EMITOR: Jurnal Teknik Elektro

Analysis of the Coal and White Leadtree Wood Co-Firing Needs as a Primary Fuel Source in the Anggrek Gorontalo Coal-Steam Electricity Power Plant (PLTU)

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Abstract *– The Anggrek coal-steam power plant (PLTU) in Gorontalo is a power generation facility that primarily utilizes coal as its energy source. In recent years, the energy industry has undergone significant changes, driven by the need to reduce greenhouse gas emissions and increase the use of renewable energy sources. Dried white leadtree wood, after being exposed to sunlight for 18 hours, has a moisture content of 40% and a high calorific value of 4,197 kcal/kg, making it suitable for blending with coal. This power plant employs co-firing, blending 1–5% white leadtree wood with 1,000 tons of coal daily. This study aims to analyze the electricity generation performance under these conditions. Additionally, it evaluates the fuel requirements, procurement of both coal and white leadtree wood, and electricity sales in kWh. The methodology involves collecting monthly data on fuel consumption and estimating the cost per kWh generated. The results indicate that coal accounts for 95% of the total fuel consumption, while white leadtree wood contributes only 5%. The estimated cost of purchasing coal for co-firing with white leadtree is IDR 520 per kg, whereas the selling price of electricity is IDR 2,500 per kWh.*

Keywords – *Coal-steam power plant; Co-firing; White leadtree wood; Fuel consumption; Electricity generation.*

I. Introduction

THE Anggrek Steam Power Plant (PLTU) located in Gorontalo is one of the power generation facilities that uses coal as the main energy source to generate electricity. In recent years, the energy sector has undergone significant changes, with a strong push to reduce greenhouse gas emissions and shift to more environmentally friendly renewable energy sources. Recent years have seen significant changes in the energy sector, with a strong push towards reducing greenhouse gas emissions and transitioning to renewable energy sources. The traditional centralized energy system is shifting to a decentralized one, incorporating renewable sources like solar and wind [1]. This transition is driven by environmental concerns and the need for energy security [2]. The oil and gas industry is adopting green production methods to achieve net-zero emission goals [3]. However, the decarbonization process presents several challenges, including high capital requirements, competition among energy sectors, and public acceptance [4]. To address these issues, solutions such as enhancing renewable energy deployment and improving energy efficiency have been proposed [5]. Countries like South Korea are exploring economically feasible paths to reduce emissions by closing old coal plants, phasing out nuclear power, and reducing demand [6]. However, the transition remains difficult, particularly for nations heavily reliant on fossil fuels [7]. These difficulties highlight the need for comprehensive energy policies and innovative strategies to facilitate a smooth and sustainable shift toward renewable energy sources. One of the steps taken is the implementation of co-firing technology, which combines the combustion of coal with biomass to reduce dependence on coal and lower the carbon footprint of the power plant [8].

Wood from the lamtoro plant that has been dried for 18 hours in the sun has a water content of around 40% and a high calorific value of 4,197 kcal/kg. This shows its suitability for mixing with coal, which is also the main fuel in PLTU. On the other hand, the coal used in PLTU has a calorific value of around

The manuscript was received on February 22, 2025, revised on March 10, 2025, and published online on March 28, 2025. Emitor is a Journal of Electrical Engineering at Universitas Muhammadiyah Surakarta with ISSN (Print) 1411 – 8890 and ISSN (Online) 2541 – 4518, holding Sinta 3 accreditation. It is accessible at https://journals2.ums.ac.id/index.php/emitor/index.

4,000 kcal/kg [9], which is included in the category of low-quality coal, such as lignite. Currently, more and more PLTU are implementing a mixture of coal and lamtoro wood. Recent studies have explored co-firing biomass with coal in steam power plants to reduce environmental impact and increase the utilization of renewable energy sources. Lamtoro wood and its biochar have been investigated as potential biomass sources [10–12]. Experimental studies involving various biomass blending percentages, ranging from 5% to 25%, have demonstrated improvements in boiler efficiency, reductions in heat rates, and significant decreases in CO_2 emissions [10, 11]. Beyond lamtoro wood, alternative biomass sources such as kedondong sawdust and kaliandra wood have also been evaluated, showing promising effects on power plant performance and emission reduction [13, 14]. Additionally, economic feasibility studies indicate that co-firing could lead to substantial fuel cost savings, making it a viable solution for reducing dependence on coal-based power generation [15]. To support these initiatives, mapping efforts of lamtoro fields have been undertaken to ensure sustainable biomass procurement and logistics [16]. Overall, the integration of biomass co-firing with coal presents a practical approach to minimizing pollutant emissions and promoting a transition towards renewable energy in power generation systems [17]. The Steam Power Plant in Anggrek District, North Gorontalo, is one that implements co-firing, with a mixture proportion of coal and lamtoro wood of around 1–5% for every 1,000 tons of coal used every day [18].

