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The potential role of natural gas flaring in meeting greenhouse gas mitigation targets

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ABSTRACT

In this paper, we compare 2015 satellite-derived natural gas (gas) flaring data with the greenhouse gas reduction targets presented by those countries in their nationally determined contributions (NDC) under the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement. Converting from flaring to utilization is an attractive option for reducing emissions. The analysis rates the potential role of reduction of gas flaring in meeting country-specific NDC targets. The analysis includes three categories of flaring: upstream in oil and gas production areas, downstream at refineries and transport facilities, and industrial (e.g., coal mines, landfills, water treatment plants, etc.). Upstream flaring dominates with 90.6% of all flaring. Global flaring represents less than 2% of the NDC reduction target. However, most gas flaring is concentrated in a limited set of countries, leaving the possibility that flaring reduction could contribute a sizeable portion of the NDC targets for specific countries. States that could fully meet their NDC targets through gas flaring reductions include: Yemen (240%), Algeria (197%), and Iraq (136%). Countries which could meet a substantial portion of their NDC targets with gas flaring reductions include: Gabon (94%), Algeria (48%), Venezuela (47%), Iran (34%), and Sudan (33%). 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%). These findings may be useful in guiding national level efforts to meet NDC greenhouse gas reduction targets.

1. Introduction

There is wide consensus in the scientific community that anthropogenic greenhouse gas emissions have begun to impact the earth's climate, and that large reductions in those emissions is required to constrain the adverse impacts of climate change. Worldwide, the largest source of emissions comes from the burning fossil fuels, widely consumed for electricity, heat, and transportation. Fossil fuels widely consumed include coal, petroleum, and natural gas.

The Paris Climate Agreement, developed under the United Nations Framework Convention on Climate Change (UNFCCC), came into force on November 4, 2016. Under the Agreement, countries have presented specific actions and targets to reduce greenhouse gas emissions. These commitments are referred to as Nationally Determined Contributions (NDCs). There are two types of NDC targets. Unconditional targets are those that countries have volunteered with no expectation for external financial and technical assistance. Conditional targets are reductions that a country lists as possible with external assistance.

One of the methods for meeting NDC targets is the reduction of natural gas flaring. Flaring is a widely-used practice to dispose of natural gas in situations where there is insufficient infrastructure to use the gas locally or move it to market. The admissibility of gas flaring reductions to meet emission reduction targets traces back to the Kyoto Protocol's Clean Development Mechanism [1].

There are gas flares at oil and gas exploration and production facilities, refineries, liquid natural gas terminals, and industrial sites such as coal mines and landfills. A recent study [2] found that 90%

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of the global flared gas volume occurs at upstream exploration and production facilities. This is referred to as “associated gas”, a byproduct of oil extraction, arising in part due to the change in pressure from deep underground reservoirs to the earth's surface. Natural gas dissolved in the oil at depth is released at the surface. Much of this associated gas is utilized or conserved because governments and oil companies have made substantial investments to capture it; nevertheless, some of it is flared because of technical, regulatory, or economic constraints. As a result, thousands of gas flares at oil production sites around the globe burn approximately 140 billion cubic meters (bcm) of natural gas annually, resulting in nearly 300 million tons of carbon dioxide (CO_2) to be emitted to the atmosphere. In terms of global warming potential, methane is 28–36 times stronger than CO_2. Therefore, flaring results in less warming impact than venting, the direct release of natural gas into the atmosphere.

Methods for reducing gas flaring include transport as gas to a market, conversion to a liquid fuel similar to gasoline, on-site utilization for heat or electric power, and reinjection into underground strata. Reductions in gas flaring are an attractive option for stepping down greenhouse gas emissions because the gas is a marketable commodity. Utilization of the gas displaces other fossil fuels, thus reducing greenhouse gas emissions.

The World Bank supports a “zero routine flaring by 2030” initiative [3]. However, regulations on gas flaring are set at national and sub-national levels. There is wide variation regarding the permissibility of flaring, conditions under which flaring is allowed, and reporting requirements. Russian law requires the utilization of 95% of associated gas. Gas flaring is illegal in Nigeria. Flaring is prohibited in Equatorial Guinea, though the government can grant exemptions. Still, flaring is legal in the USA, with state regulations setting conditions and reporting requirements.

