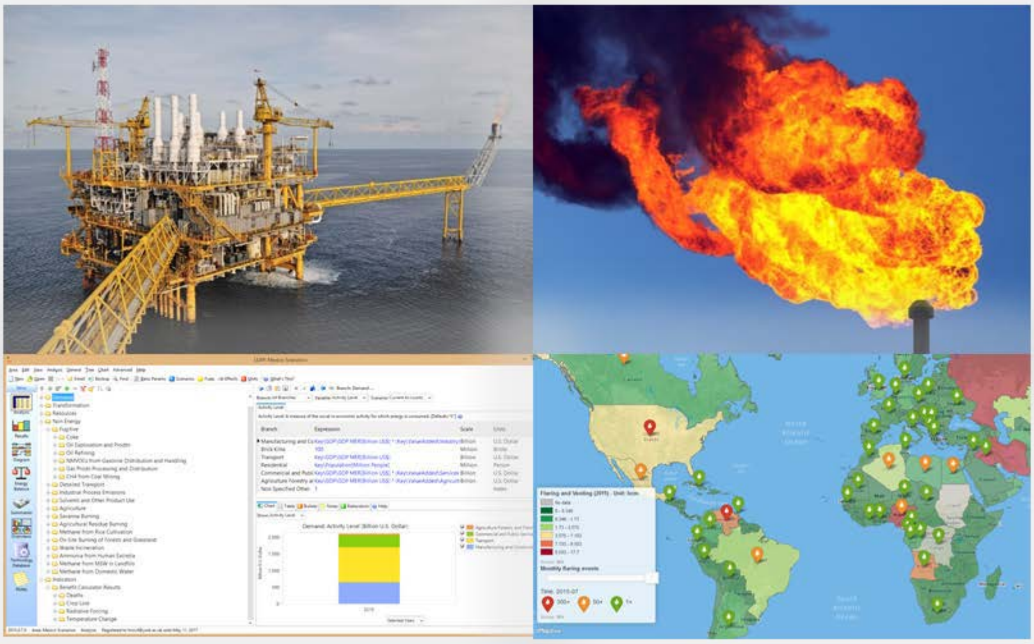
Technical note on the sources and spatial analysis of data available for the Global Gas Flaring Web Platform

Oil and Gas Initiative of the Climate and Clean Air Coalition (CCAC)



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1. INTRODUCTION

The following report describes the development of a web platform for visualizing global flaring activity. Flaring of associated gas by the oil and gas industry is still a major environmental issue despite recent global initiatives to reduce levels of routine flaring to zero by 2030. According to the World Bank, gas flares at oil production sites around the globe burn approximately 140 billion cubic meters of natural gas annually, causing more than 350 million tons of CO_2 to be emitted to the atmosphere (World Bank, 2015). The Global Flaring Web Platform has been produced for the Climate and Clean Air Coalition (CCAC) Oil and Gas Initiative in order to provide an overview of global flaring activity; complementing other data sources on flaring available elsewhere on the web and containing additional information related to potential reductions in flaring emissions and in particular black carbon (available via its website: oag.sei-international.org).

An extensive data search was undertaken at the beginning of this project that yielded only limited global coverage of flaring and its associated impacts. The location of flaring is seldom reported or mapped by companies or countries themselves. Detailed national datasets are limited to just a few countries. Until recently data on national flare volumes up until 2011 only were available from the World Bank's Global Gas Flare Reduction (GGFR) programme website and was based on older satellite technology. Recently, the US National Oceanic and Atmospheric Administration (NOAA) has published flaring data for 2012- 2014 based on data from a different satellite sensor and using a refined algorithm to detect flaring.
Due to the paucity of data at a global level there is a need to combine a range of different data sources to provide the user with an overall appreciation of where flaring is taking place and the potential impact of this on people and the environment. Therefore, the purpose of this platform developed for the Oil and Gas Initiative is to enable stakeholders to:

1. gain an overview of the scale, location and impact flaring and venting has at a global dimension;
2. visualize the changing situation – location and temporal;
3. appreciate the risk and exposure of people in terms of health; and
4. examine national data.

It has also been set up to be used to monitor progress of the Zero Routine Flaring Initiative launched by the World Bank in 2015 as information becomes available.

This platform is scalable so that when new global data sources become available they can be incorporated easily within the platform. A number of platforms already exist showing different aspects related to oil and gas production including flare detection and global flaring assessments. These include sources such as the Global Carbon Atlas, Skytruth and Flaretracker (Nigeria) which provide web-based platforms and data portals such as the World Bank and Joint Organisations Data Initiative (JODI).

1.1 About flaring

Flaring takes places during different stages of oil and gas production at onshore and offshore installations (see Figure 1.1). During the production stage, 'associated' gas which is comprised mainly of methane, can sometimes be dissolved in the extracted oil and therefore needs to be separated from it. This usually takes place on-site at the installation. Also, gas can also sometimes become trapped underground within the oil reservoir and then released as the oil is brought to the surface through extraction.

