Sustainability Improvements in Egypt's Oil & Gas Industry by Implementation of Flare Gas Recovery

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ABSTRACT

Within the global Oil & Gas (O&G) industry, gas flaring is a primary source of anthropogenic Green House Gas (GHG) emissions. During the period 1994 to 2009, estimates of annual global gas flaring volumes were approximately 150 Billion Cubic Meters (BCM), corresponding to about 880 Million Barrels of Oil Equivalent. As a result, some 400 Million Tons of Carbon Dioxide Equivalent (MtCO2e) were released yearly into the atmosphere during the same period, or 1.3 fold higher than all of Egypt’s 2009 GHG releases.

According to satellite data of the National Oceanic and Atmospheric Administration (NOAA), Egypt persistently ranked 20th among the world’s top 20 gas flaring countries during the period 2007 to 2011, where aggregate quantities of flared gas were estimated at 8.1 BCM representing lost revenues of around USD 4.2 billion.

Although gas flaring is unsustainable, it continues to be a common practice within O&G facilities in Egypt and elsewhere. As an alternative to flaring, the gaseous by-products are already being captured by some refineries and are utilised for their energy content. However, viability of flare gas recovery projects is restricted in many countries by energy subsidies, high project development costs and lack of funding.

The Clean Development Mechanism (CDM) can play a pivotal role in overcoming barriers facing flare gas recovery projects in developing countries like Egypt. Whilst leading the Middle East and North Africa region in the CDM projects, applications within the O&G industry were absent from Egypt’s CDM portfolio in 2010 and only 2 projects are under validation as of March 2012.

This work sheds light on efforts to improve sustainability of the Egyptian O&G industry by flare gas recovery. Outcomes of research conducted on Egypt’s first refinery flare gas recovery project are reviewed. The project was foreseen for implementation under CDM, therefore, the project was analysed from a triple bottom line perspective.

The economic analysis builds upon the capital budgeting theory whereby, the objective function considered by the project owner is maximization of investment returns. The Internal Rate of Return (IRR) was the metric chosen to assess the project’s potential financial viability. IRR analysis was performed with and without CDM and compared against the project owner’s current IRR.

The analyses revealed that the project fulfils the CDM criteria and also promotes sustainable development. In addition to the potential annual GHG emission reductions of 153,948 tCO2e, yielding expected revenues of around USD 1.5 million annually, the project can contribute to capacity building and employment opportunities in Egypt’s O&G industry. Registering the project under CDM
improves its economic feasibility and can provide impetus to overcome the identified project barriers. IRR sensitivity analysis revealed that the project’s IRR is highly sensitive to local prices of gas. Flare gas recovery projects promote Cleaner Production within Egypt’s O&G industry; hence, such projects should be implemented across the country’s O&G facilities. Although Egypt is not yet a member of the GGFR Partnership, the country should join this global initiative. From a future outlook, this project represents a major steppingstone for implementing zero flaring in Egypt.

*Keywords:*  
Clean Development Mechanism  
Cleaner Production  
Egypt  
Flare Gas Recovery  
Oil & Gas Industry
1. Introduction

Although the Oil & Gas (O&G) industry spans more than a century since its early beginnings in Egypt in 1860, using oil as an energy source traces back to ancient Egyptians. According to Egypt’s Ministry of Petroleum (MOP) website (2012), stone carvings dating to 4000 BC reveal that Pharaohs used oil derived from nuts, seeds and animal fat as fuel to light lamps.

Today, the O&G industry is a key revenue generating activity in Egypt’s balance of trade and a main contributor to the country’s Gross Domestic Product (GDP). Boasting significant reserves, lucrative margins, and strategic accessibility, the industry continues to be a fundamental source of foreign direct investment into the country.

According to the statistics compiled by the Central Bank of Egypt (2011), petroleum exports comprising crude oil, natural gas, and processed petrochemical products, recorded a general upward trend over the period from 2001 till 2011, increasing from circa USD 2 billion to USD 12 billion per year.

On one hand, gas flaring is a non-routine safety procedure that takes place in case of emergency shutdowns, maintenance or operational upsets to clear the hydrocarbon gas inventory from facilities’ pipelines or equipment. On the other hand, normal gas flaring refers to the continuous discharge of associated or waste gas to the flare during routine plant operations (World Bank, 2002). Since the primary focus of this article is on normal (continuous) flaring of refinery waste gas, subsequent use of the term gas flaring or flaring will primarily refer to normal flaring of refinery waste gas.

From an environmental perspective, gas flaring is associated with considerable GHG emissions; hence, it contributes to global warming. Based on the data compiled by the World Bank’s Global Gas Flaring Reduction (GGFR) Public Private Partnership, global gas flaring has been persistent at around 150 Billion Cubic Meters (BCM) during the period from 1994 to 2009, representing about 30% of the European Union’s yearly gas consumption and resulting in annual emissions of some 400 Million Tons of Carbon Dioxide Equivalent (MtCO2e) into the atmosphere (World Bank, 2012b). From a social perspective, gas flaring poses a threat to human health and ecosystems at adjacent flaring sites. From an economic perspective, gas flaring is a dissipation of non-renewable natural resources since the flared gas has an energy content (calorific value) that is wasted without use as soon as the gases are combusted in the flare (Peterson et al. 2007).

