# Flaring and Venting of Associated Petroleum Gas

## Current Development and Effects of Marginal Oil

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# 1 Summary

Vast quantities of gas are extracted in conjunction with petroleum production. This associated petroleum gas particularly contains methane. It is still not utilised in large quantities and is typically combusted (flared) near the production site, vented directly or else released into the atmosphere through leakage. The global flaring volumes of associated gas declined by 15% between 2005 and 2010, but have been hovering at a level of approximately 140 million $m^3$ ever since.

In the process, 260 million tonnes of $CO_2$ are emitted. The reduction of flaring that has been seen in Russia is largely being offset by the increase of shale oil production[1] in the USA, as a result of which the flaring of associated gas has approximately tripled there over the past ten years.

When it comes to associated gas emissions that can be identified by satellite, flaring is merely the tiny, visible tip of the iceberg. Scarcely discernible, but considerably greater, are the non-flared methane emissions of the petroleum industry. In contrast to flaring, venting is not globally monitored through regular satellite measurements, but instead through ground measurements that are moreover conducted on a solely individual basis. Thus the actual extent of global methane emissions from the petroleum industry is unknown, even though this leads to considerably higher greenhouse gas emissions than through the flaring of associated gas, since these vast quantities of released methane entail a considerably higher climate change factor. Due to the uncertainty of the measurement system, the spectrum of methane emissions resulting from petroleum production is extremely high, ranging from four (4) to 100 billion $m^3$. This corresponds to a leakage rate of between 0.1 and 2.5% (energetic proportion of methane in petroleum production) and greenhouse gas emissions of between 100 million and 2.4 billion tonnes of $CO_{2eq}$. Recent regional and local measurements in the USA and Mexico conducted with the help of aeroplanes and new satellite technologies indicate very high methane leakages of the petroleum and natural gas industries, thus demonstrating that the lower range considerably underestimates the emissions.

While the European Commission anticipates flaring and venting emissions of 2.8 g $CO_{2eq}$/MJ in its Well-to-Tank Report (version 4.0), the results of the new studies reveal an increase of these greenhouse gas emissions to up to 19 g $CO_{2eq}$/MJ. The average global reference value for diesel and gasoline fuels thus increases to over 100 g $CO_{2eq}$/MJ, 15% more than indicated in the EU-study. According to new venting calculations in countries with high, unutilised associated gas volumes, such as Russia and Nigeria, the emission value is actually rising to 127 and 167 g $CO_{2eq}$ respectively. That is 45% and 90% more than the level indicated by the EU Commission respectively. Satellite measurements of the shale oil regions in the USA reveal emission values of 158 g $CO_{2eq}$/MJ shale oil. The emission values of petroleum from these regions are thus considerably higher than the emissions from fuels produced from tar sand with approximately 110 g $CO_{2eq}$/MJ.

In addition to $CO_2$ and methane emissions, flaring and venting also cause other emissions. They burden the environment with toxic substances and additionally affect the climate through soot (black carbon) emissions. In the Arctic, flaring emissions contribute 42% of total soot emissions, thus

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[1] The terms shale oil and tight oil, as used in this report, refer to petroleum that is locked into the rock and is extracted by means of hydraulic fracturing.

intensifying the warming of this region. This has additional global consequences due to thawing permafrost and the release of carbon stored in the soil.

Marginal oil will lead to a further increase of flaring and venting globally. In the process, the increasing development of shale oil production in the USA and other regions of the world will play the largest role, since these light petroleum types entail high associated gas quantities and a high number of drillings. But also other marginal oil springs with many small sized fields in remote areas and deepwater drillings will intensify emissions from flaring and venting. The existing legal and administrative parameters have hitherto been unable to reduce flaring and venting to any considerable degree and must be significantly improved for marginal oil. In the absence of massive countermeasures, the petroleum and gas sectors will become the fastest-growing sources of anthropogenic methane emissions in the coming decades.

# 2 Technical background

## 2.1 What is associated petroleum gas?

Associated petroleum gas (APG) refers to the gas that appears both in compound form (dissolved) directly within petroleum and as a gas directly above the oil reservoir (Johnson and Coderre, 2012). It reaches the surface through petroleum extraction and once more becomes gaseous and evaporates due to the resulting drop in pressure. Associated gas can be emitted at different points of petroleum production and processing (boreholes, storage tanks etc. – see figure 1 in appendix, OGP, 2000).

Associated petroleum gas primarily consists of methane and other hydrocarbons such as ethane, propane and butane – along with small quantities of carbon dioxide ($CO_2$) and, in some cases, hydrogen sulphide and nitrogen. In addition, inert gases and heavy metals are contained in the gas. The components are essentially independent of their geographical location and can vary greatly in terms of the type and depth of the deposit. The average share in petroleum production is thus to be found within a vast range between 1% (Saudi Arabia) and 40% (Malaysia). The share of associated gas is particularly high with light oils (e.g. more than 30% with shale oil), whereas heavy oils contain only miniscule quantities of gas (Smith 2014; IPCC, 2006). Total global associated gas production is estimated at between 510 and 870 billion m3 (Bayer Technology Services, 2011; Höglund-Isaksson, 2012). That corresponds to an average global gas:petroleum proportion of 10:15%.[2]

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[2] In reference to gas weight. Thus the volume of associated petroleum gas is equivalent to 15% to 25% of global natural gas production.

## 2.2 What is done with the associated gas?

Associated petroleum gas may be utilised, flared or vented into the atmosphere (Johnson and Coderre, 2012).

### 1. Utilisation

Associated gas can be fed into the gas grid, used for energy generation on site, liquefied into LPG (liquefied petroleum gas) or injected back into the oilfield.

