Flare gas recovery as one of the clean development mechanism (CDM) practices

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Abstract. Global warming has become an important issue over the last few decades. One of the causes is the presence of Greenhouse Gases (GHG) which is emitted by human activities. Oil and gas production (drilling, work over, and refinery) for energy consume will be followed by the associated gas. The associated gas will be flared due to safety and non-economic reasons. The objectives of this study are reviewing the environmental impact and utilize technologies from flaring gas. The impact of flaring gas can lead to a decrease in human health, increased GHG, changing the plant metabolism, and decrease the production of agricultural crops. Due to these, there are some technologies to reduce flaring such as: reinjection (EOR activities), PNG, LPG, LNG, CNG, NGH, GTE, and GTL. The flare gas recovery is expected to obtain the lower value of GHG in the air and as one of the clean development mechanism (CDM) practices with a rethink, reuse, reduce, recovery, and recycle principle.

1. Introduction
Global climate changes have been the concern of many countries since UNCHE summit in Stockholm, Sweden in 1972. The summit emphasized sustainable development for future generation and supported by the Paris Agreement to reduce GHG emissions from 2°C to 1.5°C. Various efforts for reducing greenhouse gas emissions are more intensively conducted by the developed and developing countries. One of the efforts from the developed countries for reducing the GHG is through financial support. Increasing the CO2 concentration (June 2017 – June 2018 increase from 408.84 ppm to 410.79 ppm) [1], earth temperature, polar ice melting, rising of sea water level, and climate change are various symptoms of global warming caused by greenhouse gas effects.

The increase in human population is linear with increased energy consumption. The extraction of fossil fuels still dominates the world for the easiness reason. The energy reserves for petroleum source, based on the baseline calculation is 62 million TOE (Tones Oil Equivalent) in 2015 and increase to 101 TOE in 2025, 153 TOE in 2035 and 260 TOE in 2050. These reserves were also covered by the natural gas production of 25 TOE (2015), 43 TOE (2025), 61 TOE (2035) and 96 TOE (2050) [2].
Associated gas burning (average of 150 million m³ year⁻¹), from exploration activities called flaring gas, is a most potential source of black carbon of greenhouse gas emissions during hydrocarbon production and one cause of global warming [3][4][5].

In August of 2002, the World Summit on Sustainable Development of the Organization of Petroleum Exporting Countries (OPEC) has launched the GGFR (Global Gas Flaring Reduction Public-Private Partnership) which is aimed at supporting oil-producing countries to be able to optimally utilize flare gas and solving the problems in its utilization as an effort to implement CDM. The National Energy Management blueprint 2005-2025 as a reflection of the National Energy Policy Action Plan (2003-2020) of Ministry of Energy and Mineral Resources to undertake the reutilization of flare gas into a product with more economic value and profitability. The policy was followed up through the GOGII (Green Oil Gas Industry Initiative) on July 25, 2008, by the Directorate General of Oil and Gas, which has task of formulating and implementing policies and standardization of oil and gas. The objectives of the program are sustainable, environmentally friendly and clean oil and gas industries (zero flares, zero discharge, clean water, and renewable) [6]. As the government affirmation in the effort of reducing GHG, the Minister of EMR has issued Regulation Number 32 the Year 2017 about Utilization and Selling Price of Flare Gas in Upstream Oil and Gas Activities. The regulation stipulates that flare gas can be utilized by a Business Entity Holder of License for Business Management and/or Natural Gas Business License or the other government agency at a predetermined price, issued on May 2nd 2017 [3].

The objectives of this study are to review the environmental impact from flaring gas in Indonesia and the technologies for its utilization as one of CDM practises which covers the concept of cleaner processes such as minimization, control of pollution, reuse, recovery and recycling.

2. Flaring gas
A flare gas is an associated gas burned from the petroleum production process due to its uneconomical feasibility. Burning flare gas will liberate gas (hydrogen sulfide, toluene, benzene, sulfur dioxide, nitrogen dioxide and xylene), particulates, and soot (black carbon) [3][5]. Associated gas usually present in drilling, work over, and refinery and its combustion have been applied since 1935. The emergence of the idea to burn associated gas from the crude oil production is considered easy and cheap for a short period of time, without having to provide production equipment that is less feasible according to economic considerations. In addition, other reasons for gas combustion are: (1) Burning unused gas during the purification process; (2) Burning excess gas that cannot be used for commercial purposes; (3) Burning the steam collected from the top tank that occurs during the refining process; (4) Burning remaining gas when production stops and starts; (5) During the process of upset, maintenance, and equipment replacement.