Figure 1.1 Typical offshore oil production facility

Routine flaring is used as a safety measure to avoid the build-up of dangerous gas pressure or alternatively it can be vented into the atmosphere directly. Flaring and venting typically takes place at upstream oil production operations where there is often a lack of processing capacity or transportation infrastructure to take away the gas and then re-use it for other purposes. However, flaring rarely takes place during the production of natural gas.

Non-routine flaring takes place when gas is released and burnt during the exploration phase where well testing is carried out to assess potential production capacity. It also takes place when equipment needs depressurizing or for inspection, maintenance, well servicing and testing. The gas is sometime re-injected into the ground to increase pressure in extraction operations. However, the main issue why many companies flare gas routinely is that it is the cheapest and easiest option for them, especially for offshore operations or those facilities too far away from suitable markets where it could be utilized. Also, the economic return on the sale of the gas is usually low compared to the capital costs associated with capturing it because of low market prices and the actual quantity produced. This means there is often little incentive for companies to invest in technology. What is needed is for companies to be made aware of the opportunities to use this technology and the CCAC Oil and Gas Initiative has undertaken a technology mapping exercise with PEMEX in Mexico to identify potential roadmaps for implementation.

When gas is flared at an installation it is taken by pipes some distance away from the operating platform to a flare tip (see Figure 1.2) usually located in a chimney stack. Under ideal conditions, flaring of the associated gas converts the methane into CO_2 and water vapour. However, these conditions seldom exist due to a number of factors affecting the efficiency of gas combustion. These include the gas velocity (efficiency of the flare), local meteorology and type of flare burner. The volume of gas burned also depends on how long the burner is lit for i.e. whether there is a need to maintain a specific pressure in the well. Due to inefficient combustion processes there is often unburned fuel or other by-products released and one of these is black carbon (BC). Others include NO_x and non-methane volatile organic compounds (NMVOC), sulphur dioxide (SO_2), carbon monoxide (CO), heavy metals (HM) and particulates (PM_{10} and $PM_{2.5}$).

Figure 1.2 Example of gas flaring tip

The amount of greenhouse gases (GHGs) produced when gas is flared depends on the mix of hydrocarbons in the oil. Methane (CH_4) is the predominant gas in the flare which is burnt and is mixed with CO_2, nitrogen, hydrogen sulphide, and small amounts of other gases. Venting releases these gases directly into the atmosphere and the impacts can be significant in terms of climate change, in particular for CH_4 which has 25 times greater ability to trap heat in the atmosphere (global warming potential) than CO_2 over a 100 year timeframe (IPCC, 2007). CH_4 is also a precursor to the formation of Ozone which can harm human health and reduce crop yields.

Black Carbon (BC) (also known as soot) emissions are produced when there has been insufficient mixing of the gas with oxygen in the air to complete the combustion process. An example of this is clearly visible at an oil production facility in Mexico (Figure 1.3).

Figure 1.3 Emissions of black carbon from a flare in Mexico (August, 2015). Imagery from Google Earth (Digital Globe copyright)

BC is referred to as a short-lived climate pollutant (SCLP) and its impact on climate can be significant but it has the advantage that it is removed from the atmosphere quickly (a matter of days) compared to CO_2 which has the potential to remain in the atmosphere for much longer (potentially hundreds of years). Flaring contributes between 1-8% of global BC emissions (Stohl et al 2013). Reducing emissions of BC from flaring globally has been recognised by the CCAC as being important in order to mitigate climate change impacts. Flaring in and near the Arctic areas is of particular concern because studies show that the Arctic is warming twice as fast as everywhere else on the globe. Data from the NASA-supported National Snow and Ice Data Center (NSIDC) shows clear evidence that Arctic sea ice had reached its lowest winter point since satellite observations began in the late 1979 (NASA, 2015).

BC deposits in the Arctic affect climate change in two ways. Firstly, BC particles can absorb heat and melt the ice and snow. Secondly, as the BC particles change the colour of the snow/ice cap less sunlight is reflected back to space to reduce temperatures. As much as 40 per cent of BC in the Arctic originates from flaring (Stohl et al, 2013). Other sources such as biomass burning, shipping and residential waste incineration also contribute to BC emissions. However, the Arctic contains approximately 20 per cent of the World's oil and gas production and as this is likely to increase in the future there is potential for more flaring.

BC also poses a health risk as it is a major contributor to the fine particulate matter concentrations in the air ($PM_{2.5}$). It is small enough to be easily inhaled into the lungs and therefore can cause adverse health effects such as respiratory disease and exacerbate other cardio-vascular related conditions. However, very few studies have been undertaken to assess the impact of flaring on human health. People living close to flares may suffer from other health problems in combination with other pollutants (nitrogen monoxide, benzene and volatile organic pollutants). They may also suffer stress-related health risks due to noise or worry about dangers of explosion e.g. following events such as Buncefield, UK and the Texas City, US refinery in 2005.

