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ICChEAS 2019 IOP Conf. **Series: Materials Science and Engineering** 845 (2020) 012037
IOP Publishing doi:10.1088/1757-899X/845/1/012037 1 CO2 emission management in palm oil industries in Indonesia: a review Novi Sylvia^{1,2}, Yunardi ^{3*}, Husni Husin³ and Abrar Muslim ³ 1 Doctoral student at Faculty of **Engineering, Syiah Kuala University, Banda Aceh 23111, Indonesia** 2 **Department of Chemical Engineering, Malikussaleh University, Lhokseumawe, 24351, Indonesia** 3 **Department of Chemical Engineering, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia** E-mail: yunardi@unsyiah.ac.id
Abstract.

Within a few decades, Indonesia has become the largest palm oil-producing country, leaving Malaysia behind. It is undeniable that palm oil has significantly contributed to the economic growth of the country. However, the negative **impacts of the palm oil industry** are also evident, such as deforestation, environmental pollution, and social conflicts.

The **palm oil industry** has been known **as one of the big** greenhouse gases producers, including CO₂. Regardless of the pressure from the European Union, the Government of Indonesia (GOI) has committed to sustaining **the palm oil industry** since there are millions of workforces depend on their livelihood from these industries.

Concerning the negative impacts, the GOI requests that each palm oil company has to follow **the Indonesian Sustainable Palm Oil (ISPO)** certification. So far, around 20% of all palm oil industries in the country have received an ISPO certificate. It is expected by 2023, all palm oil industries have been certified by ISPO since this regulation is mandatory.

Implementing all ISPO guidelines in the palm oil industry is not only capable of sustaining the industry but also protecting the environment through the reduction of CO₂ and other greenhouse gasses. This paper will review the CO₂ management in the palm oil industry in Indonesia in the present situation, connected with ISPO as well as RSPO (Roundtable Sustainable Palm Oil). 1. Introduction Oil palm tree (*Elais quineensis* Jack) is a group of annual tropical plants, originating from Africa.

Oil palm trees came to Indonesia for the first time in 1848 and planted in the Bogor Botanical Garden. Several first oil palm plantation experiments were carried out in the southern part of Sumatra, including at Muara Enim (1869), Musi Ulu (1878), and Belitung (1890). The first oil palm plantation was established in 1911 in Tanah Itam Ulu (North Sumatra) by the Olie Palm Culture company and in Raja Island by the Huilleries de Sumatra-RCMA company. It was started with four oil palm seedlings brought by the Dutch from Mauritius in 1848 and then commercially cultivated in 1911.

The year 1911 can be regarded as the starting point of the era of the people and the Indonesian economy's dependence on oil palm [1,2]. In 1919, oil palm companies began exporting the first palm oil, Crude Palm Oil (CPO) to European countries from Tanah Deli Sumatra and Tamiang Aceh, at the amount of * To whom any correspondence should be addressed. ICChEAS 2019 IOP Conf. Series: Materials Science and Engineering 845 (2020) 012037 IOP Publishing doi:10.1088/1757-899X/845/1/012037 2 576 tons. In 1923, as much as 850 tons of Palm Kernel Oil (PKO) began to be exported to Europe.

In 1980, the area of Palm Oil had reached 294,560 ha with CPO production of 721,172 tons [3]. Indonesia produced 3 million tons of PKO and became the most significant crude palm oil (CPO) producer in the world, with a total production of 32 million tons or equivalent to around 46.6% of the world's total CPO production. The world market demand for CPO continues to increase and is estimated to reach 95.7

million tons in 2020. Meanwhile, the development of the Indonesian palm oil industry shows a positive trend, with an increase in production volume every year. This condition shows that the future of Indonesia's palm oil industry continues to grow to meet the world's CPO demand. It is undeniable that the rapid development of the palm oil industry in Indonesia has had a positive impact on the country's economy.

One indication is a decrease in poverty and an increase in the welfare of the people/community involving with the industry. The palm oil industry supports the lives of around 4.5 million farmers owning the oil palm plantation and million other people who work in this sector [4]. The palm oil industry also triggers a multiplier effect; for each increase in the final demand of CPO, there will be an increase in the output of the

national economy, which eventually will provide a significant contribution to the regional development. 2.

