Investigation of satellite Data, for flaring emissions reductions in the Oil & Gas industry

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Abstract

The world is facing an unseen climate change at an unseen pace, while the need for energy keeps growing at an unprecedented pace. During this past decade thanks to the Paris agreement a global commitment towards decarbonisation to avoid the rise of 2ºC by the end of the century. Moreover, the commitment of big key players in the oil and gas industry need to swift their business model towards a low carbon emission. Some companies like TotalEnergies have set a very ambitious roadmap to become leaders in decarbonising their upstream operations by 2030. To achieve this, their monitoring emissions reporting needs to improve and have more different sources of quantifiable data combine and then analyse. The following work aims to evaluate a new software developed by the research and development team based on satellite imagery technology to detect flaring emissions of the company's assets around the world and look at the potential of helping to reduce carbon emissions. Throughout the course of this work, a tool was created to conciliate different sources of data and analyse the advantages and limitations of this new software. This tool helps to conduct and deep overview of the reported values by the satellite and aims to helps the research team to improve their powerful new software.

Keywords: Satellite, oil & gas industry, climate change, carbon emissions, data analysis

1. Introduction

In 2015, all member states of United Nations gathered to sign the Paris agreement which defined a global agenda to reach a sustainable development scenario divided in 17 goals [1]. However, for the scope of this project only climate change and affordable and clean energy will be addressed.

Figure 1:Sustainable development goals. Ref: [1]

Climate Action

emphasizes the urgent need to tackle climate change, The Intergovernmental Panel in Climate Change (IPCC) emphasizes that rapid and sustained actions are needed in all sectors regarding all economic activities to limit global warming to 1.5 ºC above preindustrial levels, emissions must drastically decline and shall be cut by half by 2030. However, up to this day, since the Paris agreement greenhouse gases (GHG) emissions have only decreased by 0.3 percent compared to 2019 levels. Nonetheless, this falls well short of the 43% emissions reduction that is needed to be aligned with the 1.5ºC pathway.

Affordable and clean energy

Nowadays, humanity heavily relies on fossil fuels for electricity, heating and transport. In the electricity sector, the renewable sources of energy accounted for 30% of the total energy share, on the other hand, the total energy supply has increased 2.6 times since 1971, from 230 EJ to 606 EJ in 2019 [2]. Since the seventies, oil has drastically fallen from 44% to 31%, while coal has remained constant over the years around 25% of the total primary energy supply by fuel, as presented in Figure 2.

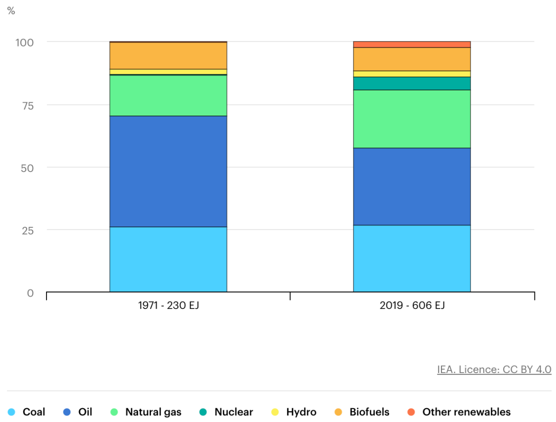

Figure 2: Total primary energy supply by fuel, 1971 and 2019. Reference: [2]

2. Oil and gas industry

Oil and gas are still the most predominant sources of primary energy, 50% of the total primary energy share, while renewables only represent 20 percent. It could be argued that significant efforts need to be done in developing low-carbon emission technologies, as this industry is facing increasing demands from the general public regarding their commitment towards the energy transition, therefore, their business models need to change to be aligned with the sustainable development goals.

In the resent day, oil and gas operations account for 15% of the total energy-related emissions globally, through its production, transport, and processing. Then the use of oil and gas result in another 40% of emissions [3].