The combustion has negative consequences for the environment (biotic or abiotic), human health, economy and safety [7]. If judging further, the negative impact of combustion of associated gas due to the inefficiency of the combustion process itself due to incomplete combustion that results in some products, CO₂, water and part of the hydrocarbon compound which will be emitted into the air [8].

3. Air impact
Carbon dioxide gas from flaring gas is a driven factor of greenhouse gas effect/GHG effect and should be a concern [9]. The GHG effect is a phenomenon of sunlight waves penetrating the earth's atmosphere but it cannot be reflected back into the atmosphere because there is such a shadow or black shield of gases formed from the greenhouse gasses so that it will be reflected back to earth. This causes the earth's surface temperature to increase as inside a building/space surrounded by glass. The greenhouse gases based on the Kyoto Protocol consist of CO₂ (carbon dioxide), N₂O (nitride/dinitrogen oxide), CH₄ (methane), SF₆ (sulfur hexafluoride), PFC (perfluorocarbons), and HFC (hydrofluorocarbons) [6].

Although the concentration of pollutants will decrease by increasing the distance of flare stack, the gasses have been emitted into the air and make the chain chemical reaction that will cause GW
indirectly. Table 1 shows the example of results of the emissions of flared gas in the Niger Delta Region of Nigeria in 2015 [5].

**Table 1. Concentration of flare gas emission [5]**

| Pollution       | Concentration (µg m\(^{-3}\)) | WHO (µg m\(^{-3}\)) |
|-----------------|--------------------------------|----------------------|
|                 | Flare Point 3 km from flare annually daily |                      |
| PM\(_{2.5}\)    | 1,959.73 391.95 10 25             |                      |
| NO\(_x\)        | 3,383.01 676.60 200 50            |                      |
| SO\(_x\)        | 31.41 6.28 125 50                 |                      |
| NMVOC           | 4,349.59 869.92 NA NA             |                      |
| CO              | 15,223.56 3,044.71 60 NA          |                      |
| OC              | 265.82 53.16 NA NA                |                      |

4. Human impact

There are several effects of flare gas on human beings comprising of respiratory disorders (asthma, bronchitis), blood disorders (leukemia, anemia), bone mass abnormalities, premature births with low weight, even fertility impairment. Exposure for a long time can cause memorial disorder, cancer, kidney disorder and lung organ damage, neurological disorders and others [7]. Acid rain also results from an emitted gas flare. Furthermore, NO\(_x\) and SO\(_x\) compounds when encountered with water will cause rainwater pH to fall down to 4.98 - 5.15 range [10]. The low pH can affect human mucous membrane, gastrointestinal wall, and abdominal ulcers. Effects of the Flare Gas for humans based on NAAQS (National Ambient Air Quality Standards) are presented in Table 2 [10].

**Table 2. Healthy impact of flaring gas**

| Pollutants               | Acceptance Level | Health Impact                                                                 |
|-------------------------|------------------|-------------------------------------------------------------------------------|
| Nitrogen oxides (NO\(_x\)) | 32 ppb \(^a\)   | Deterioration of lung function: irritation, asthmatics suspect                |
| Carbon monoxide (CO)    | 5 ppm \(^b\)    | Long-term health effects, headache, nausea, weakness                          |
| Sulfur oxide (SO\(_x\)) | 57 ppb \(^b\)   | Adverse effects on respiratory systems due to irritation and airway obstruction |
| Benzenes                | 0.096 µg m\(^{-3}\) \(^a\) | Blood disorder: leukemic, aplastic anemia, pancytopenia, leukocytes, thrombocytes |
| Toluene                 | 120 ng m\(^{-3}\) \(^b\) | Central nervous system disorder leading to narcosis, emotional imparity, headache and fatigue |
| Xylenes                 | 0.12 ng m\(^{-3}\) \(^b\) | Growth delayed, decreased fetal body weight, altered enzyme activities         |
| Styrene                 | Not Reported     | Skin irritant, eyes irritant, mucous membranes irritated, central nervous system depressant |
| Naphthalene             | 96 ng m\(^{-3}\) \(^b\) | Destroying the red blood cells membrane with the liberation of hemoglobin, irritating the eyes |
| Soot/Black Carbon       | 3.5 mg m\(^{-3}\) \(^c\) | Respiratory and pulmonary disorder cause accumulation of dust                  |
| Formaldehyde            | 0.75 ppm \(^c\)  | Lung and mucous membrane irritation, a carcinogen, and leukemic suspect        |