The palm oil industry in Indonesia Although received many critics from the developed country, particularly from the European Union, the palm oil industry has become the expectation not only from the Government side but also from the village communities. The industry possesses the significant potential to increase economic and social development in Indonesia.

As the demand for palm oil increases, more and more new lands for palm oil plantation are opened to back up the production. It is, therefore, not surprising if Indonesia produces 47 % of the world's palm oil from the plantation area of 7.9 million hectares. Also, the oil palm industry absorbs around 16.2 million workers, of which 4.2 million are direct ones, and the remaining are indirect ones.

Since the industry support the lives of million peoples both in urban and rural areas, the government and the people work together to sustain the industry even develop further [4]. Figure 1. Map of palm oil plantation distribution in Indonesia . Figure 1 presented the map showing the distribution areas of palm oil plantation in Indonesia.

Data from the Indonesian Central Bureau of Statistics (BPS) recorded that there are 1,592 large oil palm plantation companies in 2016, having a common area of oil palm plantations of 7,726 million ha out of the total oil palm plantation of 11.94 million hectares (ha). The remaining 4.66 million ha belong to individuals, cooperatives, communities, or small scale plantation companies . With this vast of palm ICCHEAS 2019 IOP Conf.

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doi:10.1088/1757-899X/845/1/012037 3 oil plantation, yearly oil production could reach up to 33.23 million tons, of which about 10.87 million tons produced by smaller scale plantations such as cooperative and communities, while a bigger portion of 22.36 million tons coming from big scale plantation companies.

In terms of plantation location, most of oil palm plantations in Indonesia are located in the island of Sumatra, with the most significant area being in the Riau Province, having 146 units of Palm Oil Mill (POM). The other growing areas of oil palm plantations are in Kalimantan and Sulawesi. 2.1. Palm oil production process Extracting palm oil from fresh fruit bunches (FFB) involves many sequential units of operations.

There are two types of oils produced from the palm tree, namely, crude palm oil (CPO)

and kernel oil. The CPO is the palm oil extracted from the fibrous mesocarp, and the latter is lauric oil produced from the palm kernel. Figure 2 presents the process flowsheet for the manufacture of palm oil from the FFB. Figure 2. Typical production process of palm oil in Indonesia.

Sterilization: Sterilization process comes first in the crude palm oil extraction. For 75-90 minutes, the fresh fruit bunches (FFB) are sterilized inside autoclave using steam at a temperature of 140°C, aiming at deactivating hydrolytic enzymes responsible for the breakdown of oil to free fatty acids and loosening the fruits from bunches. Oil cell breakdown will, then, coagulate the mucilage.

Stripping or threshing: Upon the completion of the sterilization process, fruits are stripped from the bunches and separated in a rotary drum stripper by lifting and dropping them through the stripper in order to be knocked out of the bunches. Bucket conveyor then collects the detached fruits falling through the space between the bars on the stripper and discharged into a digester.

Empty fruit bunches (EFB) resulted from the stripping operation, after all, their fruits being detached, will be wasted. **Digestion:** To digest the fruits, they are pulverized under the steam heated condition in a vertical cylindrical digester fitted with rotating arms. This process is carried out to break the mesocarp oil-bearing cells.

To facilitate the flow of the oils, hot water is added in a digester and no waste residue resulting from this step. ICChEAS 2019 IOP Conf. Series: Materials Science and Engineering 845 (2020) 012037 IOP Publishing doi:10.1088/1757-899X/845/1/012037 4
Palm oil extraction: The vertical cylindrical digester released oil mash, which then passes through a screw press and a vibrating screen, a hydrocyclone, and decanters, to separate the fine solids and water.

The oil is purified by using the centrifuge and vacuum drier before the transfer to the storage tank, where the temperature is maintained at 60°C with steam coil heating. The crude oil slurry is then fed into a clarification system for further separation and purification. The fiber and nuts are separated by passing through the depericarper [5].

