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ORIGINAL PAPER

Technical and economical/financial feasibility analyses of flared gas recovery in Egypt from oil and gas industry from international/national oil companies' perspectives

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Abstract Egypt is an importer of energy, yet 5.7 MMSCM (200 MMSCF) of natural gas is flared every day and causes a negative environmental impact. Recovery of such significant amount is crucial and accordingly there are three alternative solutions to recover these gases, namely LPG/condensate extraction, recycling, or power generation. These alternatives were studied technically, financially, and economically, and results indicate that investors' orientation and vision play a vital role in decision making especially when production sharing agreement is applied. The conflict of interest among investors was tackled and applied on a case study from different perspectives. Results indicate that the added value itself differs from one investor to another. In the case studied, international oil companies "IOCs" prefer recycling to achieve reasonable net present value "NPV" up to $40 million. National oil companies "NOCs" prefer generating power to achieve maximum net value added "NVA" up to $58 million, to maximize the environmental and social added value. The least feasible option is extracting LPG/condensate from the flared gas although Egypt is LPG importer. The conflict of interest and current oil prices are the reasons behind postponing such projects. So, Egyptian government should impose policies to reduce flared gas emissions and maximize benefits through these projects and this can be done by compromising with "IOCs" to ensure maximum financial/social benefits.

Keywords Flared gas recovery · Flared gas environmental impact · Financial feasibility study · Economic feasibility study · "IOCs" · "NOCs"

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Abbreviation

LPG	Liquefied petroleum gas
PSA	Production sharing agreement
IOCs	International oil companies
IRR	Internal rate of return
NPV	Net present value
NOCs	National oil companies
NVA	Net value added
BBL	Barrel
MW	Miga-watt
CAPEX	Capital expenditure
OPEX	Operating expenditure
BTU	British thermal unit
MMSCFD	Million standard cubic feet per day equivalent to 0.028 million standard cubic meter per day
BPD	Barrel per day
WACC	Weighted average cost of capital
MMBTU	Million British thermal unit
PG	Power generation
ROI	Return on investment
EOS	Equation of state

Introduction

Flared gas is one of the potential sources of energy that is wasted on daily basis. The world loses around 3.5% of total global production, which is burned or flared at oil and gas

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plants (Elvidge et al. 2016). More than that, recovery projects are restricted in many countries due to technical and/or financial infeasibility, lack of funding, or conflict of interest between partners. Although Egypt needs of energy, it flares around 5.66 MMSCM (200 MMSCF) of natural gas per day equivalent to annual revenue loss of more than $250 million per year and as a result Egypt is ranked among the 20 top gas-flaring countries in the world (Zgheib 2016). The World Bank stated that Egypt is a net importer of energy (World bank 2014) and subsidizes energy by around 29% of its budget (Sab 2013); accordingly, an energy subsidy reform program is launched in 2004 (Ncube et al. 2012); nevertheless, domestic market need of energy is still considered a burden on Egypt. It also worth mentioning that flared gas contributes to climate change and also impacts the environment through its combustion products (World bank 2016). Accordingly, recovering the flared gas in Egypt seems to be of great value from the financial and economical perspectives. It is proved that flared gas can be recovered through different means including:

By *recycling* the gas, the dedicated compressor boosts the pressure of the flared gas roughly from the atmospheric pressure to the required inlet pressure of the plant but the main challenge of this option is the high compression ratio/cost. This technique is being applied by leading companies worldwide including Honeywell UOP, Siemens, and John Zink (UOP 2016; JohnZink, 2006). This option also was studied and simulated by Sangsaraki and Anajafi (2015), and it was found that the reciprocating compressor availability and low cost of maintenance makes it the best choice for this process. Comodia et al. (2016) also discussed how to recover low heating value flared gas by compressing the gas to feed refinery processes. A liquid ring compressor was successfully designed for this purpose, and the payback period was estimated to be about 2.5 years with recovery of 6600 tons of CDE (carbon dioxide equivalent) per year. However, he did not discuss other comparative alternatives with their financial/economic impacts. Alternatively, the flared gas can be used as a fuel for *power generation* in small generators to reduce the amount of the natural gas fuel used for the same purpose. The main challenge is the composition of the flared gas which mainly contains high content of acid gases and water. These kinds of power generators can burn a gas with low methane percentage "down to 40%" with high sulfur content "up to 1800 ppm." This option was previously studied (Abdulrahman et al. 2015) and its feasibility in Egypt was proved but without testing the financing scheme between "IOCs" and "NOCs." In addition, Zadakbar et al. (2008) studied the feasibility of this option in two Iranian plant and he indicated that recovering the flared gas to be used in power generation in the two plants will result in 85%, 70% of emissions reduction with a payback period of 20, 4 months, respectively. Also, Heydari (2015) confirmed that this option is technically and financially feasible with 55% IRR according to his previous work. Also, *LPG & condensate* can be extracted from flared gas by different techniques such as refrigeration (mechanical "using a coolant," Joule–Thomson valve, expander, or twister supersonic refrigeration), absorption, adsorption, or membrane separation. The most commonly used technique is the refrigeration, due to the simple operability and low energy requirements, but the main drawback of this method is that some components will not be recovered such as methane and ethane and will be flared.

Since this paper covers different aspects, nomenclature list is included.

Conflict of interest

Although the common goal of all investors is to maximize the value, the value itself may defer from one investor to another. The project may be financially and economically feasible for one investor but for another one is not feasible. This is something unique and considered one of the characteristics of the oil and gas industry. The financial scheme of the industry, types of agreements in Egypt (PSA), different parties ("IOCs" and "NOCs") generate different criteria of feasibility for each party. For examples, Rahimpour et al. (2012) studied the three mentioned options and recommended gas compression option for the high IRR and low initial investment but from which point of view and for which investor! This is what missing.

The predominant oil and gas agreements in Egypt are the production sharing agreements (PSA) (Reuters (A) 2015). Through this type of agreements, most of the risks are transferred to the "IOC" including exploration risk, discovery risk, and funding risk. "IOCs" provide the entire required fund including CAPEX and OPEX and get it back as cost recovery (commonly 20% a year of CAPEX and 100% a year for OPEX) according to the agreement (Leach 2016). In return, "IOC" gets a predetermined share of production for the risk and the cost of money. "IOCs" seek the maximum financial return while "NOCs" seek the maximum social added value while sustaining resources, and here, conflict of interest comes to the scene.