### 2. Flaring

The flaring of associated gas occurs by means of special combustion facilities, so-called flare stacks, and it can occur continually, periodically or temporarily. The flaring of associated gas particularly produces $CO_2$.

### 3. Venting

Venting refers to the deliberate release of associated gas. This results in very high methane emissions, since the associated gas enters the atmosphere without combustion. The climate impact of venting is thus many times greater than that of flaring, since the global warming factor of methane is 34 times higher than that of $CO_2$.

Venting is undertaken when the combustion or utilisation of excess gas is technologically or economically not possible, e.g. when gas volume, gas pressure and the calorific value are irregular or too low to maintain the combustion (Ite and Ibok, 2013; Wells, 2014). Examples include:

- The petroleum reservoirs of the Permian Basin in Texas and New Mexico, where horizontal drillings are used to exploit old oilfields (Wells, 2014). Containing 1.8 million barrels/day, the Permian Basin is the largest petroleum production area in the USA. Although it has hitherto played only a small role in shale oil production (EIA, 2014), it represents a powerful increase in petroleum production.
- Extra-heavy oil and in situ tar sands production (Johnson and Coderre, 2011, EPA, 2011).
- Offshore and onshore oilfields in Azerbaijan.
- Accumulation of associated gas between drill tube and casing (casing head gas).

In this study, venting also encompasses leakage in petroleum production and processing, e.g. in petroleum storage tanks, gas dehydration facilities and pneumatic apparatuses.

## 2.3 How much associated gas is utilised, flared or vented?

Uncertainty regarding the detection/ registration of utilised, flared and vented associated petroleum gas is very high since there are too few measurements, resulting in too little reliable data. This is indicated by the already large range of estimated total volumes (see chapter 2.1) (Höglund-Isaksson, 2012). Rare exceptions include satellite image evaluations by the NOAA (National Oceanic and Atmospheric Administration) for the Global Flaring Reduction Partnership of the World Bank and the detailed measurements and evaluations of Johnson and Coderre (2011, 2012) of associated petroleum gas volumes in the Canadian province of Alberta.

Overall, this breakdown of the utilisation and disposal of associated petroleum gas indicates the following: Globally, around two thirds of associated gas is used and approximately one third is flared or vented. The utilisation rate for associated gas varies greatly across the world and ranges from 9% in Iraq to 99% in Norway (Höglund-Isaksson, 2012).

## 2.4 Why is associated gas flared or vented?

Only strict legal regulations, controls and constant monitoring can reduce the flaring and venting of associated petroleum gas, since the following factors make the economic use of gas difficult or impossible (OGP, 2000; Buzcu-Guven et al., 2010; Bylin et al., 2010; Johnson and Coderre, 2011; Farina, 2011):

- Low gas prices
- High investment costs, particularly in remote regions or offshore, where no gas grid is available for feeding in the associated gas and numerous small drillings make connecting to the gas grid difficult
- A low or strongly fluctuating $CO_2$ certificate price
- Toxic gas components (e.g. a high hydrogen sulphide content)
- A lack of markets in the vicinity
- It is frequently impossible in geological terms to inject natural gas back into oilfields
- Political instability in the regions and interruption of petroleum and gas production due to social unrest, thus threatening investments (Nigeria)
- Monopolistic structures that make feeding gas into the gas grid difficult or impossible
- High costs of gas liquification

Due to these factors, the revenue prospects for utilisation measures without income from the sale of $CO_2$ certificates are low, as shown by illustrations 2 and 3 in the appendix.

# 3 Monitoring of flaring and venting

## 3.1 Flaring

The NOAA evaluates the nighttime light intensity of associated gas flares on satellite images in its studies for the World Bank's Global Flaring Reduction Partnership. For this purpose, the light data is calibrated with local measurements.

The NOAA data shows that the flaring volumes between 2005 and 2010 declined by 15% to under 140 billion m3 (between 16% and 28% of global associated petroleum gas volume) and subsequently rose slightly. Particularly shale oil production in the USA is responsible for this trend reversal. There, the volume of flared and vented associated gas has nearly tripled within the past ten years (EIA, 2014).