Lamtoro biomass can also function as an alternative fuel to replace fossil fuels such as coal through the co-firing method. This process involves processing a mixture of lamtoro biomass fuel and coal in a boiler furnace at a PLTU [19]. In addition, co-firing can reduce coal use gradually, and burning this mixture is an efficient way to reduce emissions without sacrificing efficiency. The use of lamtoro biomass can also reduce the environmental impacts resulting from coal combustion [20].

II. Research Methods

i. Definition of Coal

Coal is a combustible sedimentary rock, derived from plant remains with the main composition of carbon, hydrogen, and oxygen. Coal has a color that varies from brown to black, and through physical and chemical processes, its carbon content can increase over time.

The process of coal formation begins with the remains of vegetation that undergoes humification. Over millions of years, physical and chemical changes occur that cause an increase in the carbon content in coal [21]. As shown in Figure 1, coal undergoes transformation in structure and composition due to geological processes.

Figure 1: An illustration of coal, a combustible sedimentary rock that undergoes a long-term carbonization process, significantly impacting its chemical and physical properties.

ii. Potential of EBT Lamtoro Biomass

Indonesia has a very large biomass potential to be utilized and developed as EBT (new and renewable energy), in order to achieve the net zero emission target by 2060. One such potential is biomass energy derived from plants such as Lamtoro. Therefore, the government has launched a co-firing program that introduces biomass as a partial replacement fuel in steam power plants to reduce carbon emissions and greenhouse gases [22].

Biomass sources for co-firing can be derived from agricultural waste, wood processing industry waste, household waste, and energy crops cultivated on dry land or in Energy Plantation Forest (HTE) areas, such as Kaliandra, Gamal, and Lamtoro trees. This approach, as illustrated in Figure 2, not only contributes to reducing emissions but also provides economic benefits to local communities [23].

iii. Types of Coal

Coal is a type of sedimentary rock formed from ancient plants buried in the ground and undergoing a carbonization process for millions of years. Coal can be classified into five types based on the level of its formation pro-

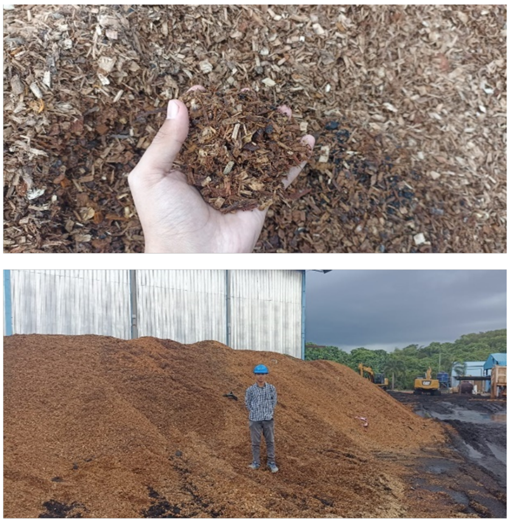

Figure 2: Lamtoro, a biomass energy source with high calorific value, which is utilized as a renewable energy resource for co-firing in steam power plants.

cess, namely peat, lignite, sub-bituminous, bituminous, and anthracite [24]. This classification plays a crucial role in determining the efficiency and environmental impact of coal combustion.

iv. DMG (Maximum Generator Power)

DMG represents the maximum power that can be achieved by the generator unit (MW) over a certain period without being affected by seasonal variations. A generator is an electric machine that converts kinetic or mechanical energy into electrical energy. In general, a generator consists of two main components: the anchor coil and the field coil, which are placed on the stator and rotor, respectively. The stator is the fixed part, while the rotor is the rotating part of the machine [25]. The efficiency of DMG directly influences the overall performance of power plants.

v. Specific Fuel Consumption

Specific fuel consumption (SFC) is the ratio of total fuel consumption to the electrical power generated in an electricity generation facility. This parameter is a crucial measure of power plant efficiency and is often used to estimate the calorific value of the fuel used for combustion [26].