Mourad et al. (2009) and De Gouvello (2010) outlined several alternatives to flaring, which are summarized as follows:

1. Reinjection of flare gas:
   a. Into oil fields for Enhanced Oil Recovery (EOR);
   b. Into wet gas fields for maximal recovery of liquids;
2. Construction of a transport infrastructure for collecting and shipping flared gas to treatment plants before subsequent use;
3. Converting flared gas to liquid: Gas-To-Liquid (GTL) or Liquefied Petroleum Gas (LPG);
4. Converting flared gas to Liquefied Natural Gas (LNG);
5. Generating electricity from flared gases;
6. Using flared gas as an onsite fuel source;
7. Using flared gas as a feedstock for petrochemicals production;
8. Burning flared gas in incinerators and recovering exhaust heat for further use (co-generation).

Following inception in Norway in 1994, the concepts and technologies of flare gas recovery have been proven and extensively applied in offshore oil and gas production facilities (Christiansen, 2001). However, economic viability of flare gas recovery projects are primarily constrained in many countries due to the following reasons (World Bank, 2005):

1. High costs of the facilities and equipment required to recover the gas;
2. High project development costs;
3. Lack of funding to undertake gas recovery projects;
4. Underdeveloped local markets in terms of demand and/or infrastructure to use the captured gas;
5. Small quantities or limited value of the gas;

Another significant factor affecting economic feasibility of flare gas recovery projects are the energy subsidies provided by many governments. In the case of Egypt, industrial (and domestic) consumers continue to enjoy large subsidies paid by the Government of Egypt (GoE) reaching some USD 16 billion in 2011, which represented about 7% of GDP and 24% of State Budget expenditures in the same year (Central Bank of Egypt, 2011). As highlighted by Abouleinein et al. (2009), energy subsidies and the current energy pricing approach set by the GoE resulted in tremendously wasteful consumption of energy and have driven energy producers away from minimizing energy waste and implementing energy efficiency/recovery measures, including flare gas recovery.

In addition to these unfavourable economic factors, flare gas recovery projects are impeded by a number of technical aspects as well. Peterson et al. (2007) described these technical challenges as a combination of highly variable flow rates and composition, low heating value and low pressure of the waste gases.

According to satellite data of the National Oceanic and Atmospheric Administration (NOAA), Egypt persistently ranked 20th among the world’s top 20 gas flaring countries during the period 2007 to 2011, where aggregate quantities of flared gas were estimated at 8.1 BCM representing lost revenues of around USD 4.2 billion.

In its report titled “Regulation of Associated Gas Flaring and Venting: A Global Overview and Lessons”, the GGFR partnership analyzed the environmental legislation within several countries including Egypt (World Bank, 2004). In the report, it was highlighted that non-marketable permission grants for gas flaring are granted by Egyptian General Petroleum Corporation (EGPC) as part of its approval on Environmental Impact Assessment’s (EIA) of the individual facilities. The report also indicated that flaring is only governed by pollutant emission levels defined per Egypt’s environment Law 4/1994, which only dictates limits for SO₂, NOₓ, and particulates. It is noteworthy to highlight that no limitations on CO₂ emissions from flaring or specific regulations banning it were stipulated in the law.

This article sheds light on efforts to improve the sustainability of the Egyptian O&G industry by flare gas recovery. The outcomes of research conducted on Egypt’s first refinery flare gas recovery project undertaken by the Suez Oil Processing Company (SOPC) are presented. The project was foreseen for implementation under the Clean Development Mechanism (CDM), therefore, the project was analysed from a Triple Bottom Line (TBL) perspective in that context.

In the subsequent sections of this article, a review of the materials and methods utilised for the analyses of the gas flare recovery project. The outcomes of the project’s TBL analysis and systems dynamics are presented in Section 3 & 4. Finally, the conclusions are presented in Section 5.

2. Materials and methods

2.1 Project description

Suez Oil Processing Company (SOPC) is one of the landmarks in the history of Egypt’s O&G industry. It is the first national oil refining company in Egypt, second only to the previously foreign owned Nasr refinery. Construction of SOPC began in 1921 and the refinery was commissioned in 1923. SOPC enjoys a strategic location on the Gulf of Suez coast, just downstream of Suez Canal international waterway. Regarding operational capacity, SOPC refinery is designed to handle 3 million tons of crude oil annually and has a yearly production capacity of 900,000 tons of high quality products.
The refinery is comprised of the following four main processing plants:

- Atmospheric & Vacuum Distillation Units;
- Catalytic Reforming Complex;
- Coker Complex;
- Lube Oil Complex.

Excess off-gases released from the four processing units (waste gases) are currently continuously discharged to the flare via two separate flare headers, namely the Distillation & Lube Oil Flare Header and Coker & Reformer Complexes Flare Header.