1.2 Measurement of emissions

In order to assess BC emissions and other pollutants, accurate and site-specific data is required from oil and gas platforms. Many companies only provide this information on a voluntarily basis. In some countries such as Mexico, where companies are state owned or partly-owned, more stringent regulations are in place and they are required to provide data on emissions. Under the United Nations Framework on Climate Change Convention (UNFCCC) many countries and those especially from lower income nations are not able to report flaring volumes. Often the resources to monitor and measure flaring accurately do not exist. Sometimes there is the lack of political will or enforcement of regulations. Even when reporting does take place there can be a high degree of uncertainty associated with the values reported as they are estimates. In 2015, the US EPA were required to revise emission factors for reporting industrial emissions as it was found they had been using outdated emission factors in compiling state emission inventories (Pasheilich,2015).

The quantification of emissions is usually based on the following formula:

Emission (type) = Activity Rate x Emission Factor

Two approaches can be taken to obtain relevant data: top-down using satellite data or bottom-up through direct measurement. Both can be costly and difficult to accomplish.

Assessing emissions from an individual flare is problematic as a number of site-specific factors can affect the values measured including composition of gases, the intermittent flow of waste gas, environmental conditions including meteorology, the height of the chimney/stack and whether air or water is pumped into the flare tip (this increases buoyancy of the gas when it is injected into the flame). These are difficult to measure and often costly. In addition, fugitive emissions come from different parts of the oil installation's infrastructure e.g. from the pipe valves, flanges and mechanical seals. It is often costly to assess leaks across the whole of the operation (ICCT, 2010). Simply, the location of offshore platforms can make quantifying these emissions extremely difficult. As a demonstration that it is possible, Norway has used technology coupled with national regulations and has seen routine flaring almost curtailed. In Norway, about 70 per cent of the platforms have metering systems (EMEP, 1996).

Disparities in the emission factors used to quantify emissions can also contribute to uncertainty in the quantification of BC emissions. A study by Weyant et al. (2016) based on a measurement campaign in the Bakken oil producing region of the US found that emission factors varied over 2 orders of magnitude. This was from non-visible smoking flares and so it is quite conceivable that those from smoking flares will be higher. New field measurement techniques are being developed such as using SKY LOSA (Line-Of-Sight Attenuation of sky-light) to improve BC estimates and derive more accurate emission factors (Johnson et al. 2011, 2012, 2013). SKY LOSA is an optical technique that measures plume velocity and monochromatic transmissivity of sky-light through the smoke plume.

Satellite data can only provide a global or regional assessment of flaring in terms of activity. Currently, satellite technology is not able to measure methane emissions from venting nor BC emissions from flaring directly (GGFR, 2012). It is reasonably good at identifying location and duration due to daily measurements but is hampered by lack of calibration data which relate brightness values recorded by the sensor to physical quanta. Data can be affected by other factors including surface reflectance from different sources (which all contribute to the signal received by the sensor), cloud cover, humidity, solar glare, artificial lighting etc. Therefore, information from satellites is currently limited to just giving an indication whether flaring emissions are increasing or decreasing rather than absolute values.

Gas flare detection from satellites on a routine basis was regularly undertaken by the National Oceanic Aeronautical Administration (NOAA) using the U.S. Air Force's Defense Meteorological Satellite Program (DMSP) satellite and since 2011 it has been using the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) satellite. The sensor collects data over a wider spectral region and at a higher spatial resolution than the previous satellite operated by NOAA e.g. each pixel represents a smaller land surface area improving detectability of the flares (NASA website). Flaring activity is detected by VIIRS as it records near-infrared and short-wave infrared data during night-time passes of sites.

Flaring activity using satellite was carried out by Casadio etc (2012) using the Along Track Scanning Radiometer (ASTR) sensor on-board the European Space Agency Earth Resources Satellites. Flaring activity was detected by the radiances from sensors in different wavelengths (short-wave, mid and thermal infrared) to estimate the effective flame temperature and size. This has the advantage of providing a detailed characterization of the active flames.

Satellite monitoring of emissions directly has also been achieved by atmospheric concentration sensing. NASA's Atmospheric Infrared Sounder (on its AQUA satellite) and the Ozone Monitoring Instrument (on AURA) have the ability to detect CO_2/methane and NO_2, respectively. Recent research by Li (2016) has estimated BC emissions by proxy using satellite sensors used to detect nitrogen oxide emissions. NO_x is produced during the combustion process and therefore by detecting the location of flaring sites and linking them with direct measurements of BC it feasible to quantify the emissions from sites elsewhere.