$$\text{SFC} = \frac{\sum \text{Coal}}{\sum \text{Electricity}} \quad \text{Ton/MWh} \tag{1}$$

Equation (1) represents the standard formula for calculating SFC, which should be measured at a stable load over a minimum period of two hours. If this period is deemed too long, data collection can be performed within a shorter duration of at least one hour [27].

vi. Gross Capacity Factor

The capacity factor is an essential performance indicator that describes the efficiency of generating units in producing electrical energy relative to their installed capacity. It is calculated as the ratio of electrical energy production over a specific period to the total installed capacity [28].

$$\text{GFC} = \frac{\text{Production realization (MWh)}}{\sum(\text{operating hours} \times \text{DMG})} \times 100 \tag{2}$$

Equation (2) defines the Gross Capacity Factor (GFC), which serves as a key metric for evaluating the effectiveness of power plant operations. The realization of MWh production for Steam Power Plants (PLTU) refers to the total amount of electrical energy generated within a specific timeframe. This metric, as emphasized in Figure 1, is fundamental in assessing both the performance of the PLTU and the demand for electricity supply [29].

In this study, researchers collect monthly data on coal and lamtoro fuel consumption for each month, assess the energy produced per kWh, and estimate operational costs. After data collection, calculations are performed to analyze the operational efficiency of the Gorontalo Orchid PLTU [30].

The research methodology follows the structured process outlined in Figure 3, ensuring comprehensive data collection and evaluation of power plant performance.

III. Results and Discussion

i. Coal Needs for Lamtoro Co-firing and kWh Produced by Gorontalo Anggrek PLTU

PLTU produces electrical energy through the process of burning coal, petroleum, or natural gas to produce steam, which is measured in kilowatt-hours (kWh). The kWh unit is used to quantify electrical energy consumption. Co-firing lamtoro with coal in PLTU (Steam Power Plant) is a strategy to reduce dependence on coal while utilizing more environmentally friendly biomass. By incorporating lamtoro, PLTU can decrease coal consumption without compromising energy production. The following tables provide calculations of kWh produced and PLTU fuel needs from 2021 to 2024.

ii. Coal and Lamtoro Demand in 2021

Table 1 presents the calculated coal and lamtoro requirements, along with the MWh produced, for the year 2021.

From Table 1, the total coal requirement in 2021 was 299,966 tons, while the lamtoro requirement was

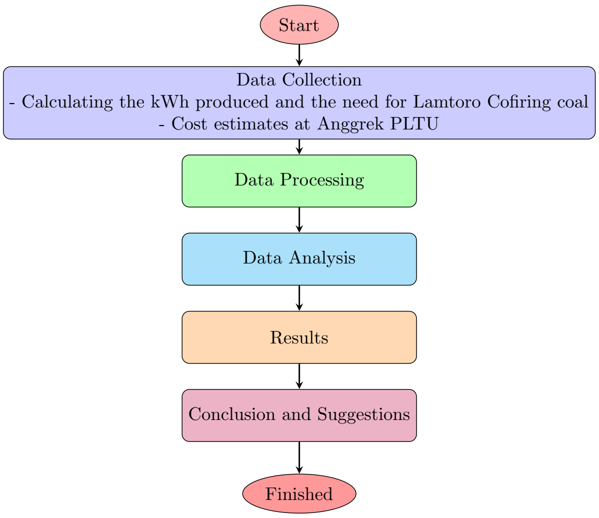

Figure 3: Flowchart illustrating the methodology used in the research, detailing the process of data collection, energy analysis, and evaluation at Gorontalo Orchid PLTU.

Table 1: Coal and lamtoro demand along with MWh generation for 2021.

Month	Coal (ton)	Lamtoro (ton)	MWh
Jan	22,770	1,198	37,200
Feb	26,158	1,376	33,600
Mar	31,346	1,649	37,200
Apr	29,088	1,530	36,000
May	32,707	1,720	37,200
Jun	21,478	1,130	36,000
Jul	27,335	1,438	37,200
Aug	19,244	1,011	37,200
Sep	24,214	1,274	36,000
Oct	24,898	1,309	37,200
Nov	20,283	1,067	36,000
Dec	20,445	1,075	37,200
Total	299,966	15,777	438,000

15,777 tons, producing 438,000 MWh.