At present, SOPC is planning to install a complete flare gas recovery system in order to minimize the quantity of waste gas normally discharged to the flare and use it internally as fuel gas for the heaters that supply the refinery’s heat requirements. The new flare gas recovery system is comprised of new headers to direct the normally flared gases from the existing flare headers into the recovery system and subsequently into the onsite fuel gas system, which provides feed gas to the refinery’s process heaters.

From the flared gas analysis developed by SOPC, it was clear that the waste gas contains carbon dioxide (\( \text{CO}_2 \)) and hydrogen sulphide (\( \text{H}_2\text{S} \)), which implies that the gas is sour. \( \text{CO}_2 \) and \( \text{H}_2\text{S} \) are both weakly acidic gases and become corrosive in the presence of water (Garverick, 1994). Accordingly, in order to utilize the recovered gas in the refinery, it is necessary to scrub the sour gases to prevent corrosion and to satisfy the preset specifications of the process heaters’ fuel gas. The flare gas recovery system will accordingly include a treatment unit for gas sweetening.

To undertake the project monitoring process for CDM, the volume of recovered gases must be measured and recorded subsequent to implementation of the project. Hence, a gas meter will be installed within the recovery system as well. A simplified block flow diagram showing the existing facilities and the envisaged new flare gas recovery system is depicted in Figure 1.

![Fig. 1. Simplified block flow diagram showing the existing and proposed new facilities associated with the flare gas recovery project at SOPC.](image-url)
2.2 Research method

2.2.1 GHG emission reduction calculations

In order to calculate the GHG emission reductions for SOPC flare gas recovery project and since the project was foreseen for implementation under CDM, a methodology approved by the CDM-Executive Board was used. Upon review of the approved methodologies database provided on the CDM UNFCCC website (2010a), the applicable Approved Methodology (AM) for SOPC flare recovery project was identified as AM 0055, version 01.2 (UNFCCC, 2008a) since this methodology considers recovery of flared waste gas. Moreover, AM 0055 is applicable for large scale projects, which is relevant for the proposed SOPC project in view of the magnitude of potential emission reductions.

The GHG emission reductions per year \( (ER_y) \) were calculated as the difference between the yearly project baseline emissions \( (BE_y) \) and project emissions \( (PE_y) \) as shown in equation (1). The project baseline scenario is defined as ‘...the scenario that reasonably represents the anthropogenic emissions by sources of greenhouse gases that would occur in the absence of the proposed project activity’ (UNFCCC, 2006b: p.16). In the case of SOPC, the baseline is continued flaring of waste gases and generating heat for use within the refinery (process heating) by burning natural gas (fuel source).

\[
ER_y = BE_y - PE_y
\]  

(1)

The baseline emissions from process heating in year \( y \) \( (BE_{ph,y}) \) measured in tons of carbon dioxide equivalent per year \( (tCO_2e/y) \) were calculated using equation (2):

\[
BE_{ph,y} = Q_{wg,y} \times LHV_{wg} \times EF_{phf}
\]  

(2)

where \( Q_{wg,y} \) is the quantity of flared waste gas that replaces the process heating fuel in year \( y \), \( LHV_{wg} \) the Lower Heating Value of the flared waste gas and \( EF_{phf} \) the emissions factor of the fuel used for process heating (natural gas). To calculate \( LHV_{wg} \), the weight percent \( (Wt) \) of waste gas component \( i \) is multiplied by its corresponding \( LHV \), and the resulting values summed, as shown in equation (3).

\[
LHV_{wg} = \sum LHV_i \times Wt_i
\]  

(3)

\( EF_{phf} \) is calculated from the carbon content of the natural gas used in the refinery, which is obtained as the product of the weight percent of natural gas component \( i \) and its corresponding carbon fraction using equation (4). To express \( EF_{phf} \) in terms of its heat content \( (kCal) \), the carbon content is divided by the \( LHV \) as illustrated in equation (5).

\[
CarbonContent_{phf} = \sum CarbonFraction_i \times Wt_i
\]  

(4)

\[
EF_{phf} = \frac{CarbonContent_{phf}}{LHV_{phf}}
\]  

(5)

The first source of project emissions is from the electricity consumption of the flare gas recovery system compressor. To calculate these emissions, the Tool to calculate baseline, project and/or leakage emissions from electricity consumption was used (UNFCCC, 2008b). Equation (6) illustrates the formula depicted in that tool for computing the annual project emissions from electricity consumption \( (PE_{EC_y}) \), where \( EC_{PJ,j,y} \) is the amount of electricity consumed by the project electricity consumption source \( j \) in year \( y \) and \( EF_{EL,j,y} \) is the emission factor for electricity generation for source \( j \) in year \( y \) (in this case, there is only one electricity consumption source).
To calculate the compressor electricity consumption, the brake horse power (BHP) was calculated using equation (7) obtained from Mokhatab et al., 2006:

\[ BHP = 0.0854 \times Z_{ave} \left[ \frac{(Q_{G,SC})(T)}{E \times \eta} \right] \left[ \frac{k}{k-1} \left( \frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - 1 \right] \]  

(7)

where \( Z_{ave} \) is the average compressibility factor, \( Q_{G,SC} \) the standard volumetric gas flow rate, \( T \) the suction temperature, \( E \) the parasitic efficiency, \( \eta \) the compression efficiency, \( k \) the isentropic exponent, \( p_1 \) and \( p_2 \) the suction and discharge pressures, respectively.

