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Flaring Emissions: Quantification and Mitigation

IEA GREENHOUSE GAS R&D PROGRAMME

International Energy Agency

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ACKNOWLEDGEMENTS AND CITATIONS

The report was prepared by:

- Lydia Rycroft

To ensure the quality and technical integrity of the research undertaken by IEAGHG each study is managed by an appointed IEAGHG manager.

The IEAGHG manager for this report was:

- John Gale

The report should be cited in literature as follows:

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Further information or copies of the report can be obtained by contacting IEAGHG at:

IEAGHG, Pure Offices, Cheltenham Office Park
Hatherley Lane, Cheltenham,
GLOS., GL51 6SH, UK
Tel: +44 (0)1242 802911
E-mail: mail@ieaghg.org Internet: www.ieaghg.org

REDUCING EMISSIONS FROM FLARING

Executive Summary

This review aims to assess the current understanding on reducing emissions from flaring in the oil and gas industry and to review literature on both the quantification of emissions and current mitigation strategies. IEAGHG published a technical review 2017-TR7 (Oct 2017) which studied emissions along the natural gas supply chain but flaring emissions were not included. This review aims to follow on from 2017-TR7 as a supplementary review on flaring emissions.

'Flaring' (also known as a gas flare or flare stack) occurs in the oil and gas industry at a variety of points along the supply chain (production both on and offshore, oil refining, chemical plants, natural gas processing plants and others). Flare gas systems are designed to dispose of waste gas via a gas combustion process which converts the emissions from methane to CO_2 to reduce the impact on air quality. The gas may be flared for a variety of reasons e.g. to prevent over-pressurisation or to remove gas during routine maintenance. Flaring is used when waste gas cannot be efficiently captured and utilised and is typically used as a control measure when vapour recovery of the gas is impractical. Methane is a commodity and when capture, transportation via pipeline or re-injection are viable options, these are preferred. Flaring is often considered a last-resort option to dispose of waste gas.

The quantification of flaring emissions on a global scale is largely based on estimates from satellite data. Direct metering is regularly undertaken at some sites but depends on the country's regulations and hence large-scale quantification is taken from extrapolating this data and large uncertainties still remain. Most data on flaring is confidential and not regularly reported given sensitives associated with the negative impacts of the associated emissions. This report outlines current quantifications methods and the regulations governing how flaring emissions are reported.

One of the main groups working on reducing flaring emissions are the Global Gas Flaring Reduction Partnership (GGFR). The partnership is part of The World Bank and has 189 member countries working towards reducing their emissions from flaring. A current initiative started by the GGFR is 'Zero Routine Flaring by 2030'. Companies such as Total has also advertised that they have reduced their flaring emission from 2005-2015 by 50% from 15 to 7.5 million m^3. The GGFR post an annual summary of upstream flaring emissions and the quantification process is gathered from a variety of sources. The GGFRs work has improved the amount of work reported on flaring emissions although publically available data directly from industry is still limited.

The flaring mitigation strategies currently in place are reviewed in this report including those by individual countries, company strategies and global schemes such as 'Zero Routine Flaring by 2030'. This review summarises the current standing of quantification methods and concludes further research is needed on direct measurement from flaring stacks to support global satellite estimates. Annual data is being collected by World Bank and the GGFR which is greatly improving the global database on flaring emissions. Current mitigation plans are ambitious and progress is being made with GGFR data showing flaring has been in moderate decline from 2015-2017. Approximately 54% of global gas flaring is represented within the 71 governments that have to date signed up to the "Zero Routine Flaring by 2030" initiative.

Contents

1. Introduction to the Flaring Process

The latest satellite data indicates that global gas flaring emissions were approximately 141 billion cubic meters in 2017, contributing to approximately 1.2% of CO_2 emissions globally (350 million tons)[1]. This is down from 148bcm in 2016. The quantifications of global emissions made by the GGFR in 2017 show that flaring increased significantly in Russia, Iran and Iraq although emissions decreased in the United States. Although oil production levels have remained relatively unchanged in the last two years, flaring has been in moderate decline. As oil production is set to increase in the next few years the reduction of routine flaring for new and old production sites is important if emissions are to be reduced.

For reference, the basics of flaring are covered succinctly in a document by the Ohio EPA[2] but in summary, flaring can occur at various stages along the upstream chain and it is undertaken:

1. During well production testing after drilling in completed;
2. For safety during emergencies and maintenance; and
3. For managing gas during compression and processing.

The gas flared is pure natural gas from the reservoir and the composition is therefore site dependant but is predominantly composed of methane. As methane is a commodity, where possible the gas is re-used: either transported to shore, used for onsite electricity generation or re-injected into the reservoir for enhanced hydrocarbon recovery. At sites where the methane cannot be utilised (this can be for a variety of reasons which is discussed later in this review) the methane is considered a waste product. Combusting the methane via the flaring process is beneficial as methane is converted to CO_2 ($CH4[g] + 2\ O2[g] \rightarrow CO2[g] + 2\ H2O[g]$ + energy) and carbon dioxide has 104 times lower global warming potential than methane.

"Routine flaring" will be the focus of the report. Various definitions regarding flaring are outlined by the GGFR[3] but importantly routine flaring is defined as:

Routine flaring

Definition	Examples of Routine Flaring
Routine flaring of gas at oil production facilities is flaring during normal oil production operations in the absence of sufficient facilities or amenable geology to re-inject the produced gas, utilize it on-site, or dispatch it to a market. Routine flaring does not include safety flaring, even when continuous.	Includes: • Flaring from oil/gas separators; • Flaring of gas production that exceeds existing gas infrastructure capacity; • Flaring from process units such as oil storage tanks, tail gas treatment units, glycol dehydration facilities, produced water treatment facilities, except where required for safety reasons.

Figure 1: Definition of 'routine' flaring by the GGFR (World Bank Website)

Other forms of flaring such as safety flaring (e.g. during maintenance or an emergency) and other non-routine flaring (such as failure of the equipment than handles or receives the gas) are harder to mitigate. Therefore, with regards to flaring mitigation, routine flaring is the main focus of reduction targets and will be the main focus of this review.

