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Economic feasibility of small-scale gas to liquid technology in reducing flaring in Iran and case study of implementing the technology at the third South Pars refinery

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ABSTRACT

The comprehensive and reliable economic evaluation of using small-scale gas to liquid (GTL) technology for flaring reduction in Iran is needed to encourage policymakers and investors to consider the advantages of this technology. This study investigates the economic feasibility of using small-scale GTL technology for flaring reduction with ten different scenarios in Iran. Additionally, the possibility of using available facilities was considered in calculating the capital expenditure (CapEx) of plants to improve the reliability and accuracy of results. The effective economic factors are determined based on the announced policies and the data of technology developers. The results showed that using the small-scale GTL plants is economically justifiable in all conditions unless the oil price experiences a significant decline in the future years. In the existing status of Iran, the internal rate of return (IRR) of 37.93% was calculated for the proposed plant to reduce the high-pressure flaring in the Third South Pars Refinery. Moreover, relying on the available equipment which can be used in developing small-scale GTL plant increased the IRR of GTL plant by reducing the CapEx by 25%. Using small-scale GTL technology for flaring reduction is a profitable alternative technology to prevent the extensive damages of the dissemination of toxic substances in the air, and it provides tremendous financial opportunity for investors in Iran.

Keywords: Small-Scale Gas-to-Liquid Technology; Economic Cvaluation; Feasibility Study; Flare Gas Recovery

1. Introduction

Since the discovery and operationalization of oil and gas fields, flaring and venting have been used as the main methods for disposing of the associated gas. Similarly, in refineries and petrochemical plants, some gases are collected from different units and burnt off in tall flare stacks. Associated gases are commonly burned due to the lack of technical refining facilities and the use of uneconomical recovery processes. There are also safety concerns in some cases regarding the recovery and utilization of these gases [1]. Additionally, considerable energy wastage and financial losses are inflicted by flaring the associated gas in addition to their detrimental environmental impacts [2]. Gas flaring disseminates more

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than 250 types of toxic substances in the air. These substances include carcinogens such as benzene, toluene, heavy metals, and sour gas containing H_2S, CO_2, and NO_X [3]. When discharged into the atmosphere, gaseous pollutants (SO_2 and NO_X) become uncontrollable and cause acid rain which is corrosive and can inflict extensive damage to human health, environment, vegetation, and surface waters [1, 4, 5].

The small-scale gas-to-liquid (GTL) technology is a well-known method of flaring reduction [6]. Natural gas is processed into several liquid petroleum products including gasoline, diesel fuel, kerosene, and naphtha. The small-scale GTL technology is similar to the conventional GTL technology in several technical aspects. A new type of reactor called the microchannel reactor are used in the Fischer–Tropsch synthesis. These reactors play a key role in facilitating the development of small-scale GTL plants, for they can be scaled up without any further design modifications. A refining unit is also planned for the input gas at the starting stage of the plant to purify the feed and separate heavier compounds [6].

The small-scale GTL plants can be designed and constructed with capacities ranging from 50 to more than 5,000 barrels per day. The capital expenditure (CapEx) reduction and the possibility of using the flare gas can decrease the costs and increase the economic justifiability of this method. Furthermore, the hefty price gap between oil and natural gas and the abundance of natural gas reserves all over the world inspired the energy experts such as the Global Gas Flaring Reduction Partnership (GGFR) Committee at the World Bank to analyze the feasibility of small-scale GTL projects in detail [7].

Recently, small-scale GTL technology is promoted as an important method for utilizing small natural gas reserves, whereas some technology developers are ready to commercialize their small-scale GTL technologies [8]. A major advantage of the small-scale GTL technology over the conventional GTL plants is the exclusion of some process units [9]. According to the economic analysis of a small-scale GTL plant based on the information presented by the manufacturer company, operational expenditure (OpEx) and CapEx are reduced by 50% in comparison with those of the conventional GTL plants [9]. In another study, Li *et al.* discussed the use of small-scale GTL plants for flaring reduction and analyzed the process design, feed gas specifications, and product features [10]. This case study involved 17.2 MMSCFD associated gas produced in the wellhead equipment and processed by a small-scale GTL plant yielding 2,000 barrels of gasoline per day. The results indicated that the plant's internal rate of return (IRR) was more than 20% [10]. The small-scale GTL technology was used as the most economically efficient method for flaring gas reduction at a flow rate of 500 MSCFD in Nigeria to produce methanol [11].

The amount of gas flared globally is reported by GGFR [12]. According to the most recent data published in 2018, Iran is the world's third-largest practitioner of this technique, burning off over 17.3 billion m^3 of gas [12]. Based on the Kyoto protocol, Iran commits to reduce 4% of its Green House Gases (GHG) emissions by 2030 [13]. Given the considerable scope of flaring in Iran, the Ministry of Petroleum (MOP) devised a plan in 2017 to reduce gas flaring and set specific goals. Accordingly, the flare gas will be sold to investors at a low price (US$ 0.005 to 0.02 per m^3), allowing them to obtain a reasonable earning in addition to helping reduce flaring by mobilizing this resource through available methods and technologies [14].

