The Potential of Palm Oil Waste Biomass in Indonesia in 2020 and 2030

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Abstract. During replanting activity in oil palm plantation, biomass including palm frond and trunk are produced. In palm oil mills, during the conversion process of fresh fruit bunches (FFB) into crude palm oil (CPO), several kinds of waste including empty fruit bunch (EFB), mesocarp fiber (MF), palm kernel shell (PKS), palm kernel meal (PKM), and palm oil mills effluent (POME) are produced. The production of these wastes is abundant as oil palm plantation area, FFB production, and palm oil mills spread all over 22 provinces in Indonesia. These wastes are still economical as they can be utilized as sources of alternative fuel, fertilizer, chemical compounds, and biomaterials. Therefore, breakthrough studies need to be done in order to improve the added value of oil palm, minimize the waste, and make oil palm industry more sustainable.

1. Background to the Study
Oil palm (Elaeis Guineensis) is a plant producing oil mostly produced and consumed all over the world. In Indonesia, this plant was first introduced in 1911 and since 1970 it has been developed fast as one of the most important commodities. Data of Directorate General of Estate Crops, Ministry of Agriculture of Republic Indonesia showed that in 1970, oil palm plantations were run only by state-owned and private enterprises while small-scale farmer plantations were found to operate in 1979. In 1970, oil palm plantation area was only 133,298 hectares and 11.3 million hectares in 2015. Compatible climate and soil condition have made oil palm plantation extensively distributed in 22 provinces spreading from the western to the eastern parts of Indonesia. In 2015, with an oil palm plantation area of 11.3 million hectares, Indonesia produced 37.5 million tons of palm oil consisting of 31.3 million tons of crude palm oil (CPO) and 6.2 million tons of palm kernel oil (PKO) [1]. Provinces in Sumatra and Kalimantan share the largest oil palm areas in Indonesia.

As an estate crop commodity, oil palm is very productive and able to produce oil seven times higher than rapeseeds (Brassica napus) and eleven times higher than soybean per hectare. Since 2004, palm oil has shared the highest in vegetable oil world market with a total production of 30 million tons and an average growth rate of 8% per year. These figures were higher than soybean production of 25 million tons and average growth rate of 3.8% per year.
During replanting activity in oil palm plantation, biomass including palm frond and trunk are produced. During harvest, palm bunches and fronds are cut off. In palm oil mills, during the conversion process of fresh fruit bunches (FFB) into crude palm oil (CPO), several kinds of waste including empty fruit bunch (EFB), mesocarp fiber (MF), palm kernel shell (PKS), palm kernel meal (PKM), and palm oil mills effluent (POME) are produced. The production of these wastes is abundant and can be found in 65% of provinces in Indonesia as oil palm plantation area.

In addition to CPO and PKO as the main products, wastes resulted from palm oil processing industry still have economical values as they can be used as sources of alternative fuel, fertilizer, chemical compounds, and biomaterials. Based on this notion, this review aims to assess the potential of wastes resulted from national oil palm plantations and palm oil processing industries and providing information on the opportunity of further utilization of them.

1.1. Methods of Data Collection and Analysis
Secondary data were used in this study. Data were collected from various related institutions including The Indonesian Central Bureau of Statistics (BPS), Ministry of Agriculture, Regional Development Planning Board (BAPPEDA), Indonesian Palm Oil Association (GAPKI), research institutions, and other related institutions.

Descriptive and forecasting data analysis methods were used. Descriptive analysis was used to identify, explain, and describe current condition and potential of oil palm development and oil palm waste availability. This analysis was done by providing explanation and detailed projection by using graphic and cross tabulation techniques and data processing by using statistical methods. Forecasting method was used to estimate the availability of oil palm wastes (MF, PKS, EFB, POME, and PKM) in 2016, 2020, and 2030. The technique used in this method was trend analysis which created a mathematical equation line to make projection in the future. A regression model was developed.

