Overcoming Barriers to Flare Reduction in Iran: A Techno-Economic and Policy Analysis of Modular NGL Solutions

Ahmad Samadi[1,*] - Mobina Naderi[2]

[1] B.Sc. Student, Department of Mechanical Engineering, Fluid and Heat Sciences, University of Science and Culture, Tehran, Iran

[2] M.Sc. Student, Department of Law, International Law, Islamic Azad University, Central Tehran Branch, Tehran, Iran

ABSTRACT

Gas flaring remains a major challenge in Iran, representing significant economic loss and environmental damage. While technical solutions exist, their implementation has been slow. This study presents an integrated analysis to address this gap, combining a techno-economic evaluation of a modular Mini-NGL unit at the Cheshmeh-Khosh oilfield with a legal and policy analysis of the barriers to its adoption. An Aspen HYSYS simulation confirmed the project's technical viability, and a discounted cash-flow analysis revealed exceptional profitability, with an IRR of 43.28% and a payback period of 1.8 years. However, our analysis of Iran's regulatory framework, benchmarked against international models (e.g., Nigeria, Russia, Norway) and its obligations under the UNFCCC and Paris Agreement [11], reveals that the primary obstacles are not technical or financial, but legal and institutional. The absence of binding domestic legislation and enforceable penalties hinders private investment despite high potential returns. The findings demonstrate that unlocking Iran's flared gas potential requires a paradigm shift from long-term policy goals to the enactment of a robust, predictable legal framework. This paper provides a roadmap for aligning Iran's economic interests with its international environmental commitments through scalable, profitable flare reduction projects.

Keywords: Gas flaring, Associated Petroleum Gas (APG), Mini-NGL, Techno-economic analysis, Energy policy, Environmental law, Regulatory barriers

1. INTRODUCTION

Gas flaring, the controlled burning of associated petroleum gas, wastes valuable energy resources and contributes substantially to global greenhouse gas emissions. According to the World Bank [1], just seven countries—Russia, Iraq, Iran, the United States, Algeria, Venezuela, and Nigeria—account for more than 65% of global flaring. In 2021, Iran flared approximately 13.26 bcm of APG, equivalent to the production of a standard South Pars gas phase, resulting in an economic loss of over USD 3 billion annually [2].

Flaring is not only an economic loss but also a source of severe environmental and health impacts. Pollutants such as SO_x, NO_x, volatile organic compounds (VOCs), and particulate matter contribute to smog, acid rain, and respiratory illnesses, while methane slip further intensifies global warming due to its high global warming potential [3, 4, 5].

Iran has invested heavily in large centralized NGL projects (NGL-1700, NGL-1800, NGL-2300, and NGL-3200), yet many face long delays or incomplete implementation due to financing and logistical barriers [6]. This situation not only prolongs economic losses but also complicates Iran's position regarding its international environmental obligations under treaties like the Paris Agreement. In contrast, modular Mini-NGL units offer a pragmatic solution for remote or medium-scale fields, providing faster deployment, lower CAPEX, and quicker monetization of LPG and condensates [7, 8].

---

[1] Ahmadsamadi@stu.usc.ac.ir

Research objective: *This study addresses the critical disconnect between the high economic potential of flare gas recovery and the slow pace of its implementation in Iran. By integrating a detailed techno-economic case study with a legal and policy analysis, this paper aims to answer two primary research questions:*

Is a modular Mini-NGL unit a technically and economically viable solution for flare gas recovery at a typical Iranian oilfield like Cheshmeh-Khosh?

If proven viable, what are the primary legal, regulatory, and policy barriers preventing the widespread adoption of such solutions in Iran, and what lessons can be learned from international frameworks to overcome them? By answering these questions, this research provides a holistic framework for policymakers and investors, connecting a profitable engineering solution to the necessary legal reforms required to implement it at scale. The national distribution of flared gas volumes is illustrated in Fig. 1

2. LITERATURE REVIEW

2.1. Global and local impacts of flaring

Globally, more than 400 Mt CO_2 are emitted annually from flaring, equivalent to the emissions of 77 million passenger cars [4]. Incomplete combustion often results in methane emissions, which have a 28–36 times stronger warming effect than CO_2 over 100 years [5]. Locally, flaring causes health hazards due to benzene, toluene, and other VOCs, linked to increased cancer incidence and respiratory diseases [9].