The environmental positive impact of these projects is the main driver for "NOCs" to execute such projects through decreasing greenhouse gases emissions. Recovering flared gas will result in using this energy to diminish the gap between demand and production. Accordingly, imports will decrease and greenhouse gases emissions will decrease. Anomohanran (2012) illustrated that 457 million ton of CO_2 was emitted from 1999 to 2009 in Nigeria because of flared gas which was reduced afterward from 43 million ton in 1999 to 27 million ton with estimated annual losses of gas of $11 billion per year. Nomohanran's valuable work illustrates the criticality of recovering these amounts of flared gas in general. Also in Nigeria, Otene et al. (2016) discussed different alternatives to recover flared gas and reached a conclusion to compress the gas to be used as a fuel. The study was comprehensive but was not extended to financial and economic dimensions. Also one of the criteria that the government cares about is the social impact of the project, which shall add another variable to the equation including saving foreign currency, injecting foreign currency, and creating employment opportunities. All these values are quantified and are taken into consideration.

Through this paper, these different options will be evaluated technically, financially, and economically from "IOCs" and "NOCs" perspectives to find the optimum feasible method to recover flared gas from the Egyptian oil and gas plants: technically, through studying the mentioned feasible recovering options and their limits according to the case study; financially, through the financial feasibility study and the added value to investors; and economically, by adding the environmental aspect and the social added value to the scene. This kind of work has been discussed before in previous literature work but from technical or financial point of view. However, the integration is not introduced so far by studying flare gas recovery projects from technical, financial, and economical perspectives including the conflict of interest between "IOCs" and "NOCs" and the social impact of the different options was not clearly discussed. These factors are the main criteria for selection and will be tackled to maximize project benefits. This paper would be of great benefit to policy makers who should immediately set rules for recovering this wasted amount of gas after realizing the different aspects introduced through this paper.

Methodology

A lot of previous studies discussed the methods of flared gas recovery from technical point of view. Some others discussed the financial feasibility of these alternatives. However, these types of projects were rarely discussed from a comprehensive perspective. This paper is an integrated study among technical, economic, and financial aspects that highlights the technical constrains, financial feasibility criteria, economic feasibility criteria, and conflict of interest among different parties. The algorithm used in the paper is illustrated in Fig. 1. This algorithm includes:

- Study the technical feasibility of the different options.
- Calculate the expected products' types/rates/specifications for the feasible technical options.
- Study the existing applied agreements in Egypt and how expenses, profit, and risks are shared between different parties.
- Execute a financial study for "IOCs" on the previous technically feasible options.
- Execute an economic study for "NOCs" on the previous technically and financially feasible options.
- If one option superiority appears for both parties, the company should proceed immediately with it.
- If not, study the economic feasibility for "NOCs" to finance these projects by debt without "IOCs" support to protect the environment and maximize the value added.

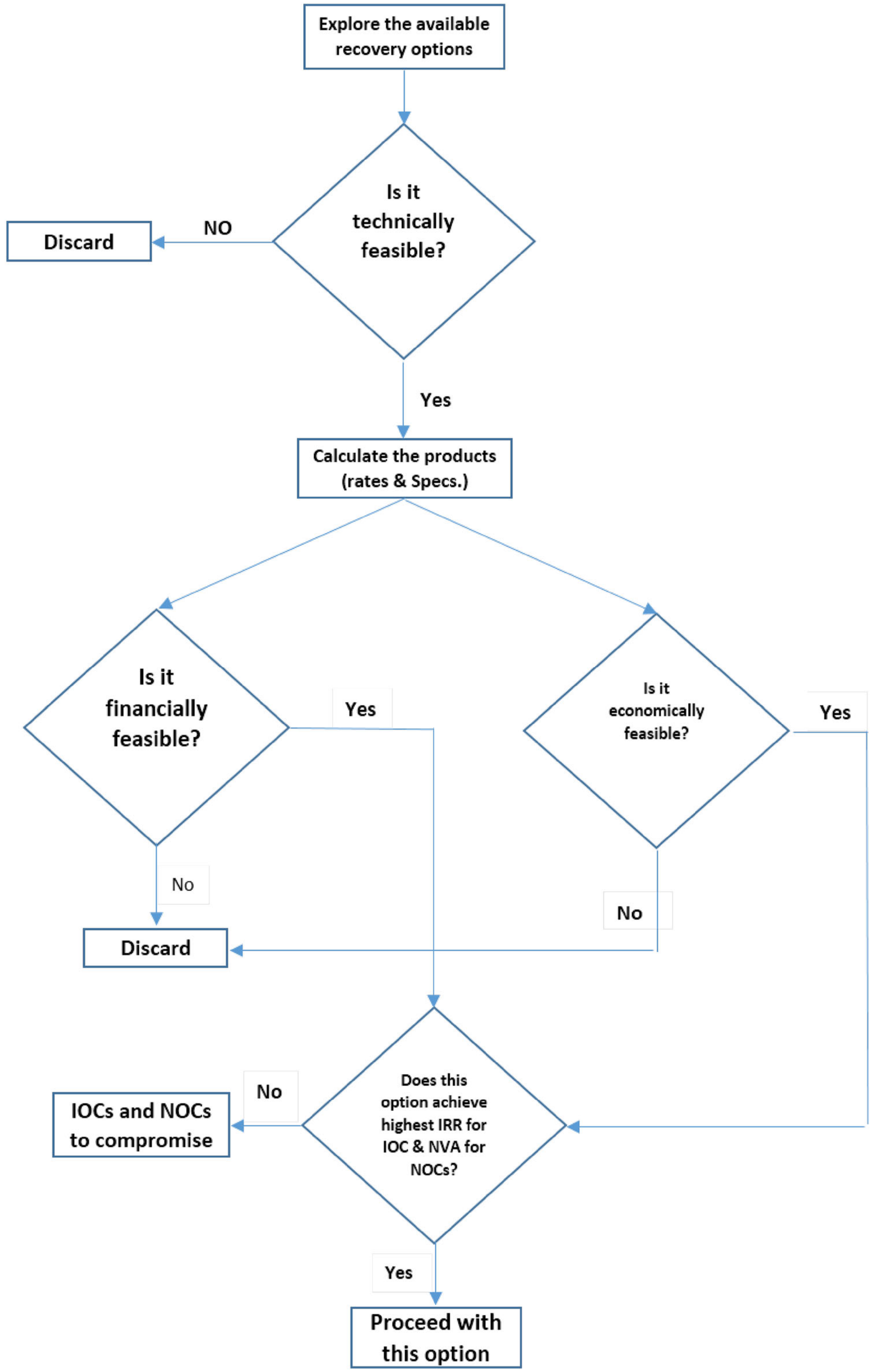
For the technical study, Aspen HYSYS process simulation software version 8.8 was used for evaluating different options and calculating the outputs of the different proposed options. For the financial and economic study, models were developed to reflect the financial and economic metrics of different options. Also the flared gas sample, which was used as a case study, is an actual sample taken from an existing oil and gas plant and is considered a reasonable representative of flared gases in Egypt.