\(^a\) Mean annual \(^b\) Mean Daily \(^c\) 8-hour average
5. Economic impact
Heat radiation from a flaring gas processes affects the microbial population in the soil. The population decline causes decreasing organic matter decomposition in the soil and causing the decrease of pH of the soil. Sour soil will cause a decrease in crop production from an agricultural field and extreme cases will continue to food scarcity, food prices increase and result in the welfare of local farmers [7]. Activity of the flare gas will lead to decreased soil fertility, biogeochemical cycles of nutrients, and microclimate conditions of a region. It has been investigated in the Niger Delta Region, Nigeria causing a decrease in maize production at 2 km distance from the flare pad. The other ways air temperature of soil and leaf could decrease humidity of 11% causing a decrease in maize production at 2 km distance from the flare pad. The other ways air temperature of soil and leaf could decrease humidity of 11% causing a decrease in maize production at 2 km distance from the pad so that the type of agricultural crops with negative response to hot temperature shouldn’t plant around the flare area [10][11].

6. Flare gas utilization/flare gas recovery
Estimated potential flaring gas in Indonesia reached 749,046 MSCFD from 8,077,714 MSCFD grand total of gas production [12]. Given the potential and contents of the flare gas and its impact, there are several benefits that can be done to reduce the flare gas for eco-efficiency of the company. But Efficiency is obtained if associated gas is utilized for (68 ± 7)% [13]. Some of Gas Flare Recovery are listed below [9][10][14].

Reinjection. This method is generally used to maintain the presence of gas for future use and increase the efficiency of oil production in EOR activities (enhance oil recovery). This is commonly used for industries that have a small gas capacity.

GTG (Gas turbine generator). The resulting gas will be used as a power plant to meet the electricity needs of both the industry itself and the household. Research in Argentina says that burning 0.45 m³ of gas can produce 40 MW of power.

PNG (Pipeline natural gas). Although it is considered uneconomical especially for pipelines from offshore to onshore, gas pipeline installations cost an average of 1-5 USD depending on the terrain, but this way can be used to reduce combustion of the associated gas.

LPG (Liquefied petroleum gas). This technology is widely used because of the ease of storage and transportation of local markets. However, the process of removing the impurities (water vapor, CO₂, mercury vapor, and H₂S) makes this less economical for associated gas processing. But, some industries is founded have developed the technology to process only LPG content from the associated gas to increase the economic value.

LNG (Liquefied natural gas). LNG has a volume of 1/600 of gas volume at room temperature and requires more investment on a large scale. Large gas reservoir >85 bscm (billion standard cubic meter) have an investment of 1 billion. The long processes gas impurities, cooled to a liquid at -162°C temperature and regasification is one economical factor of LNG processing.

CNG (Compressed natural gas). CNG is almost the same as LNG, but compression doesn’t occur before the liquid phase. So that, no regasification process is required. Volume generated is also greater than 1/1200 of the volume of gas at room temperature.

NGH (Natural gas hydrates). The gas is hydrated to crystallize and stabilize at -200°C. This method is also potential in recovering the associated gas with a higher economic value than LNG.

GTE (Gas to ethylene) and methanol ammonia produce. Methane gas from associated gas and natural gas can be converted to methanol products as a material of DME (Dimethyl ether) and olefin (ethylene and propylene) used in reactors with conventional systems in catalyst production. Methane can also be
converted to ammonia as a raw material for fertilizer production. While ethylene is a product resulting from the breakdown of hydrocarbon compounds using heat, especially on NGL production as well as associated results of petroleum fractionation. Ethylene is commonly used in the production of LDPE (low-density polyethylene) and HDPE (high-density polyethylene).

GTL (Gas to liquid). These products are gasoline, diesel and wax. Today, liquid fuels have an advantage in terms of transport and storage [14]. Generally GTL is produced only with natural gas, but in Nigeria through Chevron Nigeria Limited starts producing GTL 70% and naphthalene 30% (mid-2014) with uses 15% of the flare gas, capacity of 34,000 barrels per day and is required to support a production capacity of approximately 9.6 MMSCMD (million standard cubic meters per day).

Further related to the above technology, based on the eco-efficiency said that CNG installation is more appropriate to use at distance <2,700 km, PNG distance 2,700 - 7,600 and LNG at distance> 7,600 km [10].

