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ANALYSIS OF PALM OIL BIOMASS UTILIZATION FOR RENEWABLE ENERGY GENERATION AT PTPN IV DOLOK ILIR

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Abstract

This study analyzes the potential and utilization of palm oil biomass as a renewable energy source in the cogeneration system of PTPN IV Dolok Ilir, North Sumatra. Palm oil processing generates three primary biomass residue streams: empty fruit bunches (EFB, 22-23% w/w of FFB), mesocarp fiber (12-13% w/w of FFB), and palm shells (5-6% w/w of FFB). The installed cogeneration capacity is 2,000 kW; however, operational observations in August 2025 recorded an average actual power output of 746 kW (37.3% of installed capacity). Turbine isentropic efficiency averaged approximately 55.81%, compared to a design value of 75.00%, indicating a gap of 19.19 percentage points. Steam mass flow rates averaged 42.4 t/h against a design value of 64.9 t/h. EFB, the largest residue stream by weight, remains underutilized as cogeneration fuel. The findings highlight significant opportunities to enhance biomass-to-energy conversion through maintenance optimization and EFB valorization strategies.

Keywords: *Biomass Energy, Palm Oil Mill, Renewable Energy, Cogeneration, Energy Efficiency, PTPN IV Dolok Ilir.*

Abstrak

Penelitian ini menganalisis potensi dan pemanfaatan biomassa kelapa sawit sebagai sumber energi terbarukan dalam sistem kogenerasi PTPN IV Dolok Ilir, Sumatera Utara. Pengolahan kelapa sawit menghasilkan tiga aliran residu biomassa utama: tandan kosong kelapa sawit (TKKS, 22-23% b/b FFB), serat mesokarp (12-13% b/b FFB), dan cangkang sawit (5-6% b/b FFB). Kapasitas kogenerasi terpasang adalah 2.000 kW, namun observasi operasional Agustus 2025 mencatat rata-rata output daya aktual 746 kW (37,3% dari kapasitas terpasang). Efisiensi isentropik turbin rata-rata sekitar 55,81%, lebih rendah 19,19 poin persentase dari nilai desain 75,00%. Laju aliran massa uap rata-rata 42,4 t/jam dari nilai desain 64,9 t/jam. TKKS sebagai aliran residu terbesar belum dimanfaatkan sebagai bahan bakar kogenerasi. Temuan ini menunjukkan peluang signifikan untuk meningkatkan efisiensi konversi energi biomassa melalui optimasi pemeliharaan dan valorisasi TKKS.

Kata Kunci: Energi Biomassa, Pabrik Kelapa Sawit, Energi Terbarukan, Kogenerasi, Efisiensi Energi, PTPN IV Dolok Ilir.

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INTRODUCTION

Palm Oil Mills (POMs) are central facilities in the palm oil agroindustry, serving as the primary processing sites for Fresh Fruit Bunches (FFB) into Crude Palm Oil (CPO) and Palm Kernel Oil (PKO). Beyond their role in oil extraction, palm oil mills generate considerable volumes of biomass residues throughout the production process including empty fruit bunches (EFB), palm fiber (mesocarp fiber), and palm shell which collectively represent a substantial renewable energy resource (Mahlia et al., 2001). The strategic utilization of these biomass residues for energy generation through cogeneration systems has become a defining characteristic of modern palm oil mill operations, enabling facilities to achieve energy self-sufficiency while simultaneously reducing waste and greenhouse gas emissions (Zamri et al., 2022).

The palm oil sector in Indonesia is among the largest in the world, with millions of hectares under cultivation and hundreds of palm oil mills in operation, particularly in Sumatra and Kalimantan. North Sumatra Province is one of the leading palm oil-producing regions, hosting numerous large-scale plantations and mills operated by both government-linked enterprises such as PTPN (Perkebunan Nusantara) and private companies. PTPN IV Dolok Ilir is one such facility, situated in Simalungun Regency, North Sumatra, processing FFB from its surrounding plantation area and generating energy from the resulting biomass residues through a steam-based cogeneration system (Tambunan, 2019).

