Potential Utilization of Palm Shells and Fibers as an Electricity Source in Bungo Regency

Elsi Alfionita Syawal[1*], Ferdy Ashari Syawal[2], and Illa Aryeni[3]

[1]Electrical Engineering Study Program, Electrical and Informatics Engineering Department, Universitas Jambi, Jambi, Indonesia
[2]Environmental Engineering Study Program, Chemical Engineering Department, Universitas Riau, Pekanbaru, Indonesia
[3]Electronics Engineering Technology Study Program, Electrical Engineering Department, Politeknik Negeri Batam, Batam, Indonesia

*Email: elsialfionita@unja.ac.id

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***Abstract*—Indonesia faces an electricity crisis due to increasing demand and heavy reliance on fossil fuels. This study examines the potential of palm oil biomass waste—shells and fibers—as fuel for a steam power plant in Bungo Regency. The methodology applies the Direct Method (Equation 1) to estimate electricity potential based on a validated boiler efficiency of 73% and actual calorific values. The results reveal that palm shells have a potential of 21,024 GWh/year, while fibers can generate 49,056 GWh/year. A key novelty of this research is the determination of specific fuel requirements: 2,3 kg/kW of shells and 2,6 kg/kW of fibers are needed to produce 1 kW of electricity. These findings provide precise empirical data for regional energy planning and demonstrate that integrating palm biomass into local grids offers a sustainable alternative to fossil fuels.**

Keywords: Biomass, Electricity Demand, Palm Fiber, Palm Shell, Steam Power Plant (PLTU)

I. INTRODUCTION

Currently, Indonesia is experiencing an electricity crisis, even though the demand for electrical energy continues to rise along with population growth. This electricity crisis is caused by the depletion of conventional energy sources and the fact that many power plants in Indonesia rely primarily on fossil fuels [1].

A solution to the electricity crisis and the depletion of fossil fuels is the use of alternative energy sources. These alternative energy sources must be environmentally friendly, effective, efficient, and widely accessible to the public. In addition, ideally, they should come from renewable energy sources. One potential renewable energy source is biomass from palm oil waste. If handled correctly, palm oil biomass residues are applicable for an alternative energy source to replace coal in steam power plants. The types of palm oil waste that may be utilized as fuel in these plants are palm fiber and palm shells [2].

Indonesia is the world's largest producer of palm oil, generating a substantial amount of solid waste in the form of *palm kernel shell* (PKS) and *mesocarp fibre* (MF). According to Handaya et al. [3], these residues possess relatively high calorific values, ranging from 16–20 MJ/kg for shells and 14–18 MJ/kg for fibres, making them promising feedstocks for biomass-based power generation. Similarly, D. Erivianto [4] reported that utilizing palm oil residues as an energy source can reduce carbon emissions by up to 60% compared to coal for an equivalent amount of energy. Nevertheless, the utilization rate of palm residues as a source of electricity remains relatively low, particularly in regions with high palm oil production density, such as Bungo Regency.

Bungo Regency, located in Jambi Province, is one of the key centers of palm oil plantation that produces a large amount of biomass residue annually. Based on *Crude Palm Oil* (CPO) production data and field observations, most of the palm shell and fibre residues have not been optimally utilized. They are commonly used only as internal boiler fuel in palm oil mills or simply left to accumulate around processing areas. In fact, converting this biomass potential into electrical energy could significantly contribute to local electricity supply while supporting Indonesia's national *renewable energy mix* program.