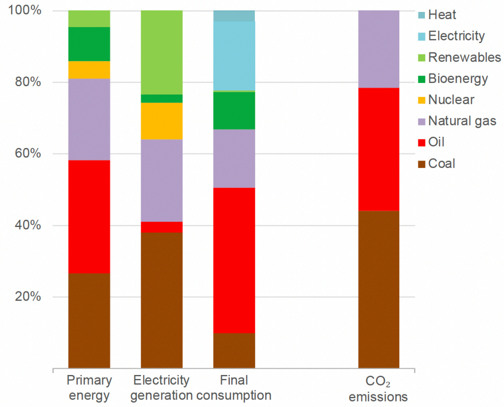

Figure 3: Overview of the global energy system, 2018. Reference: [3]

A net-zero scenario has been outlined to map out a feasible path to limit the global average temperature from rising 1.5ºC. Therefore, five key layers have been defined that involve tackling: methane emissions, eliminating all non-emergency flaring.

Flaring operations refers to the controlled burning of natural gas that is released during the production, processing and transportation of crude oil and natural gas.

From an economic perspective, tackling down methane and flaring emissions, happen to be the most cost-effective measures to cut down GHG emissions. Flaring activities, generally take place at oil and gas facilities that are translated into 250 Mt of CO_2 emissions, thus vented methane results in another 45 Mt of CO_2 emissions into the atmosphere. Furthermore, the required energy for natural gas extraction resulted in 270 Mt of CO_2 emissions and then another 35 Mt of released natural gas into the atmosphere during the refining process and transportation.

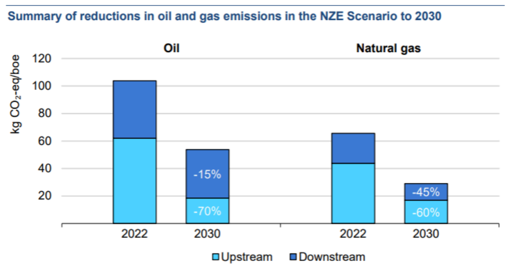

Figure 4: Summary of forecasted emissions reduction in a NZE scenario by 2030. Reference: [3]

Emissions related to extraction, methane venting and flaring emissions are also called Scope 1 and 2 emissions. The IEA claims that reducing such sort of emissions is the most cos-effective measures to cut down emissions, as it is forecasted that in a net-zero scenario it will be necessary to cut-down emissions of natural gas up to a 55%.

2.2 Flaring operations

In 2022, 140 billion cubic meters (bcm) of natural gas were flared, resulting in 500 Mt CO2-eq annual GHG emissions during this year. In a zero-emission scenario, all rutinary flaring practices will be eliminated by 2030, as nowadays 70% of emissions come from non-emergency flaring.
There are many options that require thorough examination to find alternatives for the flared gas, such as delivering it to consumers via a new or existing gas network, reinjecting it in the reservoir, or installing more compressors at the current facilities. From 2020 to 2025, flare emissions are expected to be reduced by half, and by 2030, routine flaring is expected to be fully eliminated based on the Zero Flaring Routine Initiative, launched by the world bank.

2.3 Global commitment

In today's context, there are different ways companies are facing the current climate crisis as some companies have continued with their business as usual while trying to maximize their profit regarding oil and gas extraction. However, other companies are already switching towards low carbon sources of energy, such blue hydrogen and biofuels. On the other hands, many national companies which are stated owned are reluctant to abandon such practices, as some of those companies are heavily dependent on the oil income, explaining why the decision-making process is highly policy driven.

This global commitment is at times questionable as there are many challenges of the energy transition. To switch to a sustainable model, big players in the industry will need very big investments in low carbon emissions sources of energy, as to this day they are very carbon intensive.
When evaluating a company towards a NZE future, there is a clear distinction between intensity-based targets and absolute goals. Intensity base objectives are centred around emissions per unit of energy, which can be achieved by merely enhancing the share of low-carbon energy items and creating carbon sinks, all without reducing oil production. On the other hand, when companies talk about absolute targets, it implies the number of emissions being released, in this scenario, the carbon budget is limited and will imply a drastic cut in oil & gas operations.

Another important aspect to consider is the escape of emissions covered, as there are three different scopes thar have been defined to tackle carbon emissions, as shown in Figure 5.