Biomass-based cogeneration in palm oil mills involves the simultaneous generation of thermal energy (steam) and electrical power from the combustion of biomass residues in steam boilers. The steam produced drives turbine-generator units, supplying the mill's electrical needs while exhaust steam is used for process heating, particularly in sterilization and clarification stages (Krajangsang et al., 2017). This integrated energy system dramatically reduces the reliance of palm oil mills on fossil fuels and grid electricity, contributing to both economic efficiency and environmental sustainability (Nasution et al., 2014).

Despite the well-established role of biomass in palm oil mill energy systems, studies focusing specifically on the quantitative assessment of biomass availability, energy conversion efficiency, and renewable energy potential in individual mill settings — particularly within the context of PTPN operations in North Sumatra — remain limited. Most existing literature focuses on broader regional assessments or technical analyses of individual equipment performance. A site-specific study that integrates biomass characterization, energy flow analysis, and cogeneration system performance evaluation is therefore valuable for operational planning, sustainability reporting, and policy formulation (Zamri et al., 2022).

This study aims to characterize palm oil biomass residues at PTPN IV Dolok Ilir, evaluate cogeneration system performance in terms of energy conversion efficiency and power output, and assess the sustainability implications of biomass-based energy generation for the agroindustry.

METHOD

a. Sampling Location

This study was conducted at the palm oil mill of PTPN IV Dolok Ilir, located in Dolok Ilir District, Simalungun Regency, North Sumatra Province. PTPN IV Dolok Ilir is a state-owned enterprise palm oil mill processing Fresh Fruit Bunches (FFB) from its surrounding plantation estate with a capacity of approximately 30 tonnes FFB per hour.

b. Data Collection

Primary data were collected through direct field observation over five operational days (19-23 August 2025), covering biomass residue quantities, boiler steam output, turbine power output, and operational parameters including steam inlet temperature, pressure, and outlet conditions. Secondary data were obtained from mill operational records, manufacturer datasheets, and published literature on palm oil biomass energy conversion.

c. Data Analysis

Biomass energy potential was estimated using published lower heating values (LHV) for each residue type. Cogeneration system performance was evaluated by comparing design capacity with actual operational data. Turbine isentropic efficiency was calculated using standard thermodynamic equations based on measured steam conditions. All analysis followed Moran and Shapiro (2018) and Cengel and Boles (2015).

RESULTS AND DISCUSSION

a. Palm Oil Biomass Residue Characterization

PTPN IV Dolok Ilir processes Fresh Fruit Bunches from its surrounding plantation estate, generating three primary categories of biomass residues used as boiler fuel: empty fruit bunches (EFB), mesocarp fiber (palm fiber), and palm shell. Based on standard biomass yield ratios for palm oil mills in Indonesia (Mahlia et al., 2001; Nasution et al., 2014), EFB constitutes approximately 22–23% of FFB input by weight, mesocarp fiber approximately 12–13%, and palm shell approximately 5–6%. At the PTPN IV Dolok Ilir mill, the combination of fiber and shell serves as the primary boiler fuel, with EFB typically processed separately for composting or field application, consistent with prevailing practice in North Sumatra mills (Nasution et al., 2014).

The energy content of the biomass residues is substantial. Published lower heating values for palm shell and fiber are approximately 19–21 MJ/kg and 17–19 MJ/kg respectively (Mahlia et al., 2001; Bhatia, 2014), making these residues highly competitive with low-grade coal on an energy density basis. The consistent availability of these residues as a direct byproduct of FFB processing ensures a reliable and captive biomass fuel supply for the mill's boiler, supporting continuous cogeneration operation throughout the production season.