There is a relatively limited recent literature on satellite detection of gas flaring [4–8]. There is a somewhat wider literature looking at the air pollution and emission impacts of flaring [9–17]. And a further set of research focuses on alternatives to flaring [18–23]. NOAA's Earth Observation Group operates the only global satellite remote sensing program focused on gas flaring [2]. EOG produces global flare detection data on 24 h increments using nighttime data collected by the Visible Infrared Imaging Radiometer Suite (VIIRS) data. This is the VIIRS Nightfire (VNF) product [24], which was recently used to conclude that Islamic State oil production levels have been substantially lower than previously reported [25]. EOG distills full years of VNF data to estimate flared gas volumes for individual flaring sites [2].

In this paper, we compare 2015 VIIRS-derived gas flaring estimates with the submitted NDC greenhouse gas reduction targets. The analysis is conducted for three types of flaring: upstream in oil/gas production, downstream at oil/gas processing and refineries, and industrial. The industrial category is defined as natural gas flaring detected outside of the upstream and downstream sets, including flaring at coal mines, landfills, water treatment plants, and ephemeral flaring in oil exploration areas. The results indicate the potential role of gas flaring reduction in meeting country-specific targets. Section 2 describes the methods employed to source the data. Section 3 presents results. Section 4 discusses elements of those results, and Section 5 concludes.

2. Methods

In this study, we use gas flaring estimates from 2015 derived from data collected by the U.S National Oceanic and Atmospheric Administration's (NOAA) Visible Infrared Imaging Radiometer Suite (VIIRS). The satellite collects both global daytime and nighttime data at near 1 km^2 resolution every 24 h. Nighttime VIIRS data are particularly well suited for detecting and measuring the radiant emissions from natural gas flares due to the collection of shortwave infrared (1.61 μm) data at night. This wavelength coincides with peak radiant emissions from gas flares and lies in one of the clearest atmospheric windows worldwide, ensuring a high degree of transmission from the flare to the satellite. Temperature, source size and radiant heat are calculated using physical laws [24]. Gas flares can be separated from other IR emitters based on temperature and persistence. Biomass burning and non-flaring industrial sites have temperatures in the 600–1500 K range in VIIRS Nightfire (VNF) data. Flares have temperatures ranging from 1300 to 2200 K. If temperature ever exceeded 1600 K the site is labeled as a gas flare. If a site falls in the flaring temperature range and has two or more detections per year it is also deemed to be a gas flare. This persistence test filters out biomass burning, which can reach into the low temperature range of gas flares.

Flares were divided into three categories. Upstream sites were defined as flaring sites in or near oil and gas fieldmaps from the Peace Research Institute Oslo (PRIO) [26]. Downstream flaring was labeled primarily based on refinery and gas processing sites listed by the Oil and Gas Journal for 2015 [27]. The remaining operational flaring sites were provisionally assigned to the industrial category, which includes gas flares at coal mines, landfills, water treatment facilities and other industrial sites. This labeling was confirmed through visual assessment of the high spatial resolution google earth images (Fig. 1). The labels for the initial set of sites in the industrial category were modified and finalized based on this visual inspection. The 2015 analysis identified 13,605 flaring sites worldwide, with 12,227 upstream sites, 861 downstream sites and 517 industrial sites.

A calibration has been developed for estimating flared gas volumes in terms of methane equivalents [2] based on national level estimates of flared gas volumes from Cedigaz [28]. The conversion factor is derived assuming all flares have combustion efficiency of 100%. Therefore, all carbon atoms in a methane (CH_4) molecule are converted to CO_2 molecule. Under standard environment, which is 1 atm and 25° Celsius (298 K), 1 BCM of CH_4 gas is converted to 1800.62 kilotons (kt) of CO_2 molecules. These estimates are listed as CO_2 emission equivalents, the same reporting units as the NDC targets.

NDC greenhouse gas emission targets were extracted from the summaries extracted from two sources: the World Resources Institute CAIT Climate Data Explorer [29] and the World Bank's Nationally Determined Contributions (NDCs) web site [30].[1] The NDCs indicate both unconditional and conditional greenhouse gas emission reduction targets in terms of a percentage relative to a year in the past or a business-as-usual projection for a future year. If the NDC listed the reference quantity, this number was used in our analysis. If the NDC did not list the reference quantity, the analysis is based on greenhouse gas emission quantities from EDGAR (Emission Database for Global Atmospheric Research) [31]. In either case, the target percentage was multiplied by the reference quantity to yield the target reduction quantity in kilotons of CO_2e. We are then able to compare the 2015 flaring versus the target reduction quantities. This was performed for both the unconditional NDC targets and the total (unconditional plus conditional) targets. For countries with flaring that do not have NDC targets, we performed an analysis of flaring versus total greenhouse gas emissions.