2. Area Coverage and Production of National Oil Palm Plantations
During the period of 1980 to 2015, the area of oil palm plantations in Indonesia grew by, on average, 14.26% per year from 294,560 to 11,300,370 hectares. In the same period, the national palm oil production increased by, on average, 17.46% per year from 849,121 tons (721,172 tons of CPO and 127,949 tons of PKO) to 37,541,167 tons (31,284,306 tons of CPO and 6,256,861 tons of PKO).

Detailed area coverage and production are showed in figure 1.

In an oil palm plantation, there are three types of plants, namely (a) unproductive plants (UPP) which are not in their productive age, (b) productive plants (PP) which are fruit producing plants, and (c) old/damaged plants (OP/DP) which already pass their productive age or no longer produce fruits. In 2002-2015, UPP was found to occupy 35.11% of oil palm plantation areas. In the future, there will be an increased oil palm production as more plants will be in their productive age. The development of oil palm plantation area, CPO production, and productivity of national oil palm plantations in 2002-2015 is listed in table 1.
Figure 1. Graphic of development of plantation area coverage and production of palm oil (CPO and PKO) in 1980 – 2015
Source: [1]

Table 1. Area coverage, production, and productivity of oil palm plantations in Indonesia in 2002-2015

| Year | Area Coverage (Ha) | Palm Oil Production/CPO (Tons) | Productivity (Kg CPO/Ha) |
|------|--------------------|-------------------------------|--------------------------|
|      | PP                 | UPP                           | OP/DP                    |                          |
| 2002 | 3,307,419          | 1,669,376                     | 90,267                   | 9,622,345               | 2,909           |
| 2003 | 3,428,580          | 1,780,088                     | 74,889                   | 10,440,834              | 3,045           |
| 2004 | 3,823,324          | 1,393,614                     | 67,785                   | 10,830,389              | 2,833           |
| 2005 | 4,054,683          | 1,330,454                     | 68,680                   | 11,861,615              | 2,925           |
| 2006 | 4,960,529          | 1,564,186                     | 70,199                   | 17,350,848              | 3,498           |
| 2007 | 4,881,335          | 1,791,095                     | 94,407                   | 17,664,725              | 3,619           |
| 2008 | 5,122,275          | 2,142,425                     | 99,497                   | 17,539,788              | 3,424           |
| 2009 | 5,541,422          | 2,229,469                     | 102,402                  | 19,324,293              | 3,487           |
| 2010 | 6,108,275          | 2,169,042                     | 108,078                  | 21,958,120              | 3,595           |
| 2011 | 6,550,800          | 2,332,886                     | 109,138                  | 23,096,541              | 3,526           |
| 2012 | 6,989,653          | 2,472,631                     | 110,432                  | 26,015,518              | 3,722           |
| 2013 | 7,856,254          | 2,454,080                     | 154,685                  | 27,782,004              | 3,536           |
| 2014 | 8,129,570          | 2,430,276                     | 194,956                  | 29,278,190              | 3,601           |
| 2015*| 8,503,784          | 2,567,633                     | 228,953                  | 31,284,306              | 3,679           |

Source: [1]

By comparing national palm oil production (CPO) to the area coverage, it was known that in general there was an increased national oil palm productivity from 2,909 kg/ha in 2002 to 3,679 kg/ha in 2015.

3. Oil Palm Processing and Distribution of National Palm Oil Mill Location
Palm oil mill is a place where FFB was processed into crude palm oil (CPO) and palm kernel oil (PKO). The processing of FFB into CPO involves cooking, threshing, digestion, pressing, settling, purification, and drying. Pressing process results in a waste product, namely nut/fiber. Further process
is the separation of nut and fiber followed by drying, nut cracking, kernel/shell separation, drying, pressing, and filtering until PKO is produced. By-products obtained from this process include empty fruit bunches, fiber, shell, PKM, and effluent. The flowchart of FFB processing into CPO and PKO is depicted in figure 2. The mass balance produced by a palm oil mill is shown in figure 3.

