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バージョン：

Using Satellite Data of Palm Oil Area for Potential Utilization in Calculating Palm Oil Trunk Waste as Cofiring Fuel Biomass

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Abstract: This study calculates the potential for post-replanting oil palm trunk waste in Riau Province, Indonesia, to be used as fuel for power plant cofiring. A remote sensing method that combines time series imagery from Landsat 8 and Normalized Difference Vegetation Index (NDVI) is used to detect the first year of the plantation. Determination of a 50 km radius from the power plant as the limit of the potential area of raw material is needed to get optimal transportation cost. The results obtained 268,077 tons/year of palm oil trunk, sufficient to meet the need to cofire 5% of daily fuel requirements.

Keywords: palm oil trunk; cofiring; potential waste

1. Introduction

Bioenergy is a specific form of renewable energy. It can be used for heating and cooking, generating electricity, and as a transportation fuel. The global low-carbon energy system recognizes bioenergy as an integral component. According to predictions, the demand for bioenergy is anticipated to increase twofold by the year 2050 to achieve the net zero carbon emissions goal, compared to the figures measured in 2020[1)]. Among many other renewable energy businesses, the use of bioenergy in the industry has increased by 3%[2)]. Bioenergy is renewable energy being developed as a priority, for example, in Indonesia[3)].

Indonesia has significant potential to utilize palm oil as biomass as a possible fuel source for power plants[4,5)]. Palm oil is a plantation commodity that plays a crucial role in the economic development of Indonesia. Oil palm plantation operations and crude palm oil (CPO) processing always leave biomass, often called palm oil industry waste. There are six classifications for the waste generated from oil palm plantations: empty fruit bunches, oil palm shells, mesocarp fibers, oil palm fronds, trunks grown on the plantation site, and effluent from the mill, such as palm oil mill waste (POME)[6,7)]. In rejuvenating oil palm trees, land clearing is usually done by killing the trees and removing their roots by burning or stacking them somewhere else[8)]. This type of activity causes many environmental problems, such as the impact of the poisoning process, the development of the boctor beetle population, the emergence of smoke pollution, and the risk of fire from the combustion process. Of all the existing oil palm biomass, as much as 70% comprises palm tree midrib, while empty fruit bunches reach 10%, and oil palm trunks reach 5%[9)].

Considering the planting cycle, old oil palm plants will be replanted[10)]. Industry can process waste from oil palm trunks into furniture[11)], plywood[12)], flooring[13)], and sugar[14)]; unfortunately, A substantial amount of it is wasted or discarded instead of being utilized for other beneficial purposes. Oil palm trunks have been used as a fuel source in certain situations. Sukiran, et al. (2017) conducted a review to enhance the properties of solid waste from oil palm plantations converted into fuel through the torification process[7]. According to the research by Yamada, et al. (2010)[14], the sugar content in the oil palm trunk fiber tends to increase through storage. Sugar may serve as a viable source of energy[14–16], bioethanol production, or treated thermochemically as a heat source[17–19]. However, there are some problems with direct utilization, such as high water content, and low calorific value. It is not easy to make powder to overcome this problem[17], Nudri, et al. (2021) turned palm trunks into bio-coal[20] and Kpalo, et al.(2020) mixed them with corncobs into briquettes[21].

By recognizing the untapped potential of unused palm trunks, it is possible to repurpose this organic material as a viable energy source using various techniques, including biomass cofiring. Biomass-coal cofiring can support decreased emissions of greenhouse gases and is a low-cost option for improving biomass supply infrastructure[22]. The technology for coal-biomass cofiring power plants combines coal and biomass to enhance one another's benefits. It is a practical method for reducing the excess capacity of coal-fired power plants[23]. Few studies use 5% wood biomass mixed with coal by Ringe et al.(2018) in Tennessee, USA[25] and Bromann et al. in Berlin, Germany[26]. While in Malaysia, cofiring with palm oil waste for power generation is done by Yan et al.(2020)[27], Rahman and Shamsuddin (2013)[28] in the biochar form, and Salleh et al.(2018) in the pellet form fuel[29].