Software

Aspen HYSYS version 8.8 is process simulation software developed by Aspen Tech. The software was used to model an existing plant, which is used in the case study below, with actual data and accordingly design how the flared gas can be recovered and what are the expected products with rates and specifications. The major executed processes are as follows:

- Calculate the amount of sales gas and condensate that will be resulted from recycling the flared gas by simulating the entire plant.
  - The entire plant was simulated to calculate the final products that will be resulted from introducing the flared gas to the plant. The products will include sales gas and sales condensate.
  - The plant was assumed to have the preliminary treatment units including: preliminary compression, separation, sweetening, dehydration, dew pointing, stabilization, recycling, and compression.
- Calculate the heating value of the flared gas according to the actual compositions.
- Calculate the efficiency of the existing turbines used in the field.

Fig. 1 Paper algorithm



- Calculate the amount of LPG that can be extracted from the flared gas according to the actual compositions and processes.
- Calculate the amount of condensate that can be extracted from the flared gas according to the actual compositions and processes.

- Calculate the residue gas that will be flared in case of LPG and condensate extraction.
- Calculate the amount of CO_2 that will be emitted from flared gas combustion.
  - Using Gibbs reactor to calculate the amount of greenhouse gases emitted from flaring the recovered gas for the three proposed options.

Peng Robinson property package was used. This EOS is generally recommended by Aspen Tech for general purposes. It rigorously solves any single-, two-phase, or three-phase system with high efficiency and reliability. Also, it is applicable over a wide range of conditions (Aspen HYSYS user guide 2014).

Financial model

A financial model has been developed to reflect the feasibility of the proposed options including a sensitivity analysis on flared gas rates from financial (investor) point of view. The model includes: revenue, costs (cost of goods sold, maintenance cost, wages, and transportations' expenses), depreciation scheduling, taxes, debt scheduling, weighted average cost of capital, free cash flow, net present value, and internal rate of return.

Project becomes financially feasible if the returns "profit" exceeds the opportunity cost or the cost of money. Revenue includes selling all the produced commodities including LPG, condensate, and sales gas. Cost of operations includes wages and salaries, maintenance and spare parts, and transportation expenses. Also, depreciation and taxes are taken into consideration. The maximum debt ratio is calculated according to the following equations:

$$\text{Profit} - \text{Loan Interest charges} = \text{Debt repayment} \tag{1}$$

Equaling both sides of the equation shall guarantee repayment of debt principle.

$$\text{Investment} \times \text{ROI} - \text{Loanprinciple} \times \text{Interest rate} = \text{Debt repayment} \tag{2}$$

Dividing by "Debt repayment"

$$\frac{\text{Investment} \times \text{ROI}}{\text{Debt repayment}} - \frac{\text{Loan principle} \times \text{interest rate}}{\text{Debt repayment}} = 1 \tag{3}$$

$$\frac{\text{Investment} \times \text{ROI}}{\text{Debt repayment}} - \#\text{ of installments} \times \text{interest rate} = 1 \tag{4}$$

$$\text{Debt repayment} = \frac{\text{Investment} \times \text{ROI}}{1 + (\#\text{ of installments} \times \text{interest rate})} \tag{5}$$

Then debt repayment can be calculated. Multiplying it by the number of installments will result in the maximum debt principle which can be borrowed and repaid.

According to the previous equations, the project can be totally financed by debt, regardless of the optimum capital structure. However, there is an optimum debt ratio to achieve the minimum cost of capital as when debt ratio increases, risk default increases, and cost of equity increases.

Present value of free cash flow is the discounted cash flows generated from the project. It is a future amount of money that has been discounted to reflect its current value, as if it is existing today taking into consideration time value of money (as discussed with Prof. Eskander Tooma, tenured professor of finance at the School of Business, the American University in Cairo). It can be calculated according to the following equation:

$$\begin{aligned} \text{PV} = {} & \text{FCF}_1/(1+\text{WACC}) \\ & + \text{FCF}_2/(1+\text{WACC})^2 + \text{FCF}_3/(1+\text{WACC})^3 + \cdots \\ & + \text{FCF}_n/(1+\text{WACC})^n \end{aligned} \tag{6}$$

In Egypt, the profit performance shall be expected through the first 6 years of the project and after that it will be a fixed annuity over the remaining time of the project because estimating more than 6 years usually leads to 70% error (as discussed with Prof. Samir Makari, Professor of Economics at the American University in Cairo). Consequently, the PV for the 7th year and successive years shall be calculated by: $(\text{FCF}_6 - \text{depreciation}_7)/(1 + \text{WACC})^7$

The net present value (NPV) is the difference between the present value of cash inflows PV and the present value of cash outflows "Investment." The greater the NPV, the higher the viability of the project