**Figure 2.** Flow chart of FFB processing into CPO and PKO
Similar to the distribution of oil palm plantations, national palm oil mills are distributed all over 22 provinces. Riau province has the most palm oil mills of 140 units with production capacity of 6660 tons FFB/hour followed by North Sumatra with 92 units and production capacity of 3815 tons FFB/hour and West Kalimantan with 65 units and production capacity of 5475 tons FFB/hour. In all, there are 608 units of national palm oil mills with production capacity of 34,280 tons FFB/hour. The number of national palm oil mills and their production capacity in 2014 are listed in Table 2.

Table 2. National Palm Oil Mills and Their Production Capacity in 2014

| No | Province             | Number of Palm Oil Mills (Unit) | Production Capacity (Tons FFB/hour) |
|----|----------------------|---------------------------------|-----------------------------------|
| 1  | NAD                  | 25                              | 980                               |
| 2  | North Sumatra        | 92                              | 3,815                             |
| 3  | West Sumatra         | 26                              | 1,645                             |
| 4  | Riau                 | 140                             | 6,660                             |
| 5  | Riau Islands         | 1                               | 40                                |
| 6  | Jambi                | 42                              | 2,245                             |
| 7  | South Sumatra        | 58                              | 3,555                             |
| 8  | Bangka Belitung      | 16                              | 1,235                             |
| 9  | Bengkulu             | 19                              | 990                               |
| 10 | Lampung              | 10                              | 375                               |
| 11 | West Java            | 1                               | 30                                |
| 12 | Banten               | 1                               | 60                                |
| 13 | West Kalimantan      | 65                              | 5,475                             |
| 14 | Central Kalimantan   | 43                              | 3,100                             |
| 15 | South Kalimantan     | 15                              | 770                               |
| 16 | East Kalimantan      | 29                              | 1,545                             |
| 17 | Central Sulawesi     | 7                               | 590                               |
| 18 | South Sulawesi       | 2                               | 150                               |
| 19 | West Sulawesi        | 6                               | 260                               |
| 20 | Southeast Sulawesi   | 3                               | 260                               |
| 21 | Papua                | 3                               | 140                               |
| 22 | West Papua           | 4                               | 360                               |
|    | **Total**            | **608**                         | **34,280**                        |

Source: [3]
4. Waste Production in National Oil Palm Plantations and Palm Oil Mills

Oil palm frond (OPF) consists of about 100 leaflets and each leaflet consists of lamina and midrib, central rachis, petiole, and petiole base. Leaflet has a size of 55-65 cm and tapers with a width of 2-4 cm. A mature frond has a size of up to 7.5 cm with petiole size of about one-fourth of the frond length. Spikes are found all over a frond. A frond has a convex shape and the base part is wider and harder than the tip part. The length of a frond can reach 5-9 m. OPF is a lignocellulosic material high in fiber consisting of cellulose (51%) and hemicellulose (15%) [4]. OPF biomass is obtained from replanting activity when oil palm plants are 25-30 years old and pruning activity. From replanting and pruning activities, the resulted OPF biomass is 14.4 and 10.4%, respectively [5].

Oil palm is a monocotyledon plant having a single cotyledon and therefore, its trunk has no cambium. In general oil palm plants grow with no branches. Branches are found only in plants growing with abnormality. Oil palm trunk grows straight (phototrophic) and is covered with leaf sheath. The base part of the trunk is bigger in size than the top part. Until the age of 3 years, the trunk is not visible as it is still wholly covered with leaf sheath. The height of oil palm trunk grows at the rate of about 45 cm per year depending on plant age, nutrient availability, soil condition, climate, and plant genetic. Cultivated oil palm plant can reach a maximum height of 15-18 m while wild oil palm plant can be up to 30 m height. Tenera is palm varieties commonly grown in Indonesia with average trunk length (in rejuvenation phase) of about 17-20 m, diameter 60-85 cm, volume 0.9-3 m³, and a number of plants per hectare 143. The tenera has shell 0.5-4mm thick, 60-90% mesocarp and a fiber ring. Beirnaert and Vanderweyen defined the tenera as fruit with a shell thickness of 0.5-2mm [6]. Considering the life cycle of oil palm plant with about 25 years productive period, 4%/year rejuvenating rate, and 11.3 million hectares oil palm plantation area all over Indonesia (2015), it can be estimated that there will be about 34.13 million tons/year of trunk waste production. In old oil palm plants, the trunk base has a bigger size. The trunk is usually covered with leaf sheath which will fall off when the plant reaches the age of ten years.