Despite co-firing lamtoro with coal, the number of MWh produced remained consistent throughout the year. Figure 4 illustrates the variation in coal and lamtoro demand.

The highest coal demand was recorded in May (32,707 tons), while the lowest occurred in August (19,244 tons). Similarly, the highest lamtoro demand was in May (1,720 tons) and the lowest in August (1,011 tons).

iii. Coal and Lamtoro Demand in 2022

Table 2 presents the calculated coal and lamtoro requirements, along with the MWh produced, for the year 2022.

From Table 2, the total coal requirement in 2022 was 306,875 tons, while the lamtoro requirement was 16,141 tons, producing 438,000 MWh.

Despite co-firing lamtoro with coal, the number of MWh produced remained consistent throughout the year. Figure 5 illustrates the variation in coal and lamtoro demand.

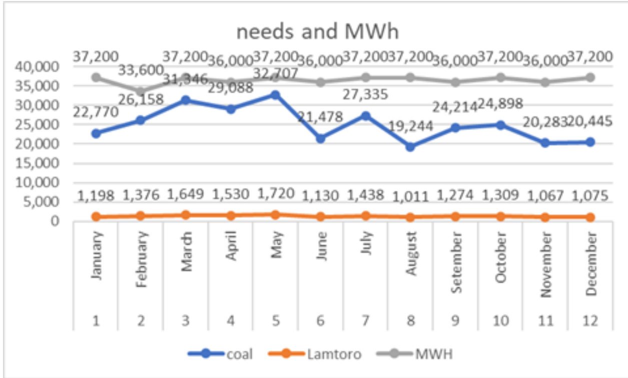

Figure 4: Monthly coal and lamtoro demand along with MWh generation in 2021.

Table 2: Coal and lamtoro demand along with MWh generation for 2022.

Month	Coal (ton)	Lamtoro (ton)	MWh
Jan	26,647	1,401	37,200
Feb	28,441	1,496	33,600
Mar	20,799	1,093	37,200
Apr	26,679	1,403	36,000
May	22,389	1,177	37,200
Jun	30,644	1,612	36,000
Jul	21,681	1,140	37,200
Aug	23,625	1,242	37,200
Sep	23,479	1,235	36,000
Oct	21,472	1,132	37,200
Nov	31,670	1,666	36,000
Dec	29,349	1,544	37,200
Total	306,875	16,141	438,000

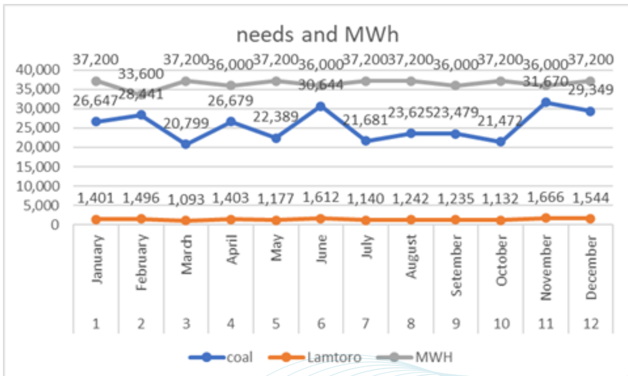

Figure 5: Monthly coal and lamtoro demand along with MWh generation in 2022.

The highest coal demand was recorded in November (31,670 tons), while the lowest occurred in March (20,799 tons). Similarly, the highest lamtoro demand was in November (1,666 tons) and the lowest in March (1,093 tons).

iv. Coal and Lamtoro Demand in 2023

Table 3 presents the calculated coal and lamtoro requirements, along with the MWh produced, for the year 2023.

Table 3: Coal and lamtoro demand along with MWh generation for 2023.

Month	Coal (ton)	Lamtoro (ton)	MWh
Jan	22,605	1,188	37,200
Feb	25,749	1,354	33,600
Mar	25,498	1,341	37,200
Apr	22,573	1,187	36,000
May	24,243	1,275	37,200
Jun	21,478	1,130	36,000
Jul	25,569	1,344	37,200
Aug	29,156	1,533	37,200
Sep	21,958	1,154	36,000
Oct	24,085	1,266	37,200
Nov	22,213	1,169	36,000
Dec	21,859	1,149	37,200
Total	286,986	15,090	438,000

From Table 3, the total coal requirement in 2023 was 286,986 tons, while the lamtoro requirement was 15,090 tons, producing 438,000 MWh.