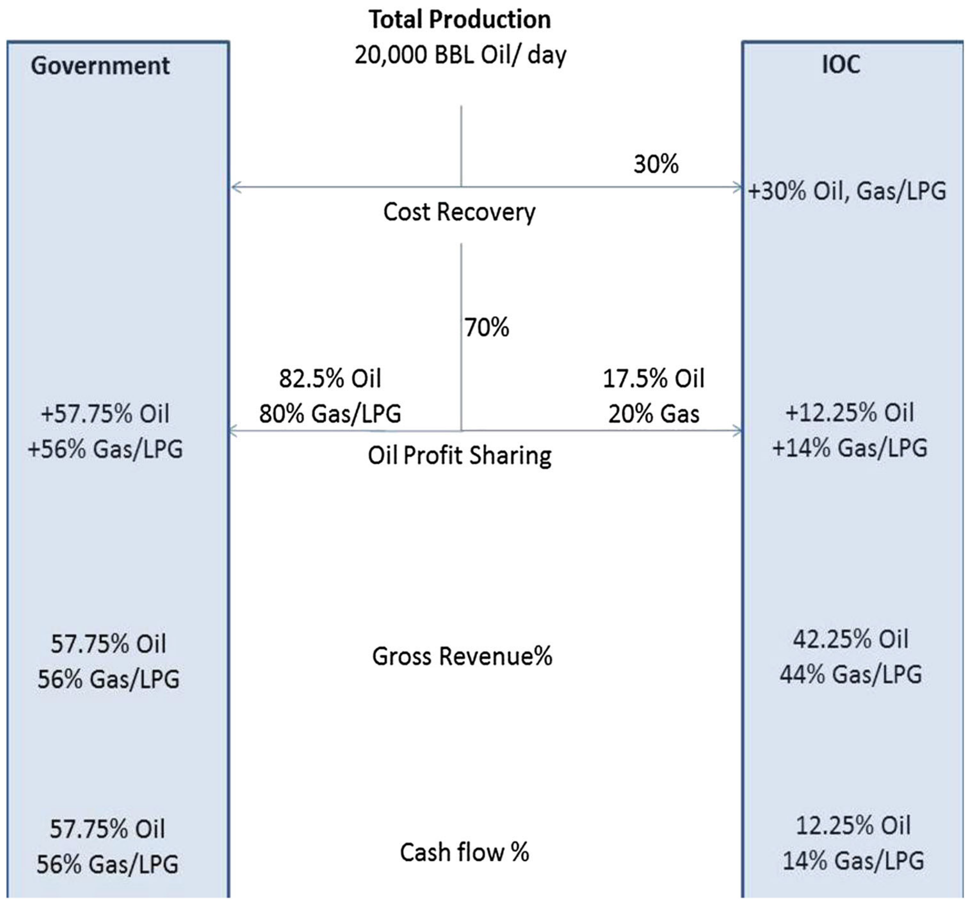
Also internal rate of return (IRR) is used to evaluate the attractiveness of a project or an investment and it is considered the interest rate at which the net present value of all the cash flows (both positive and negative) from a project or investment equal zero. It could be mathematically calculated as follows (Brigham and Ehrhardt 2007):

$$\begin{aligned} \text{Investment} = {} & \text{FCF}_1/(1+\text{IRR}) + \text{FCF}_2/(1+\text{IRR})^2 \\ & + \text{FCF}_3/(1+\text{IRR})^3 + \cdots + \text{FCF}_n/(1+\text{IRR})^n \end{aligned} \tag{7}$$

The greater the excess of IRR over the WACC, the higher the viability of the project. The WACC is calculated according to the cost of debt, cost of equity, and the debt ratio for the project.

One of the main aspects that impact the financial study is the profit scheme that is applied on PSAs. An example of this scheme is summarized in Fig. 2.

Fig. 2 Example of PSA profit scheme



Economic model

An economic model has been developed to reflect the feasibility of the proposed options including a sensitivity analysis on flared gas rates from a socioeconomic point of view. Four major differences shall differentiate between financial and economic evaluations (as discussed with Prof. Samir Makari, Professor of Economics at the American University in Cairo).

Prices

Financial evaluation deals with market prices in evaluating projects while the economic evaluation takes into consideration shadow prices.

Shadow price is an estimation of economic price which is the price that would prevail in a perfect competitive market without any distortions such as governmental intervention, taking into consideration that 75% of commodities' prices in Egypt are distorted. That is why the subsidized products' prices will be changes through economic studies to reflect the shadow price.

Vision

Financial evaluation adopts investors' point of view who cares about financial impact of the project while the economic evaluation care about both direct and indirect impact of the project including the impact on society, for example the emissions of greenhouse gases from combusting flared gases.

Returns

Financial evaluation looks for all financial transactions through the project while economic evaluation does not count for any money transactions that do not add value such as taxes and interest.

Viability

Economic evaluation takes into consideration some aspects such as job opportunities, value added, and foreign exchange effect.

- The shadow interest rate, which is also called the social discount rate SDR, shall be determined by combining the interest rate in USA and its currency increase "US dollar" compared to Egyptian pound.
- The foreign exchange market is distorted in Egypt because the official exchange rate (OER) which is lower than the fair exchange rate (FER) that is determined by supply and demand. Moreover, due to speculations, the demand is shifted to result in a new price for equilibrium which is the market exchange rate MER.
- Other important aspect is the environmental impact of the project. For example, recycling the gas will hinder the combustion of the flared gas volume. That is, the project will protect the environment from the CO_2 that shall be emitted from combusting flared gas. Each ton of CO_2 emissions enhances the greenhouse effect and costs the environment a lot. This impact was estimated (Litterman 2013; Luckow 2015) to be \$20 per ton of CO_2.

Study limitations

This study has been executed through one of the biggest processing plants in Egypt. However, there are lots of variables that cannot be sensitized all together, namely the flared gas analysis and rates, the plant operating conditions and processes, commodities spot prices, foreign currency exchange rates, subsidies, and finally agreements terms and conditions. For example:

- Flare gas analysis: More heavy components will favor condensate and LPG recovery option.
- Plant operating conditions: A lot of variables shall change the technical and financial results such as operating pressure, existing recycle compressors operating conditions, and plant processing ullage.
- Foreign currency exchange rate: This will affect the official exchange rate and shadow price and accordingly will affect projects' feasibility.
- Commodities spot price: Products' prices will directly affect projects' revenue specially when the applied agreements sell commodities according to spot prices and not fixed prices such as crude oil Brent for oil and Henry hub price for natural gas heating value.

All these variables may vary from a plant to another/from time to time/and from country to another. Accordingly, the feasibility of different options shall be changed. So, the above-mentioned results are generic and represent the conflict of interest among different parties, including their vision, how social impact and environmental impact shift their preferences, and their subsequent actions.

Case study

A flared gas sample is taken from an Egyptian oil and gas plant as per Table 1. The CO_2 content in the sample exceeds 8% by mole. This plant includes the principle treating processes such as separation through three-phase separators, dehydration through TEG, sweetening through Benfield solution, dew pointing through expander and Joule–Thomson valve, compression through compressors, and stabilization through a stabilization column as indicated in Fig. 3. Compared to other flared gas samples in Egypt, this sample is considered a typical flared gas sample. The main sources of the flared gas are purge gas, relieve valves, and leaking valves. The sample's analysis is as follows:

The heating value of the sample is 68,258 kJ/SCM (1832 BTU/SCF) and the average molecular weight is 36 g/mol. This means that flared gas contains a lot of heavy components evaporated mainly from stabilization processes.

