Multicriteria analysis of methane mitigation options on offshore oil and gas production platforms

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Abstract. The oil and gas exploration and production sector are one of the most significant methane emitters through fossil fuel combustion and fugitive emissions. In Brazil, there are few studies focused on the mitigation of methane in the oil sector. The objective of the present work is to use a multicriteria analysis methodology to compare different methane mitigation technologies applicable to offshore oil and gas platforms. In the study, six different mitigation options were compared through the analytic hierarchy process methodology, considering environmental, financial and operational criteria. The results were calculated for each mitigation option considering the scores of each criterion and their respective relative weights, obtained in the prioritization of the elements. This unique score obtained through the analytic hierarchy process made it possible to compare the mitigation alternatives. The alternative that received the best score considering the evaluated criteria was the recovery of vapor from cargo tanks associated with methane reuse, being highlighted mainly due to its high potential for mitigation.

1. Introduction
Climate change resulting from global warming, which in turn is associated with increased greenhouse gas emissions, is a critical global issue and is considered one of the greatest challenges of mankind [1]. Among the impacts associated with global warming and consequent climate change are rising sea temperatures, rising sea levels, changes in the precipitation regime, increased extreme weather events such as storms and floods, and a decrease in biological diversity [2]. The increase in concentrations of these gases in the last decades can be attributed to anthropic activities, such as deforestation for land use (burning) and burning of fossil fuels [3]. Among the main greenhouse gases (GHG) are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and water vapor.

According to the fifth report of the intergovernmental panel on climate change (IPCC) [4], the global warming potential of methane is 28 to 34 times the CO₂, considering a period of 100 years. After the agricultural sector, the energy sector is the second largest contributor. The CH₄ emissions from the energy sector are mainly due to the imperfect burning of fossil fuels and due to leaks (fugitive emissions) of gases in the processes of extraction and transport of oil and natural gas [1]. According to International Association of Environmental Conservation of the Petroleum Industry (IPIECA), there is an increase in the interest of the sector in the emissions of methane, mainly due to the tendency of increase of the...
participation of natural gas in the world energy matrix. Options to mitigate methane emissions have very specific characteristics, making it difficult to indicate general solutions for the entire industry. The analysis of methane emission mitigation alternatives and technologies focused on oil and gas production is the object of this study, which aims to identify and quantify methane emissions in offshore platforms and to evaluate the abatement technologies available using a multicriteria approach.

2. Methane emissions on the oil and gas sector

The problem with the greenhouse effect is its intensification, resulting from the increase of GHG concentration in the atmosphere over the last decades, a fact related mainly to the actions induced by human activities. Methane (CH$_4$) is one of the most significant GHG, being also the most abundant hydrocarbon in the atmosphere. CH$_4$ has the characteristic of being a short-lived GHG in the atmosphere when compared to other gases. It has been estimated that the mean CH$_4$ half-life is in the range of 10 to 15 years [3]. Projections of CH$_4$ emissions for the year 2030 point to 2700 ppb in a conservative scenario. This increase in CH$_4$ concentrations results from anthropogenic activities, such as increased food production, burning of fossil fuels and deforestation [5]. Overall, the oil and natural gas industry was estimated to be responsible for about 24% of the world's methane emissions by 2020, being surpassed only by livestock with 27%. This trend of increased methane emissions from the oil and gas industry is mainly driven by increased demand for fossil fuels, especially natural gas [6].

2.1. Methane on oil and gas sector

According to studies by the International Energy Agency (IEA), crude oil production is expected to increase from 92.4 MMbbl / day to 115.4 MMbbl / day in 2040. This increase in production has the direct consequence of the increase in emissions from this sector, requiring the industry to act to mitigate these emissions [7]. With an average production of 2.5 million barrels per day, Brazil is among the ten largest world producers of oil [8]. In 2016, maritime production accounted for 94% of national oil production and 77% of natural gas production [8]. As the intensity of the emissions is linked to the volume of production, it is necessary that the mitigation efforts be directed to the marine production area, given its high representativeness. In the year 2016, about 70% of marine oil production and 66% of natural gas were derived from floating, production, storage and offloading vessels (FPSO) type platforms.