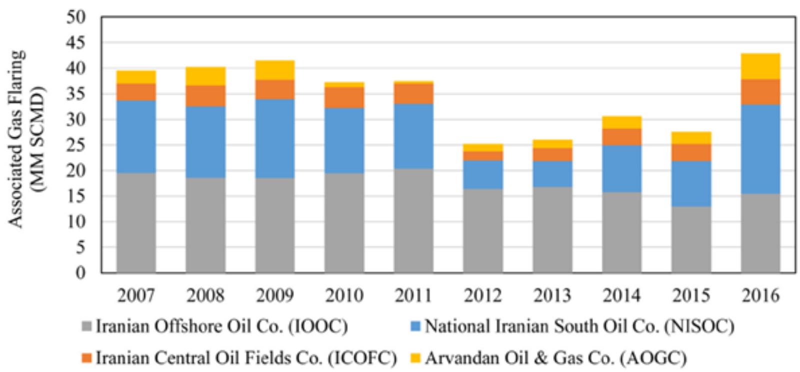

Fig. 1. *Breakdown of Flared Gas Volumes in Iran*

2.2. Economic opportunity of flare reduction

Iran currently exports about 30 MCM/d of natural gas to Turkey, generating more than USD 5 billion annually [2]. Monetizing currently flared gas could yield comparable revenues. While centralized NGL plants require high CAPEX and long construction times, Mini-NGL systems offer shorter payback and lower investment thresholds, making them suitable for scattered oilfields with medium APG volumes [7].

2.3. Technological pathways for APG utilization

Multiple strategies exist for APG management: reinjection, centralized NGL, LNG, CNG, GTL, and Mini-NGL. Each pathway involves trade-offs in scale, CAPEX, and market integration. A comparative overview of APG utilization routes is summarized in Table 1

Table 1. *Comparative overview of APG utilization pathways.*

Pathway	CAPEX level	Scale (MMSCFD)	Products	Pros	Cons
Reinjection	High	>50	Incremental oil	Supports EOR	No immediate revenue

Centralized NGL	High	100–500	Sales gas + NGL	High recovery	Long lead time, infra-dependent
LNG	Very high	>200	LNG	Long-distance transport	High complexity and cost
CNG	Medium	5–50	CNG	Simple logistics	Transport cost-intensive
GTL	Very high	>100	Diesel, naphtha	High-value liquids	CAPEX intensive
Mini-NGL	Low-Medium	5–50	LPG, C_5^+, gas	Modular, rapid deployment	Limited absolute scale

2.4. Legal and Regulatory Frameworks for Flare Reduction

Successful flare reduction initiatives globally are underpinned by robust legal and regulatory frameworks rather than voluntary measures. A comparative analysis reveals several effective models. Nigeria, through its National Gas Flare Commercialization Programme (NGFCP), imposes strict financial penalties of up to $2.00 per 1,000 scf of flared gas. Russia has adopted a different approach, mandating a 95% utilization rate for associated gas, with non-compliance risking the revocation of operating licenses. Perhaps the strictest model is in Norway, where a high carbon tax combined with a legal prohibition on routine flaring has resulted in near-zero flaring levels [10].