7. Clean development mechanism (CDM)
CDM is one of the agreements of the Kyoto Protocol 1997 to reduce emissions from Annex I Countries. The mechanism used is carbon trading for CER (certified emission reduction). CDM activities are divided into decreasing GHG degradation activities and absorption GHG from the atmosphere. Decreasing GHG is targeting for the industrial sector. Meanwhile, GHG absorption is targeted to the forestry sector [6]. Efficiency aspect is emphasized by integrating environmental and economic aspects and environmental conservation, social dynamics, and economic growth as its base. The principle and the categorized of clean production as listed below [15] and the simple concept of CDM is shown in Figure 1[16]:

- Rethink. What is more important between environment and safety? If we must flare it, it should be utilized;
- Reuse the flare gas for other purposes as above;
- Reduce this gas to minimize environment impact;
- Recovery is the same meaning as utilizing gas. Associated gas will be more useful with the other utilization. But it will give more investment to build the plant (LPG Mini Plant, CNG Plant etc);
- Recycle. The Enhanced Oil Recovery is one of these stages. The associated gas will reinject to maintenance reservoir pressure so that the fluid will flow by its self;

![Figure 1 Simple concept of CDM](image-url)
8. Conclusion
Crude oil or natural gas production activities for energy needs produce associated gas which is emerging from drilling, work over and refinery. Flaring gas has an impact on the environment, people and the economy. Air emission from flaring gas will be emerging the Greenhouse Gases that contribute to climate change. The utilization of flare gas such as reinjection for EOR activities, power plant, PNG, LPG, LNG, CNG, NGH, GTE, and GTL, as one of CDM practice can be used to produce a more environmentally friendly production process with the principle of rethink, reuse, reduce, recovery, and recycle.

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References
[1] Oxygen A P Daily CO2 2018 A pro oxygen Available at: https://www.co2.earth/global-co2-emissions. (Accessed: 7 July 2018)
[2] Dewan Energi Nasional 2016 Indonesia Energy Outlook 2016 (Jakarta: Dewan Energi Nasional Press)
[3] Republik Indonesia 2017 Peraturan menteri energi dan sumber daya mineral Republik Indonesia Nomor 32 Tahun 2017 tentang Pemanfaatan dan harga jual gas suar pada kegiatan usaha hulu minyak dan gas bumi. Berita Negara RI tahun 2017, No.652. Ditjen Perundangan-undangan Kementerian Hukum dan HAM Republik Indonesia. Jakarta.
[4] Fawole O G, Cai X M and MacKenzie A R 2016 Gas flaring and resultant air pollution: a review focusing on black carbon. Environ. Pollut. 216 182–197
[5] Giwa S O, Nwaokocha C N, Kuye S I and Adama K O 2017 Gas flaring attendant impacts of criteria and particulate pollutants: a case of Niger Delta Region of Nigeria. J. King Saud Univ. - Eng. Sci.
[6] Rangkuti Z P 2009 Model pemanfaatan gas ikutan di perusahaan migas dalam rangka mendukung mekanisme pembangunan bersih (studi kasus lapangan eksploitasi migas Tugu Barat, Indramayu, Jawa Barat) (Bogor: IPB Press)
[7] Ojiiagwo E, Odouvoa C F and Emekwuru 2016 Economics of gas to wire technology applied in gas flare management N. Engineering Science and Technology, an International Journal 19 2109–2118
[8] Ismail O S and Umukoro G E 2016 Modelling combustion reactions for gas flaring and its resulting emissions J. King Saud Univ. - Eng. Sci. 28 130–140
[9] Davoudi M, Rahimpour M R, Jokar S M, Nikbakht F and Abbasfard H 2013 The major sources of gas flaring and air contamination in the natural gas processing plants: a case study. J. Nat. Gas Sci. Eng. 13 7–19
[10] Soltanieh M, Zohрабian A, Gholiپور M J and Kalnay E A 2016 Review of global gas flaring and venting and impact on the environment : case study of Iran. Int. J. Greenh. Gas Control 49 488–509
[11] Isichei A O and Sanford W W 1976 The effect of waste gas flare on the surrounding vegetation in South-Eastern Nigeria. Journal of Applied Ecology 177–187
[12] Direktorat Jenderal Minyak dan Gas Bumi 2015 Statistik Minyak dan Gas Bumi 2015 (Jakarta: Ditjen Migas Press)
[13] Ancejonn O C D, Whyatt J D, Blackburn G A and Price C S 2015 Contributions of gas flaring to a global air pollution hotspot: spatial and temporal variations, impacts and alleviation Atmos. Environ. 118 184–193
[14] Zolfaghari M, Pirouzfar V and Sakhacenia H 2017 Technical characterization and economic evaluation of recovery of flare gas in various gas-processing plants. Energy 124 481–491
[15] Purwanto 2009 Penerapan teknologi produksi bersih untuk meningkatkan efisiensi dan
mencegah pencemaran industri (Semarang: Undip Press)

[16] Van Berkel R 2007 Cleaner production and eco-efficiency initiatives in Western Australia 1996 - 2004 J. Clean. Prod. 15 741-755