Upstream activity is, within the Brazilian oil and gas chain, responsible for the largest share of methane emission. According to [9], about 46% of methane emissions in oil and gas production systems are derived from venting, followed by 24% relative flaring, 23% of fugitive emissions and 7% of energy production.

2.2. Methane emissions sources on oil and gas production platforms

The methane emission sources on a platform are related to its process plant, which in turn is associated with the specificities of the platform. The complexity of the primary fluid processing in a marine platform varies according to the physical-chemical characteristics of the reservoirs and the technical-economic feasibility of the production project. FPSO-type platforms have a highly complex processing plant, involving stages of separation and treatment of each oil phase, as well as power generation systems, compression systems for gas injection and flaring. A typical FPSO processing plant minimally covers the following typologies of methane emission sources: turbines, flare, glycol dehydration unit, oil storage tank ventilation, process ventilation and fugitive emissions.

3. Methodology

3.1. Methane mitigation options on platforms

Methane mitigation options on offshore platforms involve different technologies as described in [10-18]. The most common methane mitigation techniques or processes include the recovery or reduction of the volume of CH$_4$ that is released directly into the atmosphere from a given equipment or process...
Considering the mitigation technologies, we will consider in this work six mitigation options that will be evaluated in this document:

- **Option A** - Recovery of methane from oil storage tanks with a vapor recovery unit (VRU) associated with process reuse;
- **Option B** - Recovery of methane from oil storage tanks with VRU associate with flaring;
- **Option C** - Recovery of methane from glycol dehydrator with a VRU;
- **Option D** - Recovery of methane from glycol dehydrator with VRU associate with flaring;
- **Option E** - Implementation of a Leak Detection and Repair program;
- **Option F** - gas-to-liquid (GTL): chemical conversion of natural gas to stable liquid hydrocarbons (syncrude).

### 3.2. Analytic hierarchy process

Multicriteria analysis is a suitable method for selecting or comparing alternatives, which involve several qualitative and quantitative aspects, by decision makers. This paper presents the analytic hierarchy process (AHP) as the multicriteria method selected to be employed in its development, being the one that best adapts to the reality of the problem, especially due to the ease and objectivity of its use, based on a hierarchical structure of simple and objective decision, with scale of values and rule of evaluation of the inconsistency of the standardized judgment as part of the method. The AHP organizes the objectives and criteria into a hierarchy represented by the evaluator’s preference [18]. Comparisons between alternatives are performed by means of individual peer evaluations of the elements of the hierarchy. The AHP method is initiated by structuring the problem into a hierarchy of criteria and indicators (sub criteria), which is followed by a prioritization process by comparing its elements. According to [18], the AHP methodology consists of four main phases: i) construction of a hierarchical structure, ii) comparative judgments, iii) consistency analysis and iv) calculation of scores and final ranking of alternatives.

### 3.3. Evaluated criteria

Three criteria were selected for the analysis of methane mitigation alternatives: environmental criteria (quantitative), financial criteria (quantitative) and an operational criteria (qualitative). The indicators that integrate the criteria are detailed below.

- **Environmental criteria**: Methane mitigation, CO₂ emissions and N₂O emissions: the environmental indicators are quantitative criteria, so for the evaluation of these indicators it was necessary to calculate the greenhouse gas emissions related to the baseline scenario and the mitigation scenario. The emissions were calculated using calculation protocols of the American Petroleum Institute (API) [19].
- **Financial criteria**: Capital expenditures (CAPEX), operational expenditures (OPEX) and revenues: The financial indicators were obtained from the literature, prioritizing studies performed by environmental agencies or companies in the sector, like EPA [15,16].
- **Operational criteria**: Technological Maturity, ease of integration with the process plant, skilled labor and operational safety: The qualification of the operational indicators mentioned above involved a subjective evaluation that varied according to the theoretical and practical knowledge of the evaluator about the technology and the processes involved. In order to reduce this subjectivity in the analysis of these indicators, it was proposed in this study the consultation of several specialists on the technologies, using a questionnaire format.