Some caution should be used with satellite data. Researchers at University of North Dakota (UND, 2015) found satellite images of flaring were processed so that they were 100 times brighter than the actual image, making flare footprints appear to be larger than they actually were. This was based on a study in the Bakken oil fields in the US.

A new generation of low cost, small satellites called smallsats (also known as nanosats, cubesats, microsats and minisats) are being deployed by government, commerce and academia for a range of purposes. Some for example known as PocketQubes, are just five cubic centimetres each weighing as little as 150 grammes. They can be stacked together to build larger satellites. CubeSats on the other hand are very small satellites built to standard dimensions .The advantage of these are that they can be built for a fraction of the cost of traditional satellites. They can also piggy-back on the launch of space rockets used for other purposes.

Euroconsult predicts that a total of 510 small satellites are to be launched by 2020 (Euroconsult, 2015). These may offer greater opportunities to monitor and measure methane and BC specifically. For example, GHGsat (GHGsat, 2016), planned to be launched in 2016, will monitor greenhouse gases and air quality gas emissions for a range of industrial sectors. These new satellites will still require calibration and validation of any measurements they take against real-world values.

The advantages and disadvantages of both approaches are shown in Table 1.1.

Satellite Data	**Measured/Metered Data**
Advantages: - covers wide geographic area, - frequent repeat time (daily images) - new low cost satellites available to detect emissions - verification of company flaring reports Disadvantages: - cannot quantify black carbon emissions - mixed reflectance signal, signal saturated by other sources - snapshot in time so may miss some flaring activity - not all flaring with flame detectable (enclosed) - relies on night-time flaring detection - affected by cloud cover	Advantages: - more accurate and continuous measurement - measure different components of oil production chain - identify leakages of fugitive emissions Disadvantages: - difficult to measure as emissions can come from all equipment - costly to measure (equipment, location) - self-reporting can lead to inaccuracies

Table 1.1 Comparison of satellite versus in situ measurements of flaring and venting

Overall, the detection of gas flares is possible using satellite technology however there is still a long way to go before accurate measurements of the emissions are routinely collected. The emission factors for BC are still being developed due to the broad range of environmental and operational conditions that BC is emitted under. Improving these emission factors will enable better assessments of the global impacts of oil and gas operations.

What clearly is lacking in order to make any meaningful assessments are emission inventories which characterise the full sources of emissions from the Oil and Gas sector. Flaring and venting appear to have been side-stepped in the compilation of GHG emissions at all levels (local to inter-governmental). Compiling these detailed inventories would enable improved modelling and assessments at all scales – global for studies of the impact on climate change to local for assessments of health impacts and damage to crops. The current situation cannot do this as there are too many uncertainties.

2. GIS ANALYSIS OF FLARING

The original intention of this project was to identify the source, location and emissions of black carbon (BC) globally but as has been shown the current state of information is at too far an early stage to be able to do this. This is in part due to the level of scientific understanding of the processes involved in the formation and atmospheric transport of BC. It is also due to the lack of monitoring and measurement being carried out at sites. Open publication of this data would also enable more informed understanding of the data obtained from satellites i.e. through calibration and validation of models. The oil and gas industry is keen to demonstrate its environmental credentials yet self-reporting is rare. Also, the industry is complicated due to ownership, production rights and the jurisdiction the production facility falls under. Satellite imagery cannot determine who is responsible for emissions. This requires other datasets which are either unavailable or too costly.

The following analysis provides an overview of what is possible with the data currently available.

2.1 Overview of flaring activity

For this analysis two time periods will be considered – the historical time period which uses data from the World Bank's GGFR up to 2011 and the recent data from NOAA 2012-2014 as these used different sources of satellite data and methods to process the data. Figure 2.1 combines this data to show the annual total volume flared for top 20 flaring countries and the rest of the World 2007-2014.