Several notable studies have been conducted on the technical and economic aspects of utilizing the flare gas produced in natural gas refineries in Iran [15, 16]. Rahimpour *et al.* studied the technical and economic feasibility of recovering the flare gas produced at the South Pars Refinery through different methods such as electricity generation, liquid fuels production with GTL technology, and compression and injection into pipelines [15]. The results demonstrated the feasibility of establishing a GTL plant with a capacity of 48,056 barrels per day, an electric power plant with a 2130 MWh capacity, or a natural gas compression plant capable of supplying compressed gas at 129 atm for injection into pipelines. A comparative analysis shows that the GTL method offers the highest rate of return (ROR) despite the massive investment it inflicts. After the GTL plant, natural gas compression provides the highest ROR and—given its lower CapEx—is the best approach to the flare gas recovery at the South Pars Refinery [15].

Other studies analyzed the feasibility of using small-scale GTL plants to reduce flaring and monetize natural gas resources. Branco *et al.* studied the technical and economic analysis of using the small-scale GTL technology to monetize natural gas. According to their results, the small-scale GTL plants with the capacity of 1000 and 5000 barrels per day are feasible, whereas the IRRs of these plants are 43% and 62%, respectively [17]. The use of small-scale GTL plants is an economically efficient method for the production of transport fuels in the United States [18]. Another study analyzed flaring reduction issues by power generation, mini-liquefied natural gas (LNG), and small-scale GTL technologies. The results of this study revealed that the IRR of the power generation option was more than the IRR of other technologies; therefore, using the power generation method is more profitable than using mini LNG and small-scale GTL technologies [19].

This study is an economic investigation into the use of small-scale GTL plants for flaring reduction in Iran and conversion of the associated gas into liquid petroleum products. This is also an economic feasibility study of using small-scale GTL technology for flaring reduction at the third South Pars Refinery selected as a case study. Studies on the economic feasibility of GTL and small-scale GTL technologies similarly assumed the fixed price for GTL products [15–20]. However, considering the long service life of GTL and small-scale GTL plants, the prices of products fluctuate over time due to various factors. Therefore, it is not accurate to assume a fixed price for all products during an extended period of 20–25 years. This study considers variable prices of GTL products based on different scenarios by taking into account the inherent uncertainties of the prices to offer a more accurate and realistic analysis of the economic feasibility of the small-scale GTL technology.

There is also some available equipment in the flaring locations such as oil and gas fields and refineries which can be used in small-scale GTL plants. Several studies on the use of GTL and small-scale GTL technologies for flaring reduction did not consider the available equipment which can be used in developing small-scale GTL plants [15, 16, 19]. This equipment can reduce the CapEx of small-scale GTL plants, especially in the utility and offsite sections. Thus, it is important to deem them to calculate the CapEx realistically. This study considers the available equipment. As a result, the calculated CapEx used in economic analysis is more realistic and reliable. Moreover, CapEx and OpEx were considered based on the information published by technology developers and a sensitivity analysis conducted concerning CapEx, OpEx, and feed gas price. In summary, the major novelties of this study are as follows:

- Calculating and considering various prices of products in 10 different scenarios
- Calculating the CapEx of a small-scale GTL plant in the third South Pars Refinery based on the possibility of using available equipment

These features improve the reliability of research results and allow them to be used for the analysis of small-scale GTL projects in various conditions.

2. Research Methodology

An accurate economic analysis of the small-scale GTL technology requires, first and foremost, an analysis of the economic factors affecting small-scale GTL technologies. For this purpose, the feed gas price will be determined based on the announced policies of the MOP of Iran. The CapEx and OpEx of the small-scale GTL technology will then be specified according to the data of the technology developers. The relationship between the GTL product price and the oil price will also be discussed. After that, the challenges of specifying the price of GTL products will be addressed, whereas the sales price of GTL products will then be calculated. With regards to these factors, the small-scale GTL technology will be economically evaluated. A sensitivity analysis will also be conducted on the IRR concerning CapEx, OpEx, and feed gas price. Figure 1 shows the research methodology for the economic evaluation of the small-scale GTL technology in Iran.

For a more accurate analysis of the potentials of the small-scale GTL technology in Iran, the high-pressure (HP) flare gas of the third South Pars Refinery was selected as a case study to evaluate the economic feasibility of using this technology. The capacity and effective economic factors of the designated small-scale GTL plant were then determined with respect to the HP flare gas specifications and the available refinery equipment. The IRR of the plant was finally calculated.

3. Economic Consideration of the Small-Scale Gas-to-Liquid Technology in Iran

It is essential to identify and determine effective economic parameters to perform the economic evaluation of the small-scale GTL technology. Different indicators such as IRR and net present value (NPV) can be employed to analyze plants and industrial projects economically. The IRR was assumed for the economic analysis of the small-scale GTL plant in Iran. All calculations were performed in COMFAR.

As mentioned earlier, the MOP of Iran has laid the foundation for profitable investment by offering flare gas at a reasonable price (US$ 0.005 to 0.02 per m^3). According to different resources and from a technical standpoint, approximately 283 m^3 of methane is required for producing one barrel of the GTL product [21]. This number can easily rise for the plants using flare gas as a feed due to the presence of heavier hydrocarbons and impurities in the flare gas. The potential of small-scale GTL plants for the use of flare gas as the feed, which can be obtained at a lower price, can considerably reduce the costs and improve the economic feasibility of the small-scale GTL plants.