Another source of project emissions not considered in AM 0055 was attributed to power and steam consumption of the treatment unit within the flare gas recovery system. Whilst emission from electricity consumption of the treatment unit was computed using equation (6), emissions from steam generation (\( PE_{Steam} \)) were calculated using the steam flow rate (\( m \)), saturated steam specific enthalpy (\( f \)), steam boiler efficiency (\( \eta_{boiler} \)) and waste gas emissions factor (\( EF_{wg} \)) as depicted in equation (8):

\[ PE_{Steam} = \left[ \frac{m \times h_f}{\eta_{boiler}} \right] \times \left[ \frac{1}{LHV_{wg}} \right] \times EF_{wg} \]  

(8)

### 2.2.2 Economic analysis

In order to assess the financial feasibility of SOPC flare recovery project independently and considering the revenue from sale of Certified Emission Reductions (CERs) if the project is registered under CDM, capital budgeting techniques were applied. As defined by Brigham & Gapenski (1994), capital budget ‘…is an outline of planned expenditures on fixed assets, and capital budgeting is the whole process of analyzing projects and deciding which ones to include in the capital budget’. Out of the five primary methods outlined by the authors, the internal rate of return (IRR) method was selected. Essentially, the IRR is the discount rate at which the present value of a project’s revenue returns equates to the present value of the project’s costs.

The IRR method was particularly chosen to evaluate the SOPC project since it provides a direct metric for comparing and ranking the project’s attractiveness based on the computed IRR under the different cash flow scenarios.

### 2.2.3 System Dynamics

The principles of system dynamics highlighted by Sterman (2000) where applied on SOPC flare recovery project to outlay and assess some of the interactions of feedback loops acting on the practice of gas flaring in Egypt. The causal loop diagram tool described by the author was used to construct a causal loop for several variables associated with gas flaring in Egypt.

### 2.3 Research material

Data on the composition of the normally flared gases at SOPC was extracted from the Request for Proposal – Supply of Flare Gas Recovery System tender document (SOPC, 2007). Natural gas was considered as the only fossil fuel combusted to generate process heat in the existing SOPC refinery heaters. Since electricity is sourced from the national grid within SOPC, the emissions factor for
electricity generation \((EF_{EL})\) was cited from the Project Design Document (PDD) of the Zafarana KfW IV Wind Farm Project, where it was computed as 0.571 tCO\(_2\)/MWh (UNFCCC, 2010b).

The parameters used to compute the flare gas recovery system’s compressor BHP and the project emissions ascribed to the treatment unit are outlined in Table 1. Meanwhile, the data used in the economic analyses for IRR calculation shown in Table 2, and the causal loop diagram were obtained from the authors’ O&G industry experience and familiarity with the CDM process.

### Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Z_{ave})</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>(Q_{G,DC})</td>
<td>5</td>
<td>MMSCFD</td>
</tr>
<tr>
<td>(T_1)</td>
<td>564</td>
<td>oR</td>
</tr>
<tr>
<td>(E)</td>
<td>0.72</td>
<td>-</td>
</tr>
<tr>
<td>(\eta)</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>(k)</td>
<td>1.3</td>
<td>-</td>
</tr>
<tr>
<td>(p_2)</td>
<td>7</td>
<td>bar.a</td>
</tr>
<tr>
<td>(p_1)</td>
<td>1.1</td>
<td>bar.a</td>
</tr>
<tr>
<td>(m)</td>
<td>16,800</td>
<td>ton/yr</td>
</tr>
<tr>
<td>(h)</td>
<td>658.7</td>
<td>kCal/kg</td>
</tr>
<tr>
<td>(\eta_{boiler})</td>
<td>80</td>
<td>%</td>
</tr>
<tr>
<td>(LHV_{wg})</td>
<td>11,666</td>
<td>kCal/kg</td>
</tr>
<tr>
<td>(EF_{wg})</td>
<td>2.8</td>
<td>tCO(_2)/tgas</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of days per year</td>
<td>350</td>
<td>Days/yr</td>
</tr>
<tr>
<td>Investment Cost</td>
<td>6,000,000</td>
<td>USD</td>
</tr>
<tr>
<td>Project Lifetime</td>
<td>20</td>
<td>Years</td>
</tr>
<tr>
<td>Manpower</td>
<td>16</td>
<td>Workers</td>
</tr>
<tr>
<td>Manpower Rate</td>
<td>800</td>
<td>USD/month</td>
</tr>
<tr>
<td>Utilities Cost</td>
<td>800,000</td>
<td>USD/yr</td>
</tr>
<tr>
<td>Maintenance Cost</td>
<td>8</td>
<td>%</td>
</tr>
<tr>
<td>Depreciation</td>
<td>10</td>
<td>%</td>
</tr>
<tr>
<td>Gas Price</td>
<td>0.3</td>
<td>LE/m3</td>
</tr>
<tr>
<td>Crediting Period</td>
<td>10</td>
<td>Years</td>
</tr>
<tr>
<td>Corporate Tax Rate</td>
<td>32.5</td>
<td>%</td>
</tr>
</tbody>
</table>