Beyond these national policies, Iran's strategy is also shaped by its international obligations. As a signatory to the United Nations Framework Convention on Climate Change [11] and the 2015 Paris Agreement, Iran is obligated to report its greenhouse gas emissions and pursue mitigation strategies. Reducing gas flaring is a direct and measurable pathway for Iran to meet its Nationally Determined Contributions (NDCs) under the Paris Agreement. Furthermore, large-scale flaring could be considered a breach of the customary "no harm" principle in international environmental law, which obligates states to prevent activities within their jurisdiction from causing transboundary environmental damage, thereby exposing the state to international responsibility. International regulations and penalties associated with gas flaring are compiled in Table 2

Table 2. *International regulations and penalties for gas flaring.*

Country	Regulatory Approach/Policy	Key Penalty / Target
Nigeria	National Gas Flare Commercialization Programme (NGFCP)	Penalties up to $2.00 per 1,000 scf of flared gas for large producers.
Russia	Federal Mandate	Requirement to achieve 95% utilization of associated petroleum gas (APG).
Norway	Carbon Tax and Strict Enforcement	A high carbon tax on offshore CO_2 emissions, making flaring economically unviable.

2.5. Evidence on modular Mini-NGL systems

Case studies from China and North America show that Mini-NGL units achieve IRRs between 15–25% with payback periods under 5 years [7,8]. Despite global progress, there is little peer-reviewed research on Iran's dispersed oilfields, which this study aims to address.

3. *METHODOLOGY*

3.1. Case study: Cheshmeh-Khosh oilfield

The baseline field data and operating assumptions are presented in Table 3. The Cheshmeh-Khosh oilfield, located in southwestern Iran, produces crude with significant APG volumes, of which 14–16 MMSCFD are flared. Field assays confirm a C_2^+-rich composition, making the site suitable for Mini-NGL deployment.

Table 3. *Field data and baseline assumptions.*

Parameter	Value	Source
APG flaring rate	14–16 MMSCFD	NISOC data
Inlet pressure	~600 psig	Field ops
Inlet temp.	35–45 °C	Field ops
Ambient temp.	2–55 °C	Climate
Composition	Rich in C_2^+	Lab assay

3.2. Process simulation (Aspen HYSYS v11)

A steady-state model was performed using Aspen HYSYS v11 software [12] with the Peng–Robinson equation of state, ensuring accurate vapor–liquid equilibrium predictions for C_1–C_6^+. The process included:

Feed separation and dehydration (TEG unit).

1. *JT expansion and cryogenic cooling for C_2^+ recovery.*
2. *Fractionation (de-ethanizer, de-propanizer, stabilizer).*
3. *Storage of LPG and condensates; sales-gas compression.*

The main process constraints adopted in the simulation are listed in Table 4 and The overall process flow of the simulated unit is illustrated in Fig. 2

Table 4. *Key simulation constraints.*

Specification	Constraint
Sales-gas CH_4 purity	≥95 mol%
Hydrocarbon dew point	Pipeline standard
Overall C_2^+ recovery	Maximized
On-stream factor	≥8000 h/year

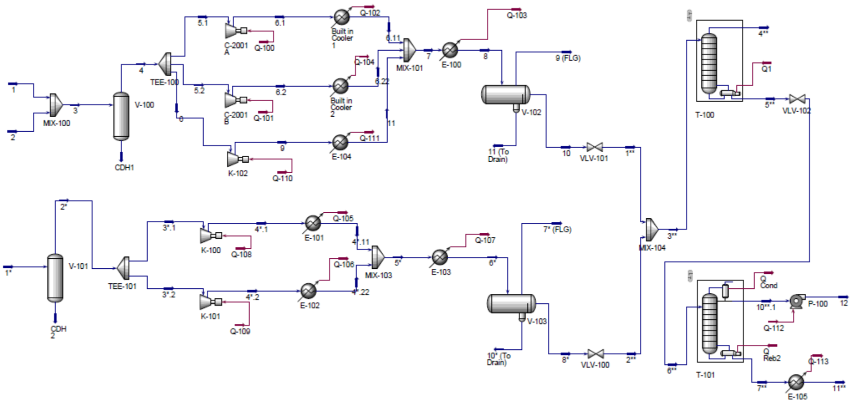

Fig. 2. *Process Flow Diagram of the Simulated Unit*

3.3. CAPEX and OPEX estimation

Equipment costs were derived from vendor quotes and literature analogs, escalated using CEPCI to 2023 USD. Total Installed Cost (TIC) included equipment, installation, civil works, I&C, storage, and contingency. OPEX accounted for utilities, chemicals, maintenance, and labor. The itemized capital cost structure is provided in Table 5.