The CapEx of GTL and a small-scale GTL plant is determined per barrel of products. In the 2000s, provider companies estimated the CapEx for establishing a GTL plant at nearly US$ 20,000–30,000 per barrel [22]. However, in the following years, some projects were forced to increase their investment considerably [23]. Thus, the high CapEx poses a significant challenge to the prevalence of GTL technology worldwide. Regarding the development of the small-scale GTL technology by several firms and the introduction of compact plants, the CapEx was reduced considerably to US$ 100,000 per barrel [7].

Different sources have estimated the OpEx of GTL and small-scale GTL plants between US$ 10 and US$ 25 per barrel [23, 24]. Based on the reports of some developers of the small-scale GTL technology, the catalysts used in this method have longer service life than that of conventional GTL plants; therefore, the OpEx of the small-scale GTL technology decreases in comparison to that of conventional GTL plants [7].

The prices of GTL and small-scale GTL products are related directly to the oil price as they are conventionally produced by refining the crude oil [25]. Another important factor in

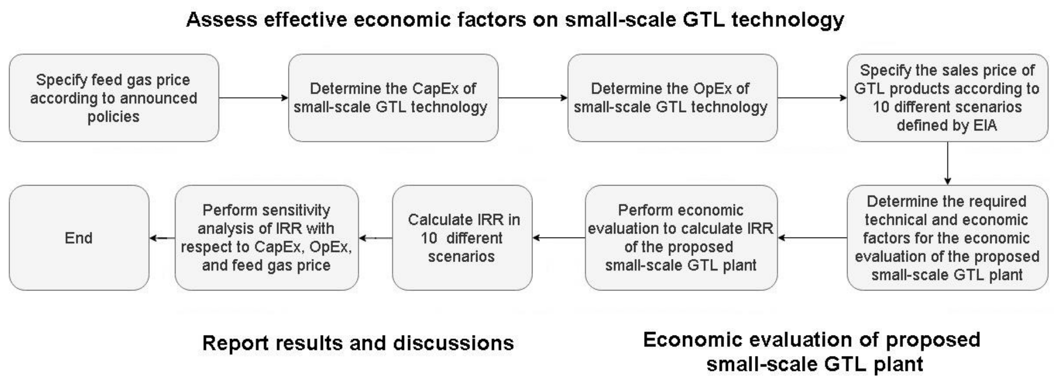

Fig. 1. Research methodology for the economic evaluation of the small-scale GTL technology in Iran

pricing these products is their high quality compared to the products produced from crude oil. This is manifested in their high price tag [25]. Regarding the lifetime of these plants (more than 20 years), it is difficult to predict the sales price of products during this period [7].

Given the unpredictable oil price fluctuations in recent decades and the sensitivity of the price to political and social turmoil around the globe, it is not reasonable to assume one specific price trend in the analysis of projects, for it reduces the accuracy of results. Therefore, considering different scenarios is an excellent strategy to limit errors in calculations and improve the results. The EIA attempts to predict the oil price and different energy market sectors including the supply and demand and the price of energy carriers [26]. Hence, by considering various assumptions and planning different scenarios, they can predict all the energy market indicators. These scenarios can be employed to evaluate project economics under different conditions to limit the risks significantly. In this study, ten different scenarios formulated by the EIA will be adopted to predict the sales price of GTL products [26]. The considered scenarios are briefly discussed in the following.

The EIA made different assumptions in the reference case (RC) scenario including a 2% annual GDP growth rate and a 0.4% annual energy consumption growth rate. Moreover, the current regulations affecting the energy sector and the technological progress and economic and demographic trends were taken into account [26]. It should be noted that the inherent uncertainties of estimations were covered by secondary scenarios making various assumptions including economic growth, the global price of oil, and technological progress. Based on the predictions of the Low Oil Price (LOP) Scenario, each barrel of crude oil will be sold at US$ 52 in 2050. However, according to the RC and High Oil Price (HOP) Scenarios, the price of oil reaches US$ 114 and US$ 229 per barrel, respectively, in the same year. Moreover, the High Oil and Gas Resources and Technology (HOGRT) Scenario allows for production at a lower price than the RC Scenario thanks to the availability of more resources and their lower prices. Finally, the Low Oil and Gas Resources and Technology (LOGRT) Scenario assumes limited resources and a higher cost [26].

Given the growing use of sustainable sources of energy, it is critical to note their impacts on the prices of oil and its products. Accordingly, other scenarios were discussed with respect to the use of the clean power plan and its effects on the above five scenarios [26]. Therefore, new scenarios include *RC* with clean power plan (RC+CPP), LOP with clean power plan (LOP+CPP), HOP with clean power plan (HOP+CPP), LOGRT with clean power plan (LOGRT+CPP), and HOGRT with clean power plan (HOGRT+CPP).

According to the different scenarios proposed by the EIA and the necessity of considering the growing use of sustainable sources of energy, this study uses the predicted wholesale price of diesel fuels (as the product) in ten different scenarios up to 2050 from the "EIA Outlook 2018" [27]. Since the wholesale price includes no tax and distribution costs, it can be assumed as the wholesale price of diesel fuels in global markets and can be used in the economic evaluation of the small-scale GTL technology [27]. Furthermore, the GTL products are more expensive than refinery products due to their high quality. The gap between the price of these products is nearly US$ 10 per barrel [25]. Thus, the final sales price was considered the sum of the wholesale price of diesel fuels plus US$ 10 per barrel as the price difference between GTL products and refinery products. Appendix A presents the predicted sales prices of the diesel fuels produced by the small-scale GTL plants based on different scenarios.