The following information/data are some characteristics of the plant:

- The inlet pressure for the plant to the separator is 2.3 MPa (22 barg).
- The outlet pressure for the plant through the export compressor is 9.1 MPa (90 barg).
- The inlet pressure for the recycling compressor of the plant is 1.05 MPa (9.5 barg).
- The maximum capacity of the plant is 11.89 MMSCMD (420 MMSCFD) of gas and 7950 m^3 (50,000 BPD) of condensate.

Table 1 Flared gas typical sample analysis

Component	Mole (%)	Mol. Wt (g/mol)
Nitrogen	0.6	28.013
CO_2	8.1	44.01
Methane	45.2	16.043
Ethane	10.3	30.07
Propane	13.6	44.097
i-Butane	4.5	58.123
n-Butane	8.1	58.123
i-Pentane	1.6	72.15
n-Pentane	1.5	72.15
n-Hexane	1.6	86.177
Benzene	0.7	78.114
n-Heptane	2.2	100.204
Toluene	1.2	92.141
n-Octane	0.3	114.231
E-benzene	0.1	106.167
m-Xylene	0.4	106.167
o-Xylene	0.1	106.167

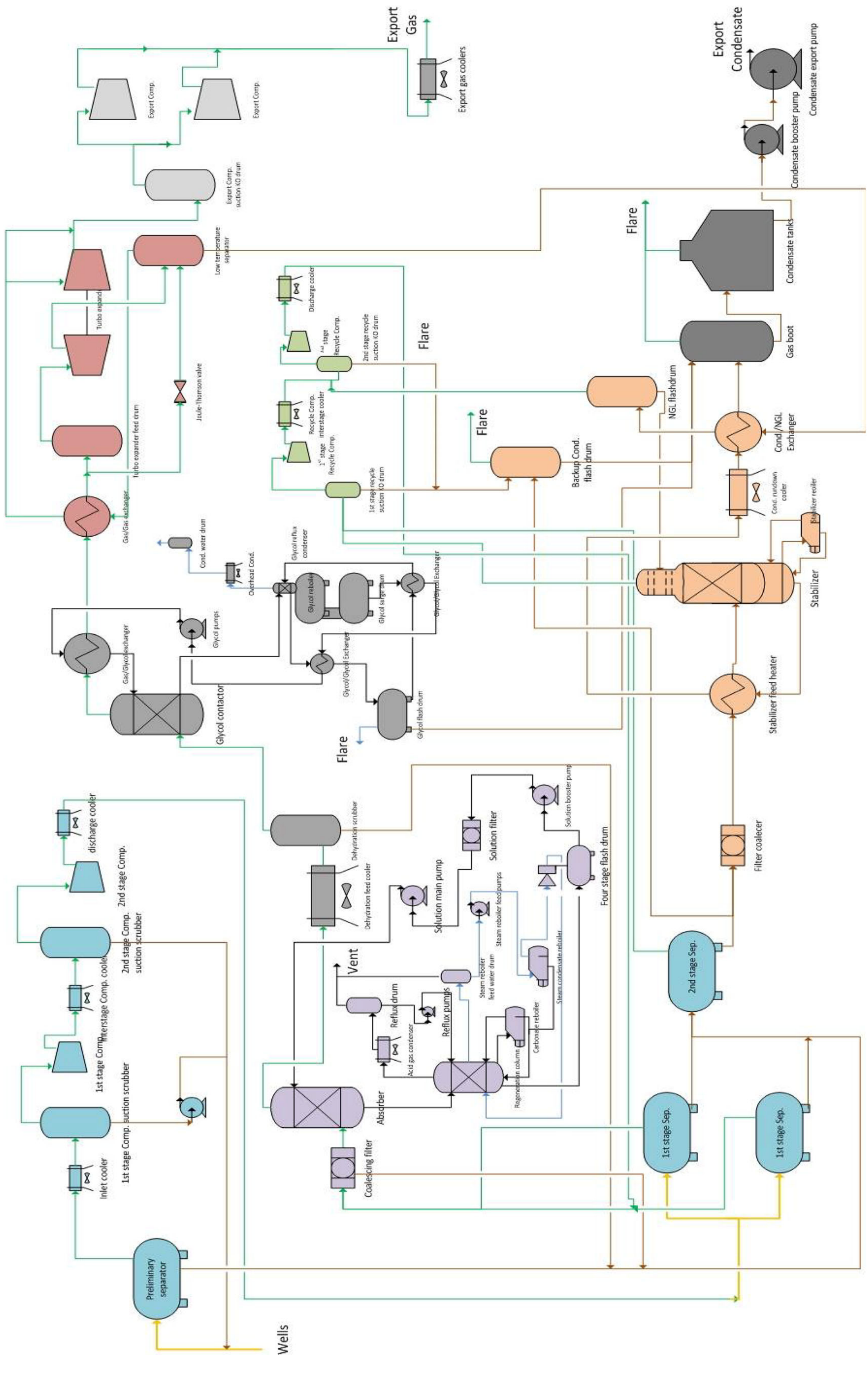


Fig. 3 Case study process flow diagram

- The actual production from the plant is 11.04 MMSCMD (390 MMSCFD) of gas and 2226 m^3 (14,000 BPD) of condensate.
- The sales gas specifications are 3% CO_2 and 4 ppm of H_2S.
- The sales condensate specifications are RVP of 69 kPa (10 PSI) and 0.5% of water cut.
- The existing turbines consume 0.5 MMSCMD (17.5 MMSCFD) of sales natural gas with heating capacity of 42,102 GJ/MMSCMD (1.13 GBTU/MMSCFD) to generate 44 MW.
- The average recovery factors for LPG are: 1–5% Ethan, 65–75% Propane, 85% i-butane, 88% *n*-butane.
- The average recovery factors for condensate are: 97% Pentane and 99.5% Hexane+.