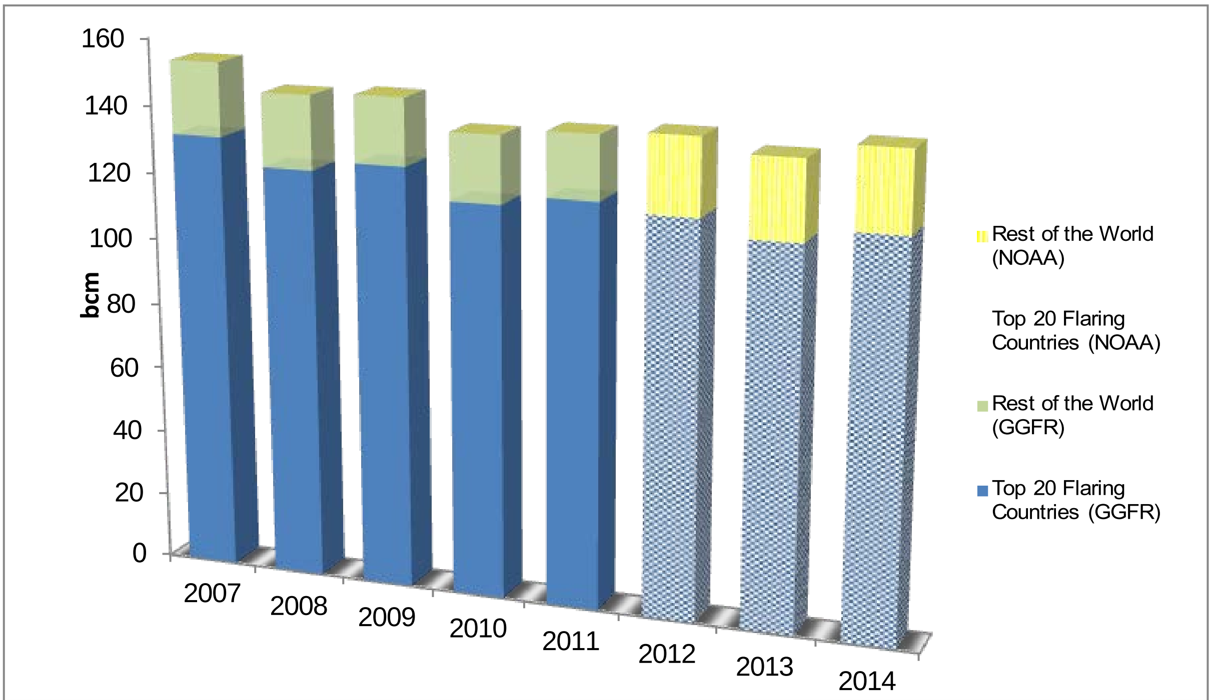

Figure 2.1 Total flared volume 2007-2014 (Sources: GGFR, NOAA)

Overall the graph shows only a limited decrease in flaring since 2007, approximately a 15 per cent reduction. Figure 2.2 shows the distribution of flaring events across the globe based on the recent NOAA satellite data. The estimated volume in billion cubic metres (bcm) are shown for each flare activity identified in 2014. Naturally, these relate to the major oil producing regions of the world.

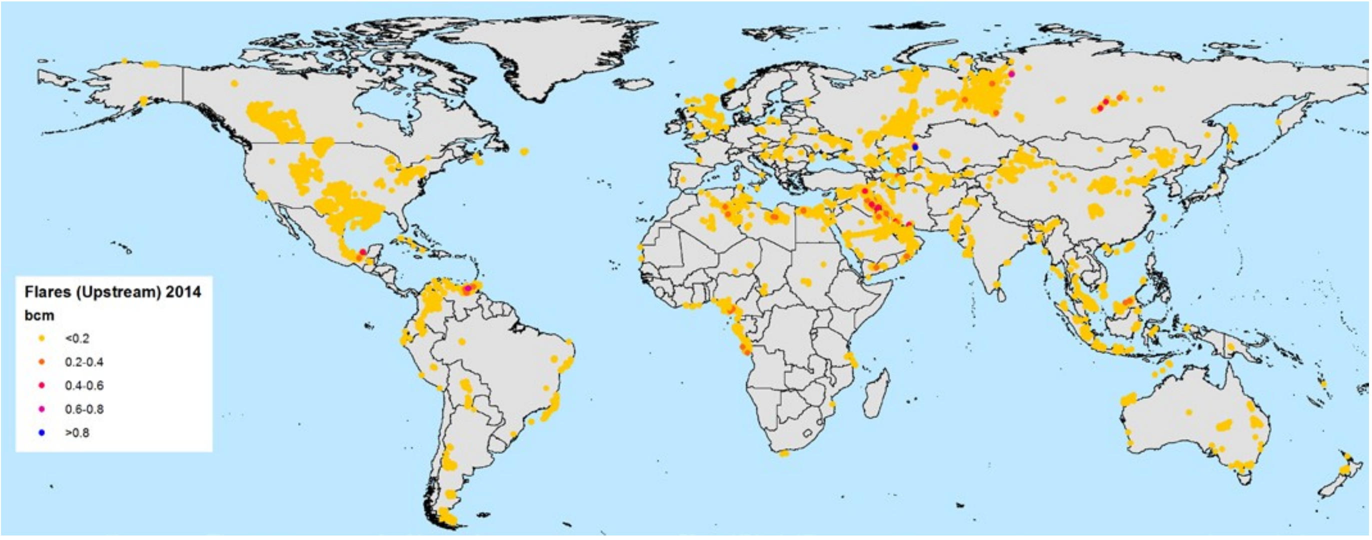

Figure 2.2 Distribution of flaring activity (2014) from NOAA VIIRS Satellite (Elvidge, 2016)

The numbers of flare sites recorded for the top 12 countries is shown in Table 2.1. Clearly, USA and Russia have very high flaring activity rates, possibly due to the large land area of each country and in the case of the USA the offshore operations in the Gulf of Mexico which contribute significantly to the higher total.