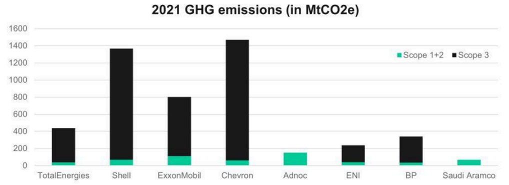

Figure 5:GHG emissions in 2021 by main oil and gas companies. Reference: [4]

Scope 1 and 2, refer to emissions released during direct operations and associated with the energy produced for the organization's activities. However, scope 3 refers to the emissions coming from the use of oil coming from the end users or the final combustion, when these products are used by the end costumers [4]. When companies only focus on scope 1 and 2, they fail to acknowledge the impact of reduced oil in the energy transition, as emissions related to scope 3 can make up to 85% of the total. However, if companies only focus on scope 1,2 and 3, which are intensive based targets, they keep leaving the door open for il and gas expansion.

2.3 TotalEnergies

TotalEnergies is one of the main actors and front-runners among oil companies, beginning their operations as an oil and gas company to become a key player in the energy industry.
The key strategy of the company was to diversify their portfolio and adapt to the future of the energy that is shaping the world, by expanding their investments across the entire energy value chain. Historically, the company's renewable energy transitions were focused on PV and biofuels [5]. Thus, the company is aligned with the Paris agreement, and it has developed its own roadmap to become carbon neutral by 2050.

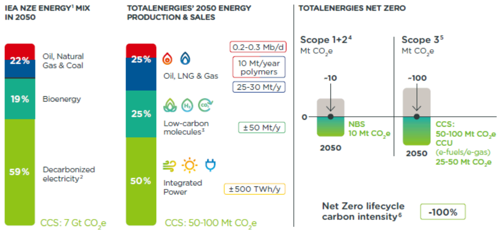

Figure 6: TotalEnergies in 2050: A vision for Net Zero Company. Reference: [6]

The company aims to produce 50% of their energy from low-carbon emission sources, by 500TWh/year and plans to develop, 100 GW 2030 and 400 GW of renewable electricity by 2050. Regarding fuels, the company will produce 50 Mt/year of decarbonized fuels, representing a 25% of their energy share, in the form of synthetic fuels, hydrogen or biogas.
The emissions caused by this sector are forecasted to be 10 Mt per year .compared to the current 400 Mt of CO2e while methane emissions will almost be eliminated, below 0.1 Mt CO2e/year [6]. However, one of the biggest challenges that all oil and gas companies face is the elimination of Scope 3 emissions, TotalEnergies envisages that by 2050 such emissions will amount to 100 Mt.
Regarding flaring, GHG emissions from the company failed by a 13% compared to levels in 2015, an equivalent reduction of 40 million tons of CO_2e. Then by 2025 the company envisages to drop flare volumes below 0.1 Mm3/d by 2025 and then reach a zero-flare target by 2030 [6].

3. Methods for global Survey of Natural gas Flaring

Flaring is common practice used to dispose of natural gas produced at oil and gas facilities that lack the necessary infrastructure to process or capture all the gas.
Nowadays, with today's commitment towards NetZero the oil & gas companies are trying to improve their performance when it comes to reporting flared volumes of natural gas.

3.1 Satellite monitoring

When the gas burned it produces a heat source at the surface of the globe that can be observed through satellite imagery, this has been observed for years through the Worldbank initiative to track down flaring detections back in 2012. This is a very attractive idea for remote locations and places where there is a lack of compelling reported data.
Moreover, this technology offers real-time data, allowing to track flaring incidents or excessive burning.
The most common technologies for flare detection are VIIRSS (Visible Infrared Image Radiometer Suite) sensor or SWIR Sentinel 2 images [7].