Table 1. Palm Oil Biomass Residue Types, Yields, and Energy Content at PTPN IV Dolok Ilir

Biomass Type	Yield (% FFB)	LHV (MJ/kg)	Primary Use
Empty Fruit Bunches (EFB)	22–23%	~16–18	Composting / Field mulch
Mesocarp Fiber (Palm Fiber)	12–13%	~17–19	Boiler fuel
Palm Shell	5–6%	~19–21	Boiler fuel

Note: LHV values from Mahlia et al. (2001) and Bhatia (2014); yield data from author's field observations at PTPN IV Dolok Ilir (2025). Yield percentages are expressed as weight/weight (% w/w) of Fresh Fruit Bunches (FFB) processed, representing individual biomass streams, not summed totals. LHV = Lower Heating Value.

b. Cogeneration System and Energy Conversion

The cogeneration system at PTPN IV Dolok Ilir follows a conventional biomass-to-energy pathway: biomass residues (primarily fiber and shell) are fed into a steam boiler, where combustion generates high-pressure steam; steam is directed to the back-pressure steam turbine-generator unit (Shinko RB5M, rated at 2,000 kW) to produce electricity; exhaust steam at reduced pressure is utilized for process heat in the sterilization station and elsewhere in the mill. This integrated system ensures that nearly all useful energy from biomass combustion is recovered for productive use within the mill (Krajangsang et al., 2017; Tambunan, 2019).

Table 2. Operational Summary Biomass Processing and Energy Output at PTPN IV Dolok Ilir

Day	Date (2025)	FFB Processed (t)	Boiler Steam Output (t/h)	Power Output (kW)	Remarks
1	19 Aug	~285	~46.3	860	High load
2	20 Aug	~260	~43.2	750	Medium load
3	21 Aug	~295	~47.8	900	Peak load
4	22 Aug	~230	~38.1	620	Low load
5	23 Aug	~220	~36.6	600	Low load
Avg	–	~258	~42.4	746	–

Note: Author's field observations and calculations, PTPN IV Dolok Ilir (2025). Load classification based on percentage of installed capacity (2,000 kW): Low load < 650 kW (< 32.5%); Medium load 650-850 kW (32.5-42.5%); High load > 850 kW (> 42.5%).

Over the five days of operational observation (August 19–26, 2025), actual power output from the turbine-generator ranged from 600 kW to 900 kW, with a daily average of 746 kW against an installed capacity of 2,000 kW. This partial-load operation pattern is consistent with the production schedules and biomass fuel throughput at the mill during the observation period. The cogeneration system sustained continuous electrical supply for all mill operations throughout the observation period, demonstrating the reliability of the biomass-based energy supply.

c. Renewable Energy Generation Performance

The results of this study confirm that palm oil biomass residues represent a significant and reliable renewable energy resource for PTPN IV Dolok Ilir. The mill's cogeneration system, powered entirely by biomass residues from the FFB processing chain, operates without any dependence on fossil fuels or external grid electricity for its core energy needs. This aligns with the broader findings in the literature on Indonesian palm oil mills, which consistently demonstrate the potential for energy self-sufficiency through optimized biomass utilization (Mahlia et al., 2001; Nasution et al., 2014).

The average actual power output of 746 kW observed during the study period represents 37.3% of the installed cogeneration capacity of 2,000 kW. This partial utilization is primarily attributable to production scheduling factors, biomass fuel throughput limitations during the observation period, and variations in FFB processing volumes. At higher FFB throughput levels, commensurate with the mill's full processing capacity, cogeneration output can be expected to scale proportionately with biomass fuel availability (Krajangsang et al., 2017).

From a sustainability perspective, the exclusive use of biomass residues as cogeneration fuel positions PTPN IV Dolok Ilir as a fossil-fuel-free energy producer for its operational needs. Biomass combustion for energy recovery also represents a preferred environmental outcome compared to open burning or landfilling of these residues, contributing to reduced methane emissions and overall greenhouse gas mitigation in the palm oil value chain (Zamri et al., 2022). Furthermore, the energy content of EFB — which is not currently used as boiler fuel at this facility — represents a significant untapped renewable energy reserve that could be mobilized through EFB pelletization, gasification, or biogas conversion technologies (Sulaiman et al., 2011).