Table 5. *CAPEX cost structure.*

Cost Element	Basis	% of TIC	Escalation index
Major equipment	Vendor/analogs	42%	CEPCI (2023)
Installation	Factor from equip	25%	CEPCI (2023)
Civil works	Local estimates	12%	Local index
I&C + Storage	Vendor data	15%	CEPCI (2023)
Contingency	Industry practice	6%	Class-4 estimate

Note: OPEX basis — Non-feedstock OPEX is assumed $708,096 in the first operating year with 5% annual escalation; Feedstock OPEX is $0.01/m³ × 6.9 MMSCFD × 350 days/year = $683,851 per year (constant).

4. RESULTS

This section details the technical and economic outcomes of the proposed Mini-NGL project for flare gas recovery at the Cheshmeh-Khosh oilfield. The technical performance is based on a process simulation conducted in Aspen HYSYS v11, while the economic evaluation relies on a discounted cash flow analysis using the data generated from the simulation and established cost estimation methodologies.

4.1 Technical Simulation Results

A process simulation was developed to model a Mini-NGL facility designed to process 6.9 million standard cubic feet per day (MMSCFD) of associated gas. The simulation confirmed the technical viability of the proposed design, which effectively separates the feed gas into three marketable products: sales gas (dry gas), Liquefied Petroleum Gas (LPG), and Pentane-Plus (C5+).
The simulated process consists of two parallel trains where the inlet gas is compressed, cooled, and separated. The dry gas stream is delivered to the National Iranian Oil Company (NIOC) as per the offtake agreement. The liquid streams are then processed through a stabilization column and an LPG column to produce the final products.

4.1.1 Product Yields

Based on the simulation, the plant is projected to produce the following annual quantities, assuming 350 operating days per year:
LPG: 1,806 kg/hr, equivalent to approximately 15,170 tons per year.
Pentane-Plus (C5+): 953 kg/hr, equivalent to approximately 8,005 tons per year.
Sales Gas: Approximately 4 MMSCFD of dry gas, which is returned to NIOC at no cost.

4.2 Economic Evaluation

The economic feasibility of the project was assessed based on estimated capital and operating expenditures against projected revenues. The project timeline assumes a one-year construction period followed by a four-year operational period. This shorter operational life is due to the long-term plan to integrate the field's gas into the larger, centralized NGL-3100 facility.

4.2.1 Capital and Operating Costs

The itemized capital cost structure is reported in Table 5. Capital Expenditure (CAPEX): The initial equipment costs were estimated using the Aspen HYSYS economic analyzer. This base cost was then adjusted to a comprehensive total capital cost using the Chemical Plant Cost Index [13] methodology, which accounts for factors like installation, engineering, and civil works. The base cost from 2018 was inflated to 2023 values using the relevant CEPCI data. The components and weightings of the CEPCI used for cost escalation are summarized in Table 6.

Table 6. *Components of the Chemical Plant Cost Index [13]*

Component of Index	Weighting of Component (%)
Equipment, Machinery, and Supports	61
Erection and installation labor	22
Buildings, materials, and labor	7
Engineering and supervision	10
Total	100

Annual CEPCI averages for the considered years are provided in Table 7

Table 7. *Chemical Engineering Plant Cost Index (Annual Averages)*

Year	CE Index
2018	603.1
2023 (March)	799.5

After applying the CEPCI adjustment for inflation and including all associated costs, the total estimated CAPEX for the project is $21,609,455.
Operating Expenditure (OPEX): Annual operating costs are composed of two main elements:
Non-Feedstock OPEX: This includes maintenance, labor, and utilities, estimated at 4% of the total CAPEX for the first year of operation, with a 5% annual escalation.
Feedstock Cost: As per the NIOC's tariff for flared gas, the cost of the raw associated gas is set at 1 cent per cubic meter [2]. The CEPCI component indices used for cost escalation are shown in Table 6.