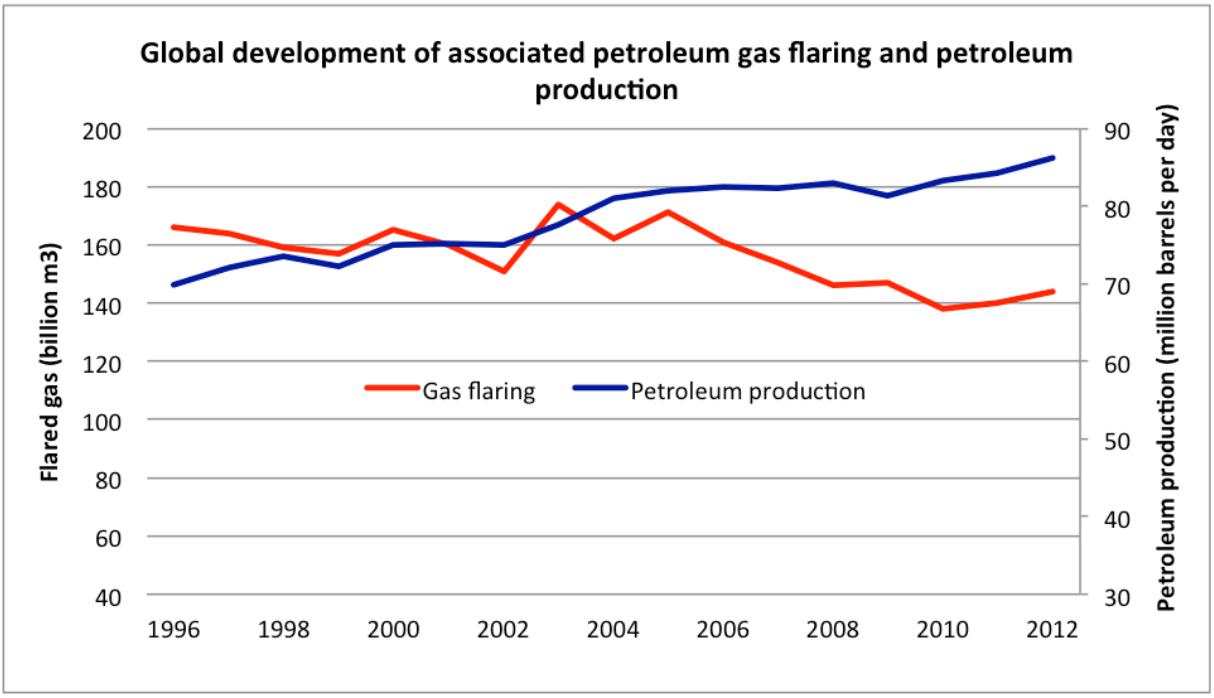

Figure 1: Global development of associated petroleum gas flaring (World Bank) and petroleum production. Hamso, 2014; BP, 2013.

In other countries, such as Venezuela, Iraq and Canada, flaring volumes are also on the rise. This increase is offsetting the continuous success of the legal regulations in Russia. The global situation is thus characterised by two trends: While older and large oilfields in particular are utilising more associated gas instead of flaring it, the many new and smaller oilfields, particularly in the case of shale oil with the need for multiple drillings, reveal the complete opposite. There, the lack of infrastructure for associated gas is leading to high flaring volumes and thus hinders economic utilisation. It is therefore to be expected that the increase of marginal oil production will lead to increased flaring and venting. Marginal oilfields are usually located in remote areas. They contain less petroleum and must be developed with elaborate technologies which, as in the case of fracking, require multiple drillings. The increase of flaring in remote new fields in eastern Siberia is a further sign of this development (Kutepova et al., 2011).

Until now, satellites have only been able to detect very large flares and have been hindered by clouds and other light sources (Leifer et al., 2013). Since 2011, flaring has been studied with a new satellite measurement procedure, VIIRS (Visible Infrared Imaging Radiometer Suite), which is characterised by fewer measurement problems and higher measurement precision (Elvidge et al., 2014). At 165 billion $m^3$, the provisional result for 2012 is considerably higher than the NOAA value of 140 billion $m^3$. A comparison of the VIIRS with the NOAA values (see the following figure and table 1 in the appendix) indicates that, in some aspects, the individual country results differ greatly. The VIIRS values for Iraq, Venezuela, Algeria, Libya and Mexico are nearly three times higher than shown in the NOAA World Bank data, whereas the VIIRS values for Russia are approximately 30% lower.

To some extent, the NOAA results deviate widely from the statistically ascertained flaring volumes of individual countries. For example, the Russian data reported by the industry is one third lower (Kutepova et al, 2011; Knizhnikov, 2012). This can only be due to calibration errors in the satellites, or to a shortage of reported data, since only a very few drillings and flares are equipped with measurement devices (Kutepova 2013, Røland 2010).