Given the considerable potential of the products for exports and tax exemptions in Iran to promote exports, the primary assumption is that the project aims to produce GTL products for export purposes.

Based on previous discussions, the CapEx and OpEx are assumed US$ 100,000 and US$ 15 per barrel, respectively [7, 23, 24]. It is assumed that 80% of the feed gas composition contains methane. Thus, approximately 340 m^3 of the feed gas is required for producing one barrel of the GTL product. The maximum feed gas price was also assumed (based on the policies announced by the MOP of Iran).

Therefore, the feasibility of using flare gas to operate a small-scale GTL plant with 1,000 barrels per day was analyzed. Table 2 and Table 3 demonstrate the characteristics of the plant thoroughly.

3.1. Case Study of the Third South Pars Refinery

The third South Pars Refinery was designed and built to produce natural gas, liquefied petroleum gas (LPG), natural-gas condensates, sulfur, and ethane [28]. The produced natural gas is delivered to land in the three-phase form through two submarine 32" pipelines. After the gas condensates are separated, the natural gas is delivered to four refinery units, each of which is capable of handling 14.1 million m^3 [28]. During the operation, the flares are responsible for receiving gas from different parts of the process and burning it safely. The bulk of gas passing through safety valves, relief valves, and blow-down valves during emergency operation or a shutdown is delivered to this unit [29]. Based on the upstream pressure and the natural gas specifications, flares are divided into three main streams: high pressure (HP), medium pressure (MP), and low pressure (LP).

The available data of the third South Pars Refinery and the flow rate of its flares were employed to analyze the economic feasibility of using a small-scale GTL plant to prevent HP gas flaring. The plant's capacity is calculated according to the flow rate of the HP flare and the composition of the gas it burns [30].

$$Capacity\ of\ plant = \frac{feed\ gas\ flow rate \times methane\ composition\ of\ feed\ gas}{required\ methane\ for\ producing\ one\ barrel\ of\ GTL\ product} = \quad (1)$$

$$6\,MMSCFD \times \frac{28252.14\,\frac{m^3}{Day}}{1\,MMSCDF} \times \frac{0.8828\,m^3\ CH_4}{1m^3} \times \frac{1\,Barrel\ per\ day}{283\,m^3\ CH_4} = 528.78\,BPD$$

The general utility and offsite equipment required in typical GTL plants include different units [31]. Naturally, some equipment is left out in specific designs by different developers following the plant specifications. Table 1 reports the utility and offsite units at the third South Pars Refinery and their functions. These units were surveyed to evaluate the feasibility of incorporating equipment into the proposed small-scale GTL plant to recover the flare gas. The utilities required for the small-scale GTL plant and some of the offsite units are already available in the third South Pars Refinery. The GTL cost breakdown diagram shows that utility and offsite equipment costs account for 15% and 20% of the total CapEx, respectively [31]. Studies show that, given the equipment available at the third South Pars Refinery, all of the costs of utilities and half of the expenses of offsite units can be ignored. Therefore, the CapEx could be reduced by nearly 25% for the plant. The CapEx of this unit can be reduced down to US$ 75,000 per barrel based on the CapEx predicted by developers in Section 3. Another significant advantage of the third South Pars Refinery is its vicinity to Port Asaluyeh, a factor that eliminates road transport expenses.

According to the scenarios, this analysis was based on the sales price of diesel fuels calculated in Section 3.2. Furthermore, the OpEx was considered at US$ 15 per barrel based on the typical predictions in the sources [23, 24], and the maximum price of feed gas was assumed. Table 2 and Table 3 demonstrate the technical and economic characteristics of the proposed small-scale GTL plant to prevent HP flaring at the third South Pars Refinery.

Table 1. Utility and offsite units at the third South Pars Refinery [29]

Unit	Description
Power generation	This unit includes four gas turbines with 33 MW capacity and one steam turbine to supply the required power for the refinery.
Steam generation	This unit consists of six boilers with 160 ton per hour capacity to supply HP steam at 44 bar and 275 °C, and LP steam at 5.5 bar and 187 °C.
Fuel gas	This unit supplies fuel gas at HP level (24-24 bar) and LP level (4-5 bar).
Nitrogen generation	This unit supplies the required nitrogen for the refinery.
Seawater	This unit includes four out-site pumps with a capacity of 2,000 cubic meters per hour and 8 bar discharge pressure and an in-site tank with 176 m3 capacity to supply required water for refrigeration system and firefighting.
Seawater desalination	This unit includes three similar units with five cells to remove mineral salts from the water.
Water polishing	This unit includes two mixed beds to collect salts from the water to prepare purified, distilled water for the boilers and turbine washing.
Industrial wastewater and sewage treatment	This unit consists of the sanitary water treatment unit, chemical water treatment unit, and oily water treatment unit.
Firefighting water	This unit includes the lower section, the upper section, and the outside battery limit (OSBL), and each section includes two jockey pumps and three main pumps
Cooling water	This unit Supplies water for the coolers of all devices in the refinery.
Condensate storage tanks	This unit consists of four storage tanks with 60000 m^3 capacity.
Chemical storage tanks	This unit includes six storage tanks
Drain	This unit includes one underground drum and one vertical pump to collect liquid drains from refinery units.
Flare disposal system	This unit includes HP, MP, and LP drums to collect the gas released from different parts of the refinery.