Despite co-firing lamtoro with coal, the number of MWh produced remained consistent throughout the year. Figure 6 illustrates the variation in coal and lamtoro demand.

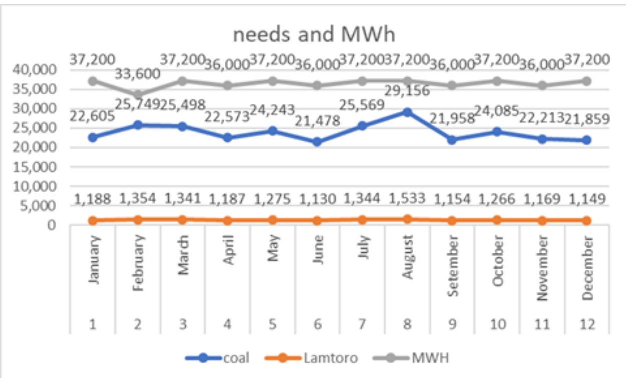

Figure 6: Monthly coal and lamtoro demand along with MWh generation in 2023.

The highest coal demand was recorded in August (29,156 tons), while the lowest occurred in June (21,478 tons). Similarly, the highest lamtoro demand was in August (1,533 tons) and the lowest in June (1,130 tons).

v. Coal and Lamtoro Demand in 2024

Table 4 presents the calculated coal and lamtoro requirements, along with the MWh produced, for the year 2024.

Table 4: Coal and lamtoro demand along with MWh generation for 2024.

Month	Coal (ton)	Lamtoro (ton)	MWh
Jan	27,269	1,434	37,200
Feb	21,036	1,106	34,800
Mar	22,105	1,163	37,200
Apr	23,770	1,250	36,000
May	24,367	1,281	37,200
Jun	25,805	1,357	36,000
Total	144,348	7,591	218,400

From Table 4, the total coal requirement in 2024 was 144,348 tons, while the lamtoro requirement was 7,591 tons, producing 218,400 MWh for the first six months.

Despite co-firing lamtoro with coal, the number of MWh produced remained consistent throughout the first half of the year. Figure 7 illustrates the variation in coal and lamtoro demand.

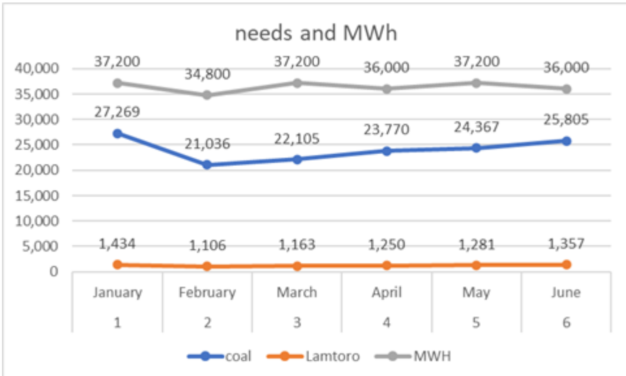

Figure 7: Monthly coal and lamtoro demand along with MWh generation in 2024.

The highest coal demand was recorded in January (27,269 tons), while the lowest occurred in February (21,036 tons). Similarly, the highest lamtoro demand was in January (1,434 tons) and the lowest in February (1,106 tons).

Estimating purchasing and selling costs at a PLTU involves analyzing the cost structure and revenue potential, considering all fuel procurement expenses and electricity sales pricing. The following tables summarize the cost and revenue estimation for fuel procurement and kWh sales.

vi. Calculation purchase and sales costs in 2021

With the calculation steps that have been carried out, you will know each unit and how many kWh are produced and the cost of purchasing fuel and selling, so the calculation Table 5 and Figure 8 are made in 2021.