In this case, the flared gas can be compressed from atmospheric pressure to 1.05 MPa (9.5 barg) to be introduced to the main recycle compressor of the plant then going through sweetening unit, dehydration unit, dew pointing unit, stabilization unit, and compression unit. "The PFD of the plant is illustrated in Fig. 3." Recycling the studied flared gas sample will result in around 19 m^3 (120 bbl) of condensate and 0.02 MMSCM (0.8 MMSCF) of sales gas per day. Alternatively, generating power from this flared gas sample will produce around 413 MW for each MMSCM (35.3 MMSCF) of flared gas. The average efficiency of the existing outdated turbines in the field is around 18% while the efficiency of the mentioned brand-new generators is around 60%. This efficiency difference will save around 5.1 MMSCM (178.5 MMSCF) of sales gas per day for each MMSCM (35.3 MMSCF) of flared gas being used in power generation. The third option is to extract LPG and condensate from this flared gas which will generate around 10 ton of LPG and 12.4 m^3 (78 bbl) of condensate on daily basis from 0.03 MMSCM (1 MMSCF) of flared gas using mechanical refrigeration according to the developed model and industry averages. However, around 64% of the flared gas feed will be flared. Table 2 highlights the technical assumptions used for the case study.

Table 2 Technical assumptions

Item	Value
Gas generator efficiency (%)	60
Existing power generation efficiency (%)	18
LPG unit power consumption (MW) for each 1 MMSCFD	0.3
Turbine lifetime (years)	25
Generator lifetime (years)	8
LPG unit lifetime (years)	10
Compressor lifetime	20
Sales gas GBTU/MMSCFD	1.12

Financial model major details

Cost of debt is the effective rate that a company pays on its current debt. Typically in Egypt, it is 10.5% calculated as follows:

$$\begin{aligned}\text{Cost of debt} &= \text{Interest rate} \times (1 - \text{taxes rate}) \\ &= 14\% \times (1 - 25\%) = 10.5\%\end{aligned} \tag{8}$$

Cost of equity is estimated by Damodaran (2016) to be 12.05% for oil and gas production and exploration companies. Taxes are calculated to be 40% as stated by the Egyptian government to oil and gas companies. These taxes are being paid by "NOCs" for both parties ("IOCs" and "NOCs") (Sackin 2013).

The remaining financial assumptions are illustrated in Table 3

Economic model major details

$$\begin{aligned}&\text{It's assumed that the shadow interest rate in Egypt} \\ &= \text{Interest rate on loans in USA} + \text{US \$} \\ &\quad \times \text{ increase compared to EGP} = 5\% + 4.9\% \approx 10\%\end{aligned} \tag{9}$$

$$\begin{aligned}&\text{It can also be determined by another way} \\ &= \text{Borrowing interest rate from a financial institute} \\ &\quad \times \text{in\$} + \text{country risk premium} \approx 3\% + 7\% \approx 10\%\end{aligned} \tag{10}$$

(as discussed with Prof. Samir Makari, Professor of Economics at the American University in Cairo).

Also the shadow exchange rate is estimated to be 11 L.E/$ compared to the official exchange rate (OER) of 8.88 L.E/$ (as discussed with Prof. Samir Makari, Professor of Economics at the American University in Cairo). From environmental point of view, it is worth mentioning that in case of recycling 0.03 MMSCM (1 MMSCF) of flared gas, 117 ton of CO_2 emissions will be saved. For power generation, it is around 60 ton per MMSCF of flared gas. For LPG and condensate extraction, it is around 2471 ton per each MMSCM (35.3 MMSCF) of flared gas. The remaining economic assumptions are illustrated in Table 4.

Results and discussion

The following section illustrates the results of the financial and economic studies from different perspectives ("NOCs" and "IOCs") and also illustrates the value added from these projects for each party. All the mentioned results are built basically on the technical results obtained for the mentioned options. These results play a vital rule in decision making specially after considering all aspects that have an impact on revenue and cost for each party separately and collectively.

Pure financial feasibility study

The first model is the financial model of the project regardless of the agreement type, source of financing (either “IOC” or “NOC”), and environmental and social aspects. Through this model, it was assumed that the project is totally financed by debt. This is feasible because the producing wells are already drilled and producing, so the raw material is guaranteed; besides, the project is controlled by government (Egyptian General Petroleum Corporation), and with high return.

It is obvious from Figs. 4 and 5 that, from pure financial point of view, although power generation will generate the maximum NPV, it will not result in the maximum return (IRR). Recycling the gas will produce the highest IRR that exceeds power generation in most cases. LPG extraction is not feasible since its IRR is lower than the WACC “10.75%.” The low feasibility of the LPG and condensate extraction option is due to subsidizing LPG to quarter of its price which is \$89 per ton instead of its global price which is around \$360 per ton. In low oil price environment, companies seek high return with low investment, thus recycling the flared gas will be the best option from this perspective.

“IOCs” financial feasibility study

However, the feasibility of the project will not be just a pure financial or technical feasibility, the type of the agreement applied, funding scheme, social impact, and also “NOCs” and “IOCs”; different visions will play a vital rule in the feasibility study.

Figures 6 and 7 illustrate the same financial metrics but from “IOCs” point of view. As indicated by the assumptions’ tables, prices had been modified to reflect the prices that “IOCs” will sell for.

For “IOCs,” flared gas recycling is considered the most feasible option compared to a higher WACC of 11.6%. Leverage was assumed to be 50% (EY 2015). Recycling the gas is still the best option with halved IRR compared to the previous pure financial study, but still attractive. Through this financial analysis, it is clear that the LPG and condensate extraction is feasible, exceeding power generation this time, but with lower IRR and NPV starting from 0.02 MMSCMD (0.8 MMSCFD). Power generation option is the least feasible with the lowest return compared to initial investment. It is assumed that CAPEX recovery shall be

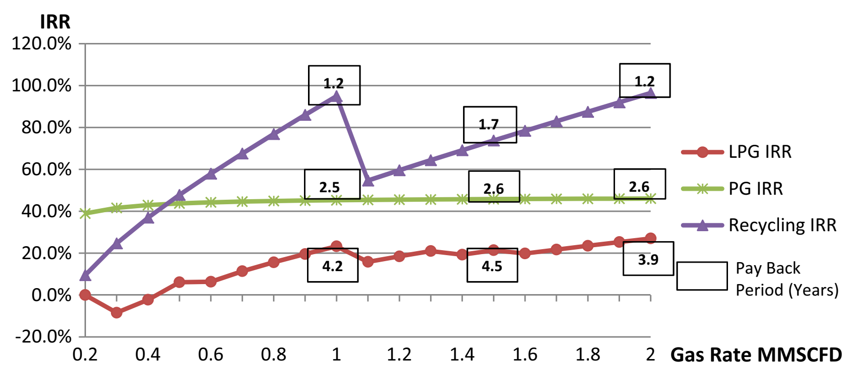


Fig. 4 Financial feasibility study (IRR)