There are a variety of reasons that methane may not be utilised at a site which leads to flaring being undertaken. A common reason for routine flaring is due to crude oil extraction in remote locations. Oil extraction often has associated gas, and when extraction occurs at a remote location the infrastructure required to utilise the gas is more expensive which makes processing the gas uneconomical. Natural gas is often flared where companies do not have the infrastructure in place for capture and transportation[4]. Natural gas requires separate infrastructure for processing and in certain circumstances (e.g. dependant on the location and current oil price) it can cost more to produce than oil for an energy-equivalent basis and for this reason associated gas can often be flared, e.g. areas such as the Bakken in North Dakota.

Flaring is also associated with other environmental concerns including heat and noise pollution as flaring is often visible. It can have severe health implications for the most local communities and these have been recorded in areas such as the Niger Delta[5] where extensive flaring has directly impacted on local communities. Flaring in the northern hemisphere has also been highlighted as a potential source of significant amounts of nitrogen dioxide and soot being deposited in the Arctic[6]. More details on black carbon and the impact of soot can be found on the Climate & Clean Air Coalition website[7] and has also been discussed in IEAGHG Information Paper 2017-46[8].

Flaring is regularly covered by NGOs, such as Friends of the Earth and Greenpeace, and is often used in the argument against the increased use of gas (especially with regards to fracking) within governments' energy strategies. For the public to engage positively with the continued use of natural gas, the reduction of flaring emissions and the associated reduction in environmental impact will be greatly beneficial.

The aim of this report is to review current knowledge regarding the CO_2 emissions associated with natural gas flaring. This will firstly include a review of current quantification methods to see how well emissions estimates are constrained and the current regulations in place to quantify emissions. Secondly, existing mitigation strategies will be reviewed to highlight the current efforts being made and the future projections for natural has flaring and the potential long-term climate impact.

IEAGHG conducted a Technical Review in 2017 (2017-TR7) "Reducing Emissions from Natural Gas Supply Chains". This was based on a Sustainable Gas Institute (SGI) Report which acknowledged flaring was a major source of methane emissions but did not include flaring in the report. The SGI study stated that whether the gas was flared, vented or collected led to huge variations in emission estimated for the 'well completions' stage of the natural gas chain. Emissions estimates ranged from zero to 6.8 million m^3 CH_4 vented per completion. This review follows on from 2017-TR7 with the aim of summarising the current status of flaring emission quantification and mitigation given its contribution to methane and CO_2 emission along the natural gas supply chain.

2. Quantification of Flaring Emissions

Estimating the global emissions associated with natural gas flaring is a complex task given the variety of point sources and extent of coverage these types of emissions have. Metering equipment is accurate and can be used to accurately quantify emissions at a specific source but the appropriate guidelines must be followed as measurements can easily become inaccurate (+/- 400%) if equipment is not used properly. In this case, emission estimates can become more effective than direct (but inaccurate) metering.

Currently, there is no global standard being adhered to with regards to quantifying flaring emissions. Legislation and regulations vary on a country or regional basis and many areas are not required to make any quantification. Global estimates are currently derived from satellite data which is verified using metered flow data. There are not enough direct observations being collected to make global estimates from extrapolating from those measurements alone. More details on the various quantification methods are summarised below.

2.1 Measurement Techniques

2.1.1 Modelling and Estimation Methods

If no continuous flow direct metering is being undertaken there are 3 main methods the oil and gas industry generally use to estimate flaring gas emission volumes[9]:

- Oil to gas ratios (GORs)
- Mass balances
- Process Simulations

GOR

The GOR method is based on the theory that the volume of gas flared is a function of the quantity of gas in the reservoir. Gas-to-oil ratio is defined by Schlumberger as “the ratio of the volume of gas that comes out of solution to the volume of oil at standard conditions” and these gas-to-oil ratios vary substantially from well to well even if producing from the same pool[10]. An accurate GOR must first be established (which can be difficult given these large variations) and then gas flaring estimates can be made given the oil production levels. For example:

The GOR from the test data is:

$$GOR = \frac{400\ m^3\ of\ casing\ gas}{4\ m^3\ of\ oil\ production} = 100\ m^3/m^3$$

The estimated casing gas vent rate for the current month is then:

$$V = GOR\ production$$
$$V = 100 M^3/m^3\ 125 m^3$$
$$V = 12.5 \text{ X } 10^3\ m^3$$

Note: Since the measured daily casing gas flow rate is •500 m^3/d, annual GOR tests are required.

Figure 2: GOR Calculation (CAPP, 2002)

The GOR calculates the total associated gas, therefore as part of the calculation other potential gas emissions must be deducted (e.g. storage tank loses, re-injection etc.) so only flaring emissions are estimated.

The standard procedure is for GOR to be measured over at least a 24 hour period at normal flow rates. In Canada, the Energy and Utilities Board have developed a directive (EUB ID 91-3)[11] which stipulates how often GOR tests are required e.g. annually for casing gas flows of up to $500m^3/d$.

Mass Balance

Total flaring can also be estimated as the difference between the calculated flow rates of all input and output gas streams and subtracting any possible onsite uses and process shrinkage. The mass balance method can only be used where the flare volume is large enough to make potential errors in the estimation negligible.

The main issues for these sorts of calculations are that the inlet stream accuracy is usually much less than for output streams as conditions are more variable and difficult to measure. Also there may not be meters on all withdrawals.

The accuracy of this method is dependent on the magnitude of the gas volume flared in comparison to total gas production and the accuracy of the flow measurements. At oil production facilities where most of the produced gas is flared, the accuracy of the mass balance approach would be expected to be within +/-15-25 %.

Process Simulation

Process simulations are most commonly used to verify direct measurements taken by a primary meter. Simulation allows for a more segmented approach in comparison to the mass balance approaches but generally cannot be applied to estimating intermittent flaring emissions. Process simulations require more data such as stream composition, process temperature and pressures. Commercial simulations are often accurate for individual processes by approximately +/- 5 to 10% (given the input data is accurate). These simulations will not take into account any unintended leakages that may be occurring.