### 3. Results

#### 3.1 GHG Emission Reductions

##### 3.1.1 Baseline emissions

The baseline emissions of the proposed SOPC flare gas recovery project were calculated as the sum of the emissions from burning the waste gas at the distillation units & lube oil complex flare (flare 1) and the coker & reformer complexes flare (flare 2). The results of the baseline emissions calculations are shown in Table 3.
Table 3

The baseline emissions of the proposed SOPC flare gas recovery project

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Flare 1</th>
<th>Flare 2</th>
<th>Fuel Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Flow Rate</td>
<td>tgas / hr</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Lower Heating Value</td>
<td>kCal / kg</td>
<td>11,086</td>
<td>11,898</td>
<td>11,013</td>
</tr>
<tr>
<td>Carbon Content</td>
<td>tC / tgas</td>
<td>0.82</td>
<td>0.74</td>
<td>0.71</td>
</tr>
<tr>
<td>CO2e ratio</td>
<td>CO2 / C</td>
<td>3.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 Content</td>
<td>tCO2 / tgas</td>
<td>3.00</td>
<td>2.70</td>
<td>2.61</td>
</tr>
<tr>
<td>Emission Factor</td>
<td>tCO2e / kCal</td>
<td>2.71E-07</td>
<td>2.27E-07</td>
<td>2.37E-07</td>
</tr>
<tr>
<td>CO2 Emissions</td>
<td>tCO2e / yr</td>
<td>44,191</td>
<td>118,570</td>
<td></td>
</tr>
<tr>
<td>Total CO2 Emissions (Baseline Emissions)</td>
<td>tCO2e / yr</td>
<td>162,761</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.1.2 Project emissions

Using the parameter values presented in Table 1, the compressor BHP amounted to 772 hp, or around 580 kW. Based on the assumed electric motor driving efficiency, the required compressor motor power is circa 645 kW, equating to about 5420 MWh. Using the value of $EF_{EL}$ mentioned in Section 2.3, the project emissions from the flare gas recovery system compressor amounted to 3,095 tCO2e/yr. Similarly, the project emissions from steam generation amounted to 3,320 tCO2e/yr based on the parameter values outlined in Table 1. Using the same $EF_{EL}$, the project emissions from electricity consumption of the treatment unit were found to be 2,398 tCO2e/yr.

3.1.3 Total emission reductions

The results of the total emission reductions computed as the difference between the baseline emissions and the project emissions amounted to 153,948 tCO2 per annum as outlined in Table 4.

Table 4

Total emission reductions from the proposed SOPC flare gas recovery project.

<table>
<thead>
<tr>
<th>Emission Category</th>
<th>Value (tCO2e / yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Emissions</td>
<td>162,761</td>
</tr>
<tr>
<td>Project Emissions</td>
<td>8,813</td>
</tr>
<tr>
<td>Compressor electricity consumption</td>
<td>3,095</td>
</tr>
<tr>
<td>Treatment unit electricity consumption</td>
<td>2,398</td>
</tr>
<tr>
<td>Steam generation for treatment unit</td>
<td>3,320</td>
</tr>
<tr>
<td>Total Emission Reductions</td>
<td>153,948</td>
</tr>
</tbody>
</table>

3.2 Project IRR and sensitivity analysis

Considering CER prices of around USD 10.0 per tCO2 as recorded in 2010 when the project was considered for implementation under CDM, revenues of around USD 1.5 million could be generated yearly as a result of the emission reductions accrued from the proposed flare gas recovery project.

Based on the outcomes of the economic analysis performed using Egypt’s subsidised natural gas price of 1.5 USD per Million British Thermal Unit (MMBTU), the IRR of the project without considering CDM was found to be 13%, whereas it reached 25% by including revenues from sale of CERs. According to SOPC performance metrics compiled by Arab Capital (2009), the company’s net profit margin and IRR were projected as 19% and 20%, respectively. Therefore, since the project IRR without CDM is less than 20%, it is highly unlikely that senior management will consider it for implementation. To assert the project’s unfeasibility in the absence of CDM, a sensitivity analysis was performed for variations of investment costs, utilities costs and gas prices. Table 5 outlines the results of the sensitivity analysis on the IRR.
**Table 5**  
Sensitivity analysis for the proposed SOPC flare gas recovery project where the impact of varying investment costs, utilities costs and gas prices on the project IRR was analysed with and without considering revenues from CDM.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variation</th>
<th>Without CDM</th>
<th>With CDM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment Cost</td>
<td>+10%</td>
<td>11</td>
<td>23</td>
</tr>
<tr>
<td>Utilities Cost</td>
<td>+10%</td>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>Gas Price</td>
<td>+10%</td>
<td>16</td>
<td>28</td>
</tr>
<tr>
<td>Investment Cost</td>
<td>-10%</td>
<td>14</td>
<td>28</td>
</tr>
<tr>
<td>Utilities Cost</td>
<td>-10%</td>
<td>13</td>
<td>26</td>
</tr>
<tr>
<td>Gas Price</td>
<td>-10%</td>
<td>9</td>
<td>23</td>
</tr>
</tbody>
</table>