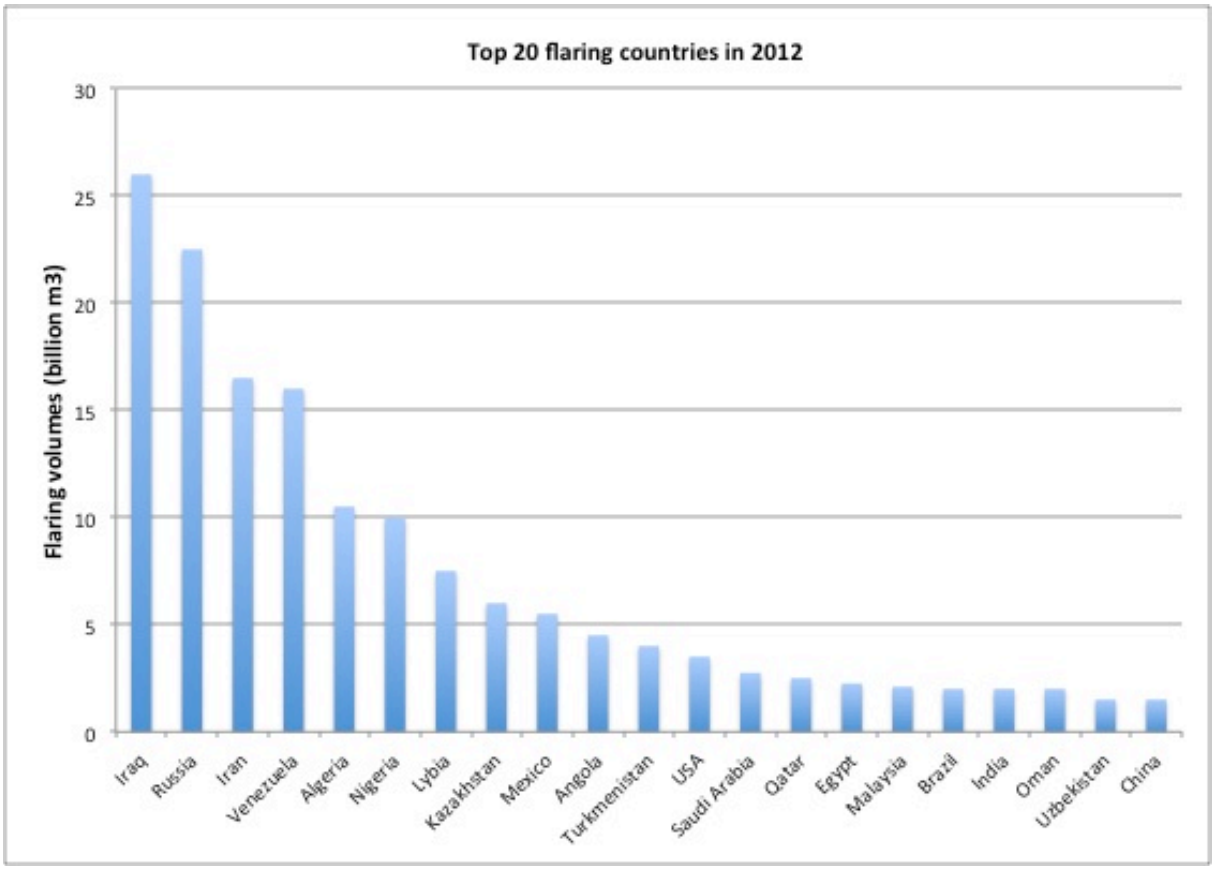

Figure 2: Global flaring quantities of associated petroleum gas with VIIRS (Visible Infrared Imaging Radiometer Suite). Elvidge et al., 2014.

### Flaring in natural gas production

The flared gas volumes of the NOAA largely concern associated petroleum gas. Although flaring does indeed occur in the natural gas industry, it occurs in considerably lower quantities, e.g. from test drillings or condensation tanks for the liquid components of natural gas. According to estimates by Höglund-Isaksson, these volumes amount to approximately 4 billion m3 annually, i.e. only 1/30 of the flared associated petroleum gas. It is uncertain how much of it the NOAA identifies with the satellite measurements. The NOAA values for Russia, i.e. for more than a fourth of all flaring volumes, include only associated petroleum gas (Elvidge et al., 2007). As far as the remaining three quarters of gas volume are concerned, flaring by the gas industry is also included, but presumably in only very small proportions. In the gas industry, gas is more likely to be flared temporarily or periodically, not continuously. Thus flaring may not be detected in the 40 to 80 measurements the NOAA conducts annually. However, emissions from condensation tanks should be attributed to the petroleum industry, since the liquid components of natural gas are utilised in the production of liquid fossil fuels. Overall, the NOAA values thus effectively depict global flaring volumes. Flaring volumes occurring only in gas production, e.g. in test drillings, amount to only a few percentage points of the overall flaring volume of the NOAA. At the same time, Russian flaring volumes from condensation tanks must also be included in the NOAA volumes.

## 3.2 Venting

While the combusted volumes of associated petroleum gas can be ascertained with relative precision by means of satellite data, the measurement of methane emissions by venting requires considerably greater effort (Bylin, 2013). The detection of methane emissions is particularly hindered by the presence of a great number of different methane sources and sinks, which are globally distributed in a highly heterogenous manner (Ito and Inatomi, 2012; Bousquet et al., 2011). Methane emissions can be of biogenic, thermogenic or pyrogenic origin. Biogenic sources encompass anaerobic environments such as wetlands and rice fields, low-oxygen fresh water reservoirs (dams), ruminant animals and organic waste (liquid manure, waste water and rubbish dumps). Thermogenic methane, which developed over millions of years as the result of geological processes, is released through the production of natural gas, petroleum and coal, as well as through volcanoes. Pyrogenic methane results from the incomplete combustion of biomass and fossil fuels (Ciais et al., 2013). Overall, between 700 and 1,200 billion $m^3$ of methane are emitted globally every year, including between 50% and 70% that are of anthropogenic origin (Ciais et al., 2013; Bousquet et al., 2011). The range of methane emissions from all fossil energy production (petroleum, gas and coal) is likewise very great and lies between 107 and 171 billion $m^3$ (Ciais et al., 2013).

Despite many decades of research, global methane accounting is highly error-prone (Nisbet et al., 2014). Climate experts describe it as “ill-quantified” (van Amstel, 2012). This particularly applies to methane emissions from petroleum extraction which, in contrast to the study of flaring with satellites, i.e. the top-down approach, can only be measured with coarse resolution. Maximal precision currently amounts to 10.5 x 10.5 km, meaning that satellite images only detect the cumulative emissions of various biogenic, thermogenic or pyrogenic sources without the ability to identify and localise them separately (Leifer et al., 2013). Satellites can thus not be used to calculate the share of petroleum extraction in total methane emissions. Satellite data must be compared with ground measurements with the help of vehicles, measuring towers, aeroplanes and drones (bottom-up approach), whose availability is limited (Bergamaschi et al., 2013; Leifer et al., 2013; Karion et al., 2013; Wecht et al., 2014a; Nisbet et al., 2014). Despite this vast data deficit, budgets for methane emissions monitoring are on the decline (Nisbet et al., 2014). This makes the bottom-up approach difficult. The few bottom-up studies that are available make use of petroleum industry reports, individual measurements and empirical data from individual regions in order to extrapolate them to global values. Hovering somewhere between four and 96,5 billion m$^3$, the range of these bottom-up results is very high. Both the lower and upper ranges represent extrapolations of global petroleum production:

- **The lower value** is a projection of data from the OGP (International Association of Oil & Gas Producers) onto global petroleum production (calculation of the **JEC Consortium of the EU Commission** for the Well-to-Tank Report, Version 4.0; Edwards et al., 2013).
- **The upper value** is a projection of Canadian measurement findings onto global petroleum production (calculation of the **IIASA (International Institute for Applied Systems Analysis)** for the GAINS model; Höglund-Isaksson, 2012b).