Table 2. Technical characteristics of proposed small-scale GTL plant for flare gas recovery in Iran

Characteristic	General condition	Case study at the third South Pars Refinery
Plant Capacity	1,000 barrels per day	≈530 barrels per day
Product	Diesel fuel	Diesel fuel
Amount of feed gas consumed	340 m^3/bbl	6 MMSCFD (320.57 m^3/bbl)
Workdays	330 Days	330 Days
Plant service life	20 years (2020 to 2039)	20 years (2020 to 2039)

Table 3. Economic characteristics of proposed small-scale GTL plant for flare gas recovery in Iran

Characteristics	General condition	Case study at the third South Pars Refinery
CapEx	100,000 US$/bbl	75,000 US$/bbl
OpEx	15 US$/bbl	15 US$/bbl
Discount rate	15%	15%
Feed gas price	0.02 US$/$m^3$	0.02 US$/$m^3$
Product sales price	According to EIA scenarios from 2020 to 2039	According to EIA scenarios from 2020 to 2039

4. Results and Discussions

This study performed an economic evaluation of small-scale GTL plants and calculated the IRR under different scenarios. Figure 2 shows the results. The small-scale GTL plant is justifiable when the calculated IRR exceeds the assumed discount rate. The economic analysis results reveal the efficiency of a small-scale GTL project with a capacity of 1,000 barrels per day under all scenarios except the LOP and the LOP+CPP scenarios. The IRR of the project was smaller than the assumed discount rate (15%) under these two scenarios. The calculated IRR in the RC scenario is 28.84%, which indicates the economic feasibility of using the small-scale GTL technology in the status quo of Iran. The highest values of IRR under HOP+CPP and HOP scenarios were calculated 50.12 % and 48.76%, respectively. Regarding the inherent dependence of liquid petroleum products' prices on oil prices, increasing oil prices will increase the profitability of the small-scale GTL technology. Considering the

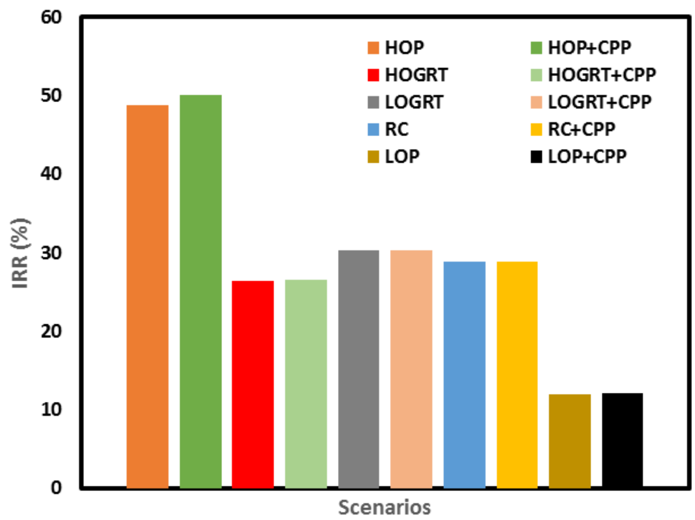

Fig. 2. The calculated IRR for the proposed small-scale GTL plant in different scenarios

calculated IRR in LOGRT and HOGRT scenarios, it is concluded that the increasing consumption of oil and gas resources and improvement in the technology for exploiting these resources will decrease the profitability of the small-scale GTL technology.

Additionally, the increasing use of sustainable energy sources and their impacts on the energy market will have slight effects on the feasibility of small-scale GTL plants in the future.

4.1. Sensitivity Analysis

Based on the discussions regarding the effective economic factors of GTL projects, it is essential to analyze the sensitivity of these factors to the economic feasibility of the project in making the final decision. Thus, the sensitivity analysis of IRR was conducted with respect to the feed gas price, the CapEx, and the OpEx. The feed gas price is an effective parameter in evaluating the feasibility of small-scale GTL projects. Naturally, a lower feed gas price increases the economic feasibility of the project. The feed gas price is a function of several factors; however, in general, the feed gas is likely to be found at a low price in countries with large natural gas reserves. The effect of feed gas price on the IRR was analyzed under different scenarios while keeping other factors constant (Fig.3).

According to the results of the sensitivity analysis, small-scale GTL plants are economically feasible for a feed gas price of up to US$ 0.38 per m^3 under *HOP* and *HOP+CPP* scenarios (Fig.4). The results under the *RC* scenario show that the small-scale GTL technology is affordable for a feed gas price up to US$ 0.15 per m^3 currently in Iran. Moreover, the volatility of the feed gas price does not affect the economic feasibility of the small-scale GTL plant under *LOP* and *LOP+CPP* scenarios, as the venture remains ineffectual in any case.

The CapEx has a significant effect on the justifiability of the small-scale GTL technology. Assessing the IRR variations with respect to the CapEx can be an excellent measure for evaluating the economic feasibility of small-scale GTL projects. Figure 5 demonstrates the effect of CapEx on the IRR under different scenarios.