2.1.2 Direct Metering

The GGFR's 2008 technical report (prepared by Clearstone Engineering) "Guidelines on Flare and Vent Measurement"[7] gives a complete overview of flow measurement systems available at the time including operating range and accuracy. Fluenta (a UK based developer of flare gas measurement equipment) have also published a more recent overview (May 2016)[12] which looks at the most popular flare gas meter technologies available and compares them in terms of reliability and accuracy. A full description of each meter type and how it works can be found in these two reports. A summary is presented below of how metering is utilised and the current status of various technologies.

There are many variables and potential challenges for a plant when selecting a metering system. The specific problem posed by flaring is measuring large flow ranges such as very low flow under normal conditions and sudden very high flows during blow-down conditions. Other variables that need to be taken into account include the gas composition, low pressure conditions and dirt/wax/condensate potentially clogging the flow, calibration requirements, monitoring length requirements and compliance with local regulations. A detailed list of all the considerations is included in "Gas Flaring in Industry: an Overview" (E. Emam, 2015)[13].

The main 3 types of meters utilised to measure flow in flare stacks are:

- Ultrasonic
- Thermal
- Differential pressure with averaging pitot tubes

In summary, ultrasonic flowmeters are currently the leading technology and the industry standard due to their wide range, non-intrusiveness and their measurement stability. Thermal flowmeters are used but they need to be calibrated with the gas being measured, which is an added difficulty as although methane is the continuous sweep gas other gases are added to the system from various process units. As thermal meters rely on thermal properties of the gas mixture, uncertainties in composition can affect accuracy. Averaging pitot tubes have low ranges and are subject to clogging.

Ultrasonic methods measure the time it takes for ultrasonic waves to travel across a pipe both upstream and downstream. The flow is calculated by taking the time difference between these two values. One of the major advantages of the ultrasonic method is that it is not impacted by the composition or cleanliness of the gas flowing. Furthermore there are no mechanical parts within the monitor, which limits the requirements for maintenance and support.

Overall the main challenge posed by metering gas flares is the unpredictability of gas volumes and the need to be able to measure large fluctuations in gas flow volume. The potential variability of gas composition and atmospheric conditions also makes metering difficult. It is therefore important to consider the "turndown ratio"[14] of the meter. This is the range of flow the meter could potentially measure within an acceptable accuracy range. E.g. a turndown factor of 10 means it can measure gas flows within a factor of 10 to each other (10,000 to 100,000 or 100,000 to 1 million m^3 per day). For example, ultrasonic meters have a turndown factor of 3000 whereas thermal meters are usually around 600.

Fluenta currently estimate that there are 3000 meter installation worldwide. To put this in perspective there are an estimated 6900 flares in the USA[15], and 2000 in Russia.

2.1.3 Satellite Observations

Full details on the methodology to estimate flare gas volumes from satellite data can be found on the World Bank website[16]. In summary, since 2012, the National Oceanic and Atmospheric Association (NOAA) have utilised their satellite programme (designed to acquire weather data) to detect heat emissions using high resolution infrared detectors. Their new (post-2012) detectors are now able to differentiate heat from visual light which has vastly improved the detection of flares in comparison to light sources from surrounding towns and cities.

Only temperatures above 1400 degrees Kelvin are selected in order to filter out heat sources such as biomass burning. In the first three years of operation the NOAA’s radiometer automatically detected over 16,000 flares in operation annually around the globe. Due to range of unpredictable external factors the satellite must be calibrated using direct observations. The NOAA take these direct measurements from the CEDIGAZ database (a non-profit French organisation specialising in natural gas information). The database consists of flare gas volumes from a variety of countries and was used to develop a correlation coefficient between satellite data and observed emissions which led to the follow equation used by World Bank and the GGFR:

$$\text{Satellite flare volume estimate} = 0.0281 \times \text{VIIRS radiant heat}$$

Where VIIRS is the “Visual and Infrared Radiometer Suite” of detectors used by the NOAA on their weather satellite to collect flaring data.

A special report was published in the Oil & Gas Journal[17], funded by the GGFR when they first began compiling global data in 2007. Although this methodology is now outdated it discusses the satellite system used, how the global map is compiled, volume estimates are made and the initial study outcomes.

2.2 GGFR Global Gas Flaring Estimates

The Global Gas Flaring Reduction Partnership (GGFR) is an initiative led by the World Bank Group established in 2002. It is a public-private initiative comprising international and national oil companies, national and regional governments, and international institutions. GGFR works to increase the use of natural gas associated with oil production by helping remove technical and regulatory barriers to flaring reduction. Their work includes conducting research, disseminating best practices, and developing country-specific gas flaring reduction programs. The GGFR partners are shown in Table 1:

Governments	Companies	Organizations
Alberta (Canada) Algeria Azerbaijan Cameroon Republic of Congo France Gabon Indonesia Iraq Kazakhstan Khanty-Mansiysk Kuwait Mexico Nigeria Norway Qatar United States of America Uzbekistan	BP Chevron Eni Equinor ExxonMobil Kuwait Oil Company Pemex Qatar Petroleum Shell SNH (Cameroon) SOCAR Sonatrach Total	European Bank for Reconstruction and Development The World Bank European Union

Table 1: GGFR Partners (GGFR website)

The GGFR publish the largest collection of flaring data in their annual summary on global flaring emissions which has been undertaken since 2003. The annual data from 2017 was published in July 2018 on the World Bank website[18] and shows a significant decline in gas flaring despite a 0.5% increase in global oil production. In 2017, Russia (the largest emitting country), Venezuela and Mexico showed a significant reduction in flaring emissions. Iran and Libya showed notable increases in flaring. The top 3 emitting countries are Russia, Iraq and Iran which collectively produced 55.4bcm of the 140.6bcm global total (39.4%) estimated by the GGFR.

A summary of the GGFR data by country from 2013-2017 is in Appendix A. 60 countries are included in the data analysis and data from 2013 onwards is included as this is when the new more accurate detectors came into use.