Despite these great uncertainties, there are many indications that the lower range considerably underestimates the global methane emissions of the petroleum industry:

- **Vast data gaps in the emissions statistics of the petroleum industry**

The OGP data is based on reports from its members. However, they cover only about 30% of global and 10% of petroleum production in the countries of the former Soviet Union (Edwards et al., 2013). As a result, the statistical gaps in the regions with high flaring figures are particularly large, meaning that many very large methane emitters do not appear in the OGP statistics, e.g. Azerbaijan with over one billion cubic metres of methane from venting (SOCOR, 2007). Due to this volume, the JEC value could already rise by one quarter, even though Azerbaijan produces only around 1% of global petroleum. The petroleum industry itself admits that venting emissions generate the greatest uncertainty regarding the GHG balance (IPIECA et al., 2009).

- **Very high methane leakage rates in recent on-site measurements**

Recent regional and local measurements in the USA and Mexico undertaken with the help of aeroplanes and new satellite technologies indicate very high methane emissions from the petroleum and natural gas industry:

  - 10% leakage (averaged) for shale oil in the Bakken and Eagle Ford fields, i.e. 100 g methane/m$^3$ petroleum (satellite data analysis by the University of Bremen in 2014 together with the University of Maryland and the Centre for Ecology and Hydrology of the UK with SCIAMACHY – Scanning Imaging Absorption Spectrometer for Atmospheric Cartography; Schneising et al., 2014)

- A 4% leakage rate in the greater Los Angeles area (Peischl et al., 2013)
- A 6.2% to 11.7% leakage rate in the state of Utah (USA) (Karion et al., 2013)
- Surface measurements and comparison with satellite data for oilfields in the southern USA and old oilfields in California and Mexico using EOR (Enhanced Oil Recovery) techniques with gas injection (Leifer et al., 2013)
- Measurements using drones over shale oil regions in the USA (Caulton et al., 2014).

- **Very high IPCC default values for methane emissions from petroleum production**

  - At 41 g methane/$m^3$ petroleum (leakage rate of 4%), the IPCC default value for developing countries is more than fifty times higher than the average JEC value of 0.8 g methane/$m^3$ petroleum (leakage rate of 0.1%; Schwietzke et al., 2014b; IPCC, 2006). The leakage of approximately 2% of the IIASA value thus appears plausible as a global average.
  - Even using the low default values of the IPCC, the result is a global volume of over 70 billion $m^3$ methane, thus representing an order of magnitude similar to the IIASA value (Schwietzke et al., 2014b).

- **The methane value of the petroleum industry in the EDGAR data bank of the European Commission is five times higher than the JEC Consortium**:

The methane value for the global petroleum industry of the Emissions Database for Global Atmospheric Research (EDGAR) of the European Commission amounts to 23 billion $m^3$ compared to 4 billion $m^3$ of the JEC (Schwietzke et al., 2014b).

# 4 Emissions from the flaring and venting of associated gas

The flaring and venting of associated petroleum gas causes a variety of air pollutant emissions whose composition depends on a number of factors (Buzcu-Guven et al., 2010; Johnson and Coderre, 2012):

- Composition of the associated gas
- Disposal method: Flaring or venting
- Combustion efficiency of the flare

In addition to carbon dioxide, flaring also produces air pollutants such as particulate matter in the form of soot, uncombusted petroleum and carbon monoxide (particularly when the calorific value of the combustible gas is low), as well as other byproducts of incomplete combustion. When the raw combustible gas contains hydrogen sulphide (H2S), sulphur dioxide (SO2) can also develop.
Soot emissions are not only a toxic burden on the environment, but they also impact the climate. In the Arctic, flaring causes 42% of total soot emissions (black carbon), thus intensifying warming in this region and global climate change due to thawing permafrost soils and through the release of soil carbon stocks. In addition to climate effects, these pollutant emissions have further significant effects on the environment, on the employees of the petroleum and natural gas industry, and on the

local population (if existing) in the form of corresponding negative health consequences (Donner and Winter, 2012).

Since methane is the chief component of associated petroleum gas, direct venting releases a significant quantity of methane in conjunction with H2S and volatile organic compounds (VOC) into the atmosphere. Since methane's climate change potential is 34 times higher than that of $CO_2$, greenhouse gas emissions are thus considerably higher than those resulting from the combustion of associated gas (Johnson and Coderre, 2012).

The flaring and venting volumes of associated petroleum gas described in chapter 2.3 lead to the following global greenhouse gas emissions:

- Combustion (flaring) of associated gas: 270 million t $CO_2$.
- Inefficient flaring (incomplete combustion): 26 to 881 million t $CO_{2eq}$. Alongside the default value for flaring efficiency of the Environmental Protection Agency (EPA AP-42), which is 99%, the assumption behind this is also a significantly poorer efficiency, amounting to 75% (i.e. 25% of associated gas enters the atmosphere uncombusted), in order to depict the effect of this factor on overall emissions.[3]
- Venting and leakage: 100 to 2,400 million t $CO_{2eq}$.

Resulting from the above, the following values concern the specific emissions of fossil fuels:

- Combustion (flaring) of associated gas: 1.45 g $CO_{2eq}$/MJ
- Methane emissions due to incomplete flaring: 0.14 - 4.77 g $CO_{2eq}$/MJ
- Venting and leakage: 0.5 g - 12.78 $CO_{2eq}$/MJ
- The entire range of GHG emissions due to flaring and venting thus amounts to between 2 and 19 g $CO_{2eq}$/MJ.

