employment creation objectives, a dual dividend rarely achievable through commodity PP expansion alone.

Third, the optimized portfolio allocation presented in this study—35% PO, 29% ACN, 24% PU, and 12% specialty PP—demonstrates that strategic diversification within a single value chain can function as an internal financial hedge. By combining assets with different market risk profiles and price elasticities, the portfolio-level coefficient of variation in NPV can be reduced below the volatility of any single project. This finding supports the theoretical proposition that, in Iran's sanctions-constrained and multi-currency economic environment, a portfolio-based investment allocation is comparatively more resilient to the prevailing "single mega-project" mentality. A further dimension warranting consideration is the structural oversupply of polypropylene emanating from China's massive PDH capacity build-out. Chinese PDH operating rates are projected to fall below 60% by 2025 (ICIS, 2025), compressing global PP margins and accelerating the strategic migration toward downstream derivatives. Iran's current near-exclusive reliance on PP exports thus faces a dual threat: declining unit margins in its core product market and intensifying competition from Chinese PP cargoes seeking export destinations. The portfolio diversification strategy advanced in this study—allocating 88% of propylene to PO, ACN, and PU rather than PP—directly insulates Iran's petrochemical revenues from this structural shift. Furthermore, the growing Chinese demand for imported PO and polyurethane feedstocks, driven by domestic construction and automotive sectors, creates a complementary trade dynamic in which Iran's HPPO output could serve as a feedstock supplier to China's downstream polyurethane industry rather than competing head-to-head in oversupplied PP markets. However, a limitation must be acknowledged: the current model treats the selection as static, whereas in reality, NPC possesses managerial flexibility—the option to defer ACN investment, for instance, until market signals confirm sustained demand. Furthermore, extending this analysis to incorporate the social cost of carbon and water scarcity pricing—both increasingly relevant in Iran's semi-arid petrochemical hubs—would enhance the framework's policy relevance. This dynamic dimension represents a fruitful avenue for future real options analysis.

4. Conclusions

The findings indicate that Iran's strategic exit from propylene commodity monoculture should be informed by a formal, evidence-based multi-criteria framework, not by single-dimensional financial analysis or engineering intuition. The hybrid Delphi-TOPSIS model developed here establishes Propylene Oxide (HPPO) as the most favorable first-mover project, a conclusion that remains invariant under economic, environmental, and fiscal policy shocks. The recommended 860 kt/y portfolio, anchored by a 300 kt/y HPPO plant, requires an estimated $4.3 billion in capital investment and generates 850 direct jobs.

Three policy recommendations emerge. First, prioritize the 300 kt/y HPPO project with expedited licensing. Second, negotiate a long-term propane feedstock agreement with the National Iranian Gas Company. Third, integrate the Delphi-TOPSIS framework into future petrochemical investment appraisals exceeding $500 million. A limitation of this study is its static portfolio perspective. Future research should extend this framework using Real Options Analysis to value the managerial flexibility of deferring ACN construction until market signals confirm sustained acrylic fiber demand growth, thereby capturing the value of waiting under uncertainty. A further limitation is the domestic-only composition of the Delphi panel, which may underweight technology risk factors that international licensors would prioritize.

Author Contributions

All authors contributed equally to the conception, design, data collection, analysis, and writing of this manuscript. All authors reviewed and approved the final version.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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