4.2.2 Project Revenues

The revenue stream of the Mini-NGL recovery unit is primarily generated from the sale of recovered condensate, liquefied petroleum gas (LPG), and natural gas liquids (NGL). The projected revenues were calculated based on forecasted international crude oil prices, applying appropriate conversion factors to derive product-specific price assumptions. The crude oil price trend that serves as the basis for these estimates is illustrated in Fig. 3.[14]
For each product, annual sales volumes were obtained directly from the process simulation results, while unit prices were adjusted for transportation and marketability factors. the total revenues used in the cash-flow (see the 'Revenues' row in Table 8), which highlights the contribution of each product category to the overall income of the project.
This structured revenue estimation ensures consistency with standard economic evaluation practices and provides a reliable basis for subsequent cash flow and profitability analysis.

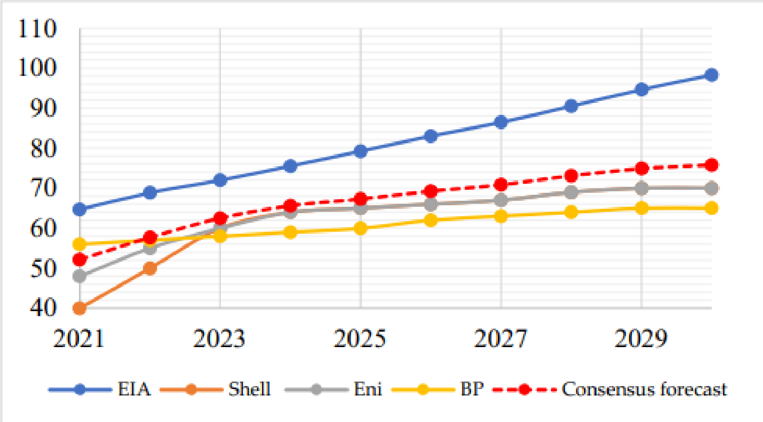

Fig. 3. *Crude oil price forecast (USD/barrel)*

4.2.3 Financial Indicators

A discounted cash flow analysis was conducted over the project's five-year life (1 year construction + 4 years operation) using a discount rate of 10%. The annual project cash flow is summarized in Table 8

Table 8. *Project Cash Flow (USD)*

	Year 1	Year 2	Year 3	Year 4	Year 5
Initial CAPEX	(21,609,455)	-	-	-	-
Non-feedstock OPEX	-	(708,096)	(743,500)	(780,675)	(819,708)
Feedstock Cost	-	(683,851)	(683,851)	(683,851)	(683,851)
Revenues	-	13,397,487	13,650,601	13,982,238	14,235,352
Net Cash Flow	(21,609,455)	12,005,540	12,223,250	12,517,712	12,731,793

The analysis yielded the following key economic indicators, which strongly support the project's financial viability. The key economic indicators of the project are reported in Table 9

Table 9. *Key Economic Indicators for the Project*

Economic Indicator	Value
Net Present Value (NPV)	$17,507,260
Internal Rate of Return (IRR)	43.28%
Payback Period	1.8 years

The results demonstrate a robust and highly attractive investment case. A positive NPV of over $17.5 million indicates significant value creation, while the exceptionally high IRR of 43.28% is well above the industry's typical hurdle rates. Furthermore, the very short payback period of 1.8 years highlights the project's ability to quickly recoup its initial investment, making it particularly appealing for private investors. These strong financial metrics are achieved despite the conservative assumption of a short four-year operational lifespan.

5. DISCUSSION

The results presented in the previous section indicate that the deployment of a modular Mini-NGL unit at the Cheshmeh-Khosh oilfield is not only technically feasible but also exceptionally profitable. This section interprets these findings, compares them with existing literature, and discusses their broader implications for policy and future research.