3.3 Project barriers

Barriers affecting the implementation of SOPC flare gas recovery project as well as the diffusion of flare gas recovery technology in Egypt arise from technological, administrative and common practice issues.

From the technological aspect, the design of flare recovery systems entails several technical challenges due to the following constraints:

- **Technology not sourced from local suppliers**: Since the recovery system’s know-how is provided by international suppliers, SOPC is faced with limited choices for sourcing technology and maintenance services. After installation, SOPC will rely solely on the supplier(s) for future repairs and queries concerning operation of the system.

- **Inadequate internal capability and experience**: Despite SOPC’s long running history, extensive expertise, and professionalism in refinery operations, there is a lack of familiarity with the operation and technology of flare recovery systems amongst the refinery’s operations team.

- **Safety and operational considerations**: Positive pressure at the compressor suction must be maintained constantly to prevent any air backflow, which would otherwise cause an explosive mixture. Moreover, because the recovery system is an alternative way for safe disposal of waste gas without flaring, it should be regularly maintained to ensure its safe and efficient performance.

- **Equipment performance vis-à-vis waste gas**: The pressure, composition, and flow rate of the recovered gas is subject to wide fluctuations since it is a by-product of various oil refining processes. This high variability poses a technical challenge in designing the recovery system and exposes refinery personnel to high operational uncertainties. During periods of low waste gas flow, the recovery system will operate below design conditions and its efficiency could be negatively affected. Hence, performance of the recovery system is subject to high risks and uncertainty owing to variability of waste gas conditions.

- **Power consumption**: By virtue of its compression mechanism, electricity consumption of the liquid ring compressor (if selected within the flare gas recovery system) is constant irrespective of the waste gas flow rate. Such constant power consumption must be considered in the design of the electrical distribution and management system.

In addition to the above, export of the recovered gases to other users outside SOPC facilities is impeded by the high variability of the waste gas composition. Therefore, SOPC will not be able to maintain a constant recovered gas composition to meet requirements of prospective external buyers. To improve its energy efficiency performance, SOPC would rather use the recovered gas onsite. However, since electricity for SOPC users is sourced from the local grid, there are currently no power generation turbines within the refinery. This makes it impossible for them to currently use the option of onsite electricity generation using the recovered waste gas.

It is imperative to note that during the concept design of the project, the engineering contractor solicited interest to quote offers for the flare gas recovery system compressor from several compressor...
vendors. Due to specificity of the waste gas conditions, only one vendor, Garo, appeared to provide a positive response. The compressor type proposed by Garo was a liquid ring compressor. A similar case was also illustrated by Barauni Refinery flare gas recovery project where only the bid provided by Garo was technically acceptable (UNFCCC, 2006a). Such a limited response from the solicited vendors might lead to a sole (single source) bid, which entails additional administrative efforts during bid evaluation and award. Moreover, sourcing of spare parts as well as maintenance services could be time consuming due to limited availability, and subjects SOPC to risks of monopolistic prices.

As highlighted in the La Plata Refinery Project PDD (UNFCCC, 2007) and reiterated by Worrell & Galitsky (2005), the majority of similar refinery gas flaring projects were implemented in industrialised countries, especially in the United States, and few similar projects were implemented in developing countries. Accordingly, business-as-usual in oil refineries in Egypt is gas flaring and this clarifies why the SOPC project is not common practice in Egypt.

3.4 System dynamics of flare gas recovery in Egypt

A causal loop diagram for gas flaring in Egypt’s O&G industry depicting foreseen interactions of both international and local factors including CDM, GGFR, GoE regulations against flaring, the price of natural gas and government subsidies is depicted in Figure 2.

Fig. 2. The impact of international and local variables on gas flaring in Egypt’s oil & gas industry illustrated using a causal loop diagram.

As depicted in the causal loop diagram, gas flaring was found to be directly affected by variables including oil production rates, flare gas recovery project barriers, government regulations against gas flaring and the economic viability of flare gas recovery projects. In addition to the negative causality of both the economic viability of recovery projects and government regulations against flaring on gas
flaring, since an increase in any of these variables leads to a decrease in gas flaring, both variables negatively affect the recovery projects’ additionality\(^1\) as well. This leads to a reduced opportunity for CDM implementation as demonstrating the recovery project’s additionality becomes more challenging, which in turn strengthens the barriers against implementation of flare gas recovery projects. Although the local price of natural gas is affected by the supply and demand forces in addition to government subsidies, the effect of the latter is only relevant since the energy prices in Egypt are currently regulated by the government.