It is necessary that the environmental and financial indicators are on the same numerical scoring scale to be comparable and can be used in the AHP. In this paper, a numerical scale was used for its quantitative indicators based on scores ranging from 1 to 5. For the less favorable values, scores 1 and for the more favorable values, scores 5, intermediate scores were calculated via linear interpolation. The
operational criteria utilized the same scale to indicate the favorability of each indicator for the mitigation option, according to the evaluator’s understanding.

3.4. Platform selection for analysis
The platforms selected were FPSO Cidade de Itajaí, FPSO Cidade de Santos and P-50, all belonging to petroleum company Petrobras. The criterion used to choose these platforms was to analyze the influence of the different processing capacities and fluids produced in the comparison of the mitigating measures. The platforms FPSO Cidade de Itajaí and P-50 are platforms whose main fluid produced is oil, but with different production capacities. The FPSO Cidade de Santos is a non-associated gas production platform. For the estimation of greenhouse gas emissions, public operating data were obtained from the selected offshore platforms for the year 2016. These data include values such as oil and gas production, self-consumption and gas flaring.

4. Results and discussion
The results of the multicriteria analysis for the six mitigation options correspond respectively to the individual results of the three criteria considered: environmental, financial, operational criteria and the final result of the AHP, encompassing all the results.

4.1. Environmental criteria scores
The environmental criteria cover the methane mitigation and emission of \( \text{CO}_2 \) and \( \text{N}_2\text{O} \) associated with each mitigation alternative. As discussed previously, the greenhouse gas emissions were estimated utilizing the available data for each platform. The results of the environmental criteria are presented in Figure 1.

![Figure 1](image)

**Figure 1.** Environmental criteria scores for each mitigation option and platform.

We can observe that the mitigation scenarios with the best scores in terms of environmental criteria were the vapor recovery of the storage and reuse tanks in the process (option A) and recovery of flare gas and storage tanks with submission to the GTL file (option F). Both scenarios have a high potential for mitigation of methane emissions, which strongly influenced high scores. Despite the high potential for methane mitigation, the option B score fell below option A and F scores, due to the additional \( \text{CO}_2 \) emissions associated with flare vapor recovery. The scenario of implementation of fugitive emissions program (option E) presented intermediate scores, being higher in platforms I and II due to the greater potential of methane mitigation. The \( \text{CH}_4 \) recovery from glycol dehydrators (option C and D) showed the lowest environmental scores because of the low potential for methane mitigation.

4.2. Financial criteria score
The financial indicators, CAPEX, OPEX and revenues, were calculated for each mitigation alternative. The values were estimated based on international references such as [10,11,15,16]. The results of the financial criteria are presented in Figure 2.

We have found that the mitigation scenarios with the highest scores (above 4) in terms of financial criteria are the vapor recovery of the storage tanks (options A and B) and vapor recovery in the glycol dehydration units (options C and D). These alternatives presented the lowest values of investment and
operation cost that the other options analyzed. It is also possible to note that the presence of revenue associated with the mitigation options A and C that predict reuse of recovered gas in the process, did not significantly influence the final score of the criterion. Option F, referring to the GTL process, presented the lowest financial score among the options evaluated, below the level of 2 points. This financial result can be attributed to the high values of investments costs (CAPEX) and operation costs (OPEX) associated to technology. Although the Revenue values were also significant, they were not enough to increase the final score of the option.

![Figure 2](image_url)

**Figure 2.** Financial criteria scores for each mitigation option and platform.

### 4.3. Operational criteria score

Unlike the environmental and financial criteria that have values that can be quantified, such as emissions and costs, the operational criteria and its indicators have qualitative aspects. In order to reduce the subjectivity of this analysis it was proposed to use the opinion of a group of specialists. The score obtained for each criterion, alternative and platform were calculated by the arithmetic mean of the scores indicated by each specialist. The results of the operational criteria are presented in Figure 3.