The Normalized Difference Vegetation Index (NDVI) is widely utilized in various applications related to oil palm plants. Galvez-Valencia et al. (2021) employed NDVI to identify diseases, pests, and susceptibility to compaction or abortions in female flowers. Nurul Fatin et al. (2019) employ NDVI, Enhanced Vegetation Index (EVI), and Shortwave Infrared Water Stress Index (SWISI) to identify drought years based on MODIS-SPI-based index calculations in Negeri Sembilan[31]. Lee et al. (2022) utilized NDVI, along with other vegetation indices such as Normalized Difference Red Edge (NDRE), Optimised Soil-Adjusted Vegetation Index (OSAVI), and Merris Terrestrial Chlorophyll Index (MTCI), to detect Basal Stem Rot (BSR) disease[32]. Ang et al. (2022) also used NDVI and an ensemble machine learning algorithm to predict oil palm yield[33]. Tugi et al. (2015) employed NDVI and Modified Soil-Adjusted Vegetation Index 2 (MSAVI2) to determine the spectral response curve of oil palm tree growth for smallholders[34]. Amirruddin and Muharam (2019) assessed the nitrogen status of young and prime mature oil palm plants using NDVI[36]. Shafri et al. (2012) compared NDVI from remote sensing images with airborne hyperspectral indices to assess and map stressed oil palm trees[37]. Oon et al. (2019) monitored natural and production landscapes managed under different systems by comparing vegetation indices (NDVI, EVI, and SAVI) values between other land covers in the tropics[38]. Samseemoung et al. (2011) employed NDVI to detect upper stem rot disease (Phellinus Noxius) in young and mature oil palm plants by comparing it with green normalized difference vegetation index and chlorophyll content[39]. Avtar et al. (2020) monitored oil palm trees' health conditions and growth using NDVI and normalized difference red edge index (NDRE) in precision agriculture practices[40]. Worachairungreung et al. (2023) combine NDVI with other data, such as surface reflectance (SR) and land surface temperature (LST), as input for machine learning to classify land use/land cover, especially for oil palm[41]. Finally, Sari et al. (2022) combined Landsat-8 NDVI, NDMI, and Sentinel-1 VV and VH to improve the accuracy of land cover maps for developing oil palm and rubber plantation discrimination[42]. Limited studies discuss the utilization of NDVI for palm trunk potential calculation.

This study will calculate the potential of palm oil trunk waste using remote sensing imagery and NDVI as fuel for a steam power plant with a case study in Riau Province, Indonesia.

2. Methods of Data Collection

In this study, secondary data is used. Data was collected from various sources related to oil palm plantations. Spatial approaches and earth imaging are used to estimate the extent and age of oil palm crops. The spatial boundaries of the Riau province are derived from Rupa Bumi Indonesia (RBI) data[43] sourced from Geospatial Information Agency (BIG). The Ministry of Agriculture (2019)[44] and ISPO (Indonesian Sustainable Palm Oil)[45] plantation data are used to determine the oil palm plantation area's boundaries.

Several methods can be used to calculate plant age, Ani (1971)[46] calculates the appropriate age for replanting oil palm in Malaysia by comparing the income obtained from the sale of CPO and kernels so that the optimal age is above 31 years. At this age, the tree will be too tall and not suitable for harvesting. Azman and Mamat (2022)[10] use the same method using the price of fresh fruit bunches, technology yield data, and the latest discount rate. The optimal age is 25 years. In Indonesia, the age of oil palm trees is set at 25 years as an uneconomical age because the effectiveness of harvesting will be low if the height of oil palm trees exceeds 12 meters[47]. Fitrianto, et.al.(2018)[48] used a remote sensing technique based on the canopy density of oil palm trees to calculate plant ages, and Danylo, et.al.(2021)[49] used the function time series image collection and the Normalized Difference Vegetation Index (NDVI) to detect palm oil plantations. In this study, we calculated the age of plants using the approach taken by Daylo, et.al (2021)[49] backward 25 years. All image data processing and processing uses the Google Earth engine.