As described above in Section 2.1.3 the GGFR calculate global emissions estimates from satellite data. When the GGFR started collecting data in 2003 flaring data was inconsistent and often under reported[19]. Since then they have worked to improve global flaring estimates and provide standards for emission quantification.

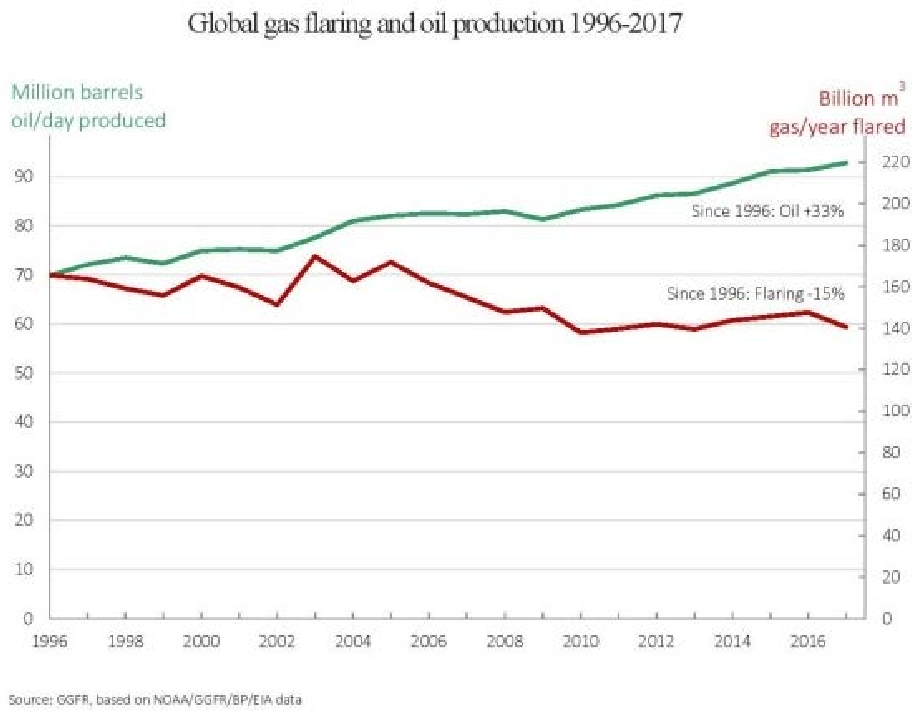

Figure 3: Summary of oil production and flaring trends, GGFR 2017

As presented in Figure 1 the global trend since 2013 has shown that although oil production has increased by a third globally flaring emission are down 15%.

Another dataset produced by the GGFR is flaring intensity (the volume of gas flared per barrel of oil produced). This shows that some countries may have low emissions, such as Spain which flared 6 million m^3 of gas, may actually have quite intense flaring emissions for the amount of oil produced, i.e. 7.1m^3 a barrel. In comparison, larger emitters such as the U.S and Russia have significantly lower intensity ratings.

2.3 Policy and Legislation

Globally, the policy and legislation surrounding flaring and the quantification of emissions varies from country to country. It is the host government's responsibility to develop policy and regulate flaring in their country. Therefore to reduce flaring emissions the host governments need to fiscally stimulate gas utilisation over flaring by making it economically viable to do so either through incentives or penalties.

The GGFR published a report "Guidance on Upstream Flaring and Venting: Policy and Regulation"[20] published in 2009. This is an extensive report which includes some generic lessons that can be taken from oil producing companies on associated gas utilization. Flaring legislation is governed by oil and gas regulations in the associated country although petroleum contracts and agreements are often unclear regarding the treatment of associated gas. Many regulatory regimes (e.g. in Canada and the UK) require gas to be utilized wherever it is shown to be economically viable. Only if all available options are sufficiently uneconomic may gas be flared.

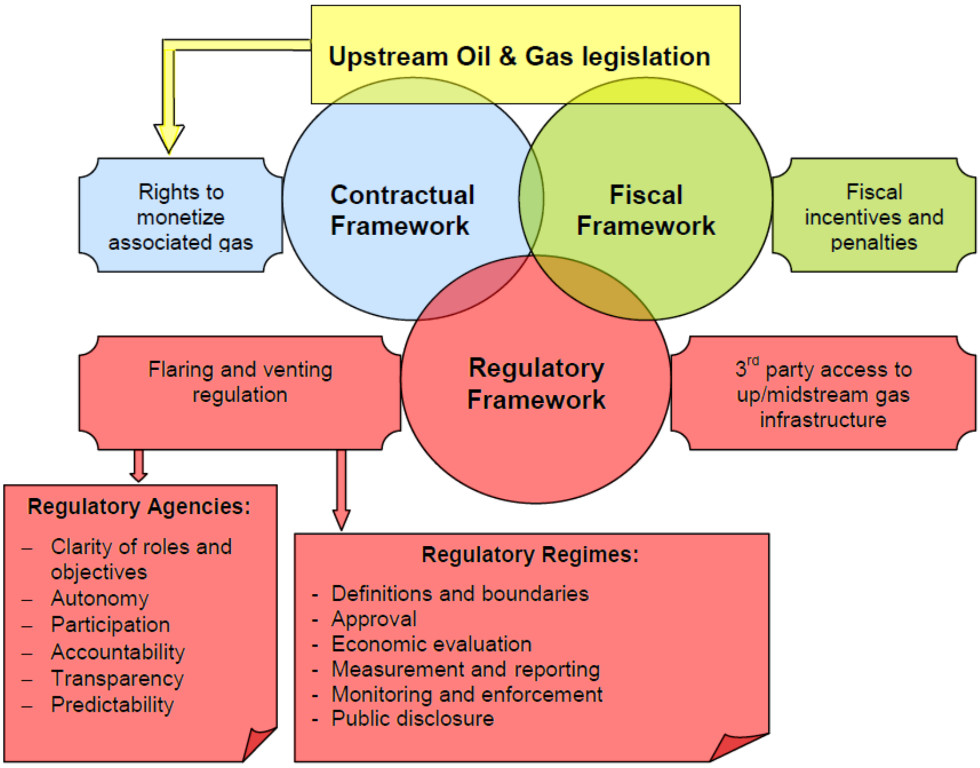

Figure 4: Flow chart showing the interdependence of O&G Legislation, and contractual fiscal & regulatory frameworks (GGFR 2009)

Figure 4 shows how (through the production of contracts and licenses) oil and gas legislation determines all elements of the industry including how flaring should be treated fiscally and contractually. The GGFR report also covers in detail the key features of a good flaring regulatory regime including: regulatory approval, measurement, economic evaluation, monitoring, reporting and enforcement.