Table 5: Fuel Purchase Costs and MWH Sold in 2021 (in Rp)

Month	Coal	Lamtoro	MWH
Jan	11,840,400,000	622,960,000	80,536,640,000
Feb	13,602,160,000	715,520,000	69,682,320,000
Mar	16,299,920,000	857,480,000	75,842,600,000
Apr	15,125,760,000	795,600,000	74,078,640,000
May	17,007,640,000	894,400,000	75,097,960,000
Jun	11,168,560,000	587,600,000	78,243,840,000
Jul	14,214,200,000	747,760,000	78,038,040,000
Aug	10,006,880,000	525,720,000	82,467,400,000
Sep	12,591,280,000	662,480,000	76,746,240,000
Oct	12,946,960,000	680,680,000	79,372,360,000
Nov	10,547,160,000	554,840,000	78,898,000,000
Dec	10,631,400,000	559,000,000	81,809,600,000

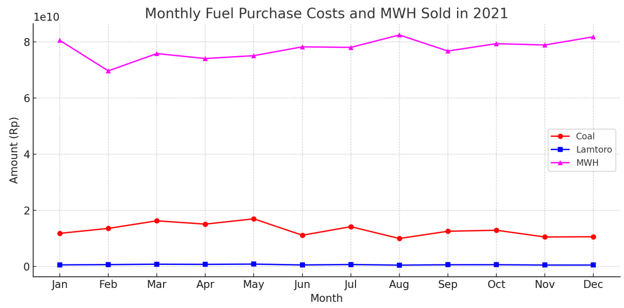

Figure 8: Monthly fuel purchase costs and MWH sold for each month in 2021.

Based on the calculation above to find out the cost of buying coal and lamtoro needed for the two PLTU units is for coal amounting to Rp. 155,982,320,000 and for lamtoro amounting to Rp. 8,204,040,000 and the kWh produced is sold for Rp. 930,813,640,000 for 1 year in 2021.

vii. Calculation Purchase and Sales Costs in 2022

With the calculation steps that have been carried out, the unit consumption, energy produced in kWh, and associated fuel purchase and sales costs are known. The complete calculation results are shown in Table 6 and Figure 9.

Based on the calculation in Table 6, the total coal purchase cost for two PLTU units in 2022 amounts to Rp. 159,575,000,000, while the total lamtoro purchase cost is Rp. 8,393,320,000. The total income from kWh sold throughout the year reached Rp. 927,031,480,000.

Table 6: Fuel purchase costs and MWH sold in 2022

Month	Coal (Rp)	Lamtoro (Rp)	MWH Sold (Rp)
Jan	13,856,440,000	728,520,000	78,415,040,000
Feb	14,789,320,000	777,920,000	68,432,760,000
Mar	10,815,480,000	568,360,000	81,616,160,000
Apr	13,873,080,000	729,560,000	75,397,360,000
May	11,642,280,000	612,040,000	80,745,480,000
Jun	15,934,880,000	838,240,000	73,226,880,000
Jul	11,274,120,000	592,800,000	81,133,080,000
Aug	12,285,000,000	645,840,000	80,069,160,000
Sep	12,209,080,000	642,200,000	77,148,720,000
Oct	11,165,440,000	588,640,000	81,245,920,000
Nov	16,468,400,000	866,320,000	72,665,280,000
Dec	15,261,480,000	802,880,000	76,935,640,000

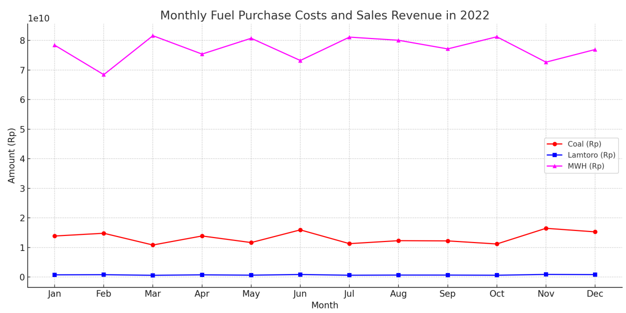

Figure 9: Monthly fuel purchase costs and MWH sold for each month in 2022.

viii. Calculation purchase and sales costs in 2023

With the calculation steps that have been carried out, you will know each unit and how many kWh are produced and the cost of purchasing fuel and selling, so the calculation Table 7 and Figure 10 are made in 2023.

Table 7: Fuel purchase costs and MWH sold in 2023.