COUNTRY	FLARE COUNT
USA	2398
RUSSIA	1032
CANADA	327
NIGERIA	325
CHINA	308
IRAN	245
ALGERIA	159
MEXICO	148
INDONESIA	144
SAUDI ARABIA	139
EGYPT	125
KAZAKHSTAN	124

Table 2.1 Number of flares detected in 2012 from NOAA VIIRS Satellite (Elvidge, 2016)

However, in terms of flaring volume the data shown in Table 2.2 has different characteristics.

Rank	COUNTRY	*bcm*
1	RUSSIA	19.3
2	IRAQ	14.6
3	IRAN	12.7
4	USA	10.7
5	VENEZUELA	10.2
6	NIGERIA	8.4
7	ALGERIA	7.6
8	MEXICO	5.00
9	KAZAKHSTAN	4.03
10	MALAYSIA	3.4
	GLOBAL TOTAL	*141.6*

Table 2.2 Top 10 flaring countries from NOAA VIIRS data, 2014 (NOAA, Elvidge 2016)

The top 10 countries account for nearly 70 per cent of flaring with highest volumes coming from Russia, Venezuela, Iraq, Kazakhstan, Iran and the US. The total volume flared globally has actually increased slightly to 142 bcm per year compared to 2012. In fact 47 out of 92 countries increased flaring between 2012 and 2014. So efforts to reduce flaring through technological substitution, gas utilization and regulation appear to have been negated through increases in production and subsequent flaring elsewhere. The data does not actually indicate whether flaring has taken place because of routine or non-routine flaring and so this could be explained by an increase in oil exploration where flaring is necessary. Data for each country has been aggregated and total flaring volume per year is shown in Figure 2.3 for 2014.

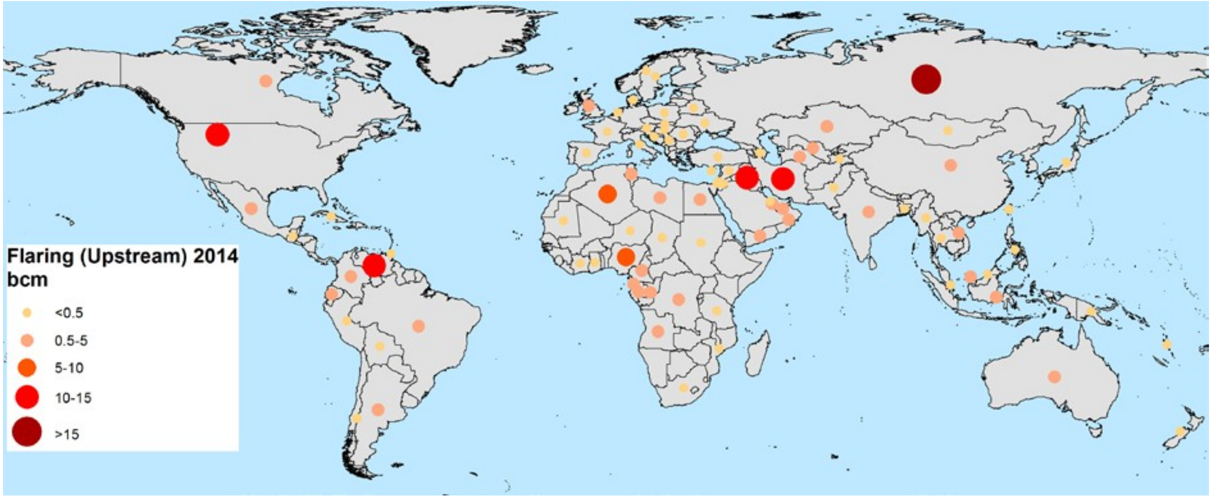

Figure 2.3 Flaring volume 2014 from NOAA VIIRS satellite (Elvidge , 2015)

The comparison between the two sources (GGFR and NOAA) has highlighted a couple of discrepancies between the estimated flaring volumes. For example, data from GGFR estimates that in

2011, Mexico flaring was 2.4 bcm whereas in this new database flaring is reported at 4.4 bcm in 2012 representing a significant increase in flaring. For Nigeria, the difference is in the opposite direction where the NOAA data show less flaring. Reasons for this are unclear. It could be that the use of an improved satellite sensor leads to greater accuracy in detecting the flares and eliminating those that are not due to its higher spectral resolution.

2.2 Black Carbon emissions

It has already been identified that assessments of BC emissions from satellite data are not yet possible. However, bottom-up approaches have been attempted to compile emissions inventories across the globe. For example, the global BC map from IIASA shown in Figure 2.4 uses modelled BC emissions from the energy production industry but does includes other sources in addition to oil and gas production. Again, the highest emission values are located in the major oil producing regions however many of these are off-shore.