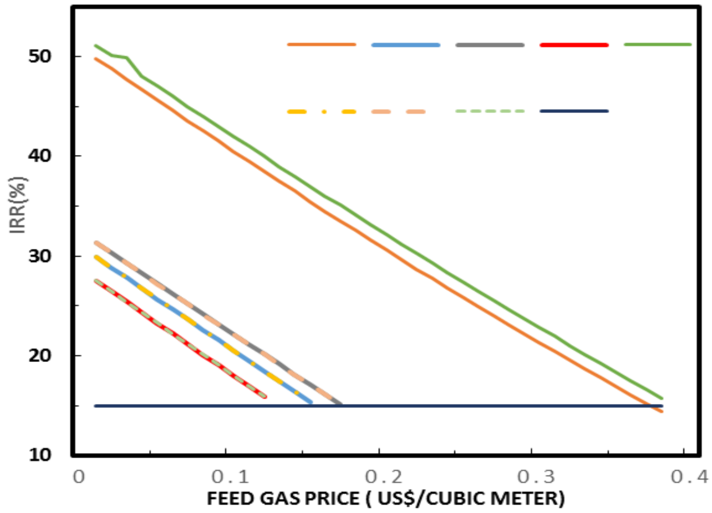

Fig. 3. The sensitivity analysis of IRR with respect to feeding gas price

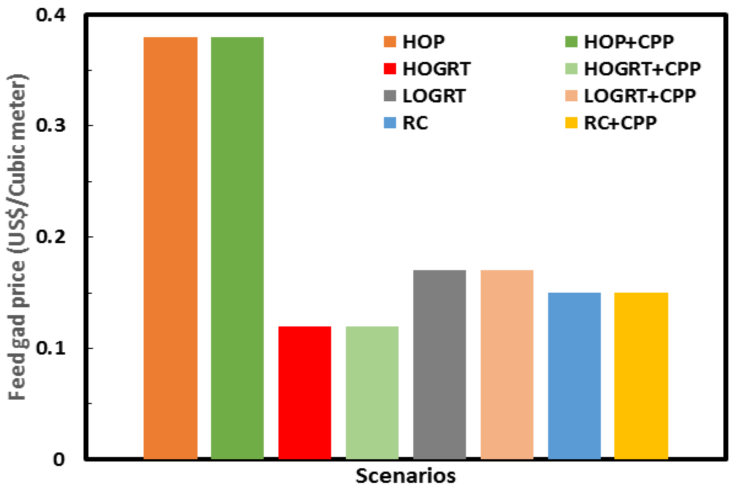

Fig. 4. The highest calculated feed gas price for the economic feasibility of the proposed small-scale GTL plant

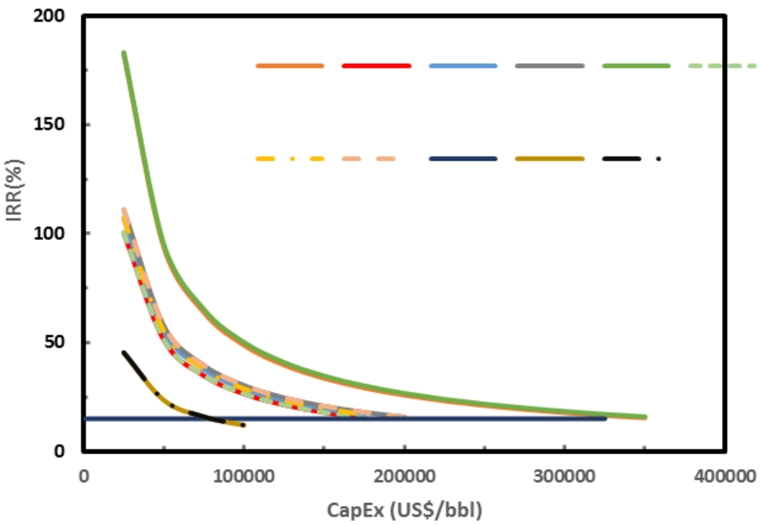

Fig. 5. The sensitivity analysis of IRR with respect to CapEx in different scenarios

According to the results, increasing the CapEx will decrease the IRR of the small-scale GTL plant under all scenarios. Evidently, this trend decreases dramatically at first, whereas the slope of this trend decreases afterward. The abrupt changes in the slope of the downward trend in the IRR occurred within the US$ 50,000–75000 range. Therefore, decreasing the CapEx of the small-scale GTL technology below this range will increase profitability significantly.

The results show that sustainable energy resources do not change the calculated CapEx for the economic feasibility of the small-scale GTL plants. In HOP and HOP+CPP scenarios, the small-scale GTL technology can be justified up to CapEx of US$ 350,000 per barrel. Moreover, the small-scale GTL technology will be profitable up to CapEx of US$ 175,000 per barrel under the RC scenario. As discussed in the previous section, the project is not economically feasible under LOP and LOP+CPP scenarios. The small-scale GTL project becomes economically feasible by reducing the CapEx down to US$ 75,000 per barrel. The technology becomes justifiable under these scenarios only when the CapEx is reduced (Fig.6).

The OpEx is a factor affecting the justifiability of the small-scale GTL plant, whereas the sensitivity of the IRR with respect to OpEx can be employed to evaluate the small-scale GTL technology. The OpEx was considered to range between US$ 5 and US$ 25, according to different sources [23, 24]. Figure 7 shows that the increasing OpEx will decrease the IRR of the small-scale GTL plant. Based on the results, the Opex has no significant effects on the profitability of the small-scale GTL technology.