Several previous studies have investigated the energy potential of palm biomass. Siddique [5] analyzed the exergy value of palm fibre for power generation and found that it becomes economically feasible when system efficiency exceeds 20%. Masrajuddin et al. [6] examined the *co-gasification* of palm residues and reported a thermal efficiency of 28% in a 75 kW pilot-scale system. Furthermore, A. Bampenrat [7] tested the use of *producer gas* derived from palm kernel shells in a 5 kW generator and found that the fuel consumption rate was approximately 0,9 kg per kWh. These findings indicate that palm shell and fibre have high potential as alternative fuels. However, a significant research gap remains, as these studies are often based on generic values or small-scale pilot systems, lacking localized empirical data that accurately determines the specific biomass requirements per unit of power (kg/kW) under real operational conditions. This research presents a novelty by establishing the exact amount of palm kernel shells and fibers (kg) needed to generate 1 kW of electricity by integrating actual local feedstock characteristics and verified conversion efficiencies in Bungo Regency. By utilizing the direct method (equation 1) with a documented boiler efficiency of 73% and specific enthalpy values (710,9 kcal/kg for saturated steam and 90,03 kcal/kg for feedwater), this study provides practical and high-precision data that has not been comprehensively reported in previous literature.

To date, no comprehensive study has been conducted to accurately determine the amount of palm shell and fibre needed to produce 1 kW of electricity, particularly by incorporating actual calorific values and conversion efficiency under local conditions in Bungo Regency. Such information is essential for designing small- and medium-scale biomass power plants and for formulating sustainable palm residue management policies at the regional level.

Therefore, this study aims to analyze the energy potential of palm shell and fibre residues in Bungo Regency and to estimate the biomass fuel requirements needed to produce 1 kW of electricity. The findings are expected to provide accurate and practical empirical data that can support the development of efficient and environmentally friendly local biomass power systems, contributing to Indonesia's transition toward green and sustainable energy.

II. METHOD

A. Bungo Regency's Electricity System

The number of electricity customers in Bungo Regency continues to increase year after year. This is due to the increasing population in Bungo Regency, which has resulted in an increase in electricity customers in the residential, industrial, commercial (business), and public sectors. Almost all electricity in Bungo Regency is sourced from PT PLN, which is interconnected with the Ombilin Padang and Palembang hydroelectric power plants. However, several factories in Bungo Regency supply their own electricity using their own coal-fired power plants [8].

B. Steam Power Plant (PLTU)

PLTU is a type of thermal power plant widely used due to its high efficiency, resulting in economical electrical energy production. In a PLTU, the energy stored in the fuel is turned into electricity. The process of changing energy happens in three steps [9]:

1. The fuel's chemical energy becomes heat energy, creating high-pressure and high-temperature steam.
2. The heat from the steam is used to make mechanical energy, which driving the turbine rotation.
3. The spinning motion from the mechanical energy is then used to create electrical energy.

The method used to calculate boiler steam capacity in a coal-fired power plant is the direct method. In the direct method, the energy contained in the steam is compared with the energy contained in the boiler fuel. In this method, efficiency can be evaluated using the following equation:

$$\text{Efisiensi Boiler } (\eta) = \frac{Q \times (hg\text{-}hf)}{q \times GCV} \quad (1)$$

Consists of several important components that represent energy conversion in a boiler system. The term Q refers to the amount of steam produced per hour (kg/h), indicating the output capacity of the boiler, while hg is the enthalpy of saturated steam (kcal/kg), representing the total energy content of the generated steam, and hf is the enthalpy of feedwater (kcal/kg), which is the initial energy of water before heating; the difference (hg−hf) therefore shows the useful heat added to convert water into steam. On the input side, qqq denotes the amount of fuel consumed per hour (kg/h), and GCV (Gross Calorific Value) represents the total heat energy available in the fuel (kcal/kg). Altogether, the numerator Q×(hg−hf) expresses the useful energy output in the form of steam, while the denominator q×GCV represents the total energy supplied by the fuel, so the efficiency η indicates how effectively the boiler converts fuel energy into useful steam energy.

Where:
hg = Enthalpy of saturated steam in kcal/kg steam.
hf = Enthalpy of feed water in kcal/kg water.
Q = Amount of steam produced per hour in kg/h.
q = Amount of fuel used per hour in kg/h.
GCV = Heating value of fuel in kcal/kg.

The process of producing PLTU fuel can be seen in Figure 1.