[1] Note that the CAIT and World Bank NDC data sets are now in a combined NDC Partnership tool: Climate Watch on: https://www.climatewatchdata.org/.

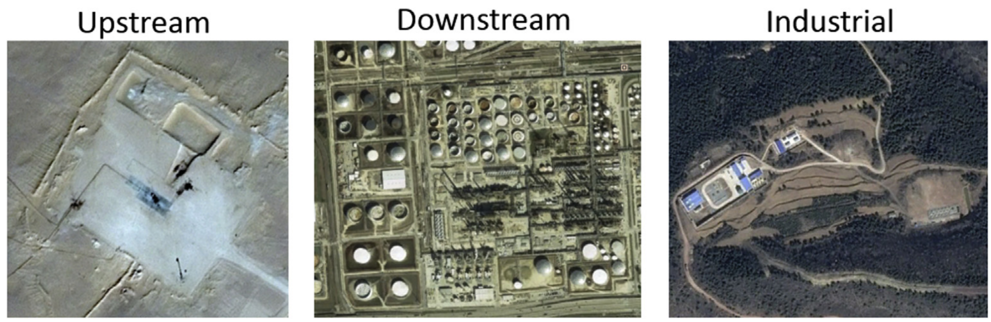

Fig. 1. Examples of high spatial resolution images from the three categories of gas flares. Upstream site is in Algeria at 31.818 n, 6.232 e. Downstream site is on the southern edge of Houston, Texas, USA at 29.717 n, 95.132 w. The image for the "industrial" category is a coal mine in China, located at 35.659 n, 112.179 e.

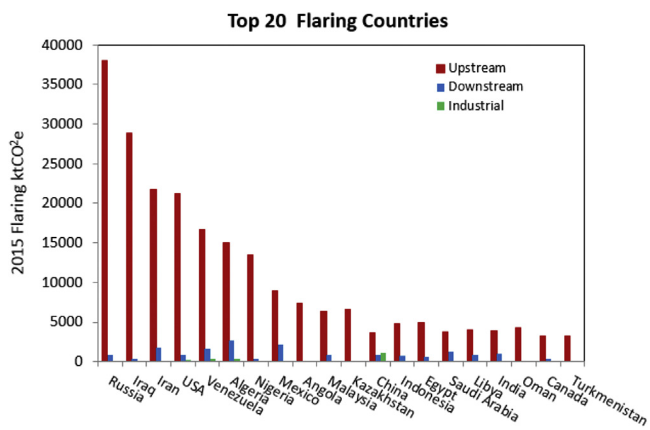

Fig. 2. Top 20 countries for total gas flaring in 2015.

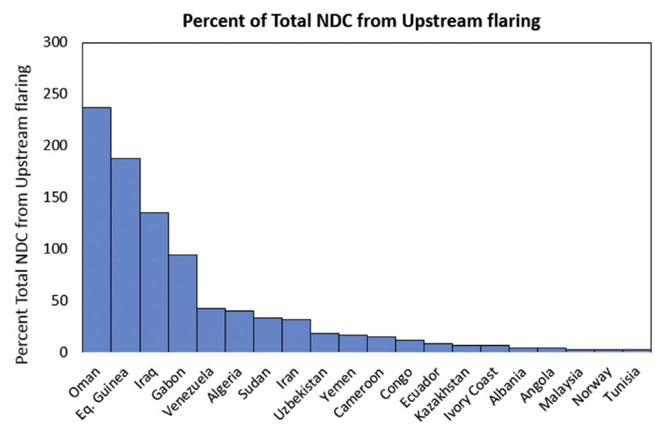

Fig. 4. Percent of the total NDC target that could be met with reductions in upstream flaring – top 20 countries.