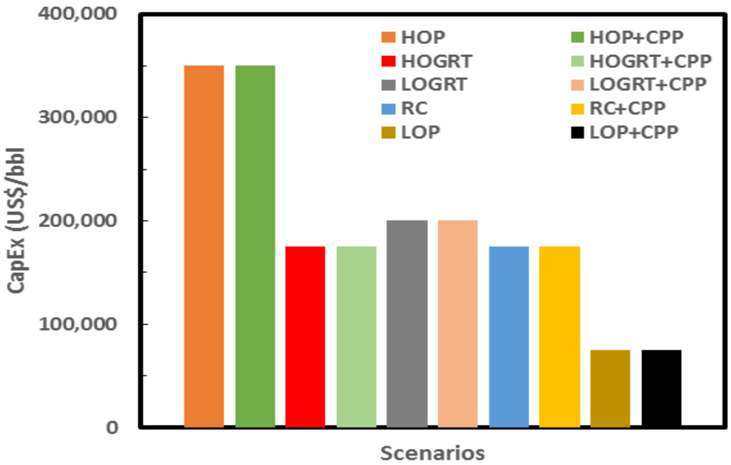

Fig. 6. The highest calculated CapEx for the economic feasibility of the proposed small-scale GTL plant in different scenarios

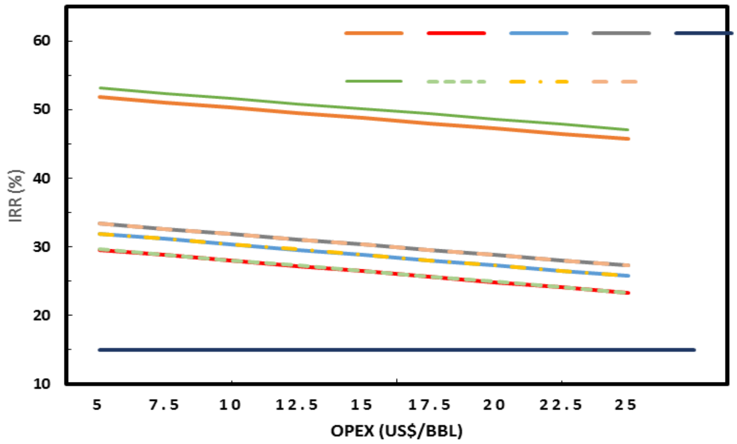

Fig. 7. The sensitivity analysis of IRR with respect to OpEx in different scenarios

According to Fig.7, the IRR is not considerably affected by the *CPP* scenario, regardless of the OpEx. Furthermore, based on the calculations under *LOP* and *LOP+CPP* scenarios, changes in the OpEx do not affect the economic feasibility of the small-scale GTL plant, and the project remains economically inefficient.

4.2. Case Study Results

The economic evaluation of a small-scale GTL plant was analyzed for the recovery of the HP flare gas at the third South Pars Refinery. Fig. 8 demonstrates the calculated values of the IRR under different scenarios. The results indicate the economic efficiency of using a small-scale GTL plant under all scenarios. The IRRs of the plant under LOP and LOP+CPP scenarios were calculated to be 16.13% and 16.17%, respectively. Regarding the assumed discount rate, the calculated IRRs under these two scenarios are marginally profitable. Furthermore, the IRR was calculated at 37.93% under the RC scenario, something which shows the economic feasibility of the small-scale GTL technology at the current time (Fig. 8). The highest IRRs were calculated 65.44 % and 65.46% under HOP+CPP and HOP scenarios, respectively. Thus, the payback period is shorter than two years. Therefore, increasing the oil price will escalate the profitability of small-scale GTL plants due to the direct relationship between the oil price and the prices of liquid petroleum products. The difference between IRRs under LOGRT and HOGRT scenarios could indicate that the growing use of oil and gas resources and improvement in the technology used to exploit these resources will decrease the IRR of the small-scale GTL plant by 4.8 %.

According to the calculated IRRs under different scenarios, the increasing use of sustainable and renewable sources had no considerable effects on the profitability of the small-scale GTL plant for the HP flare reduction at the third South Pars Refinery. Therefore, if a small-scale GTL plant makes a profit under the specified scenario, the increasing use of sustainable sources will not affect its economic feasibility.

5. Conclusion and Policy Implications

This study analyzed the economic feasibility of implementing the small-scale GTL technology in Iran. Considering various product prices in different scenarios revealed notable results, whereas using different scenarios provided a great opportunity for consultants and analysts to recommend sensible policies to decision-makers in different economic conditions. Moreover, the IRR was calculated 28.84% under the RC scenario, something which

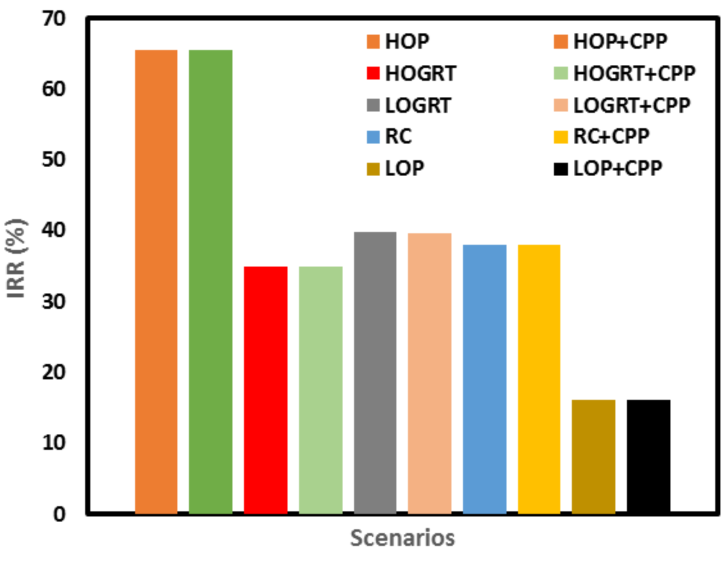

Fig. 8. The calculated IRR of proposed small-scale GTL plant for the recovery HP flare of third South Pars Refinery under different scenarios