| Year | FFB      | EFB      | MF       | PKS      | POME     |
|------|----------|----------|----------|----------|----------|
| 2002 | 40,093,104 | 9,417,663 | 5,369,331 | 2,587,503 | 22,718,497 |
| 2003 | 43,503,475 | 10,218,742 | 5,826,053 | 2,807,599 | 24,650,962 |
| 2004 | 45,126,621 | 10,600,011 | 6,043,428 | 2,912,353 | 25,570,707 |
| 2005 | 49,423,396 | 11,609,301 | 6,618,858 | 3,189,655 | 28,005,447 |
| 2006 | 72,295,200 | 16,981,770 | 9,681,886 | 4,665,741 | 40,965,606 |
| 2007 | 73,603,021 | 17,288,970 | 9,857,032 | 4,750,144 | 41,706,674 |
| 2008 | 73,082,450 | 17,166,691 | 9,787,316 | 4,716,548 | 41,411,696 |
| 2009 | 80,517,888 | 18,913,237 | 10,783,081 | 5,196,412 | 45,624,939 |
| 2010 | 91,492,167 | 21,491,038 | 12,252,774 | 5,904,663 | 51,843,443 |
| 2011 | 96,235,588 | 22,605,243 | 12,888,020 | 6,210,790 | 54,531,271 |
| 2012 | 108,397,992 | 25,462,129 | 14,516,828 | 6,995,720 | 61,423,019 |
| 2013 | 115,758,350 | 27,191,040 | 15,502,539 | 7,470,738 | 65,593,718 |
| 2014 | 121,992,458 | 28,655,400 | 16,337,421 | 7,873,071 | 69,126,235 |
| 2015 | 130,351,275 | 30,618,843 | 17,456,846 | 8,412,527 | 73,862,704 |
Meanwhile, other types of waste including oil palm frond and trunk are produced in oil palm plantation activities. Frond waste is produced every time the frond part is pruned during harvest time or biennially maintenance. Oil palm frond biomass is produced by 6.3 tons per year. In 2015, with 11.3 million hectares of oil palm plantation area, 71.2 million tons frond biomass was produced. Total national oil palm frond production as a waste during the period of 2000-2015 is listed in Table 4.

Table 4. Total National Oil Palm Frond Production in 2000-2015

| Year | Area Coverage (Ha) | Frond Production (Tons) |
|------|-------------------|-------------------------|
| 2002 | 5,067,058         | 55,616,029              |
| 2003 | 5,283,557         | 57,992,322              |
| 2004 | 5,284,723         | 58,005,120              |
| 2005 | 5,453,817         | 59,861,095              |
| 2006 | 6,594,914         | 72,385,776              |
| 2007 | 6,766,836         | 74,272,792              |
| 2008 | 7,363,847         | 80,825,585              |
| 2009 | 7,873,294         | 86,417,275              |
| 2010 | 8,385,394         | 92,038,085              |
| 2011 | 8,992,824         | 98,705,236              |
| 2012 | 9,572,715         | 105,070,120             |
| 2013 | 10,465,020        | 114,864,060             |
| 2014 | 10,754,801        | 118,044,696             |
| 2015 | 11,300,370        | 124,032,861             |

Oil palm trunk biomass is produced from the regeneration of old plants (25-30 years old) which are classified as old/damaged and unproductive plants. By using a rejuvenation rate of 4% of total plantation area, it was estimated that in 2015, the rejuvenation area was 452,015 hectares. Based on an assumption that there were 143 plant populations per hectare of oil palm plantation area, in 2015, the potential oil palm trunk waste was estimated to reach 34.13 million tons trunks.