With the upper range, the average global reference value for petroleum rises to more than 100 g $CO_{2eq}$/MJ (emissions from extraction, transport, processing and fuel combustion = well-to-wheel – WTW). This represents an increase of 15% compared to the WTW value of the JEC study on fossil diesel. In countries with high unutilised gas volumes, such as Russia and Nigeria, the emissions value resulting from the new venting calculations actually rises to 127 and 167 respectively, i.e. 45% and 90% more than the JEC value respectively. Satellite measurements from oil shale regions in the USA reveal emission values of 158 g $CO_{2eq}$/MJ. The emissions values from petroleum from these regions thus are lying considerably higher than the emissions from fuels made from tar sands (approximately 110 g $CO_{2eq}$/MJ).

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[3] Studies show that the EPA default value (EPA AP-42) of 99% for the combustion efficiency of flares is too high. Evaluations of experimental studies and tests undertaken by the EPA reveal that many factors influence combustion efficiency and can lead to a range from below 60% to 100% (OAQPS, 2012). Factors for flare efficiency particularly include lateral winds, starting speeds, gas composition and calorific value (Cid- Vázquez and Rodríguez-Tovar, 2013). Case studies for two large flares reveal 95% flare efficiency (Willis et al., 2013). A 95% value is also used as a default value for other studies (Wells, 2012; Keesom et al., 2012).

# 5 Conclusion and outlook

After flaring and venting declined over a five-year period, the trend has reversed in the USA over the past two years due to increased shale oil extraction. In some other countries, such as Venezuela, Iraq and Canada, flaring volumes are also on the rise. This increase is offsetting the continuous success in Russia over the past two years. The global situation is thus characterised by two trends. While particularly older and large-scale oil fields utilise more associated gas than they flare, the many new and smaller oilfields, especially those intended for the extraction of shale oil, which require multiple drillings, indicate the exact opposite trend. The lack of infrastructure for associated gas utilisation leads to high flaring volumes, making economic utilisation difficult. It is thus to be expected that flaring and venting will increase due to increased marginal oil production. Marginal oilfields are largely located in remote areas, contain less petroleum and need to be developed with elaborate technologies such as fracking, which requires multiple drillings. The increase of flaring in remote new fields in eastern Siberia is a further indication of this development.

To this must be added a further, previously neglected problem affecting both marginal oil and conventional oil production: Methane emissions from the deliberate venting of associated gas and leakage. Just how high the methane emissions caused in this way actually are remains unknown, since detection requires considerably greater effort than for flaring. As a result, the number of unreported cases and the range of results are high. Recent local measurements suggest that previous estimates were far too low. Further studies will thus be necessary in order to arrive at a more detailed picture. When it comes to marginal oil, both venting and flaring are especially relevant. When less associated gas is utilised, it is likely that not only more gas is combusted but also vented and emitted due to leakage. A higher number of drilling facilities for marginal oil hinders measures intended to control and prevent leakage, since it leads to more potential leakage sources. In addition, tar sand and heavy oil production directly releases a great deal of associated gas.
To this should be added the flaring and venting emissions arising from gas condensate production, which must be included in petroleum production. In this way, a portion of gas production emissions has to be allocated to fossil fuels. This particularly holds true for the very high methane leakages of the condensation tanks. However, leakage from gas drilling must also be allocated proportionately to fossil fuels. Increasing global shale oil production is making these emissions rise and thus represents another effect of marginal oil.

As a result, a number of challenges must be overcome to prevent a further increase in flaring and venting. First, measurements of these emissions must be improved in both quantitative and qualitative terms. So far, only a fraction of greenhouse gas effects from flaring and venting have been detected, even though they could represent a share of up to 5% of total global greenhouse gas emissions. That is why measurement facilities need to be deployed at all possible leakage sites and must be continually monitored by independent testing institutes. The reliable, precise and continuous detection of flaring and venting volumes is the precondition for the legal regulations to achieve their objective. As long as we do not know how much gas is being flared, vented and lost through leakage, our reduction goals will remain ineffective.

The challenges for legal measures and monitoring are growing massively as a result of the use of marginal oil. Existing legal and administrative framework has previously not been able to reduce flaring and venting in any significant way. Current efforts in the regions with the highest emissions (particularly Russia and Nigeria) are being stymied by a lack of flaring and venting laws, transparency, independent and adequately equipped government authorities, an accurate and regular flaring reporting system and by widespread corruption (Olivier et al., 2012; Otiotio, 2013). Marginal oil will exacerbate this situation: Flaring and venting sources in remote locations are increasing enormously. In a politically ordered environment like the USA, this has led to a quadruplication of flaring volumes within five years. What will be the consequences of marginal oil in politically unstable regions? The Ceres Organisation fears that, without massive countermeasures, the petroleum and gas industry will become the fastest growing source of anthropogenic methane emissions in the coming decades.