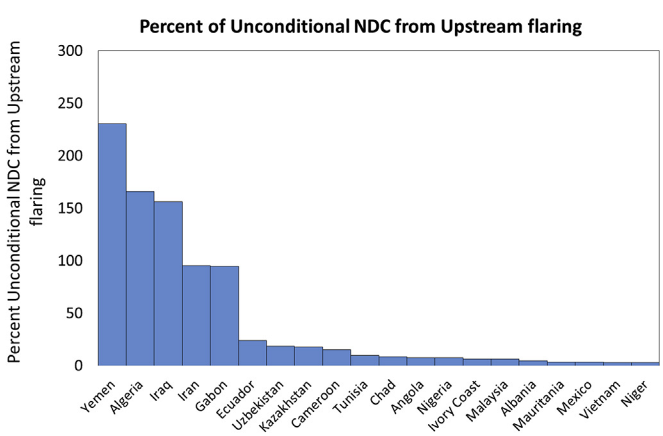

Fig. 3. Percent of the unconditional NDC target that could be met with reductions in upstream flaring – top 20 countries.

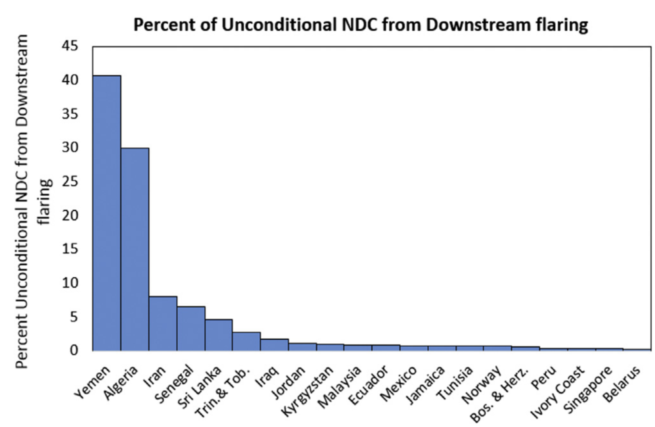

Fig. 5. Percent of the unconditional NDC target that could be met with reductions in downstream flaring – top 20 countries.

3. Results

3.1. Global flaring

Table 1 summarizes the global results on flaring emissions versus NDC targets. Overall, upstream flaring accounts for 90.6% of all flaring worldwide, downstream 8.4% and industrial 0.99%. This is in line with the findings from the 2015 study [2]. The estimated total emissions from flaring in 2015 is 285,347 kt of CO_2 equivalents. This represents 1.86% of the unconditional NDC target and 1.46% of the total NDC target. The upstream flaring would cover 1.69% of the unconditional and 1.32% of the total NDC target. Downstream flaring could cover 0.16% of the unconditional and 0.12% of the total NDC target. The industrial category could cover only a very small part of the NDC targets—0.018% of the unconditional and 0.01% of the total NDC target.

3.2. National results for upstream flaring

In 2015, upstream gas flaring was detected in 88 countries (Table 2). The vast majority of gas flaring is concentrated in a limited set of countries (Fig. 2). 85% of the 2015 flaring is

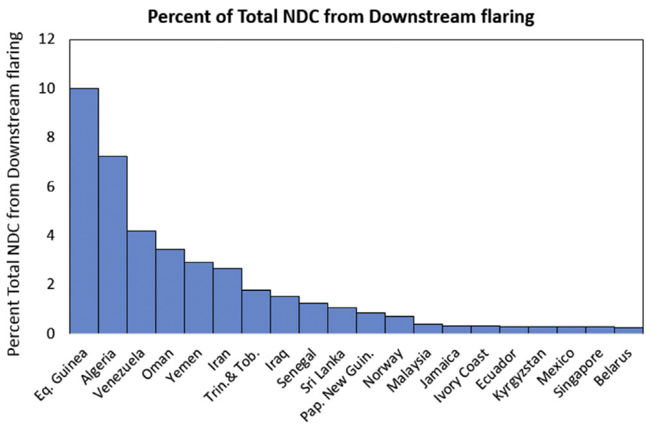

Fig. 6. Percent of the total NDC target that could be met with reductions in downstream flaring – top 20 countries.

concentrated in twenty countries. Russia leads here, with 38,047 kt of emissions from flaring. There is a relatively rapid fall off for the next eight countries – Iraq, Iran, USA, Venezuela, Algeria, Nigeria, Mexico and Angola. After this the next eleven countries are in the 3000 to 6000 kt range (Kazakhstan, Malaysia, Egypt, Indonesia, Oman, Libya, India, Saudi Arabia, China, Turkmenistan and Canada).