5.1. Comparative Analysis and Project Attractiveness

The economic indicators for the Cheshmeh-Khosh project (IRR of 43.28%, payback period of 1.8 years) are significantly more favorable than those reported for similar international Mini-NGL deployments. For instance, studies [7,8] in North America reported IRRs in the range of 18–22% with payback periods between 4 and 5 years. The superior performance of the Cheshmeh-Khosh case can be attributed to several key factors:
Rich Gas Composition: The associated gas at Cheshmeh-Khosh has a high content of C3+ hydrocarbons, leading to higher yields of valuable liquid products (LPG and Pentane-Plus) per unit of feed gas.
Favorable Feedstock Pricing: The feedstock cost, set at 1 cent per cubic meter by NIOC's directive, is relatively low, which significantly enhances the project's profit margins.
Modular Design Efficiency: The project's small scale and modular nature reduce CAPEX, shorten the construction timeline, and allow for a much faster path to revenue generation compared to large, centralized NGL plants.

This combination of factors makes the project a highly competitive and attractive investment, even when benchmarked against international case studies. The exceptionally short payback period of 1.8 years minimizes investment risk and is particularly appealing for private sector investors operating in dynamic economic environments.

5.2. Market Resilience and Economic Viability

The project's remarkably high Internal Rate of Return (IRR) of 43.28% indicates a substantial cushion against market volatility and operational risks. This high rate of return suggests that the project's profitability would remain robust even under moderate adverse fluctuations in product prices (LPG and condensate) or unforeseen increases in operating costs. This inherent economic resilience is a critical advantage for small-scale energy projects and underscores the financial soundness of using Mini-NGL technology for monetizing flared gas in Iran.

5.3. The Domestic Policy Gap: From Objectives to Enforceable Legislation

The strong economic viability demonstrated in this study (IRR of 43.28%) highlights a critical paradox: if flare reduction is so profitable, why does it remain a persistent problem in Iran? Our findings suggest that the primary barriers are not technical or financial, but rather policy-driven and institutional. For years, Iran's strategy has centered on large, centralized NGL megaprojects, many of which have faced significant delays. This research provides empirical evidence that decentralized, modular Mini-NGL units offer a pragmatic and rapidly deployable alternative.
However, attracting the necessary private investment for such projects requires a paradigm shift from long-term policy objectives to binding and enforceable domestic legislation. As seen in the comparative experiences of Nigeria, Russia, and Norway, progress is driven by clear rules, such as mandatory utilization targets or significant financial penalties, which create a compelling and predictable business case for compliance. The absence of such a robust domestic framework in Iran creates significant regulatory risk, deterring investors despite the high potential returns quantified in our analysis.

5.4. State Responsibility and the Sovereignty-Obligation Nexus

Beyond domestic policy, the issue of gas flaring places Iran at a critical juncture between its sovereign right to exploit natural resources and its international environmental obligations. Continued large-scale flaring undermines Iran's credibility under the UNFCCC and the Paris Agreement [11]. By failing to implement feasible and profitable mitigation projects, Iran risks triggering international state responsibility for breaching its commitments.

This responsibility arises not only from treaty violations but also from customary international law, particularly the "no harm" principle, which prohibits causing transboundary environmental damage. The emissions from flaring are not merely a domestic issue; they contribute to the global climate commons and can have regional impacts. Therefore, enacting a strong domestic legal framework is not only an economic choice but also a necessary step to mitigate legal and diplomatic risks on the international stage. Adopting such measures would effectively align Iran's principle of permanent sovereignty with its international responsibilities, creating a sustainable path for its energy sector.

5.5. Socio-environmental Co-benefits

Beyond the compelling financial returns, the project delivers significant environmental and social co-benefits. By capturing and processing 6.9 MMSCFD of gas that would otherwise be flared, the project directly eliminates the emission of greenhouse gases (CO_2, methane) and harmful local pollutants (SO_x, NO_x, VOCs). This leads to improved local air quality and reduces associated health risks for nearby communities. Furthermore, the production of LPG can enhance local energy security, particularly in rural areas, by providing a cleaner alternative to biomass or kerosene. These outcomes align directly with the UN Sustainable Development Goals, specifically SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). Furthermore, by mitigating the transboundary effects of air pollution, such projects help fulfill Iran's obligations under the customary international "no harm" principle.