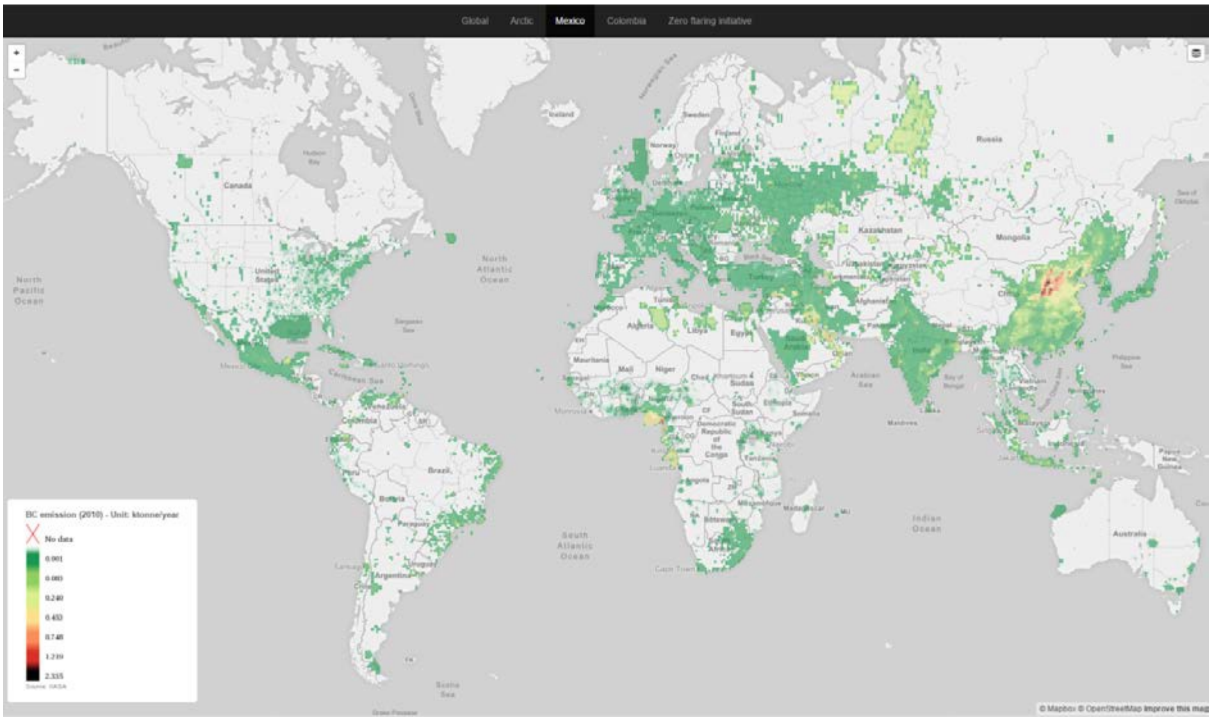

Figure 2.4 Gridded Black Carbon ECLIPSE (Source: IIASA)

There may also be a mismatch between the BC map and recent flaring activity. For example high BC emissions are located south of Beijing, China and this correlates well to the flaring events shown (Figure 2.5) However, such high emissions could also be due to other activities related to energy production included in this category.