The 2015 gas flaring emissions were compared against unconditional and total NDC reduction targets. Fig. 3 shows that three countries could meet 100% of their unconditional NDC targets by reducing upstream flaring – Yemen (230%), Algeria (166%) and Iraq (156%). Two countries could meet more than 90% of their unconditional targets with upstream flaring – Iran (95%) and Gabon (94%). After this there is a 70% drop down to Ecuador, which could meet 24% of their unconditional target with upstream flaring. Countries that could meet 5–20% of their unconditional targets include Uzbekistan, Kazakhstan, Cameroon, Tunisia, Chad, Angola, Nigeria, Ivory Coast and Malaysia.

The rankings change when the total NDC targets are considered - conditional and unconditional (Fig. 4). The leading countries here are Oman (236%) and Equatorial Guinea (187%), countries that only have conditional NDC targets. Iraq drops from 156% for unconditional to 135% for the total NDC target. Gabon has no conditional target, so its ranking stays at 94%. Countries that could meet a substantial portion of their total NDC target from upstream flaring include Venezuela, Algeria, Sudan and Iran. Countries that could meet 5–20% of their total NDC target include Uzbekistan, Yemen, Cameroon, Congo, Ecuador, Kazakhstan and Ivory Coast.

Table 1
Global results comparing gas flaring to NDC reduction targets.

Global emissions (ktCO2e)	45,366,440
Conditional %	9.35%
Unconditional %	33.80%
Conditional reduction target (ktCO2e)	4,243,761
Unconditional reduction target (ktCO2e)	15,335,069
Total NDC reduction target (ktCO2e)	19,578,831
Total flaring (ktCO2e)	285,347
% of Total NDC target for total flaring	1.46%
% of Unconditional NDC target for total flaring	1.86%
Upstream flaring (ktCO2e)	258,579
% of Total NDC target for upstream	1.32%
% of Unconditional NDC target for upstream	1.69%
Downstream (ktCO2e)	23,953
% of Total NDC target for downstream	0.12%
% of Unconditional NDC target for downstream	0.16%
Industrial flaring (ktCO2e)	2814
% Total NDC for industrial flaring	0.014%
% Unconditional NDC for industrial flaring	0.018%

3.3. National results for downstream flaring

Only two countries could meet a substantial portion of their unconditional NDC targets by reducing downstream gas flaring—Yemen (40%) and Algeria (30%) (Fig. 5). Four countries could meet 2–8% of their unconditional targets with downstream flaring—Iran (8%), Senegal (6.4%), Sri Lanka (4.6%), Trinidad and Tobago (2.7%).

When downstream flaring is considered vis-à-vis the total NDC reduction targets all the numbers are less than 10% (Fig. 6). The leading country in terms of meeting the total NDC target from downstream flaring is Equatorial Guinea (9.99%). This is followed by Algeria (7.2%), Venezuela (4.2%), Oman (3.4%), Yemen (2.9%), Iran (2.7%), Trinidad and Tobago (1.8%), and Iraq (1.5%).

3.4. National results for industrial flaring

Reductions in industrial flaring could meet about 4% of the unconditional reduction targets for two countries: Algeria (4.1%) and Bosnia and Herzegovina (3.8%) (Fig. 7). After these two, all of the other countries fall below 0.3%. For the total NDC targets (Fig. 8), only three countries fall near 1% - Bosnia and Herzegovina (1.5%), Algeria (1%), and Venezuela (0.86%). None of the other countries reach 0.1%.

3.5. National results for total flaring

The greenhouse gas emissions for all flaring is calculated by adding the emission estimates for upstream, downstream and industrial flaring. The results for unconditional NDC targets (Fig. 9) look quite similar to those from upstream flaring, with three countries having the potential to exceed their targets through flaring reduction – Yemen (271%), Algeria (200%) and Iraq (158%). Each of these is notched up from the upstream numbers because of the addition of a substantial amount of downstream flaring.