The NDVI calculation in this study was carried out on cloud-free pixels using Landsat 8 OLI/TIRS imagery in the Riau Province region with an acquisition date of 1 January 2021 to 31 August 2021 so that the band used is band 5 for the NIR band and band 4 for the band red. In the Red spectrum, vegetation would absorb a significant amount of energy from the wavelength, causing the reflected spectral value to be lower. In the NIR spectrum, however, vegetation would only slightly absorb energy from the wavelength, increasing the reflectance of the spectral value[50)].

NDVI calculation uses Google Earth Engine Analysis via a raster calculator. It's a tool that performs calculations based on existing raster pixel values. After the NDVI value is obtained, the next step is to classify using the program stages of Property, Style, Render Type (Pseudocolor single band) feature, discrete interpolation, and Equal Interval mode. Making a linear regression equation between the NDVI and the findings of the calculation of carbon stocks allows for the estimation of carbon stocks using NDVI[51)]. Estimation of the predicted association between carbon stocks and the values of NDVI and EVI was done using carbon stock estimations[51)] using regression equation y = a+bX, where y is the estimated carbon stock, and x is the NDVI. The calculation begins by finding the value of b using the equation[51)]:

$$b = \frac{n\sum_{i=1}^{n} x_i y_i - (\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)} \quad (1)$$

$$a = \frac{\sum_{i=1}^{n} y_i}{n} - b\frac{\sum_{i=1}^{n} x_i}{n} \quad (2)$$

$x = NDVI/EVI\ value$

$y = carbon\ value$

After getting the values of b and a, then determine the correlation value of the Pearson equation as follows[51)]:

$$r = \frac{n\sum_{i=1}^{n} x_i y_i - (\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{\sqrt{\left[n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2\right]\left[n\sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2\right]}} \quad (3)$$

$r = Coefficient\ correlation$

$n = Number\ of\ Plot$

$x = NDVI/EVI\ value$

$y = carbon\ value$

The regression equation that has been obtained is then used as a formula for the raster calculator feature in the QGIS Las Palmas 2.18 Software to determine carbon stocks based on NDVI.

To measure the number of trees per unit area, samples were taken from numerous plants in the province of Riau and used to calculate plant density. The use of the AGB (above ground biomass) method. Weight above ground (AGB), excluding all foliage, solid wood and bark on live trees with a DBH of 2.4 cm or greater is referred to as AGB[51)]. When mass per unit area is used to express it, such as tons (t)/ha, it is referred to as biomass density. Based on Asari et al. (2017)[52)], published values on the quantity of AGB oil palm plantations range from 50 tons/Ha to over 100 tons/Ha towards the end of the plantation economic life span after 20-25 years. After 20–25 years, the plantation's economic life cycle is ending. Allometric equations, which provide a non-destructive and indirect measurement of biomass, are often preferred when predicting the annual growth rate (AGB) of forests or plantations[53)].

All plot oil palm trees were tagged and numbered. The main components of oil palm (stems, midribs, midrib bases, and roots) were measured following a non-destructive sampling method successfully used and tested in previous studies[54)]. Leaflet dry weight, fragment dry weight > 30 cm. Measurements were carried out mainly to determine the main components of oil palm biomass, especially stems, midribs, midrib bases, and roots. In addition, epiphytes growing at the base of the palm midrib were also measured. In this study, the non-destructive sampling method refers to sampling the components of the palm oil without destroying the entire oil palm destructively. Five oil palm trees were randomly selected from a 28-year-old plantation and measured for height, trunk diameter, and volume. Figure 1 is the ground truth sampling point for the test of the accuracy of the biomass value on a Landsat pixel with a size of 3x3 (90 meters x 90 meters). Fresh components were weighed in the field, and sub-samples of each component were weighed and dried to determine dry weight. The stems are divided equally into four parts. The stem sub-sample (0.5 m fragment) was extracted from randomly selected sections, then divided into eight sections, collected, and dried to a constant weight. The weight of the trees was calculated and matched with the calculated weight of the biomass value from the NDVI approach.