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# 7 Appendix

| | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **Change from 2011 to 2012** | **Change in % 2011-2012** |
|---|---|---|---|---|---|---|---|---|
| Russia | 52,3 | 42 | 46,6 | 35,6 | 37,4 | 34,8 | -2,6 | -7% |
| Nigeria | 16,3 | 15,5 | 14,9 | 15 | 14,6 | 14,7 | 0,1 | 1% |
| USA | 2,2 | 2,4 | 3,3 | 4,6 | 7,1 | 11,6 | 4,5 | 63% |
| Iran | 10,7 | 10,8 | 10,9 | 11,3 | 11,4 | 10,7 | -0,7 | -6% |
| Iraq | 6,7 | 7,1 | 8,1 | 9 | 9,4 | 10,3 | 0,9 | 10% |
| Algeria | 5,6 | 6,2 | 4,9 | 5,3 | 5 | 4,9 | -0,1 | -2% |
| Kazakhstan | 5,5 | 5,4 | 5 | 3,8 | 4,7 | 4,6 | -0,1 | -2% |
| Venezuela | 2,2 | 2,7 | 2,8 | 2,8 | 3,5 | 4,3 | 0,8 | 23% |
| Saudi Arabia | 3,9 | 3,9 | 3,6 | 3,6 | 3,7 | 3,9 | 0,2 | 5% |
| Angola | 3,5 | 3,5 | 3,4 | 4,1 | 4,1 | 3,8 | -0,3 | -7% |
| Libya | 3,8 | 4 | 3,5 | 3,8 | 2,2 | 3,2 | 1 | 45% |
| Canada | 2 | 1,9 | 1,8 | 2,5 | 2,4 | 3,0 | 0,6 | 25% |
| Indonesia | 2,6 | 2,5 | 2,9 | 2,2 | 2,2 | 2,5 | 0,3 | 14% |
| China | 2,6 | 2,5 | 2,4 | 2,5 | 2,6 | 2,1 | -0,5 | -19% |
| Oman | 2 | 2 | 1,9 | 1,6 | 1,6 | 2,1 | 0,5 | 31% |
| Mexico | 2,7 | 3,6 | 3 | 2,8 | 2,1 | 2,0 | -0,1 | -5% |
| Egypt | 1,5 | 1,6 | 1,8 | 1,6 | 1,6 | 2,0 | 0,4 | 25% |
| Qatar | 2,4 | 2,3 | 2,2 | 1,8 | 1,7 | 1,8 | 0,1 | 6% |
| Uzbekistan | 2,1 | 2,7 | 1,7 | 1,9 | 1,7 | | | |
| Malaysia | 1,8 | 1,9 | 1,9 | 1,5 | 1,6 | 1,5 | -0,1 | -6% |
| Total Top 20 | 132 | 124 | 127 | 118 | 121 | 123,8 | 2,8 | 2% |
| Rest of world | 22 | 22 | 20 | 20 | 19 | 18 | -1 | -5% |
| **Global flaring** | **154** | **146** | **147** | **138** | **140** | **144** | **4** | 3% |

Table 1: Development of flaring from 2007 to 2012 in billion m³. GGFR Global Gas Flaring Reduction Partnership (GGFR).

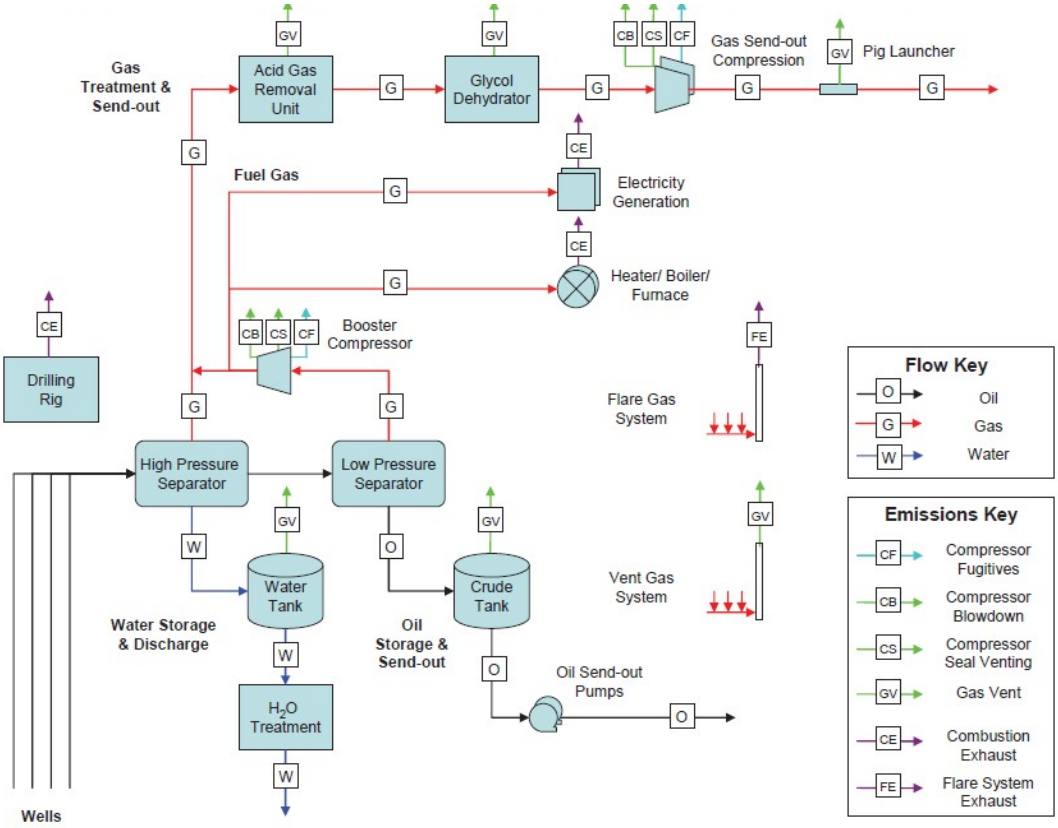


Figure 1: Sources of methane emissions on an offshore platform. Bylin et al. 2010.