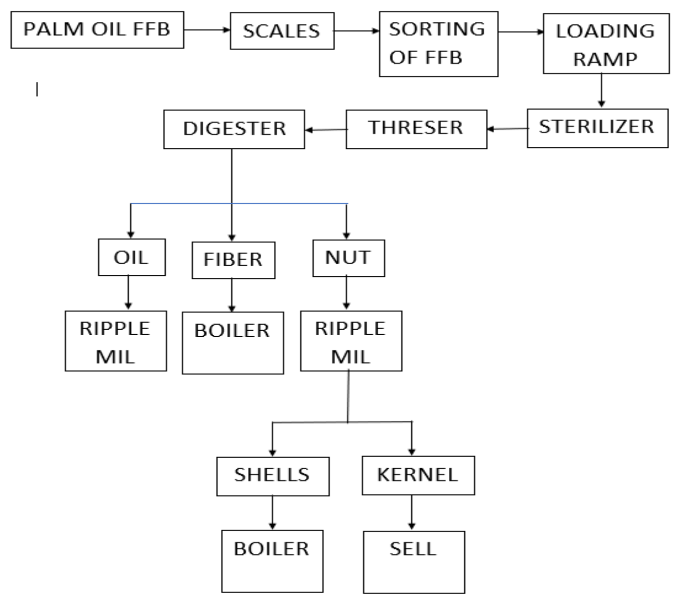

Figure 1. The Process Cycle Of Fuel Production In Steam Power Plants (PLTU) [10]

Figure 1 explains the process of making PLTU fuel starting from fresh fruit bunches (FFBs) to plantations are transported by truck to the palm oil mill for processing. The initial process at the mill involves boiling the fresh fruit bunches using a sterilizer to separate the loose fruit bunches from the empty fruit bunches. During the boiling process, not all loose fruit bunches are separated from the empty fruit bunches, so they are further separated using a thresher [11] – [13].

The empty fruit bunches separated from the loose fruit are sent to a storage facility via a conveyor belt, which can be used as plant fertilizer. Some are pressed using a manual press to produce fiber, while the loose fruit bunches are fed into a digester to produce palm oil in the form of Crude Palm Oil

(CPO) [14] – [16].

The skin of the loose fruit that comes out of the digester becomes fine fibers or fiber. The fiber from the empty fruit bunches and loose fruit skin is used as fuel in the PLTU (power plant), and the nuts that come out of the digester are processed again in a polishing drum to separate the fiber still attached to the nuts. Then the nuts are broken using a ripple mill to produce shells and kernels. The kernels are sold to produce Crude Palm Kernel Oil (CPKO), which is processed by other factories, while the shells are used as boiler fuel in the PLTU [17] [18].

C. Steam Power Plant (PLTU) Production Process

The primary raw material in the production process of a steam-fired power plant (PLTU) is water. The water source for the process at the PLTU comes from a reservoir. The reservoir is a partially dammed community-owned river located not far from the PLTU site. Water from the source is processed through water treatment to produce water suitable for use in the PLTU with a pH of 8,0-9,5. The PLTU production process cycle can be seen in Figure 2.