Table 5. Oil palm trunk biomass production during plant rejuvenation

| Year  | Rejuvenation Area (Ha) | Trunk Biomass Production (Tons) |
|-------|------------------------|---------------------------------|
| 2002  | 202,682                | 15,302.515                      |
| 2003  | 211,342                | 15,956.342                      |
| 2004  | 211,389                | 15,959.863                      |
| 2005  | 218,153                | 16,470.527                      |
| 2006  | 263,797                | 19,916.640                      |
| 2007  | 270,673                | 20,435.845                      |
| 2008  | 294,554                | 22,238.818                      |
| 2009  | 314,932                | 23,777.348                      |
| 2010  | 335,416                | 25,323.890                      |
| 2011  | 359,713                | 27,158.328                      |
| 2012  | 382,909                | 28,909.599                      |
| 2013  | 418,601                | 31,604.360                      |
| 2014  | 430,192                | 32,479.499                      |
| 2015* | 452,015                | 34,127.117                      |
5. Pro\textit{jection National Oil Palm Waste Production in 2016, 2020, and 2030}

Projected production of national EFB, MF, PKS, POME, oil palm frond, and oil palm trunk was made based on data obtained from 2002 to 2015. By using a trend analysis, the growth trend of EFB, MF, PKS, POME, oil palm frond, and oil palm trunk production in several years to come was estimated. This projection was used to determine the potential national production of oil palm wastes in 2016, 2020 and 2030.

Therefore, in 2016, there would be a production of 31,380,742 tons EFB, 17,891,231 tons MF, 8,621,859 tons PKS, 75,700,657 tons POME, 128,914,621 tons frond, and 59,722,455 tons trunk. In 2020, there would be a production of 37,816,105 tons EFB, 21,560,251 tons MF, 10,389,975 tons PKS, 91,224,865 tons POME, 128,914,621 tons frond, and 59,722,455 tons trunk. In 2030 a total production of 53,904,512 tons EFB, 30,732,801 tons MF, 14,810,264 tons PKS, 130,035,387 tons POME, 128,914,621 tons frond, and 59,722,455 tons trunk was estimated (Table 29). The same estimated yearly production of frond and trunk from 2016 to 2020 and 2030 is caused by the moratorium of land use extension for oil palm plantations as instructed by the President of Republic Indonesia in 2016.

The potential production of solid and liquid wastes from oil palm industry in the future is huge. Therefore, efforts to utilize them as product with economic value need to be done. POME can be utilized to produce biogas/biomethane for power generator. The electricity produced can then be used fulfill the power need of the mill and people living around the mill location. The liquid waste resulted from the use of POME for biogas/biomethane processing is still rich in nutrients which can be further used as fertilizer, land application, and source of nutrient-rich-medium for microalgae growth. CO$_2$ resulted from this process can also be used for microalgae growth. Palm Kernel Shell (PKS) and Mesocarp Fiber (MF) are commonly used as boiler fuel to drive production machinery and material to surface road around a palm oil mill. PKS can be processed into biopellet to be used as fuel for self-use or export. Oil palm frond, trunk, and empty bunch can be used as mulching material to help maintain soil humidity and inhibit weed growth, raw material for composting, material for covering plant vegetation, and a source of fiber for various composite products.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4.png}
\caption{Graphic of projected national EFB, MF, PKS, POME, oil palm frond, and oil palm trunk production in 2016-2030}
\end{figure}
Oil palm biomass in the form of oil and its wastes are in abundance in Indonesia. Therefore, breakthrough studies need to be conducted in order to improve the added value of oil palm, minimize the waste, and make oil palm industry more sustainable.

6. Conclusions
In 2030, it was estimated that there would be a production of 54 million tons EFB, 31 million tons MF, 15 million tons PKS, 130 million tons POME, 115 million tons oil palm frond, and 59.7 million tons oil palm trunk. Further research and technology development need to be done in order to improve the added value of oil palm waste biomass.

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