The fundamental basis of flare detection is the Plancks law which calculates the radiant emissions of radiant bodies based on their absolute temperature.

$$B_\lambda(\lambda, T) = \frac{2hc^2}{\lambda^5} * \frac{1}{\exp\left(\frac{hc}{\lambda k_{BT}}\right) - 1} \quad \text{Eq.1}$$

Where B denotes the spectral radiance, λ corresponds to the wavelength, T is the absolute temperature of the material (K), kB is the Boltzmann constant, h is the Planck constant, and c being the speed of the light.
Then, with Stefan-Boltzmann's Law it is possible to calculate the radiant heat from a source area.

$$RH = \varepsilon\sigma T^4 S \quad \text{Eq.2}$$

Where RH is the radiant heat in megawatts (MW), σ equals to the Stefan-Boltzmann Constant, T is the temperature in K, S is the area of the heat source and ε being the emissivity of a corpse.
Flare detection methods include full field-of-view and subpixel techniques. In full field-of-view pyrometry, the object's temperature is approximated by analyzing radiance within a spectral channel.

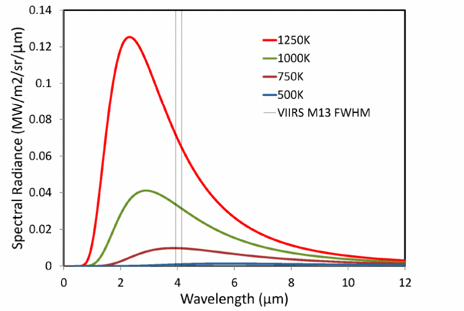

Figure 7: Enhancing Temperature Estimation Accuracy for Hot Objects. Reference: [7]

As depicted in Figure 7, each Planck curve don't intersect each wavelength peak's, as is specific for each temperature. There are some considerations to consider obtaining suitable spectral bands, it should cover a bandpass where there are significant changes in the emitted radiance for the temperature range of interests, the bandpass should be free of solar contamination for better performance during the day and night.
Satellite observations of 'hot pixels' typically deal with sub-pixel sources that are notably smaller than the actual pixel size. In such instances, the emitted radiance includes both a background and a component from the hot source. The subpixel technique focusses on the detecting a small hot surface if the background around it is determined.
example. At present, the VIIRS technology manages to provide pixels with hot source detection, especially when looking at images collected in the 1.6 µm channel, which normally corresponds to a flare temperature of 1720K.

3.2 Ultrasonic Flowmeters

The use of ultrasound technology to measure flow is a well stablished practice in the industry. However, it is more challenging to apply ultrasonic techniques to gas flow measurement than liquid due to a variety of reasons, such as low acoustic impedance, or large pressure variations for example.

This technology is based on the transit time and transfection principle. One of the big technical challenges in flare gas ultrasonic flow metering is to deal with extremely high flare flow, above 80 m/s during emergency flaring, for example. Traditional flowmeters are based on differencial pressure, thermal mas and vortex shredding; however, they present limitations when it comes to flow variation.

Time-transit ultrasonic flowmeters are based on the simple principle of "time of flight" as shown in Figure 8, referring to the time that takes to travel against the flow (upstream), t_{up}, is longer than the time that it takes the following flow (downstream), t_{dn}. The time difference between both flows Δt, is proportional to the velocity as it is shown in the following equation.

$$V = \frac{P}{2cos\theta}\left(\frac{1}{t_{dn}} - \frac{1}{t_{up}}\right) = \frac{P}{2cos\theta}\left(\frac{\Delta t}{t_{dn}t_{up}}\right) \quad \text{Eq. 4}$$

As it can be seen, V is the flow velocity to be measured, while P is the ultrasonic path length, and θ angle represents the acute angle between the ultrasonic path and the axis of the pipe.

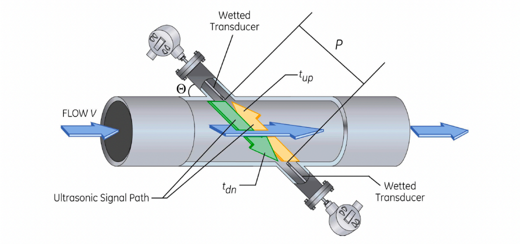

Figure 8: The operating principle of a transit-time based ultrasonic flowmeter. Reference: [8]

3.2 Virtual Flow metering

Virtual Flow metering is an increasingly attractive method for estimation of multiphase flowrates in oil and gas production systems. This technology is based in numerical models are deployed to estimate the flowrates by using readily available field measurements such as pressure and temperature, such approach is called "machine learning" [9]. Such models rely on preestablished pressure-volume-temperature (PVT) data, that provide the general characteristics of the fluid under specific conditions and are derived using fluid properties models.