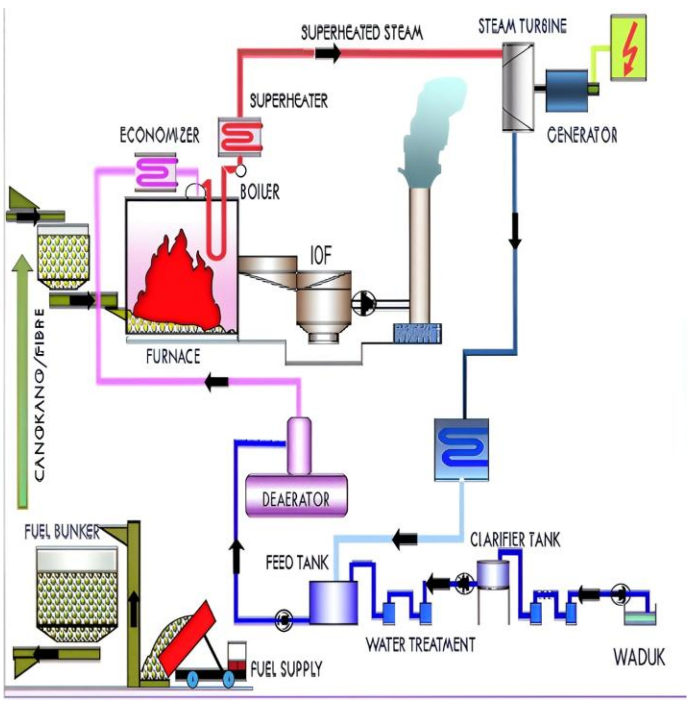

Figure 2. Steam Power Plant Production Process Cycle [18]

Based on Figure 2, it can be concluded that water from the water treatment process is first heated in the feed tank to a temperature of approximately 90°C, consistent with the recorded feedwater enthalpy (hf) of 90,03 kcal/kg,. Then, it is reheated in the deaerator to a temperature of approximately 105°C to remove dissolved gases. From the deaerator, the water is pumped to the economizer and pre-heated to approximately 180°C–220°C using flue gas recovery. The water from the economizer is then pumped into the boiler and heated using shell and fiber fuel to produce steam. The steam is further dried in a superheater, producing superheated steam at a temperature of approximately 380°C–400°C and a pressure of 40 bar, which aligns with the documented vapor enthalpy (hg) of 710,9 kcal/kg. This steam drives a steam turbine at an average speed of 5.400 rpm. The turbine shaft is connected to the generator rotor, producing electrical output to power the palm oil mill, rubber factory, and residential lighting. Figure 2 illustrates this refined PLTU Production Process Cycle.

D. Research Methods

The research methods used can be seen in Figure 3.

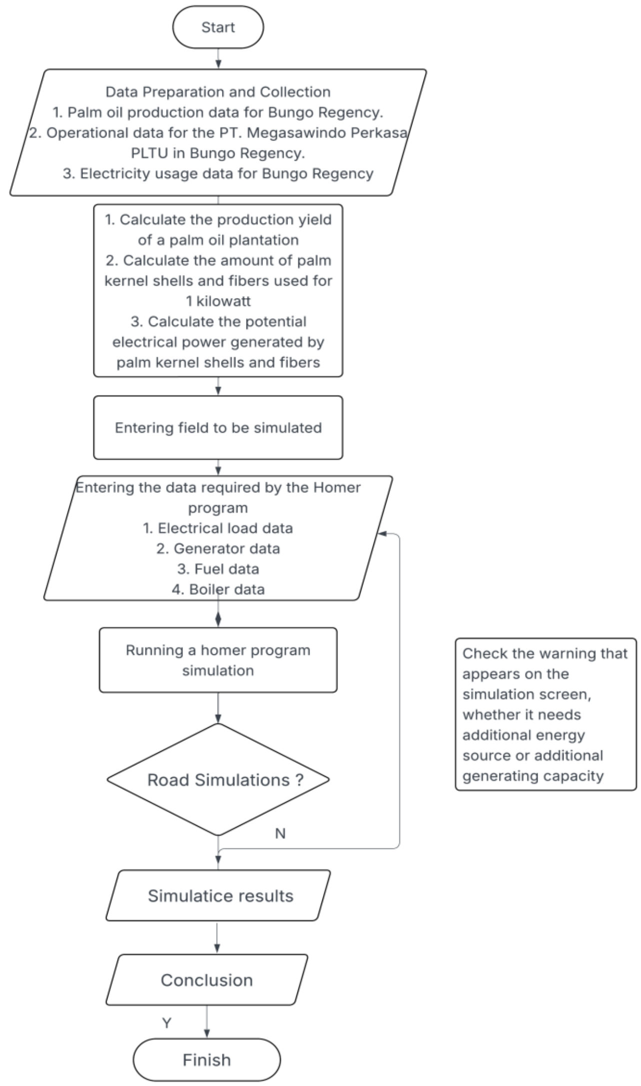

Figure 3. Flowchart Research Method [19]