At this stage, the crude palm oil (CPO) constitute a mixture of palm oil (35-45%), water (45-55%), and the variable portion of fibrous materials. Having passed the screw presser, the CPO will be pumped to a horizontal or vertical clarification tank in order to skim the oil from the top of the clarification tank. The CPO is then passed through a high speed, centrifuge, and a vacuum dryer before being transferred to storage tanks.

This process produces waste in the form of decanter wastewater and decanter cake. 2.2. Emissions in palm oil mills (POM) The continuous development of the palm oil industry in the country will have an impact on increasing solid, gas, and liquid wastes resulted from FFB processing. Solid waste coming out of POM includes empty bunches amounting to about 23% of FFB, boiler ash (about 0.5% of FFB), fiber (around 13.5% of FFB) and shells (around 5.5% of FFB).

In the extraction process, every 100 tons of fresh fruit bunches processed will produce 20 tons of shells, 7 tons of fiber, and 25 tons of empty bunches [5,6]. Solid waste coming out of the POM generally does not require complicated handling. Solid waste can be used again as fuel, fertilizer and animal feed, and can be sold to generate additional income.

Fiber, shells, and FFB can be used as fuel, while boiler ash can be applied directly as a potassium fertilizer. Also, empty bunches can be converted into fertilizer by making mulch and composting; and core pulp can be utilized used as animal feed.

2.2.1. Emissions from transportation vehicles and agriculture machine In general, the fuel used inside the plantation area is in the form of fossil fuels, especially diesel oil.

Diesel fuel is used for agricultural machinery in the sections of maintenance, harvesting, harvest collection, and internal transportation between oil palm plantations and factories. 2.2.2. Emissions from combustion in boilers The boiler is the primary source for the production of the energy required in the POM because the electricity used in the POM is not from the state electric company of Indonesia. The fuel used to start the boiler is fiber and palm kernel shells.

The boiler produces steam, which in turn is used to drive turbines to run the generator. All processes and operations in the POM required electricity supported by this internal generator. Figure 3. Palm fiber and kernel shell residues. ICChEAS 2019 IOP Conf. Series: Materials Science and Engineering 845 (2020) 012037 IOP Publishing doi:10.1088/1757-899X/845/1/012037 5 In general, all palm oil mill in Indonesia utilizes solid wastes resulted from the processing of palm oil as fuel in the forms of fiber and kernel shells, as shown in figure 3. The fiber and shells obtained from the palm oil extraction process are used as the primary fuel in the palm oil mill boiler (POM) [6].

Based on several studies, it shows that the heating value of the waste can cover the need for steam used to drive a steam turbine. The electricity produced is used to meet all the electricity needs in the mill [7]. The kernel shell is reported to have a calorific value of 16.9 MJ /kg, while the fiber has a calorific value of 9.2 MJ / kg [8].

Table 1 presented the heating value for each type of solid wastes produced in the palm oil mill [9]. Tabel 1. The heating value for each type of solid wastes in the palm oil mill. Biomass waste Caloric value (MJ kg⁻¹) Element Content (%) C H N O Empty fruit bunch (EFB) 18.54 44.09 6.18 1.62 48.11 Fiber 18.12 45.19 6.62 1.44 46.75 Shell 18.98 47.64 6.57 1.08 44.71 To decrease the dependence of fossil fuels, the Government of Indonesia encourages every sector to utilize renewable energy resources, such as solar, wind, and biomass.

It is in line with the government policy that the palm oil industry utilizes fiber and shells to produce energy needs within the industry or even share the excess energy to the national electricity company. However, it should be noted that biomass combustion is frequently regarded as one of the primary sources of particulates and pollutant gas emissions.

Every combustion process is expected to occur in a complete mode, so the result of the combustion will produce energy, carbon dioxide, and water. The same case is also expected in the combustion biomass in the boiler of palm oil mill, as shown in reaction 1. $CH_2O + O_2 \rightarrow CO_2 + H_2O$ (1) In equation (1), the CH_2O represents the average composition of cellulosic biomass materials.