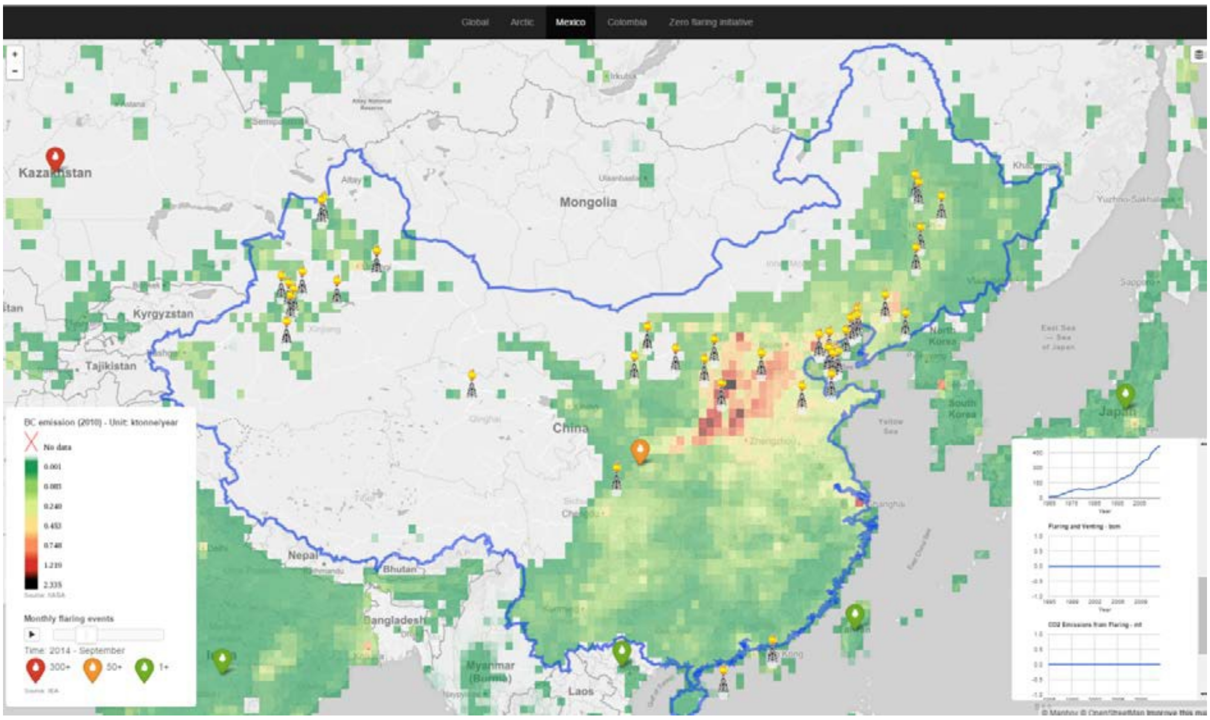

Figure 2.5 Gridded Black Carbon map (China) from ECLIPSE v5 (IIASA)

The following maps show high BC in the Gulf of Mexico and in Gulf of Guinea West Africa and these are again related to flaring activity (Figure 2.6).

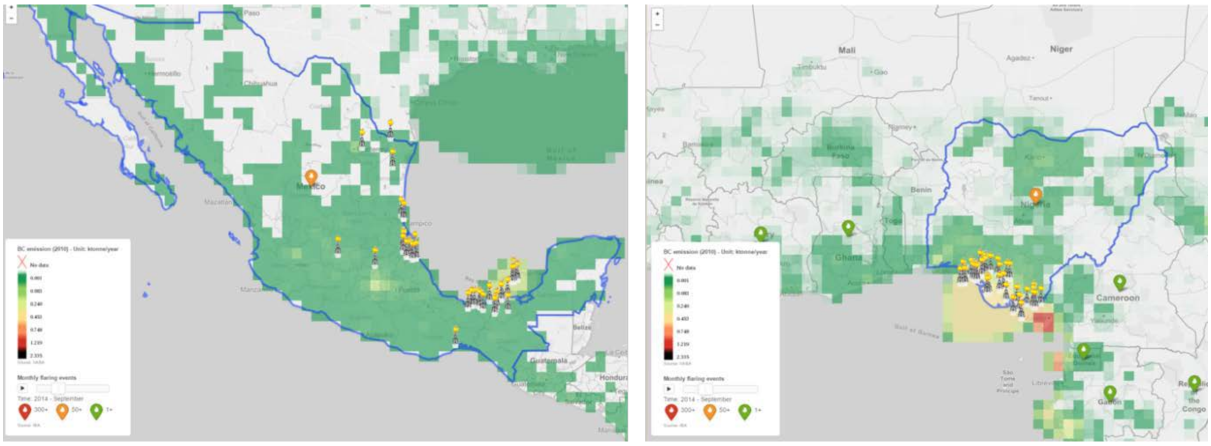

Figure 2.6 Gridded Black Carbon map (Mexico and Nigeria) from ECLIPSE v5 (IIASA)

3. SUMMARY

This report has described the data sources used to enable the visualisation of flaring from the oil and gas industry. The data has been obtained from a range of sources and was originally compiled in GIS and then exported as images, tables and GIS files to be used on an online map server. Details of this are available in a supplementary report (Report 3.1.2a – Use of the Gas Flaring Web Platform).

Further data will be added from national and intergovernmental agencies as well as from operating companies as they become available. However, data is very limited, inaccurate or remains undisclosed which hinders what can be shown. Some data is not spatially mapped to particular oil wells as companies may only report total flaring emissions covering all operations and may even include production in other countries. One of the prime data sources is from NOAA that provides access to daily, processed VIIRS satellite data. This data was also used by SKYTRUTH (current provider of the dataset used for the platform).

This project has highlighted that there is insufficient data available on a global basis to fully estimate the impact of flaring and its contribution to black carbon emissions to the atmosphere. Flaring and venting has received a considerable amount of exposure in the media and the CCAC has identified it as one of its initiatives. However, there is a need for better data collection and measurement. Firstly, satellite data can provide fairly regular updates to show the locations of flare events. Care needs to be taken in order to eliminate non-flare sites which can contribute to over-estimations of flare activity. Oil companies need to record their flaring activity along with other production data which may then be verified. This includes the spatial location of sites. They also need to provide measurements of actual flare events and also venting. This information also needs to be made available so that emissions inventories can be compiled more accurately.

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