For the total NDC targets (Fig. 10), again the results are quite similar to the upstream flaring results. Countries with the potential to meet their total NDC reduction targets from gas flaring reductions include Oman (240%), Equatorial Guinea (197%), Iraq (137%) and Iran (103%). Gabon (94%) comes close to having enough gas flaring to meet their total NDC reduction target. Countries that could meet nearly half of their total reduction target include Algeria (48%) and Venezuela (47%). Countries that could meet one third of their total emission reduction targets with gas flaring reductions include Iran (34%) and Sudan (34%). Countries that could meet 5–20% of their total NDC target include Yemen (19%), Uzbekistan

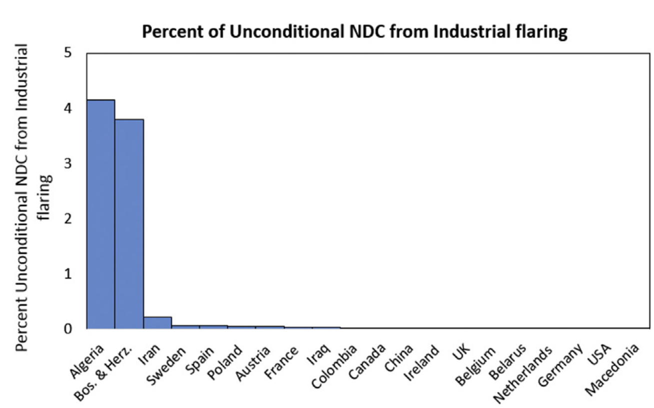

Fig. 7. Percent of the unconditional NDC target that could be met with reductions in industrial flaring – top 20 countries.

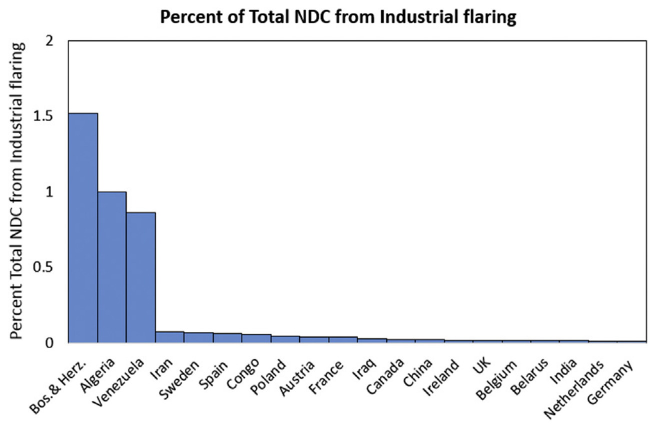

Fig. 8. Percent of the total NDC target that could be met with reductions in industrial flaring – top 20 countries.

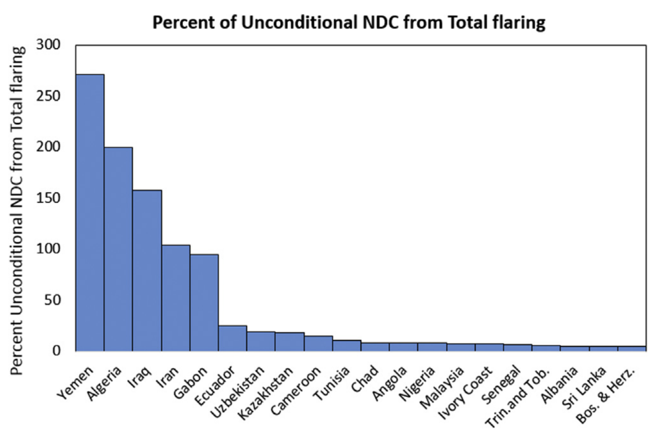

Fig. 9. Percent of the unconditional NDC target that could be met with reductions in total flaring – top 20 countries.

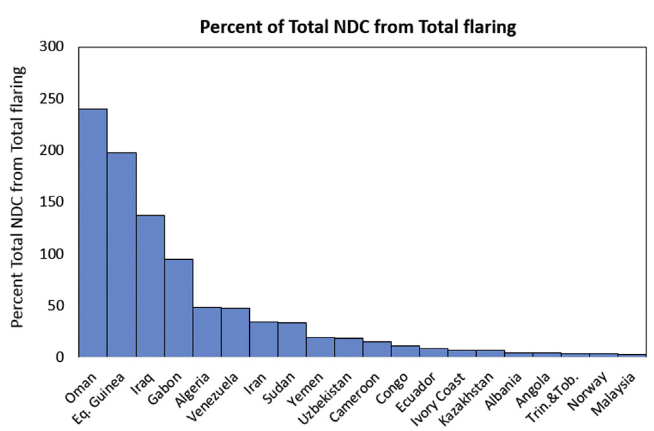

Fig. 10. Percent of the total NDC target that could be met with reductions in total flaring – top 20 countries.