As incomplete combustion will most probably occur, other unwanted species that the above mentioned in equation (1) may be formed, such as carbon monoxide (CO), methane (CH₄), non-metal hydrocarbons (NMHC) and particulate matter (PM). Besides, nitrogen and sulfur species (especially NO_x and SO_x) are also formed, which may also pollute the environment.

Unburned fuel will come out together with exhaust gas through the chimney, identified by the appearance of black smoke during the burning process, as shown in Figure 4. Figure 4. The smoke of a chimney resulted from biomass burning in the boiler of palm oil mill. ICChEAS 2019 IOP Conf. Series: Materials Science and Engineering 845 (2020) 012037 IOP Publishing doi:10.1088/1757-899X/845/1/012037 6 Pollutants, of any kind, not only threaten human health but also affect agriculture crops, forest species, and ecosystems.

Referring to the regulation by ministerial of environment article 7 of 2007 [12] as shown in table 2, Indonesia has set the air emission-quality standard from stationary combustion sources. As for the palm oil industry, the primary concern of this regulation is to control the dark smoke and dust emissions from combustion waste, which is a mixture of fiber and shells. The article also stated that the maximum permissible dust concentration level in CO₂ gases is at 12%. Tabel 2. Standard of air emission.

Standard Parameter Quality Particulate 300 mg m⁻³ Sulphur Dioxide (SO₂) 600 mg m⁻³ Nitrogen Oxide (NO₂) 800 mg m⁻³ Hydrogen Chloride (HCl) 5 mg m⁻³ Chlorine Gas (Cl₂) 5 mg m⁻³ Ammonia (NH₃) 1 mg m⁻³ Hydrogen Fluoride (HF) 8 mg m⁻³ Opacity 30% 2.2.3. Emissions from liquid waste Palm Oil Mills (POM) produce liquid waste, better known as POME (palm oil mill effluent).

POME is waste-water produced by palm oil mills mainly from boiled condensate, hydro-cyclone water, and sludge separator. For every ton of FFB treated, about 0.6 to 1 m³ of POME is formed. POME is rich in organic carbon with a COD value of more than 40 g/L and nitrogen of about 0.2 and 0.5 g/L ammonia nitrogen and total nitrogen. The characteristics of POME are shown in table 1.

POME sources come from different processing units: 100% total POME, 60% comes from the clarification station, 36% comes from the cooking station, and the remaining 4% comes from the core station. Generally, POME is treated by a pool system. Naturally, the oxygen available in the treatment pond system is not able to meet the aerobic decomposition needs of organic matter contained in liquid waste, so the decomposition process runs anaerobically and produces biogas, which later is released into the atmosphere.

Most of the biogas produced from POME decomposition are methane (CH₄), convertible to CO₂ emissions, which is a source of GHG emissions. 3. Management of CO₂ emissions in Indonesia Export of Crude Palm Oil from Indonesia to several European Union countries has been rejected from 2012-2014. This happens because of competition with other products that produce renewable energy.

The European Union requires the use of renewable energy to reduce GHG emissions by a minimum of 35%, while Indonesia's CPO is only 19% [13, 14]. In 2011, the European Commission recognized ISCC as one of the first certification schemes to demonstrate compliance with the requirements of the European Union Renewable Energy Directive (EU-RED) (International Sustainability & Carbon Certification (ISCC)).

Meanwhile, according to a study by the United States Environmental Protection Agency (EPA) conducted in early 2012, by applying the Notice of Data Availability (NODA), GHG emissions from renewable diesel palm oil and Indonesian palm oil biodiesel can only meet 11-17 percent of the GHG emission reduction limits. This value is obtained using an emission factor from peatlands of 95 tons CO₂ per ha/year.

In the Renewable Fuel Standard (RFS) program implemented in the United States,

renewable energy requirements must meet the minimum 20 percent threshold for reducing greenhouse gas (GHG) emissions [15,16]. ICChEAS 2019 IOP Conf. Series: Materials Science and Engineering 845 (2020) 012037 IOP Publishing doi:10.1088/1757-899X/845/1/012037 7 The Presidential Regulation No.