From Figure 3, we can see that the research steps include: gathering data, applying a specific formula to calculate the electricity generation potential from palm kernel shells and fibers, calculating potential power generation, calculating the cost of generating power, determining how much water is needed per kW, doing a simulation, and then making a conclusion. To ensure technical rigour and address unit consistency, the direct method was employed to calculate the boiler steam capacity, comparing the energy contained in the steam directly with the fuel's energy. The calculation incorporates specific operational parameters from PT Megasawindo Perkasa: a thermal efficiency of 73%, saturated steam enthalpy (hg) of 710,9 kcal/kg, and feedwater enthalpy (hf) of 90,03 kcal/kg. These parameters were validated against actual production data, where palm shells (calorific value:

5.656 kcal/kg) and fibers (calorific value: 4.875 kcal/kg) are utilized as primary fuels. This refined approach provides a transparent basis for estimating the annual generation potential of 21,024 GWh/year from shells and 49,056 GWh/year from fibers, ensuring the results are realistic and grounded in field verified data.

III. RESULT AND DISCUSSION

A. Data Description

To complete the data required for analysis and calculations in this study, data relevant to the research objectives are needed. The data were collected according to the research application, namely energy consumption and energy production in Bungo Regency in 2024. The data are as follows:

1) Electricity consumption data in Bungo Regency in 2024 show in table I.
2) Palm oil plantation production data in Bungo Regency in 2024 show in table II.
3) Steam Power Plant (PLTU) production data from PT Megasawindo Perkasa in January 2024 show in table III.

TABLE 1
ELECTRICAL WNWRGY CONSUMPTION IN BUNGO REGENCY

No.	Month	Installed Power (VA)	Power Capacity (MWh)
1	January	297.286.350	252.693.398
2	February	299.059.900	254.200.915
3	March	299.808.100	254.836.885
4	April	303.662.850	258.113.423
5	May	304.618.750	258.925.938
6	Juny	306.869.650	260.839.203
7	July	307.932.450	261.742.583
8	August	309.193.200	262.814.220
9	September	311.042.900	264.386.465
10	October	312.807.800	265.886.630
11	November	317.718.100	270.060.385
12	December	319.307.700	271.411.545
	Amount	3.689.307.750	3.135.911.588

Table I explains electricity consumption data across Bungo Regency from January to December. Looking at table I, we can see that in December, both installed power and capable power reach their highest levels. Installed power is 319.307.700 VA, and capable power is 271.411.545 W.

TABLE II
PALM OIL PLANTATION PRODUCTION IN BUNGO REGENCY IN 2024

No	Plantation Types Bungo Regency	Palm Oil Production per Year (Tons)
1	Smallholder Plantations	100.676
2	Private Core Plantations	145.396
3	Private Plasma Plantations	246.072
4	Trans-PIR	492.144
	Amount	984.288

Based on Table II, we can see that palm oil plantations are made up of Smallholder Plantations, Private Core Plantations, Private Plasma Plantations, and Trans Pear Plantations. The Trans Pear Plantations produce the most palm oil.

TABLE III
PRODUCTION OF PT MEGASAWINDO PERKASA STEAM POWER PLANT (PLTU) ON JANUARY 19, 2025

Steam Power Plant Operation Date	19 January
Total Boiler Operation (Hours)	24
Amount of Steam Generated (kg/Hour)	31.418,21
Amount of Water Used (kg/Hour)	32.389,90
FFB/Day (tons)	483,72
Power Generated (kWh)	2.094,5
Vapor enthalpy (hg) kcal/kg	710,9
Water enthalpy (hf) kcal/kg	90,03
Calorific Value of Shell (kcal/kg)	5.656
Calorific Value of Fiber (kcal/kg)	4.875
Boiler Efficiency	73%

Table III explains the PLTU production data from PT Megasawindo Perkasa. Based on Table III, we can see that calorific value of Shell 5.656 kcal/kg and calorific value of Fiber 4.875 kcal/kg. The daily production capacity of PT Megasawindo Perkasa is approximately 483,72 tons of FFB. The boiler system utilized at PT Megasawindo's power generation unit operates on a 24 hour continuous cycle with a recorded thermal efficiency of approximately 73%.