(19%), Cameroon (15%), Congo (11%), Ecuador (8%), Ivory Coast (7%) and Kazakhstan (7%).

3.6. Countries with no NDC

A limited set of the signatories have submitted NDCs without quantified emission targets, including several countries with substantial flaring. By calculating the flared gas percentage of the reference emissions it is possible to examine the potential for these countries to reduce greenhouse gas emissions through utilization of gas currently flared (Fig. 11). The three leading countries here are Timor Leste, Turkmenistan, and Libya. Even in these countries the potential for meeting any future NDC target is modest, in the range from seven to ten percent.

4. Discussion

There is wide variation in the percentage of the NDC targets that could be met by a reduction of gas flaring. Russia and the USA are among the largest gas flaring nations, yet the flaring accounts for less than 2% of their NDC targets. In contrast, Iraq has the second largest flared gas volume, which could cover their NDC target more than two times. Three variables go into the calculation, the total greenhouse gas emission in the reference year, the percentage of the NDC target, and flared gas emissions. For the 20 leading gas flaring countries, the percentage of the unconditional NDC target is a leading determiner of the percentage of the NDC target that can be met with gas flaring reduction (Fig. 12). The oil-producing countries with low NDC target percentages have the highest potential to meet those targets with gas flaring reductions. Russia is in a class of its own, committing to a 70% reduction in greenhouse gas emissions from a base year of 1990. As a result, the potential contribution of gas flaring reduction is quite low, only 1.52%, despite the fact that Russia is the leading country in terms of flared gas volume. For the USA, with a 30% reduction target, gas flaring reduction potential contribution to the target is only a tenth of a percent.

5. Conclusions

Globally, flaring reductions could provide less than 2% of the emission reductions presented in the NDCs, 1.86% and 1.46% for unconditional and total NDC reduction targets respectively. Within an individual country the potential to meet NDC targets varies as a function of the flared gas volume, total projected emissions and the NDC goal as a % of total projected emissions. In general, gas flaring reduction has low potential to meet NDC targets in countries with high projected emissions, even if there are substantial amounts of gas flaring. This includes leading gas flaring countries such as Russia and the USA. The converse to this is countries that have substantial amounts of gas flaring and low NDC target. Most countries will inevitably need to develop a mix of reduction sources

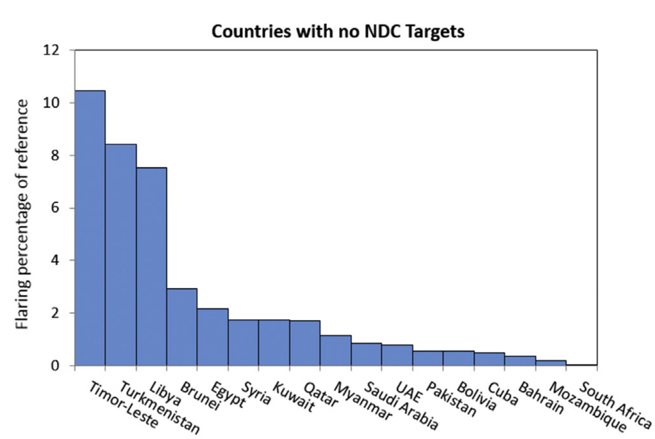

Fig. 11. Gas flaring as a percentage of total emissions for signatories who have not established NDC target levels.

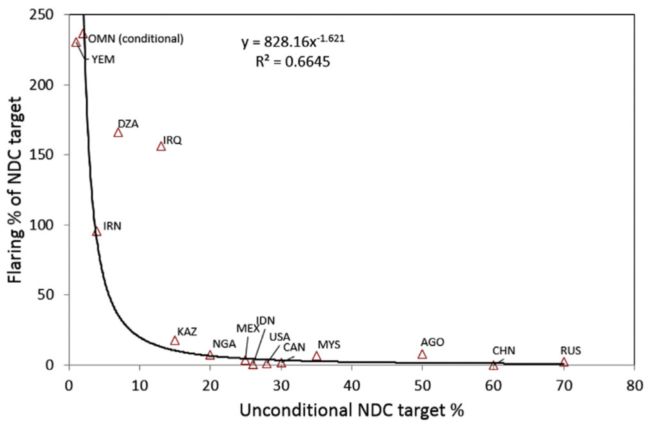

Fig. 12. Countries with high potential to meet their NDC targets have substantial gas flaring and low NDC target levels.