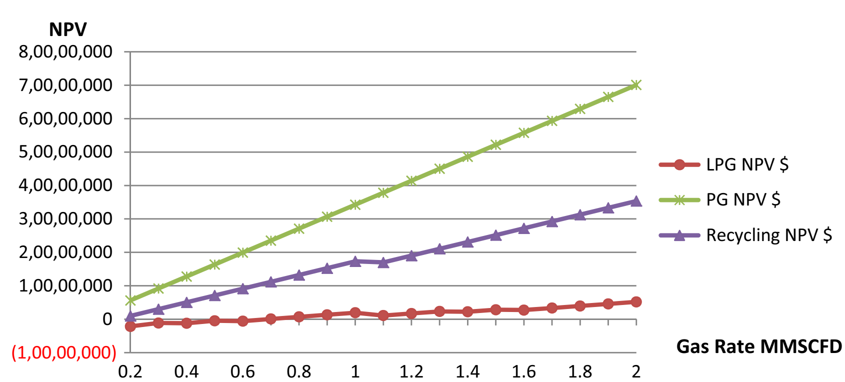


Fig. 5 Financial feasibility study (NPV)

20% on yearly basis. Differences in the model include difference in the gas prices which is already stated in the agreement and in most cases is equal to \$2.52 per GJ (0.95 MMBTU) without estimated increase in the upcoming 5 years (Reuters (A) 2015; Reuters (B) 2015).

"NOCs" economical feasibility study

The project's feasibility will be extremely different from "NOCs" point of view because:

- No direct investment required.
  - "IOCs" pay all the direct investment.
  - Costs are recovered through production revenue.
- Social impact of the project will be taken into consideration.
  - CO_2 emissions reduction is taken into consideration, as one ton of CO_2 is estimated to cost the society \$20 (Litterman 2013; Luckow 2015).
  - Any money transactions that do not add value such as taxes and interest are excluded.
  - Foreign currency transactions' impact has been taken into consideration.
- Economic feasibility study including shadow prices will be implemented.
- Prices that shall prevail in perfect competitive market are being used without any distortions such as governmental intervention; taking into consideration that 75% of commodities' prices in Egypt are distorted (as discussed with Prof. Samir Makari, Professor of Economics at the American University in Cairo).

Figure 8 illustrates the economic feasibility study of the project from "NOCs" point of view. The study includes the shadow prices for commodities, exchange rate effect, currency transactions effect, environmental impact, and social discount rate. It is worth mentioning that IRR calculations cannot be implemented as there is no direct investment in the project. As illustrated, the previous results did not take into consideration the environmental and social impact of the project. Nevertheless, environmental impact and social benefits are greatly influential on these results as "NOCs," which represent the government, aim to achieve the highest financial and social return and save the environment as well. Benefits behind reducing emissions are quantified as per Table 4.

For "NOCs," it is clear from Fig. 8 that power generation is the most attractive option followed by gas recycling option because the shadow prices were used this time and the environmental impact was quantified.

Now, it seems that there will be a conflict of interest in executing such project between "IOCs" and "NOCs." That

Fig. 6 "IOC" financial feasibility study IRR

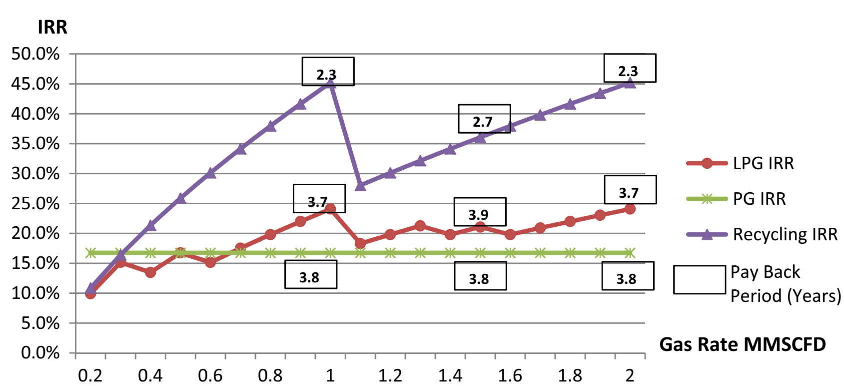
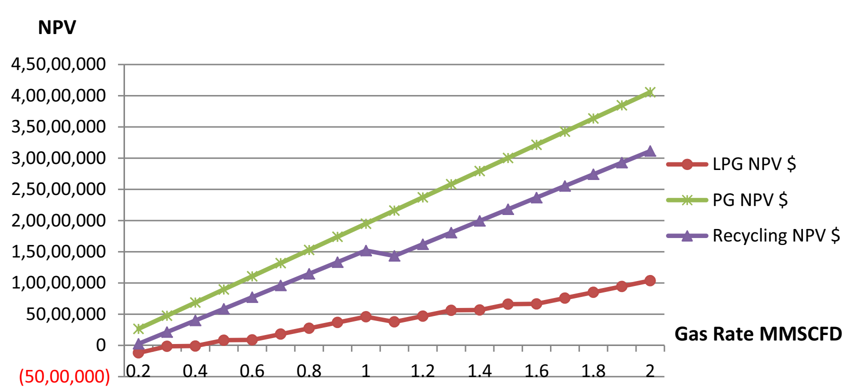