B. Calculating Power Generated from Palm Kernel Shells and Fibers from PT Megasawindo Perkasa Steam Power Plant (PLTU) Production Data

Based on the research conducted, the production results of the PT Megasawindo Perkasa PLTU are as shown in Table IV. Table IV explains the production data of PT Megasawindo Perkasa PLTU, where it can be concluded that palm shells are obtained from 5% of fresh fruit bunches is 24.186 kg/days while fibers are obtained from 13% of fresh fruit bunches is 62.883,6 kg/day. The number of shells used/hour is obtained from the comparison of the amount of shells/day to the total number of boiler operations and vice versa to obtain the number of fibers used/hour. Meanwhile, to find out the amount of electrical power produced by shells/hour, it is obtained from the comparison of the steam capacity of the shells to the amount of steam used/kW and a similar method to find out the amount of electrical power produced by fibers/hour.

TABLE IV
RESULTS OF PRODUCTION FROM PT MEGASAWINDO PERKASA'S STEAM POWER PLANT (PLTU) ON JANUARY 19, 2024

Subject	Results
Fresh Fruit Bunches (FFB)	483,72 ton = 483.720 kg/day
Palm kernel shells = 5% FFB	5% x 483.720 kg = 24.186 kg/day
Palm fiber = 13% FFB	13% x 483.720 kg = 62.883,6 kg/day
Total boiler operation	24 hours
Efficiency (η)	73% = 0,73
Amount of steam/kilowatt = Q/P	31.418,21:2.094,5 = 15
Fiber calorific value (GCVs)	4.875 kcal/kg
Shell steam capacity	16.399,83 kg/kWh
Fiber steam capacity	15.018,38 kg/kWh
Number of kernel shells used per hour	2.466,1 kg/hour
Amount of electricity generated from the kernel shells per hour	1.093,3 kwh
Number of fibers used per hour	2.620,2 kg/kWh
Amount of electricity generated from the fibers per hour	1.001,23 kwh
Shell calorific value (GCVc)	5.656 kcal/kg
Vapor enthalpy (hg)	710,9 kcal/kg
Water enthalpy (hf)	90,03 kcal/kg
Fiber calorific value (GCVs)	4.875 kcal/kg

In addition to the production of the PT Megasawindo Perkasa Steam Power Plant (PLTU), the results of palm oil plantations in Bungo Regency are also obtained annually, as can be seen in Figure 4.

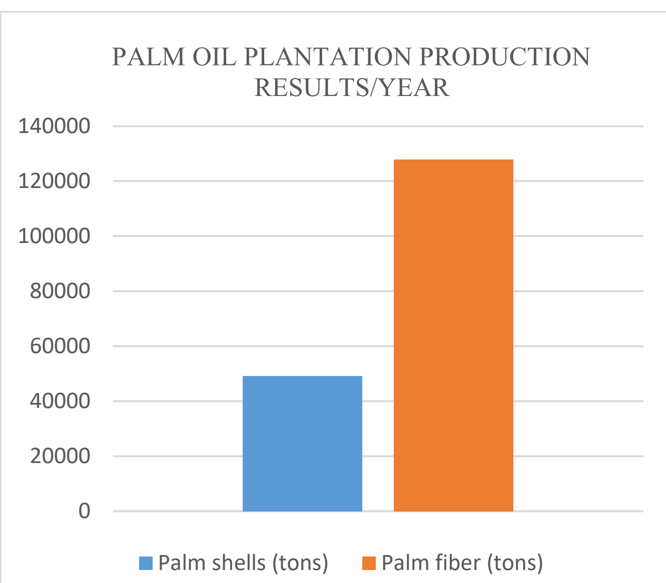

Figure 4. Palm Oil Plantation Production Results/Year

Figure 4 explains the comparison of palm oil plantation production in Bungo Regency in one year, where the palm kernel shells produced amounted to 49.214,4 tons, while the palm fiber produced was approximately 127.957,44 tons. Furthermore, it is known that palm kernel shells are obtained from 5% of fresh fruit bunches (FFB) and palm fiber is obtained from 13% of fresh fruit bunches (FFB).