to achieve their NDC reduction targets. However, there are three countries that could meet more than 100% of their unconditional NDC targets from gas flaring reductions: Yemen, Algeria and Iraq. Iran and Gabon could meet more that 90% of their unconditional targets from upstream gas flaring.

Upstream flaring dominates over downstream and industrial flaring, both in terms of flaring site numbers and emission totals. Upstream flaring accounts for 90.6% of all flaring detected by VIIRS in 2015, with the capacity to cover 1.69% of conditional and 1.32% of total NDC targets. Countries that could exceed their unconditional NDC targets from upstream flaring reductions include Yemen (230%), Algeria (166%) and Iraq (156). Countries with the capacity to cover their total NDC reduction targets with upstream flaring include Oman (237%), Equatorial Guinea (111%) and Iraq (128%). It should be noted that the NDC targets for Oman and Equatorial Guinea are only conditional, with no unconditional target levels.

It is noteworthy that almost all gas flaring is illegal in two of the countries with the largest upstream flaring amounts: Russia and Nigeria. This is an indication that bans on gas flaring may not be effective by themselves and additional government incentives may be key to reducing flaring levels. This situation also points out the difficulty in enforcing gas flaring regulations given the remote location of many flares.

Downstream and industrial flaring account for 8.4% and 0.99% of global flaring, respectively. While the potential to meet the global NDC reduction target is low, there is a limited set of countries with potential to meet a portion of their NDC targets through reduction in downstream and industrial flaring, especially in the unconditional category. . The two leading countries in terms of capacity to meet their unconditional NDC targets by reducing downstream gas flaring are Yemen (40%) and Algeria (30%). Other notable countries having capacity to meet a portion of their unconditional NDC targets with downstream flaring include Iran (8%), Senegal (6.4%), Sri Lanka (4.6%), Trinidad and Tobago (2.7%). Reductions in industrial flaring could meet about 4% of the unconditional reduction targets for two countries – Algeria (4.1%) and Bosnia and Herzegovina (3.8%).

Several countries with no NDC targets could achieve modest greenhouse gas reductions though the curtailment of gas flaring. This includes Timor Leste, Turkmenistan, and Libya. Gas flaring in these countries is 7–10% of their total greenhouse gas emissions.

One of the arguments used against forced reductions in fossil fuel combustion is that this could result in lower economic output and reduced standards of living. This argument cannot be made against gas flaring reductions, which produces an energy source commodity with market value. The predominance of upstream flaring indicates that upstream flaring should be the primary flaring type considered in efforts to reduce fossil fuel greenhouse gas emissions.

These initial results can be used by countries to inform their investment strategy for achieving greenhouse gas emission reduction targets. Countries that can meet more than 10% of their NDC targets from gas flaring should have a high incentive to invest in gas flaring reductions. Countries that can exceed their NDC target through gas flaring reductions may use these results as a basis for increasing their NDC reduction targets. Countries that have yet to establish NDC targets can use these results as input to their NDC deliberations. Several of the leading gas flaring nations, such as Russia and the USA, have extremely low percentage of their NDC targets that could be achieved through gas flaring reductions. In these cases, other rationales for gas flaring reductions will likely need to be promoted, such as concerns over air pollution and full utilization of fossil fuel resources.

In order to confirm greenhouse gas emission reductions from gas flaring, there needs to be a monitoring, verification, and reporting (MRV) system for global gas flaring. Satellite observations are key to such an MRV system due to the wide spatial distribution and remote setting for most gas flaring sites. NASA and NOAA plan to continue flying a series of VIIRS instruments over the next two decades, extending past the 2030 date set for accomplishing the NDC reductions. The second VIIRS was successfully launched in November of 2017. Three more VIIRS instruments are planned, with launches approximately every five years. Thus, VIIRS can be regarded as one of the key observing systems for tracking flaring reductions in support of the Paris Climate Agreement.

Acknowledgements

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.esr.2017.12.012.

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