Fig. 7 "IOC" financial feasibility study NPV



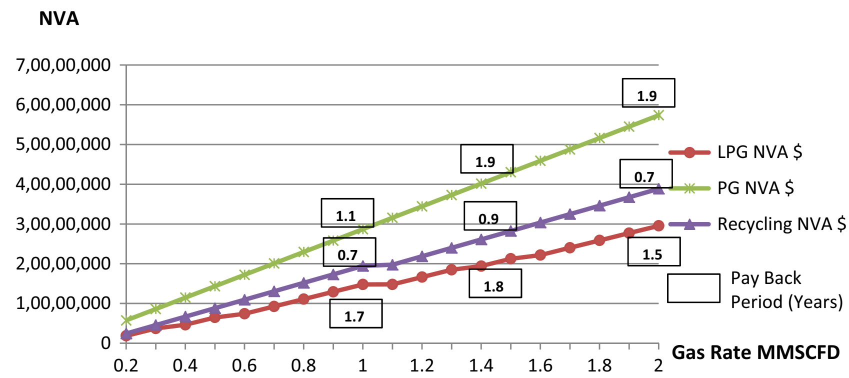


Fig. 8 "NOCs" economic feasibility study NVA

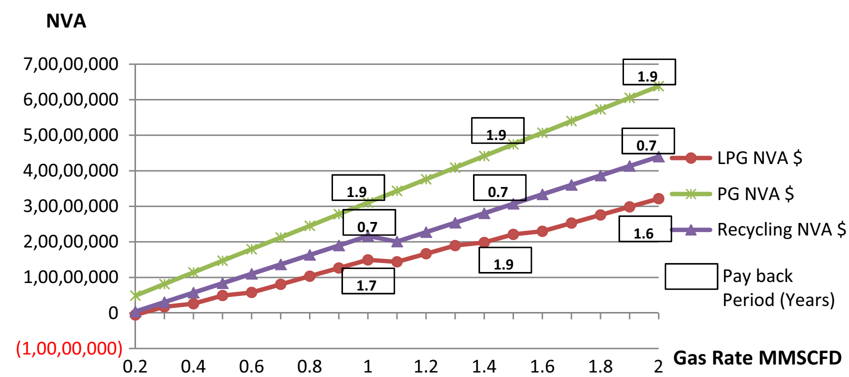


Fig. 9 "NOCs" economic feasibility study if financed by "NOC"

is why Fig. 9 illustrates the economic feasibility study if the project was fully financed by the government represented in "NOCs" through a debt.

It seems that power generation still the best option for "NOCs" even if the project was fully financed through a debt burdened by "NOCs" without "IOCs" support. Figures 8, 9 illustrate how environmental impact and social considerations shall turn the tables and accordingly change decisions. Therefore, policies should be in place to highlight the environmental impact and to induce the concerned parties to quantify this impact and take social factors into consideration and implement such projects accordingly.

Conclusion

Flared gas recovery project is crucial and should be executed nowadays in Egypt to decrease the current local deficit between energy demand and supply. The technicality of this project has been validated through different options and is being introduced by well-established companies around the world. Some different techniques including recycling, power generation, or LPG and condensate extraction from the flared gas were proved to be technically/financially/economically feasible. This study clarifies that the feasibility of the project will mainly depend on the investor orientation and vision. Through the attached case study, "IOCs" considering recycling the flared gas are the only feasible option to generate satisfying IRR up to 45% and also will generate a net present value up to $40 million. Nevertheless, "NOCs" would prefer generating power from the flared gas to achieve the highest net value added up to $60 million accompanied by high social impact although it has the highest capital cost among the proposed options which is around $3.6 million for each 1 MMSCFD (0.03 MMSCMD) of recovered gas. As previously mentioned, conflict of interest is one of the main reasons behind postponing such projects in Egypt.

The main reason behind the different results from these studies is the economic perspective that is adopted by "NOCs." The government, represented in "NOCs," looks at some aspects other than financial aspects such as environmental impact, shadow prices, and social impact. In the same context and in general, extracting LPG and condensate from flared gas can be seen from the first sight as a very attractive option because Egypt imports LPG since the year 1996 till now (UN Data 2016). However, the study indicates that it is the least feasible and attractive option to implement and is not recommended at all. Finally, Egyptian government should impose policies to reduce flared gas emissions and maximize benefits through these projects and shall take the necessary actions to start recovering this flared gas either by cooperation with "IOCs" through recycling the flared gas and to accept the low NVA, or by executing the project itself by financing through a debt to guarantee the maximum financial and social benefits.

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Appendix

See Tables 3, 4.

Table 3 Financial assumptions

Item	Value
LPG in Egypt ($/ton per day) subsidized (Egyptian Ministry of Petroleum 2016)	89
LPG in Egypt ($/ton per day) international (LPG CIF China Port 2016) (Sale of aviation fuel and other products 2016)	360
Condensate price in Egypt ($/BPD) International (Crude Oil Brent 2016)	50
Gas price in Egypt ($/GBTU) Agreement (MABRO 2006) (Egypt: : Operating challenges to persist despite optimism over Zohr gas discovery 2016)	2650
Gas price in Egypt ($/GBTU) domestic (Egypt to lift natural gas prices for homes, businesses 2016)	3189
US dollar official price (EGP) (Exchange Rates 2016)	8.88
Gas generator ($/MW)	875,000
Turbine ($/MW)	775,000
LPG unit $(0.3 MMSCFD) (0.008 MMSCMD)	2,000,000
LPG unit $(0.5 MMSCFD) (0.014 MMSCMD)	3,000,000
LPG unit $(1 MMSCFD) (0.03 MMSCMD)	4,000,000
Compressor ($/1 MMSCFD)	2,000,000
Average Salary ($/technician/year)	10,200
Average salary ($/engineer/year)	12,800
Gas generator maintenance ($/year)	136,800
Turbine generator maintenance ($/year)	1,152,000
LPG unit maintenance ($/year)	100,000
Compression maintenance ($/year)	160,000
LPG transportation ($/ton/km)	0.04
Average distance to LPG destination (km)	150
Taxes in Egypt (%) (Egypt Tax Guide 2013, 2013) (Corporate Tax Rates 2016)	40
Energy price increase 2017 (%) (World Bank Commodities Price Forecast 2015)	4.10%
Energy price cumulative increase 2018 (%)	8.30%
Energy price cumulative increase 2019 (%)	12.90%
Energy price cumulative increase 2020 (%)	17.50%
Depreciation method	DDD
Cost of equity (%) (NYU, Stern “Damodaran” 2016)	12.05%
Cost of debt (%) (EL Sewedy electric company consolidated financial statements 2016)	10.75%
Cost recovery (oil, LPG, and gas)	20%
IOCs profit share	20%

Table 4 Economic assumptions

Item	Value
LPG ($/ton per day) international price	360
Condensate price in Egypt ($/BPD) international price	50
Gas price in Egypt ($/GBTU) international price (Henry Hub Natural Gas Spot price 2016)	2360
US dollar shadow price (EGP)	11
Social discount rate	10.00%
Financing (debt percentage) (%)	100%
Cost recover (oil, LPG, and gas)	20%
IOCs profit share	20%
CO2 Greenhouse impact $/ton (Litterman 2013; Luckow 2015)	20

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