5.6. Limitations and Directions for Future Research

This study provides a robust techno-economic assessment based on a steady-state simulation. However, certain limitations should be acknowledged, which also point to avenues for future research:

Dynamic Simulation: Future work should include dynamic simulations to model plant behavior during startup, shutdown, and turndown scenarios, which would provide deeper insights into operational flexibility and control strategies.

Uncertainty Quantification: A stochastic analysis, such as a Monte Carlo simulation, could be employed to quantify the impact of simultaneous variations in product prices, feed gas composition, and capital costs on the project's financial indicators.

Integration Opportunities: Research could explore the feasibility of integrating the Mini-NGL unit with other technologies, such as flare-to-power generation or carbon capture, to further enhance environmental performance and create additional value streams.

6. CONCLUSION

This study addressed the critical disconnect between the high economic potential of flare gas recovery and the slow pace of its implementation in Iran. By integrating a techno-economic case study with a legal and policy analysis, this paper has demonstrated that while modular Mini-NGL units are an exceptionally profitable and technically viable solution, the primary impediments to their widespread adoption are not technical or financial, but rather legal and institutional.

The techno-economic analysis confirmed that the Cheshmeh-Khosh project offers a very high Internal Rate of Return (IRR) of 43.28% and a rapid payback period of 1.8 years, highlighting the immense economic value locked within Iran's flared gas. However, the policy analysis revealed that this potential remains untapped due to the absence of a robust and predictable regulatory framework. In contrast to international models that rely on binding domestic legislation and enforceable penalties, Iran's current approach is insufficient to de-risk investments for the private sector.

In conclusion, this research provides a clear roadmap for change: Iran has the technical solutions and the economic incentives to resolve its flaring problem. The critical next step is to create a modern legal framework that aligns the nation's economic interests and its principle of sovereignty over natural resources with its international environmental commitments under the UNFCCC and the Paris Agreement [11]. The widespread adoption of profitable, scalable projects like the one analyzed here is contingent upon this essential policy reform.

REFERENCES

[1] World Bank. (2022). Global Gas Flaring Reduction Partnership (GGFR) report. World Bank Group.
[2] NIOC. (2021). National Iranian Oil Company annual report on gas flaring.
[3] Ajugwo, A. O. (2013). Negative effects of gas flaring: The Nigerian experience. Journal of Environment Pollution and Human Health, 1(1), 6-8.
[4] Elvidge, C. D. et al. (2018). Global gas flaring: Satellites and statistics. Energy Policy, 123, 117-125.
[5] IPCC. (2021). Climate Change 2021: The Physical Science Basis. Intergovernmental Panel on Climate Change.
[6] Hosseini, S. et al. (2020). Challenges of NGL projects in Iran. Iranian Journal of Oil & Gas Science and Technology, 9(2), 34-48.
[7] Gao, X., Liu, J., & Zhang, Y. (2019). Technoeconomic evaluation of modular NGL units in remote oilfields. Journal of Natural Gas Science and Engineering, 65, 178-190.
[8] Liu, J., Zhang, Y., & Wang, H. (2022). Mini NGL technology for flare gas recovery: A case study in China. Energy Reports, 8, 540-552.
[9] EPA. (2020). Health and environmental impacts of flaring. U.S. Environmental Protection Agency.
[10] Sands, P., Peel, J., & Fabra, A. (2018). Principles of international environmental law (4th ed.). Cambridge University Press.
[11] UNFCCC. (2015). Paris Agreement. United Nations Framework Convention on Climate Change.
[12] AspenTech. (2022). Aspen HYSYS v11 user guide. Aspen Technology, Inc.
[13] CEPCI. (2023). Chemical Engineering Plant Cost Index. Chemical Engineering Magazine.
[14] Park, C. S., et al. (2016). Contemporary engineering economics. Pearson Education.