There is currently no international best practice or generally accepted method as to who should regulate gas flaring and venting. In most developing countries profiled in the GGFR's 2009 report, institutional responsibilities for gas flaring and venting are often non-transparent, conflicting, and ineffective. For reference, Appendix A of the GGFR report includes regulatory profiles of 10 countries or areas including Norway, the UK, North Africa and the Middle East. In most oil-producing countries profiled, the ministry responsible for managing a country's hydrocarbon resources has the primary responsibility of regulating gas flaring and venting as part of its overall obligation to oversee oil production.

The European Union has adopted an Emissions Trading Scheme (ETS) since 2005 which requires detailed emissions reporting from power stations, industrial plants and the airline sector, which therefore includes flaring emissions. Anyone found not meeting the obligation to report flaring emissions will face substantial financial penalties although it does contain the caveat that companies with offshore operations have lower restrictions to reflect the particular technical challenges of operating in remote and hostile environments. A wealth of material is available on how to measure flaring and venting in line with EU regulation, e.g. "Measuring Flare Gas Within the European Union Emissions Trading Scheme" published by Fluid Components International[21].

In Nigeria the Government is responsible for oil and gas industry regulations and they have also signed to numerous international conventions. Since 1984 gas flaring has been illegal in Nigeria but there have been difficulties accessing the latest technology to effectively measure and quantify flaring meaning enforcing these regulations has been challenging. A recent report by the country's Petroleum Revenue Special Task Force estimates that a total of $58 million of outstanding fines remain unpaid[22].

3. Mitigation Strategies

Flaring has long been highlighted as an environmental concern, especially given its contributions to greenhouse gas emissions. The Paris Agreement has now been signed by 195 countries worldwide meaning they have now committed to reducing their greenhouse gas emissions and many governments are now looking on how to reduce emissions including those from flaring. The World Bank's 'Zero Routine Flaring by 2030' program was launched in April 2015 and is currently endorsed by 28 governments and 36 oil companies. The main focus for mitigation strategies to reduce emissions from gas flaring are mainly focused on reducing 'routine flaring' emissions. Routine flaring is no longer seen to be regularly undertaken by new oil and gas developments but still occurs in older operational rigs.

The role of natural gas flaring in countries reaching their emissions targets under the Paris Agreement has recently been reviewed in 2018 by C. Elvidge et. al[23]. The study compared satellite derived from 2015 satellite data with countries contributions to greenhouse gas reduction targets under the UNFCC Paris Agreement. Three categories of flaring were covered (upstream O&G, downstream refining and transporting and industrial flaring) although upstream flaring dominates contributing 90.6% of the emissions from all flaring. Flaring only represents 2% of global emissions reduction targets as it is concentrated in a limited number of countries. Flaring reduction will therefore be a key strategy for certain countries reaching their emissions reduction targets with Yemen (240%), Algeria (197%) and Iraq (135%) able to meet their reduction targets through flaring reductions alone. The report also concluded Gabon (94%), Algeria (48%), Venezuela (47%), Iran (34%), and Sudan (33%) could all meet a substantial amount of their target reductions through flaring mitigation. On the other hand, several countries with large flared gas volumes could only meet a small portion of their NDC targets from gas flaring reductions, including the Russian Federation (2.4%) and the USA (0.1%).

As well as global collaborative efforts, such as the GGFR, individual companies have also started initiatives to reduce their own flaring emissions. Eni S.p.A (Italian oil and gas company) launched a programme in 2007 which aimed to reduce gas flaring and utilise the excess gas to produce electricity for the local population (both for domestic use and to be exported). Eni also pushed for the re-injection of the gas into the reservoir if electricity generation was not possible to help further reduce emissions. This is not an easy task and has required large investment for the required major infrastructure changes. Through talking to governments and resource holders Eni has promoted these large-scale changes.

Eni's efforts to date have achieved a reduction of 75% within their operations of the volume of gas sent to flaring compared with 2007. The group also adhere to the Global Gas Flaring Reduction (GGFR) "Zero Routine Flaring by 2030" initiative which is discussed in more detail in Section 3.1 below. The Eni project to reduce flaring in the M'Boundi, Congo (see case study below) was awarded a prize by World Bank. More than two billion dollars have been invested since 2007 and Eni are still continuing with this initiative to date. More funding has been secured and over the next four years (the company will invest an additional €400 million over the life of the plan) and Eni foresees a further reduction of 25% in the daily volume sent to process flaring (compared with 2015).

Shell have also publicised their efforts to reduce flaring emissions with upstream flaring contributing to 11% of their overall greenhouse gas emissions in 2017[24]. A majority of Shell's flaring currently occurs in Iraq, Nigeria, Malaysia and Qatar and increased 10% from 2016 to 2017 to reach 8.2million tonnes. Shell have committed to the 'Zero Routine Flaring by 2030' initiative and are currently working to bring more gas gathering facilities online in Nigeria.

Total is involved with several initiatives including the Climate and Clean Air Coalition and has publicised it will no longer undertake any routine flaring on new oil developments. Between 2005 and 2014 Total reduced flaring by 50% across their sites[25] although this excludes new facilities coming on stream. They aim to reduce routine flaring by 80% from 2010-2020.

Exxon are yet to commit to the 'Zero Routine Flaring by 2030' initiative and (alongside many other large oil and gas companies) are regularly criticised for not committing to reducing enough of their greenhouse gas emissions[26], especially associated with flaring. They currently aim to reduce the amount of natural gas they burn by 25% within two years.