indicates the current justifiability of the small-scale GTL plant, whereas the IRR was calculated 48.76% under the *HOP* scenario. Thus, increasing the oil price will increase the profitability of small-scale GTL plants. Furthermore, this technology is economically efficient both at present and in the future under various secondary scenarios unless the oil price experiences a significant decline. The increasing consumption of oil and gas resources and improvement in the technology used to exploit these resources and their effects on the liquid petroleum products price decreased the profitability of the small-scale GTL technology. Moreover, the growing consumption of sustainable energy sources is not a threat to the profitability of the small-scale GTL technology, for it has no significant effects on the IRR.

The implementation of the small-scale GTL technology at the third South Pars Refinery was analyzed in this case study. The results showed that the small-scale GTL technology was efficient under all scenarios. The idea of using available equipment, which can be used in developing small-scale GTL plants, played a key role in decreasing the estimated CapEx and increasing the IRR of the project. In addition, relying on the available facilities at the third South Pars Refinery decreases the CapEx by 25%, whereas the CapEx reduced to US$ 75,000 per barrel. This can improve the IRR of the project. The idea of using available equipment will encourage policymakers and investors to use small-scale GTL technology for flaring reduction in refineries and petrochemical plants. Finally, the abundant reserves of natural gas in Iran can lay the foundation for expanding the use of GTL technology in different capacities.

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Appendix A: The estimated GTL diesel price based on different scenarios

Table A. 1. The calculated GTL diesel price in different scenarios

	GTL Diesel Wholesale Price($/BBL)		
Year	Reference Case Scenario	High Oil Price Scenario	Low Oil Price Scenario
2020	98.69	152.91	53.34
2021	105.56	171.53	56.13
2022	108.04	179.21	56.78
2023	110.49	184.61	57.39
2024	112.90	191.78	58.28
2025	114.75	198.43	58.85
2026	115.50	202.94	58.55
2027	117.39	211.08	59.72
2028	119.39	213.12	60.48
2029	121.50	219.10	61.52
2030	122.95	221.05	62.33
2031	125.25	223.93	63.59
2032	126.08	226.58	63.65
2033	127.89	228.43	64.34
2034	129.89	232.62	65.20
2035	130.93	234.20	66.03
2036	131.78	236.61	66.73
2037	134.66	237.64	67.38
2038	135.66	240.22	68.17
2039	136.90	243.70	69.20

Table A. 2. The calculated GTL diesel price in different scenarios

	GTL Diesel Wholesale Price($/BBL)	
Year	High oil and gas resources and technology Scenario	Low oil and gas resources and technology Scenario
2020	97.17	100.95
2021	97.01	108.96
2022	98.80	112.81
2023	100.45	114.64
2024	103.04	118.31
2025	104.53	121.53
2026	106.99	122.21
2027	108.38	125.26
2028	110.88	127.33
2029	112.33	130.96
2030	114.07	133.15
2031	115.13	134.23
2032	115.19	136.49
2033	117.14	137.58
2034	118.43	139.98
2035	119.53	142.23
2036	119.90	142.40
2037	120.94	145.17
2038	121.60	146.37
2039	122.51	148.03

Table A. 3. The calculated GTL diesel price in different scenarios

	GTL Diesel Wholesale Price($/BBL)		
Year	Reference Case Scenario with Clean Power	High Oil Price Scenario with Clean Power	Low Oil Price Scenario with Clean Power
2020	98.70	152.89	53.43
2021	105.58	171.42	56.24
2022	108.18	179.12	56.83
2023	110.66	184.81	57.38
2024	112.99	191.76	58.34
2025	114.69	198.44	58.90
2026	115.29	202.86	58.59
2027	117.39	211.06	59.78
2028	119.32	212.26	60.59
2029	121.65	217.29	61.83
2030	123.13	221.20	62.76
2031	125.23	223.93	63.81
2032	126.68	227.54	63.88
2033	127.96	229.53	64.62
2034	129.62	232.70	65.57
2035	130.98	233.82	66.38
2036	131.96	236.50	66.94
2037	134.77	237.75	67.28
2038	135.96	239.96	67.93
2039	137.17	241.85	69.13

Table A. 4. The calculated GTL diesel price in different scenarios

	GTL Diesel Wholesale Price($/BBL)	
Year	High oil and gas resources and technology Scenario with Clean power	Low oil and gas resources and technology Scenario with Clean Power
2020	97.17	100.95
2021	97.01	108.96
2022	98.80	112.81
2023	100.45	114.64
2024	103.04	118.31
2025	104.53	121.53
2026	106.99	122.21
2027	108.38	125.26
2028	110.88	127.33
2029	112.33	130.96
2030	114.07	133.15
2031	115.13	134.23
2032	115.19	136.49
2033	117.14	137.58
2034	118.43	139.98
2035	119.53	142.23
2036	119.90	142.40
2037	120.94	145.17
2038	121.60	146.37
2039	122.51	148.03