The flowrate is given by the following correlation: $Q_{Flare} = K\sqrt{\Delta P * \frac{P}{T}}$. Where ΔP corresponds to the pressure difference, P is the pressure at the K.O drum and T is the temperature. The K factor refers to the uncertainty factor of the pressure measurement.

4 Tool Development

The developed tool was built through Excel macros to conciliate the satellite data gathered from the R&D team. Demeter is a web tool application developed by TotalEnergies R&D division which covers the following themes: vegetation, water, renewable energies and greenhouse gases, this technology gathers images though sentinel 2 imagery technology. Combined with artificial intelligence, the images contain crucial information for the implementation of energy solutions.

The main goal of the developed tool is to reconciliate data from the metering system at the oil and gas extraction stations and the metering system, virtual flow metering and ultrasonic sensors.

4.1 Tool structure

The tool was conceived from a user-friendly interface, making it easily adoptable by different departments in the company, Figure 9, shows the interface in the excel sheet.

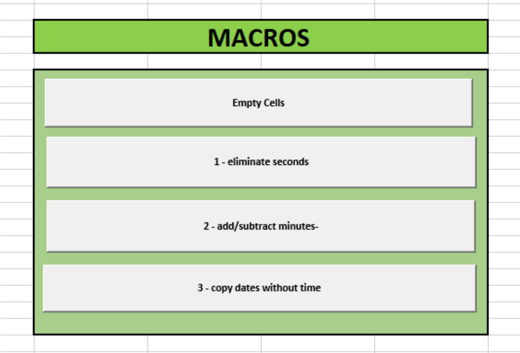

Figure 9: Macros programs for the analysis.

To begin with, firstly the user needs to empty the cells by clicking on the macro, then the next step consists in introducing the satellite date of the asset in the excel sheet. Once the required data has been introduced, the user needs to eliminate the seconds from each of the dates. Then it is needed to execute macro number 2 to add/subtract minutes for the analysis. Lastly, execute macro number 3 to copy the dates without time.

The next step consists in gathering the data from the flow meter, by introducing the code of the PI tag, in a software shown as a tab, integrated in the excel of the company.

	\\PI-CENTER-HQ\EBJ_DFGFT400404	\\PI-CENTER-HQ\EBJ_DFGFT400424
	HP Flare Nm3/h	LP Flare Nm3/h
30-mars-22 00:00:00	366.2351379	103.2335663
30-mars-22 00:01:00	360.8171387	392.552887
30-mars-22 00:02:00	367.6444092	327.4264832
30-mars-22 00:03:00	363.0099792	71.31774139
30-mars-22 00:04:00	364.1037903	153.0896759
30-mars-22 00:05:00	361.495697	114.1810837
30-mars-22 00:06:00	360.7896729	119.7660522
30-mars-22 00:07:00	364.8711243	120.378624
30-mars-22 00:08:00	362.5655212	210.4563141
30-mars-22 00:09:00	362.0181274	411.3142395
30-mars-22 00:10:00	363.8477478	396.3289185
30-mars-22 00:11:00	365.9327393	0
30-mars-22 00:12:00	369.0332031	118.1135254
30-mars-22 00:13:00	535.9257202	129.949173
30-mars-22 00:14:00	357.2358398	160.6493835

Figure 10: PI tags data flare.

The gathered values will be presented as in Figure 10, and they need to be corrected to kSm^3/h, by multiplying each cell by 1.054, this formula is based on the ideal gas law. Standard conditions for gas are recognized as a temperature of 15 degree Celsius and a pressure of 101.325 kilopascals (kPa).

Regarding the data process, there is a specific excel sheet called "sorted_data", in this step, the user needs to match the downloaded PI tags values with the satellite results by using the "xlookup" function and then sum the values for the events containing the same date.