At a local scale the North Dakota Industrial Commission have been heavily involved with flaring mitigation given the intensity of flaring that occurs across the Bakken Shale operations in that region of the US. In 2004 they published Commission Order 24665[27] which stated the policy goals to: 1) reduce the flared volume of gas 2) reduce the number of wells flaring and 3) reduce the duration of flaring from wells. The Commission establishes the following gas capture goals:

74% October 1, 2014 through December 31, 2014
77% January 1, 2015 through March 31, 2016
80% April 1, 2016 through October 31, 2016
85% November 1, 2016 through October 31, 2018
88% November 1, 2018 through October 31, 2020
91% beginning November 1, 2020

The action items resulting from the order included:

1) Require a sworn affidavit that the operator has provided Gas Production Forecast data to midstream gas gathering companies and developed a Gas Capture Plan for increased density, temporary spacing, and proper spacing cases.
2) Require Gas Capture Plans for all applications for a permit to drill filed by an operator who has failed to meet gas capture goals in any of the most recent three months.
3) Semi-annual meetings with midstream gas gathering companies.
4) Semi-annual Gas Capture Improvement Plan meetings with operators who have failed to meet gas capture goals three or more of the most recent six months.
5) Annual review of gas capture goals, gas capture progress, and extenuating circumstances to be presented by Department of Mineral Resources each December.

6) Track flaring on/off the Fort Berthold Indian Reservation.
7) Report capture status versus goal.

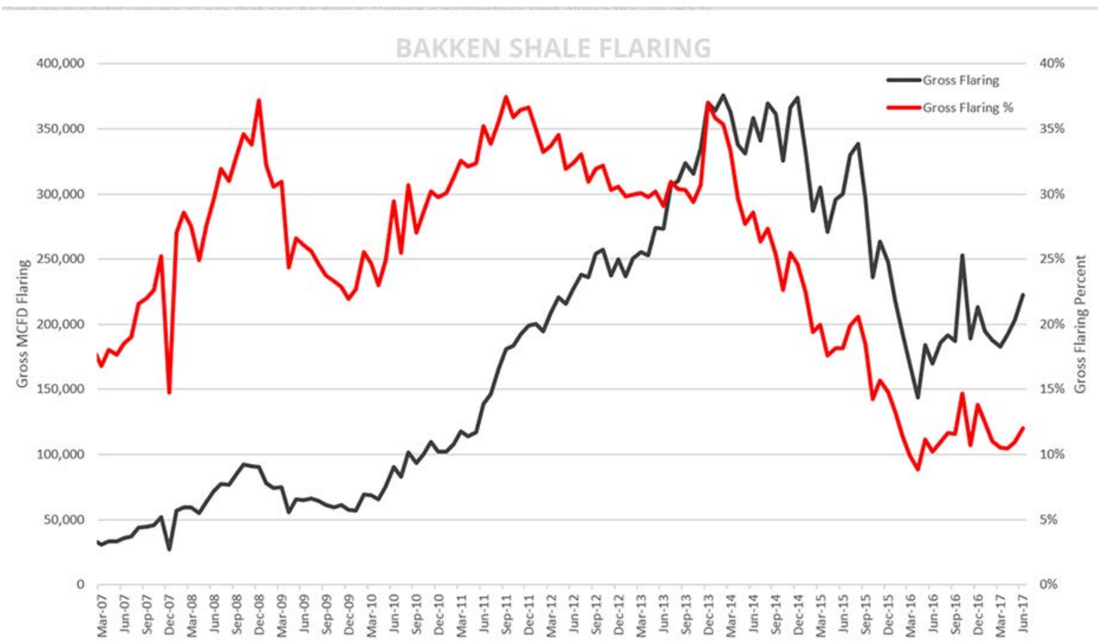

Figure 5: Flaring Emissions by Year for the Bakken Shale, North Dakota Department of Mineral Resources

As demonstrated in Figure 5 these mitigation methods were very effective in reducing flaring emissions by approximately two thirds from 2014 to 2016. Even with these measures in place though, emissions from 2017 have begun to slowly increase again[28] which has been attributed to a 2016 oil price downturn leading to developers having to extract from more productive units, which in turn produce more gas.

3.1 Zero Emissions by 2030

The 'Zero Routine Flaring by 2030' initiative (introduced by the World Bank) is the main global collaboration working towards mitigating emissions from flaring. Appendix B illustrates current endorsers of the initiative which includes governments, oil companies and development institutions. Together the current endorsers represent over 50% of global flaring emissions. The World Bank Group hope that many more large emitting companies and governments will soon join the initiative with a full list of benefits outlined on their website[29]. The initiative is not legally binding (and has no associated penalties) but demonstrates a clear commitment to the public from all companies and governments involved and will be verified through satellite observations.

The initiative relates specifically to routine flaring and not flaring due to non-routine or safety reasons. Governments and oil companies that endorse the "Zero Routine Flaring by 2030" Initiative commit to "publicly report their flaring and progress towards the Initiative on an annual basis. They also agree to the World Bank aggregating and reporting the same."

Endorsers provide flaring data for the first full calendar year after they have endorsed the Initiative.

Reported flaring from governments and oil companies	Total flaring in 2016 (million Sm^3)
1. Endorsing governments	29,623
2. Endorsing companies	12,540
3. Endorsing companies in endorsing countries	4,542
4. Non-endorsing companies in endorsing countries (1-3)	25,081
5. Endorsing governments and companies (1+2-3)	37,621

Figure 6: Zero Routine Flaring by 2030 Reported Flaring (World Bank Website)

The World Bank state that the initiative is realistic and it is not encouraging uneconomic investments but is designed to stimulate the right environment for co-operation between all stakeholders so that economic solutions are found through appropriate regulation. Potential costs associated with flaring reduction at this scale are currently unknown although onshore mitigation will be significantly cheaper than offshore. Studies to date estimate 6-9 US$/ft3/day (85 - 125 US$/t CO_2/day) for onshore projects which implies a potential cost of well over US$100 billion to eliminate the gas currently flared although this does take into account the revenues from utilization of the gas[30].