4. Discussion

From an environmental perspective, SOPC flare gas recovery project will result in a reduction of GHG emissions from the refinery since normal waste gas flaring will be eliminated. In addition, by eliminating the emissions of the flare, the project will soften the impacts of the refinery on the surrounding environment, particularly the Gulf of Suez coastline adjacent to the flare. On an aggregate level, GHG emission reduction within SOPC also means that the global GHG emissions attributed to gas flaring will be reduced as well. In other words, this project fulfils the GGFR partnership’s overarching objective of reducing gas flaring globally. As a stepping stone towards implementation of the zero flaring concept in Egypt, where the gas used for the flare pilot is also recovered, SOPC flare gas recovery project could in turn result in additional future GHG emission reductions in Egypt’s O&G industry.

Regarding the social perspective, the project will create employment opportunities for local engineering and construction companies that will be contracted to design and implement the project. Moreover, as a new application of flare gas recovery in Egypt, the project can serve as an exemplar for the viability of such projects within the O&G industry. Hence, it is foreseen that the project could be mimicked across all petroleum facilities thereby resulting in further employment opportunities and ecological benefits.

By virtue of reducing gas flaring, the project can enable Egypt to become an active member of the GGFR partnership. As a member, Egypt will gain access to global best practices of the industry and receive support and know-how conducive of expanding applications of flaring reduction projects. If selected for SOPC project, this will mark the first application of the liquid ring compressor type in Egypt’s O&G sector. This exposure will assist in capacity building and enhancing the level of skills within the Egyptian O&G sector. Through transfer of proven flare gas recovery technology and installation of state-of-the-art equipment, the project will modernize the SOPC refinery facilities and enhance its operability. Similar benefits will also accrue across the entire sector since this project is expected to be replicated within other refineries.

Notwithstanding the project barriers described in Section 3.3, it is expected that registering the project under CDM will enhance its appeal as a major milestone in the O&G industry and provide the project with the impetus needed to overcome these barriers. In addition, the environmental, social, and economic benefits identified previously will all accrue following realization of the project under CDM.

In view of the results of the sensitivity analysis performed, it is evident that the IRR is highly sensitive to the local price of gas since its variation resulted in the most profound changes in IRR values. Furthermore, since the highest value of IRR without CDM is still below the 20% threshold, it could be established that the project will only be feasible if CDM is considered.

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\(^1\) Additionality means that the GHG emissions saved by the project must be additional to any reductions that would have naturally occurred anyway from business-as-usual (without implementing the project). Under Article 12 of the Kyoto Protocol, CDM projects must realize ‘reductions in emissions that are additional to any that would occur in the absence of the certified project activity’ (UNFCCC, 1998: p.12).
Analysis of the causal loop diagram revealed that two factors are double edged swords with respect to gas flaring, namely, the local price of natural gas and government regulations against flaring. When considered in isolation of their other effects, these two factors create negative feedback on gas flaring. This implies that increasing local prices of natural gas or setting stringent regulations against gas flaring will result in decreased gas flaring. The negative feedback resulting from increases in gas prices is expected because as the price escalates, it becomes more economical to recover and use flared gases to reduce onsite consumption of gas. Similarly, with introduction of laws prohibiting flaring, the quantities of flared gas should decline.

Nonetheless, when the CDM route is considered as the prime driver for flare gas recovery projects, these two factors create a positive feedback loop that reinforces gas flaring. In other words, increases in natural gas prices and formulation of laws that prohibit gas flaring should result in an increase in gas flaring. This is justified in view of the recovery projects’ additionality, which is weakened as a result of the increase in recovery projects IRR without considering CERs revenue and presence of legal drives for reducing flaring anyway. Accordingly, from a CDM perspective, absence of government regulations against flaring and low natural gas prices both increase the likelihood of realizing flare gas recovery projects under CDM.

In light of the preceding discussion, the CDM eligibility of the proposed SOPC flare gas recovery project is summarized in Table 6. As outlined in the table, the additionality of the emission reductions expected from the project were asserted in view of economic, technical and regulatory factors pertaining to the current state of Egypt’s O&G industry. In line with the three pillars of sustainable development, Egypt’s sustainable development criteria are built upon environmental economic and social aspects. Since the TBL analyses of the project revealed several merits under each of the three aspects, the project fulfils Egypt’s sustainable development criteria. Although not common practice in Egypt’s O&G industry, the flare gas recovery technology is applied worldwide in other refineries. Accordingly, the proposed project is technically feasible and yields measurable emission reductions. Since the project will be executed within an existing facility, an Environmental Impact Assessment (EIA) was not required as stipulated by Egypt’s environment Law 4/1994.