Based on the production data of PT Megasawindo PLTU, we can see that the amount of palm oil waste needed to produce 1 kW of electrical power can be seen in Figure 5.

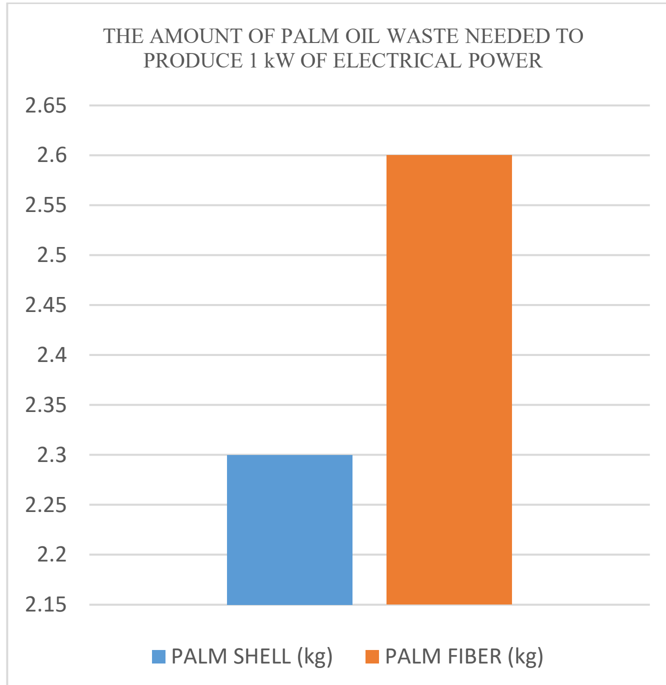

Figure 5. The Amount of Palm Oil Waste Needed to Produce 1 kW of Electrical Power

Figure 5 illustrates the amount of palm oil waste used to produce 1 kW of electricity, using the production data from the PT Megasawindo Perkasa coal-fired power plant (PLTU). Based on this data, the amount of palm kernel shells used to produce 1 kW is calculated by dividing the number of kernel shells used per hour by the amount of electricity generated from the kernel shells per hour. Similarly, for palm fibers, the yield is 2,3 kg/kW of palm kernel shells and 2,6 kg/kW of palm fibers.

C. Potential Energy Generated by Palm Shells and Palm Fibers in One Year

Based on the results of palm oil plantation production in Bungo district, we can find out the potential power generated by palm shells and palm fibers in one hour and one year, this can be seen in Figure 6.

Figure 6 explains the potential electrical power generated by palm kernel shells and palm fibers. Palm fibers generate more electrical power compared to palm kernel shells. The potential electrical power generated by palm kernel shells is 2,4 MW and 21,024 GWh/year, while the potential electrical power generated by palm kernel shells is 5,6 MW and 49,056 GWh/year. The potential electrical power generated by palm shells is obtained from the comparison of the number of palm shells produced from palm plantation production to the number of palm shells required/kW and vice versa to produce the potential electrical power generated by palm fibers is obtained from the comparison of the number of palm fibers produced from palm plantation production to the number of palm fibers required/kW.