3.2 M'Boundi Project, Republic of Congo Case Study

In the republic of Congo nearly half the population currently have no access to electricity[31]. Eni (an Italian O&G company) have been operating in the Republic of Congo since 1968 in the hydrocarbon exploration and production sector[32]. Eni signed an agreement with the Republic of Congo in 2007. It presented a four-year plan to the Congolese authorities, setting out its commitment to produce electricity for the country thanks to two electric power stations and eliminate gas flaring by 2012.

In 2009 Eni established a gas flaring reduction program at the M'Boundi Field in the Congo, re-using the associated gas for the generation of electricity to benefit the local population. Since 2014 the M'Boundi has been a zero process flaring plant when a new gas compression train entered service allowing for the re-injection of associated gas. Since August 2014, the Oil Center M'Boundi has re-injected approximately 1 million Sm^3/day of gas. Through the gas-fired power station projects (CEC and CED), M'Boundi has flared almost no gas since 2014, thus contributing significantly and positively to the reduction of Eni Congo's gas flaring[33].

3.3 Niger Delta, Nigeria Case Study

Flaring in the Niger Delta region of Nigeria is particularly controversial given ongoing conflict in the area which has ethnic, economic and environmental causes[34]. The GGFR estimates currently show Nigeria to be the 6th largest emitter and in a country where gas demand is much higher than current supply the utilization of the gas currently flared would be of great benefit to the local population where currently 66% of people live below the poverty line. Many endorsers of the 'Zero Routine Flaring by 2030' such as BP, Shell and Total currently operate flares in the Niger Delta and the hope is that global initiatives will work to mitigate flaring in Nigeria as soon as possible.

The AAAS Geospatial Technologies and Human Rights Project, in partnership with AI-USA, undertook a survey of the Niger Delta region using space borne infrared hotspot detections from 2000 to 2010, supplemented by high-resolution visible-band satellite imagery[5]. 14,059 land based gas flares were identified associated with 74 separate flaring sites. Analysis showed that 48 of these sites were located such that their thermal radii (temperatures +4.3°C) covered human habitat or agricultural land. In some cases local communities were within 100meters of a flare. Despite the government banning flaring in 2008, 41 flares were still active in this study in 2010. Thousands still live within areas which have significantly elevated heat levels. In addition to the health, safety, and quality of life issues arising from this situation, peer-reviewed research shows that these higher temperatures are associated with reduced crop yields, potentially in conjunction with other environmental factors such as acidified rain from SO_2 pollution.

A study undertaken by Hassan & Kouhy in 2013[35] investigated the factors that caused changes in emissions due to flaring in Nigeria from 1965-2009. The report concluded:

1. Changes in CO_2 emissions due to ANG (adsorbed natural gas) flaring is significantly determined by crude oil produced, gas-to-oil ratio, investment in gas utilization project, export price of natural gas and the Nigeria's participation in GGRF partnership via the ratification of Kyoto Protocol;

2. Homemade gas flaring reduction policies and regulations have insignificant impact on changes in CO_2 emission consequent of gas flaring over time. This exposes the weakness of the homemade gas flaring reduction policies and their inefficient enforcement mechanisms;

3. An internationally oriented policy appears to be effective in bringing about significant decline in CO_2 emission as a result of gas flaring;

4. There is evidence of general lack of environmental concern by companies operating in the upstream sector for the apparent negative environmental consequences of gas flaring, and;

5. Changes in the level of the emissions over time is not an important factor considered by NNPC (Nigerian National Petroleum Corporation) in deciding how much gas-flaring-related information to disclose in its ASB (Annual Statistics Bulletin).

The study also stated that future research should investigate how corporations operating in less developed countries like Nigeria can become more transparent in their disclosures of environmentally sensitive activities.

4. Summary

In recent years companies and governments have pledged to reduce their flaring emissions and annual global flaring emissions have been seen to reduce by approximately 20 billion m^3 from 2004-2017, even though oil production is still increasing. The 'Zero Flaring by 2030' initiative has led to large emitters publically pledging the significantly reduce their emissions in the near future although some large companies and governments are yet to join.

Global estimates of greenhouse gas emissions associated with flaring have significantly improved since 2013 due to the work of NOAA and the GGFR and new satellites more accurate satellites being utilised. Some improvements are still required but as direct measurements improve this in turn will allow for better calibration of current satellite data. Local direct quantification is driven by the host country's policies and legislation. This still varies largely from country to country but for those already regulating many standards are available on how to accurately measure the flow rate from flaring stacks.

Calculating the emissions along the natural gas supply chain and incorporating flaring is challenging as flaring emissions are very site specific. When flaring is undertaken it is likely to produce a majority of the emissions across the supply chain and hence its mitigation is important in reaching long-term climate goals.

The 'Zero Routine Flaring by 2030' will be publishing annual summaries of emissions by each of its endorsers which alongside the GGFR global satellite data will provide an ongoing global database of flaring emissions. The progress of this initiative is important and will hopefully drive more stringent quantification, reporting and mitigation measures for local host countries.