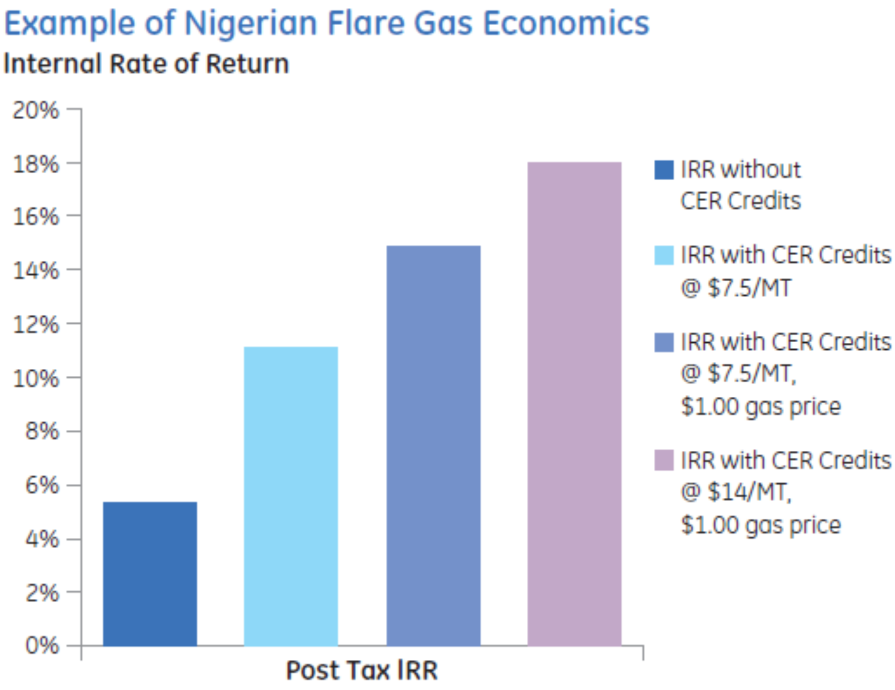
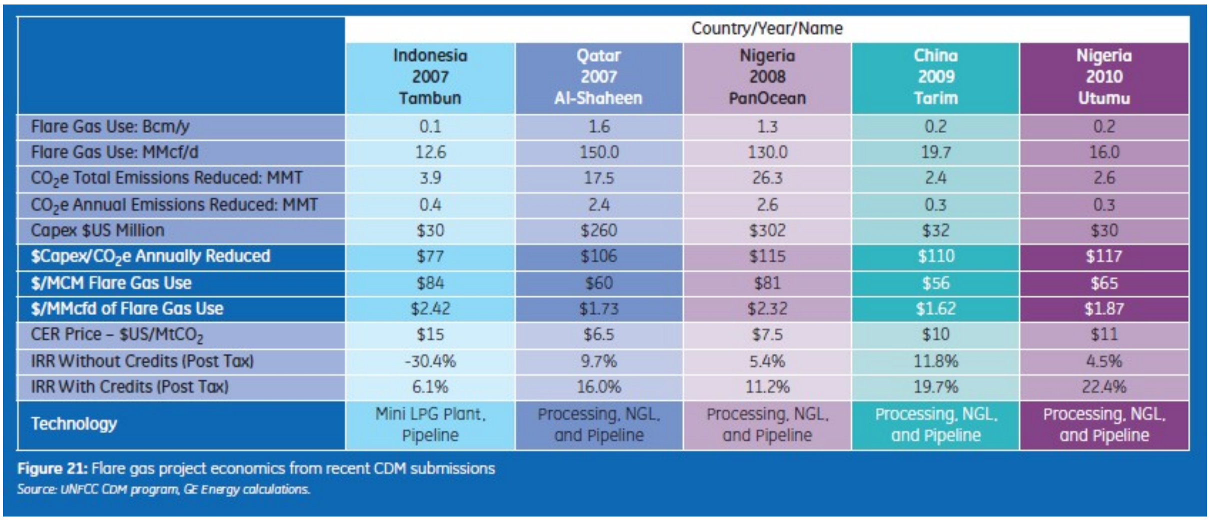


Figure 2: Economic assessment of flaring prevention measures in Nigeria. Farina 2011



| | Country/Year/Name | | | | |
|---|---|---|---|---|---|
| | **Indonesia 2007 Tambun** | **Qatar 2007 Al-Shaheen** | **Nigeria 2008 PanOcean** | **China 2009 Tarim** | **Nigeria 2010 Utumu** |
| Flare Gas Use: Bcm/y | 0.1 | 1.6 | 1.3 | 0.2 | 0.2 |
| Flare Gas Use: MMcf/d | 12.6 | 150.0 | 130.0 | 19.7 | 16.0 |
| $CO_2$e Total Emissions Reduced: MMT | 3.9 | 17.5 | 26.3 | 2.4 | 2.6 |
| $CO_2$e Annual Emissions Reduced: MMT | 0.4 | 2.4 | 2.6 | 0.3 | 0.3 |
| Capex $US Million | $30 | $260 | $302 | $32 | $30 |
| **$Capex/$CO_2$e Annually Reduced** | $77 | $106 | $115 | $110 | $117 |
| **$/MCM Flare Gas Use** | $84 | $60 | $81 | $56 | $65 |
| **$/MMcfd of Flare Gas Use** | $2.42 | $1.73 | $2.32 | $1.62 | $1.87 |
| CER Price – $US/Mt$CO_2$ | $15 | $6.5 | $7.5 | $10 | $11 |
| IRR Without Credits (Post Tax) | -30.4% | 9.7% | 5.4% | 11.8% | 4.5% |
| IRR With Credits (Post Tax) | 6.1% | 16.0% | 11.2% | 19.7% | 22.4% |
| **Technology** | Mini LPG Plant, Pipeline | Processing, NGL, and Pipeline | Processing, NGL, and Pipeline | Processing, NGL, and Pipeline | Processing, NGL, and Pipeline |

**Figure 21:** Flare gas project economics from recent CDM submissions

*Source: UNFCC CDM program, GE Energy calculations.*

Figure 3: Economic assessment of flaring prevention measures in various countries. Farina 2010.