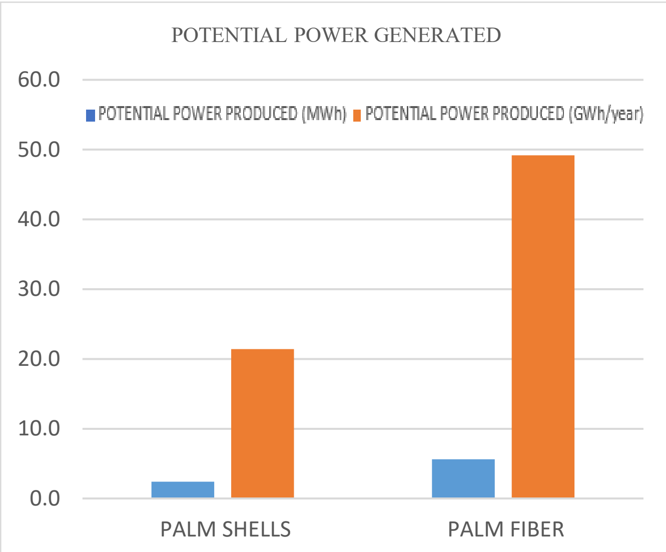

Figure 6. Potential Electrical Power Generated by Palm Shells and Fibers

So the potential electrical power that can be used to meet the electricity needs of the Bungo Regency community in a year is 70,08 MWh year consisting of 21,024 GWh year of palm kernel shells and 49,056 GWh/year of palm fiber so that it can meet the electricity needs in Bungo Regency based on the data on electricity consumption in Bungo Regency, the amount of electricity consumption in a year is 3,14 GWh. The amount of palm shells and palm fibers used to meet annual electricity needs in Bungo district can be seen in Figure 7.

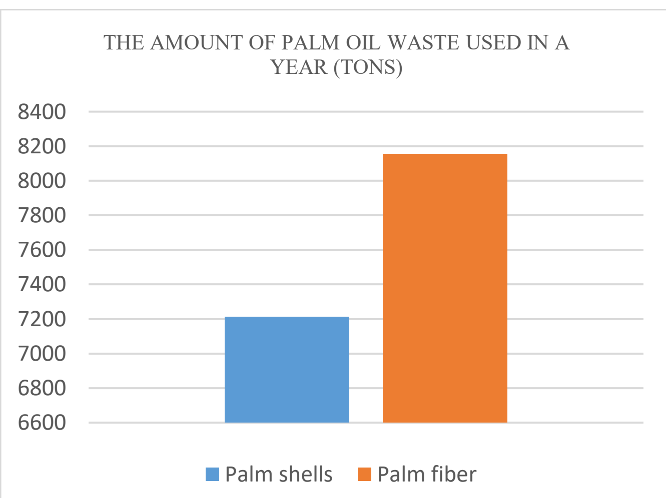

Figure 7. The Amount of Palm Oil Waste Used in A Year (Tons)

Figure 7 explains the amount of palm shells and palm fibers used in a year to meet the electricity needs of Bungo Regency, namely by multiplying the amount of palm shells needed per kW by the amount of electricity used in a year in Bungo Regency, so that 7.212.596 tons of palm shells/year are obtained, and vice versa to find the amount of palm fibers used in a year to meet the electricity needs of Bungo Regency, namely by multiplying the amount of palm fibers needed per kW by the amount of electricity used in a year in Bungo Regency, so that 8.153,37 tons of palm fibers/year are obtained.

IV. CONCLUSION

As indicated by the research results, the finding suggest that this study successfully analyzed the potential utilization of palm shells and fibers. So, the potential power generated by palm shells is 21,024 GWh/year, so the potential power generated from palm fibers is 49,056 GWh/year, which is sufficient to meet the electricity demand of Bungo Regency community of 3,14 GWh/year. This study contributes to the field by providing a precise assessment of biomass fuel requirements, identifying that 2,3 kg/kW of palm shells and 2,6 kg/kW of fibers are required to produce 1 kW of electricity. Unlike generic estimations, these findings offer an empirical framework for regional policymakers and engineers to evaluate the feasibility of biomass-based power integration in areas with high production density like Bungo Regency. The potential power that can be utilized in the Steam Power Plant (PLTU) to meet the electricity needs of Bungo Regency is 8 MW/hour, sourced from 2,4 MW generated by palm shells using 5.520 kg of shells and 5,6 MW generated by palm fibers using 14.560 kg of fibers. Compared to previous studies, this research presents a novelty by determining the exact amount of palm shells and fibers needed to generate electricity, making it possible to assess whether a certain region can implement palm waste utilization as an energy source. For future research, development can be directed toward optimizing the power plant using HOMER simulations to obtain more detailed cost analysis and a reliable system.

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