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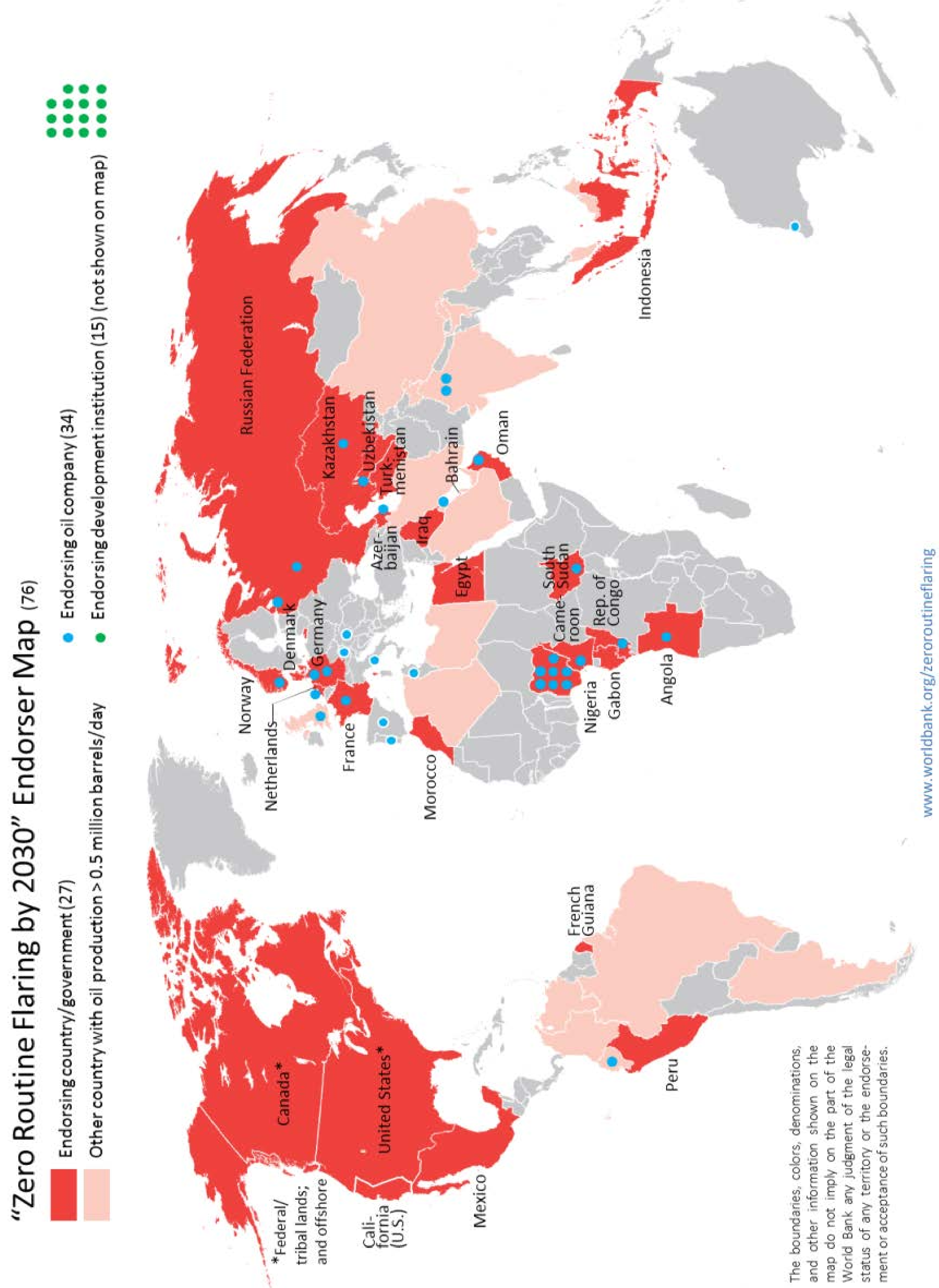
Appendix A
GGFR Data on Flaring by Country 2013-2017 (World Bank Website)

Gas flaring data 2013-17 (billion cubic meters)

		2013 bcm	2014 bcm	2015 bcm	2016 bcm	2017 bcm	2016-17 change bcm	2013-17 change bcm
1	Russia	19.9	18.3	19.6	22.4	19.9	-2.5	0.0
2	Iraq	13.3	14.0	16.2	17.7	17.8	0.1	4.6
3	Iran	11.1	12.2	12.1	16.4	17.7	1.3	6.6
4	United States	9.2	11.3	11.9	8.9	9.5	0.6	0.3
5	Algeria	8.2	8.7	9.1	9.1	8.8	-0.3	0.6
6	Nigeria	9.3	8.4	7.7	7.3	7.6	0.3	-1.7
7	Venezuela	9.3	10.0	9.3	9.3	7.0	-2.4	-2.3
8	Libya	4.1	2.9	2.6	2.4	3.9	1.6	-0.2
9	Angola	3.2	3.5	4.2	4.5	3.8	-0.7	0.6
10	Mexico	4.3	4.9	5.0	4.8	3.8	-1.0	-0.5
11	Malaysia	2.8	3.4	3.7	3.2	2.8	-0.3	0.0
12	Oman	2.4	2.6	2.4	2.8	2.6	-0.2	0.2
13	Kazakhstan	3.8	3.9	3.7	2.7	2.4	-0.2	-1.3
14	Egypt	2.4	2.8	2.8	2.8	2.3	-0.5	0.0
15	Indonesia	3.1	3.1	2.9	2.8	2.3	-0.4	-0.8
16	Saudi Arabia	2.0	1.9	2.2	2.4	2.3	-0.1	0.3
17	Turkmenistan	2.3	2.0	1.8	1.8	1.7	-0.2	-0.6
18	China	1.9	2.1	2.1	2.0	1.6	-0.4	-0.4
19	Gabon	1.4	1.5	1.6	1.6	1.5	-0.1	0.1
20	India	1.7	1.9	2.2	2.1	1.5	-0.6	-0.2
21	United Kingdom	1.4	1.3	1.3	1.3	1.4	0.0	0.0
22	Canada	1.5	2.1	1.8	1.3	1.3	0.0	-0.2
23	Syria	0.4	0.4	0.5	0.6	1.2	0.6	0.8
24	Rep. of the Congo	1.4	1.3	1.2	1.1	1.1	0.0	-0.3
25	Brazil	1.3	1.5	1.3	1.4	1.1	-0.3	-0.2
26	Ecuador	0.8	1.0	1.1	1.2	1.1	-0.1	0.3
27	Cameroon	0.8	0.9	1.1	1.1	1.0	-0.1	0.2
28	Qatar	1.4	1.3	1.1	1.1	1.0	0.0	-0.4
29	Vietnam	1.1	1.1	1.0	0.9	1.0	0.1	-0.1
30	UAE	1.2	0.9	1.0	0.8	1.0	0.1	-0.3
	Rest of world	12.5	12.8	11.1	10.0	8.4	-1.6	-4.0
	Global total	139.6	143.9	145.6	147.6	140.6	-7.1	1.0

Source: NOAA, GGFR. Rounded numbers.

Appendix B
Zero Routine Flaring by 2030 Endorsers (World Bank Website)



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mail@ieaghg.org
www.ieaghg.org