Table 3. Renewable Energy Utilization Summary Design vs. Actual at PTPN IV Dolok Ilir

Parameter	Design / Installed Capacity	Actual Average (Aug 2025)
Installed Power Capacity	2,000 kW	–
Average Power Output	–	746 kW (37.3% of capacity)
Biomass Fuel Used	Palm fiber + shell	Palm fiber + shell
Energy Source	100% Biomass	100% Biomass
Fossil Fuel Dependency	None	None
EFB Energy Utilized	Not used (potential resource)	Not used (composted)

Note: Author's calculations based on manufacturer datasheet and field observations, PTPN IV Dolok Ilir (2025)
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d. Implications for Agroindustry Sustainability

The findings of this study have several important implications for the sustainable energy management of PTPN IV Dolok Ilir and for the broader palm oil agroindustry in North Sumatra. First, the demonstrated capacity for energy self-sufficiency through biomass cogeneration confirms that palm oil mills need not depend on fossil fuels or external grid power for their operational energy requirements — a conclusion consistent with the national energy policy direction toward renewable energy expansion in Indonesia (Nasution et al., 2014).

Second, the gap between installed capacity (2,000 kW) and observed average output (746 kW) suggests that further optimization of production scheduling, biomass fuel management, and load consolidation could substantially increase the renewable energy output of the cogeneration system.

Increasing the utilization factor of the installed capacity would directly improve the energy efficiency of biomass use and reduce the specific biomass consumption per unit of electrical output (Zamri et al., 2022).

Third, the currently unutilized energy potential of EFB represents a significant opportunity for renewable energy expansion at the mill. EFB constitutes the largest biomass fraction by weight (22–23% of FFB input) and contains substantial energy value. Conversion of EFB to boiler fuel through densification (pelletization or briquetting), or to biogas through anaerobic digestion, could meaningfully increase the total renewable energy output and improve overall cogeneration system performance (Sulaiman et al., 2011; Mahlia et al., 2001).

Palm oil processing at PTPN IV Dolok Ilir generates three primary biomass residue streams empty fruit bunches (EFB), mesocarp fiber, and palm shell of which fiber and shell serve as the main boiler fuel for the cogeneration system. These residues possess high energy content (LHV of 17–21 MJ/kg for fiber and shell), supporting reliable and continuous cogeneration operation throughout the production season. The cogeneration system operated exclusively on biomass fuel throughout the observation period, achieving an average power output of 746 kW (37.3% of the 2,000-kW installed capacity). The partial-load operation reflects production scheduling and FFB throughput variability rather than fundamental limitations of the biomass energy supply.

CONCLUSIONS

This study demonstrates that palm oil biomass residues at PTPN IV Dolok Ilir constitute a substantial and reliable renewable energy source, sustaining the mill cogeneration system without any fossil fuel dependency. All three residue streams together provide sufficient fuel for continuous boiler operation, confirming the viability of biomass-based energy self-sufficiency in palm oil mill operations. However, actual cogeneration performance falls considerably short of installed design capacity. Power output operates at roughly one-third of available capacity, driven by suboptimal steam utilization, turbine efficiency losses below design specifications, and incomplete valorization of available biomass particularly empty fruit bunches which are directed to composting rather than energy recovery.

These findings indicate significant untapped potential for improving renewable energy output and overall agro-industrial energy sustainability. Realizing this potential requires a holistic approach combining technical maintenance, operational optimization, and strategic integration of underexploited biomass streams. This study provides a practical reference for palm oil mills seeking to enhance energy efficiency and reduce environmental footprint through optimized biomass utilization.

RECOMMENDATION

To improve biomass utilization and renewable energy output, the following measures are recommended: (1) optimizing production scheduling and load management to increase cogeneration system utilization toward rated capacity; (2) ensuring consistent biomass fuel quality through improved fiber and shell handling and storage practices; (3) evaluating the feasibility of EFB energy recovery through pelletization, gasification, or biogas conversion to mobilize the currently unutilized largest biomass fraction; and (4) conducting periodic energy audits of the full cogeneration system to identify further efficiency improvement opportunities.

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