Month	Coal (Rp)	Lamtoro (Rp)	MWH (Rp)
Jan	11,754,600,000	617,760,000	80,627,640,000
Feb	13,389,480,000	704,080,000	69,906,440,000
Mar	13,258,960,000	697,320,000	79,043,720,000
Apr	11,737,960,000	617,240,000	77,644,800,000
May	12,606,360,000	663,000,000	79,730,640,000
Jun	11,168,560,000	587,600,000	78,243,840,000
Jul	13,295,880,000	698,880,000	79,005,240,000
Aug	15,161,120,000	797,160,000	77,041,000,000
Sep	11,418,160,000	600,080,000	77,981,760,000
Oct	12,524,200,000	658,320,000	79,817,480,000
Nov	11,550,760,000	607,880,000	77,841,360,000
Dec	11,366,680,000	597,480,000	81,035,840,000

Based on the calculation above to find out the cost of buying coal and lamtoro needed for the two PLTU

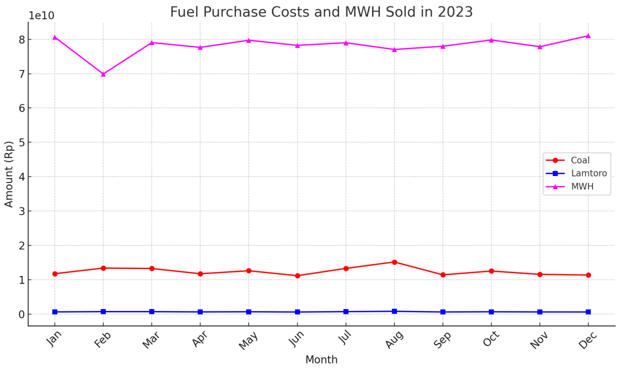

Figure 10: Graph of monthly fuel purchase costs and MWH sold in 2023. The curve illustrates the trends for Coal, Lamtoro, and MWH throughout the year.

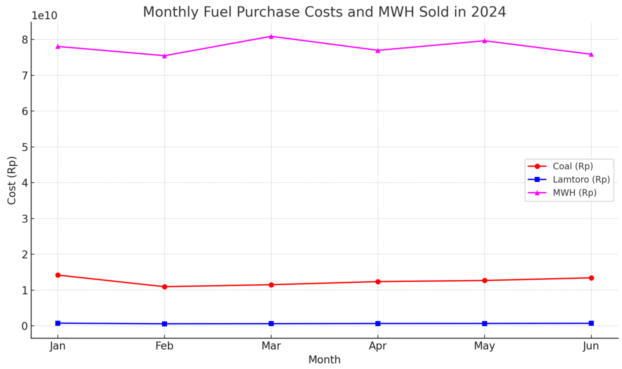

Figure 11: Monthly fuel purchase costs and MWH sold in 2024, showing trends in coal, lamtoro, and electricity production values.

units is for coal amounting to Rp. 149,232,720,000 and for lamtoro amounting to Rp. 7,846,800,000 and the kWh produced is sold for Rp. 937,919,760,000 for 1 year in 2023.

ix. Calculation Purchase and Sales Costs in 2024

With the calculation steps that have been carried out, you will know each unit and how many kWh are produced and the cost of purchasing fuel and selling, so the calculation Table 8 and Figure 11 are made in 2024.

Table 8: Fuel purchase costs and MWH sold in 2024 (in Rp)

Month	Coal	Lamtoro	MWH
Jan	14,179,880,000	745,680,000	78,074,440,000
Feb	10,938,720,000	575,120,000	75,486,160,000
Mar	11,494,600,000	604,760,000	80,900,640,000
Apr	12,360,400,000	650,000,000	76,989,600,000
May	12,670,840,000	666,120,000	79,663,040,000
Jun	13,418,600,000	705,640,000	75,875,760,000

Based on the calculation above to find out the cost of buying coal and lamtoro needed for the two PLTU units is for coal amounting to Rp. 75,060,960,000 and for lamtoro amounting to Rp. 3,947,320,000 and the kWh produced is sold for Rp. 466,989,640,000 for 6 months in 2024.

IV. Conclusion

Based on calculations, the average coal and lamtoro requirements for the two PLTU units are for coal as much as 259,543,750 kg/year and lamtoro as much as 13,649,750 kg/year. In addition, the kWh produced is 383,000,000 kWh/year with the highest operating time of 744 hours and the lowest operating time is 672 hours for 3.6 years in 2021–2024. Based on calculations, the average estimated coal purchase for the two units is IDR 134,962,750,000/year and lamtoro is IDR 7,097,870,000/year, while kWh sales reach IDR 815,688,630,000/year for 3.6 years in 2021–2024.

Acknowledgment

The author gratefully acknowledges the support and contributions of all parties involved in the completion of this research. Special thanks to the supervisor for insightful guidance, the family for continuous encouragement, and colleagues for their collaboration throughout the process.

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