5. Case studies

Case studies have been conducted to evaluate the performance of the Demeter tool, and conciliate the data from both teams, and provide insight to uncommon flaring events that may require in depth-analysis.

The employed methodology for each of the conducted analysis the study period is the same, starting on the 01/01/2021 to 30/05/2023.

To perform this study, it was important to define the key parameters by understanding the needs of the demeter team. The main concern was to analyse how the geography (onshore or offshore) and the zone hemisphere, affected the performance of the collected satellite data. Another important parameter was to analyse the flowrates once the image was filtered through the artificial intelligence.

The implemented KPIs were determined based on the encountered limitations that satellite technology nowadays presents, as cloud coverage is one of the biggest issues when it comes to detect flaring activities. The KPIs for the study were the following: number of detections, high flaring events and false detections.

5.1 Results and analysis

Limited to a 6-month internship, the analysis focused on strategically selected assets anonymized and ordered alphabetically. Assets ranged from equatorial offshore (Asset A) to African onshore (Assets B&C) and offshore assets in the North Sea (Assets D,E,F). Results presented with Demeter values in blue and PI tag values in red. Analysed events using satellite-provided images and observed infrared pixel intensity. The vertical axes on the graphs represents the flowrate (burned gas) in kSm3/h, and the horizontal axes the dates (Gregorian calendar).

It shall be mentioned that each of the assets present very different behaviours due to the sort of asset, their location, and oil and gas extraction rate.
Figure 11, for example show a very good performance over the study period, high flaring events were analysed to understand the degree of overestimation and if the high flaring events appeared in the data base of the company. Moreover, as it can be seen for each of these events there is a clear relationship between the flared volume and pixel intensity as at higher flowrates pixels become brighter and smaller in size due to a better detection of the satellite, satellite values appear in blue dots and PI values in red. Most of the studied events appeared in the database as a major source of flaring event, whether it was due for a shutdown in the installation or non-routine flaring operations.

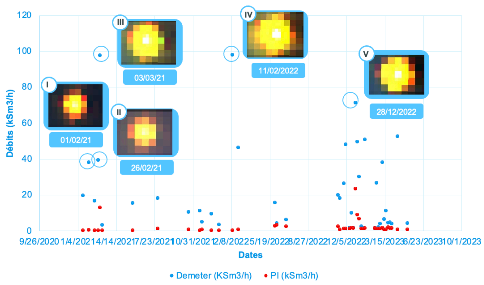

Figure 11: Asset B - preliminary results

However, it can be appreciated that in general there tends to be an overestimation of the flared volumes by the satellite, as the gap between PI tag values and satellite values.
However, all the assets present very different behaviour that will be discussed in the following section.

5.2 Discussion

Satellite technology shows promising results for flaring detection but is still room for improvement. Each asset shows different behaviour based on their location and hemisphere. Assets in the tropics are more likely to report false detections, while performance in the North Sea assets drastically improves due to atmospheric correction. Assets B and C, though they are close to each other, face overlap issues in satellite imagery, potentially leading to missed detections, this is due to how satellite captures images. Asset A presents challenges with limited data and false detections. Offshore assets generally outperform onshore ones, with North Sea assets showing exceptional performance. Despite some gaps in data reporting, technology holds potential for emissions improvement.

6. Conclusions

This master thesis provided a deep analysis of the potential of satellite technology for monitoring flaring operations within the oil & gas industry, with the aim of advancing GHG monitoring for sustainable development goals. TotalEnergies, aiming to become a leader in the energy transition, has set and ambitious roadmap to cutdown in flaring and methane emissions.
The tool designed for user-friendliness, successfully integrates satellite and ultrasonic flowmeter data for emissions reporting. However, there are clear limitations that have been discussed in the previous section, particularly in assets in the tropics and in close-proximity asset imaging, although, satellite accuracy needs to be refined through training the artificial intelligence.
In the future, leaders in the energy industry must decarbonize their practices through implementing Scopes 1, 2 and 3 to avoid a fatal climate catastrophe.

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