61 of 2011 concerning the National Action Plan for Reducing Greenhouse Gas Emissions and Presidential Regulation Number 62 of 2013 concerning the Management Agency for Reducing Greenhouse Gas Emissions from Deforestation, Forest Degradation, and Peatlands are Indonesian government's policies that support emissions reduction. The government also requires palm oil plantations and palm oil mills to implement Indonesian Sustainable Palm Oil (ISPO) with the issuance of Permentan No. 11/Permentan/OT.140/ 3/2015 concerning the Indonesian Mandatory Sustainable Palm Oil Certification System (ISPO).

Also, there is a voluntary certification, namely RSPO (Roundtable Sustainable Palm Oil). The application of ISPO and RSPO is intended to ensure the sustainability of oil palm plantations [17, 18, 19, 20]. To meet the criteria, below are a joint list of efforts undertaken by ISPO and RSPO: ? Limiting land clearing in areas with high carbon content such as primary forests and peatlands. ? Paying attention to soil and water conservation when opening / adding new land.

? Using fertilizers according to fertilizer recommendations and the use of empty bunches for fertilization. ? Controlling the use of pesticides. ? Making methane capture facilities in palm oil mills effluent. ? Managing of water level in peat areas. ? Utilizing shells and fiber for boiler fuel as renewable energy. ? Making efficient use of fossil fuels and electricity. 4.

Best management practice through RSPO Figure 5 illustrates the waste produced from FFB processing into CPO and the kernel, as well as how it is treated. The green box represents lower GHG treatment in the plant area itself compared to the orange box. This section discusses the Best Management Practice (BMP), which directly and indirectly reduces GHG emissions in factories.

Some BMPs such as methane capture and joint composting were included in previous RSPO BMPs. Although it is effective in reducing GHG emissions, it has not yet become a common practice in the palm oil industry. Methane capture and composting have the potential to be applied to reach zero waste in the palm oil mills.

POME processed in methane capture can produce biogas, which can be used further for renewable energy production. In the case of renewable energy from biogas, it is used to

replace existing biomass-based electricity production combined with increased efficiency in Combined Heat and Power (CHP). Meanwhile, excess biomass available for fuel can be used for other production (e.g., paper production).

POME can also be used in co-composting facilities to produce organic fertilizer. BMP aimed at reducing GHG emissions in factories and plantations by reducing the application of chemical fertilizers. This section also covers emerging technologies such as improved biogas for transportation fuels, which have been proven in other sectors, but has yet been adopted in the palm oil sector [21, 22] Implementation of BMP in factories can reduce GHG emissions elsewhere or contribute to a broader context.

For example, biogas produced by the capture of methane that is converted to electricity can replace fossil fuel-based power plants. Implementing proper air pollution devices as well as adequate height of stack would lead to a better air quality in the surrounding areas of the palm oil mills [23]. An increase in CHP can lead to biomass savings. Excess biomass can be sold or transported elsewhere for renewable energy generation [24].

Biomass can also be used as material to produce paper, thus avoiding the cutting down of trees. On the other hand, joint composting using EFB and POME can reduce chemical fertilizers on plantations. Besides, the factory implements several BMPs for optimal GHG emission reductions in a reasonable economic investment.

Some BMP implementations are not only motivated by GHG reduction but also the goal of sustainability, efficiency, and process improvement. Most factories with internal demand for electricity or those close to the network, choose the capture of methane and biogas for electricity generation [25]. ICChEAS 2019 IOP Conf. Series: Materials Science and Engineering 845 (2020) 012037 IOP Publishing doi:10.1088/1757-899X/845/1/012037 8 Figure 5.

Waste utilization in palm oil mills. 5. Conclusion The oil palm industry actively applies BMP to improve its plantation development and management practices in order to reduce emissions. Emission reduction is made through various ways including engagement with smallholders to reduce deforestation, adopting practices without fuel, replacing synthetic fertilizers with factory by-products or organic fertilizers, thus, reducing the use of fossil fuels, and other methods.

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