As a prerequisite for CDM registration and following the stakeholder consultation carried out at Suez Governorate in 2011, the Letter of No Objection and Letter of Approval obtained from Egypt’s Designated National Authority (DNA) and the project was subsequently submitted for validation by the Designated Operational Entity (DOE) assigned by the CDM Executive Board. As of Mar 2012, the project is under validation and it is anticipated that the project will pass the validation stage and become registered as Egypt’s first large scale CDM application in the O&G industry and the country’s first refinery flare gas recovery project.

Table 6
CDM eligibility criteria for the proposed SOPC flare gas recovery project.

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<th>Criteria</th>
<th>Justification</th>
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| Additionality of Emission Reductions (ERs) | • Economic:  
  o Project IRR is less than Suez Oil Processing Company profit margin and IRR;  
  • Technical:  
  o No alternative plans to limit gas flaring;  
  o Flared gas is sour and wet; requires further processing to render it useful; thus few alternative outlets exist for gas use;  
  o Proposed recovery compressor type (liquid ring) is unprecedented in the Egyptian petroleum industry;  
  • Regulation / Market:  
  o There are no government targets for elimination of normal gas flaring  
  o Egypt is not currently a member of the Global Gas Flaring Reduction (GGFR) partnership;  
  o Absence of environmental or energy (market) regulations to incentivize reduction or prevention of gas flaring;  
  o Prospect of sole bidding limits appeal of implementation. |
Promotes Sustainable Development

- Environmental:
  - Reduces GHG emissions;
  - Contributes positively towards GGFR goals of reducing flaring worldwide
- Economic:
  - Reduces on-site fuel consumption; thus volume of fuel gas replaced could be exported at international prices to generate more revenues;
  - Expands energy supply at Suez Oil Processing Company;
  - Modernizes production facilities at Suez Oil Processing Company by installation of state-of-the-art equipment;
  - Contributes in technology and skills transfer to enhance capacity within the Egyptian petroleum sector;
- Social:
  - Project will deploy local contractors for engineering and construction services creating opportunities for direct and indirect employment;
  - Project can be an exemplar which demonstrates applicability of flare gas recovery; therefore, it can trigger similar installation at other facilities;
  - It can enable Egypt to become an active member of the GGFR partnership;
  - It could be a step towards implementing zero normal flaring at Egypt.

Technical Feasibility

- Gas treatment technologies (including sweetening and molecular sieves) are proven, low risk and manageable;
- Liquid ring compression technology has been proven globally albeit not yet in Egypt;
- Liquid ring compressor was not previously used in other facilities in Egypt;

Measurable Emission Reductions (ERs)

- Emission reductions from direct elimination of gas flaring are measured by the volume of gas recovered & compressed for further use as fuel gas.

Environmental Impact Assessments (EIA)

- Not required since the project is within boundaries of the existing refinery.

Stakeholders’ Comments

- Stakeholder consultation was conducted within Suez governorate in 2011.

Host Country Approval

- Letter of No Objection and Letter of Approval obtained from Egypt’s Designated National Authority (DNA).

5. Conclusions

Drawing on the outcomes of the CDM analysis, it is concluded that the project promotes sustainable development along the TBL aspects of the environment, society and economics. Accordingly, it fulfils the sustainable development criteria of Egypt (the host country). The project was found not to be common practice in Egypt’s O&G industry. If implemented as CDM, it is foreseen that the technical, operational and administrative barriers would be overcome. Moreover, annual revenues amounting to USD 1.5 million generated from the sale of CERs render the project economically feasible under CDM. From an innovation standpoint, it is emphasized that the project will expose SOPC to state-of-the-art applications in the petroleum industry. Hence, the project is a major stepping stone towards implementation of zero flaring in Egypt’s O&G industry.

In light of the system dynamics analysis, it is remarked that government regulations preventing gas flaring and local price of natural gas are mixed blessings when it comes to reduction of gas flaring and CDM opportunities for flare gas recovery. Considering the untenable financial burden of energy subsidies on the GoE budget, local energy prices should be re-assessed. Raising local energy prices particularly for industrial consumers will catalyse adoption of energy efficiency measures, ration energy consumption, and free more financial resources for the GoE to allocate to other public services (health services, education or public transport).
Accordingly, SOPC flare gas recovery project is recommended to be pursued actively as CDM, particularly in view of the murky future of CDM post 2012. The project is fully eligible and sustainable development benefits will ensue from its realization. It is also advocated that the project is taken as an exemplar to demonstrate the positive outcomes of CDM on Egypt and its O&G industry.

Although Egypt is not yet a member of the Global Gas Flaring Reduction (GGFR) Partnership, it is highly recommended for the country to seek membership of this global initiative. This will enable Egypt to benefit from the experience of member organizations and tap global best practices on flare reduction through recovery. Upon personally inquiring about membership procedures, Lingertat (2010) advised that members have to endorse the GGFR charter and the Voluntary Standard for Global Gas Flaring and Venting Reduction in addition to committing to provide data and resources including annual gas flaring volumes. Egypt’s fulfilment of these requirements is deemed greatly possible.
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