The number of oil palm trees is 136-140 per hectare. However, those that can survive to the age of more than 25 years only reach around 120 palm trees per hectare[8)]. The calculation of the total biomass of dry oil palm trunks for area expansion based on the Malaysian Palm Oil Board (MPOB) reference is 74.48 kg per hectare[55)]. The oil palm trunk contains four times as much water as dry matter per tree[56)].

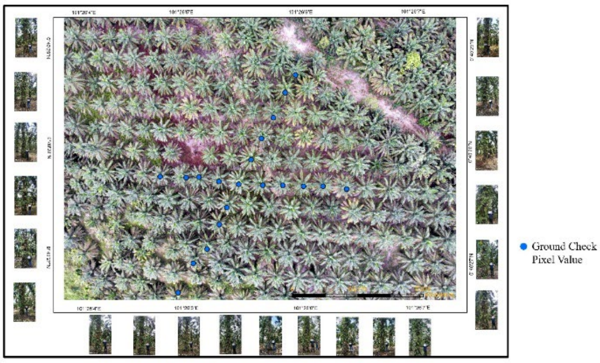

Fig. 1: Non-destructive sampling

Limitation of the area of raw materials is needed so that the effect of transportation does not have a major impact on the purpose of using biomass to reduce emission values.

In the raw material supply chain, the farther the distance from the source of raw materials, the greater the transportation contributes to additional emissions and the higher the cost[57]. The location and capacity of the raw materials, the mode of transportation, the pre-processing of the biomass, and the processing facilities determine the best supply chain configuration[58]. This study determined a radius of 50 km[24] from power plant Tenayan Raya to see the amount of potential waste from palm trunks.

3. Result and Analysis

Identify oil palm land with a historical time series for the past 25 years to obtain potential palm oil ready for replanting. The target area examined is based on a map of oil palm plantations registered with the Ministry of Plantations and ISPO members. Identification of the first year the crop pattern was formed. The year of replanting is when the plant has reached the age of 25. Farmers replant when they have the funds, so grouping is done every five years. Fig.1 is a map of the distribution of years of oil palm replanting.

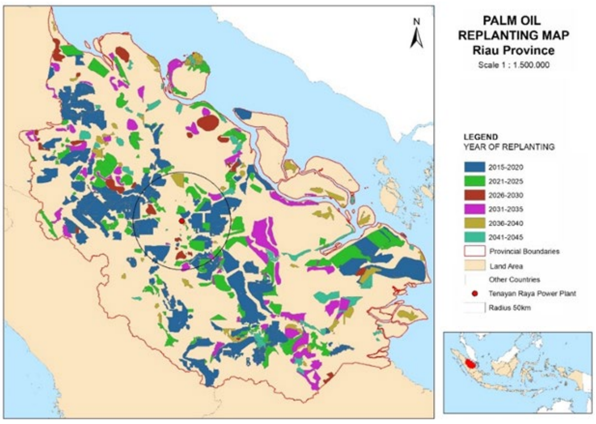

Fig. 2: Map of years of the distribution of oil palm replanting

Based on the map in Fig.2, the oil palm cover is then mapped based on the NDVI value, which has been converted into biomass value. The results of the study show a strong correlation between NDVI and carbon stock, the value of the magnitude of the correlation coefficient (r) is 0.9006 with a linear regression equation Y = 570.06x – 217.46(see Fig.3). Previous research has been carried out by Rachdian (2018)[59] in plantations oil palm by obtaining the regression equation Y = 38.39 + 26.24x, namely Y = carbon stock and x = NDVI. Another study that shows the estimated value of carbon with a similar approach, Pandapotan Situmorang et al. (2016)[51] has a regression equation of the regression equation Y = 204.37x –102.1, namely Y = carbon stock and x = NDVI.