![Figure 3](image_url)

**Figure 3.** Operational criteria scores for each mitigation option and platform.

By analyzing the scores, it can be observed that the option of monitoring and repairing leak program (alternative E) presented the best operating score among the technologies evaluated. What motivated this high score was the fact that the monitoring and repair of leaks is a technique known by the market and already performed in other subsectors of the oil and gas industry, such as refining. The fact that the option does not interfere with the normal operation of the unit also influenced the high score. Recovery technologies also received high scores due mainly to their technological maturity and ease with integration with the process plant. The difference between alternatives A and B scores for C and E were related to the need to install a flash vessel associated with the glycol regeneration step (alternatives C and E). As expected, the low scores of the GTL Process (scenario E) in the indicators of technological maturity and integration with the process plant strongly influenced the final score of the operational criteria. The need for a significant physical space in the process plant added to the fact of the unit's high energy demand, makes its implementation with a mitigation option a technological challenge.

### 4.4. Final results and ranking of options

With the final scores of each criterion (environmental, financial and operational) it is possible to carry out the last stage of the proposed multicriteria analysis, obtaining individual scores for each mitigation
option. This final individual score consolidates all the criteria evaluated so far, allowing the comparison of technologies. The Figure 4 presents the final results of the AHP performed for the present study, consolidating all previously calculated results into a single score for each mitigation alternative considered.

![Figure 4. Final scores for each mitigation option and platform.](image)

It can be observed that the option that presented the highest score was the vapor recovery of the oil storage tanks with reuse in the process (option A). This option was predominant mainly due to its high potential for methane mitigation without the consequence of an increase in the emission of other greenhouse gases. In addition, this mitigation option provides revenue associated with its financial flow derived from the possibility of delivering additional gas to the market (gas not consumed internally). The option that reached a second-high scoring plate, close to 4 points, was the vapor recovery in storage tanks with flaring (alternative B). Although this scenario presents CH$_4$ mitigation potentials close to Option A, it also presents additional CO$_2$ emissions related to the burning of the vapor recovered in the flare, which resulted in the reduction of the environmental criteria scores. By forwarding the recovered vapor to the flare, this mitigation option has no revenue, which has minimized its financial score.

The option F regarding the recovery of gas from flare and storage tanks to be sent to the GTL process received the lowest scores among the evaluated options. Despite its high mitigation potential, the GTL process presents a very significant cost, significantly higher than other technologies. In addition, the GTL process presents a series of critical operational parameters such as low technological maturity for offshore units, high-energy demand and the need for physical space for the processing module.

Considering the calculated scores and the determinants listed above, it was possible to establish a ranking of the mitigation option alternatives evaluated. This ranking, a product of the Multicriteria Analysis carried out, aims to facilitate a possible decision regarding the choice of the best technology for CH$_4$ mitigation in offshore oil and gas production platforms. The ranking is in Table 1.

| Mitigation options | Score interval |
|--------------------|---------------|
| Option A           | 4.65 – 4.38   |
| Option B           | 4.14 – 4.04   |
| Option E           | 3.75 – 3.30   |
| Option C           | 3.29 – 3.18   |
| Option D           | 3.28 – 3.18   |
| Option F           | 3.15 – 3.04   |

5. Conclusions
The AHP proved to be a practical and efficient methodology in the multicriteria evaluation of the different methane mitigation alternatives considered in the paper. The selected environmental, financial and operational criteria for assessing mitigation options covered both the quantitative and qualitative characteristics of the technologies. The alternative of vapor recovery of storage tanks with gas reuse in
the process presented the best result among mitigation options evaluated. The high score of this alternative in the AHP can be attributed to factors such as the high methane mitigation potential, the low implementation and operational costs, the possibility of revenue from the use of the recovered gas and the operational knowledge of this technology. The result was consistent with significant studies conducted for the industry, which list the installation of VRU associated with oil storage tanks as one of the most cost-effective technologies in the oil and gas exploration and production sector. In general, the present work presented expressive results that can help and guide decision makers in choosing the best methane mitigation technologies to be implemented in offshore oil and gas production platforms.

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