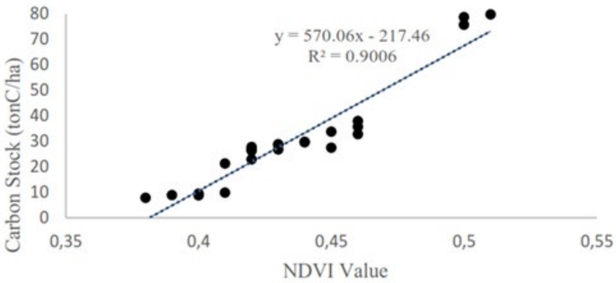

Fig. 3. Results Carbon Stock vs NDVI

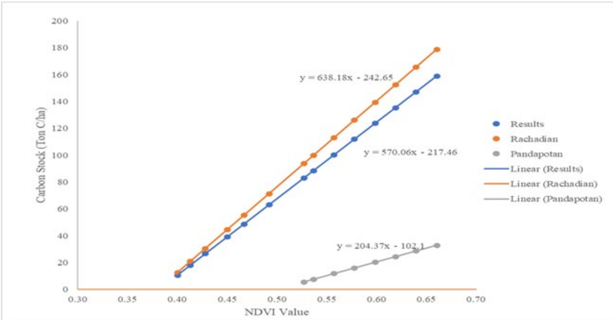

Fig. 4. Comparative Carbon Stock vs NDVI

Fig.4, comparation between results calculation with previous research. Our results with Rachdian[59] have similar slopes compared to Pandapotan[51]. Our research location (Riau) is close to Rachadian (south Sumatra) so it has the same plant characteristics (similar atmospheric, geological, and cultural). While the research location Pandapotan (Aceh) is far different. The large X value is of oil palm plantations caused by many middle to old oil palm plantations, causing a high NDVI value to correlate with the high carbon stock value in the Riau province.

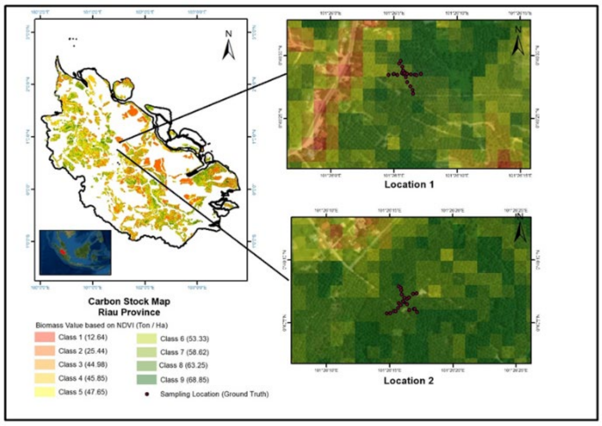

Fig. 5. Map of the distribution of biomass values based on NDVI

By altering the distribution of older vs younger plants, the projected potential area will contain a plant prepared for replanting. Fig.5 and Table 1 show the class distribution of the NDVI in the registered plantation area.

Table 1. Biomass value based on NDVI

Class of ages TM	NDVI	Biomass Value (Ton/Ha)
Class 1	<0.1	12.64
Class 2	0.100 – 0.300	25.44
Class 3	0.400 – 0.412	44.98
Class 4	0.413 – 0.427	45.85
Class 5	0.428 – 0.449	47.65
Class 6	0.450 – 0.466	53.33
Class 7	0.467 – 0.491	58.62
Class 8	0.492 – 0.526	63.25
Class 9	0.527 – 0.5632	68.85

The results of the calculation of the area of oil palm cover in Riau province (see table 2) based on the historical map covering an area of 1,742,603.15 hectares, then calculating the area of oil palm cover in Riau province using the NDVI method, obtained an area of 1,722,997.28 hectares, and generate 128,328,838.32 tons of biomass (2021-2045).

Table 2 Calculation of the area of oil palm plantations based on the year of replanting in Riau province.

Year of Replanting	Historical* Map (Hectar)	NDVI metode (Hectar)**	Biomass (Ton)
(2021 – 2025)	742,426.03	725,160.76	54,009,973.65
(2026 – 2030)	137,266.06	136,993.72	10,203,292.59
(2031 – 2035)	438,077.25	437,118.06	32,556,553.47
(2036 – 2040)	200,921.36	200,371.21	14,923,647.48
(2041 – 2045)	223,912.45	223,353.53	16,635,371.13
TOTAL	1,742,603.15	1,722,997.28	128,328,838.32

*proceed from historical Landsat images 25 years backward
** proceed from NDVI raster

The area of oil palm cover in Riau province, with a radius of 50 KM from PLTU Tenayan, was calculated based on a historical map and covered 176,290.55 hectares. However, the area of oil palm cover in Riau province with a radius of 50 KM from PLTU Tenayan was calculated using the NDVI method. It covered an area of 86,383.79 hectares, producing 6,433,865.04 tons of biomass between 2021 and 2045 (table 3).

The potential for dry oil palm trunks are available in RIAU at a radius of 50 km is 268,077 tons/year. This potential can meet the cofiring needs of PLTU (Riau Case Study–PLTU Tenayan) with a maximum cofiring of 5% and a PLTU Capacity Factor of 80%, which requires replanting of oil palm biomass of 192 tons/day or 55,296 tons/year.

Table 3. The results of the calculation of the area of oil palm plantations based on the year of replanting radius of 50 km.

Year of Replanting	Historical Map (Hectar)	NDVI metode (Hectar)	Biomass (Ton)
(2021 – 2025)	139,234.69	69,464.37	5,173,706.01
(2026 – 2030)	12,297.62	2,672.64	199,058.29
(2031 – 2035)	18,514.84	9,518.84	708,963.57
(2036 – 2040)	5,177.47	3,870.79	288,296.50
(2041 – 2045)	1,065.93	857.15	63,840.67
TOTAL	176,290.55	86,383.79	6,433,865.04

The potential for dry oil palm trunks in RIAU at a radius of 50 km is 268,077 tons/year. This potential can meet the cofiring needs of PLTU (Riau Case Study–PLTU Tenayan) with a maximum cofiring of 5% and a PLTU Capacity Factor of 80%, which requires replanting of oil palm biomass of 192 tons/day or 55,296 tons/year.

The limitations of using biomass in cofiring are that it dramatically affects the heat capacity required by the boiler design. So the resulting emission reduction is not too significant, but it is hoped that this mixture can reduce the use of fossil fuels in the future[60]. A new boiler design suitable for higher biomass blends is needed, rather than using an existing boiler to achieve higher emission reductions.

The potential for oil palm trunk biomass exceeds the calculated data because the calculations are only for registered oil palm plantations. It makes it easier for the Power Plant to transact with plantation owners with a clear and registered status, not to mention the potential for replanting waste carried out before 2021 and oil palm plantations that have not replanted with plants over 30 years old.

4. Conclusion

Based on the calculation results, the potential for utilizing palm trunks as cofiring fuel for the Tenayan Raya power plant is more than sufficient. The need for cofiring fuel for a 5% generator of 55,296 tons/year will be fulfilled with the availability of palm trunk waste of 268,077 tons/year in a 50 km radius around the power plant. This excess amount of potential waste can be used for fuel in other forms, such as being processed into bioethanol

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