Analysis of Exhaust Gas Utilization at Belawan Gas Turbine Power Plant (PLTG) Lot 3 to Improve Efficiency through a Combined Cycle System with a Steam Turbine

Arighi Denny Saputra, Pristisal Wibowo, Siti Anisah

Abstract

This study analyzes the utilization of the exhaust gas from the Belawan Lot 3 gas turbine (GTPP) via a single-pressure Heat Recovery Steam Generator (HRSG) to improve plant efficiency and reduce emissions in line with Indonesia's NZE 2060 target. The reference HRSG design adopts T_gas,in = 537 °C, p_drum = 93 barA (T_sat ≈ 306 °C), pinch point (PP) = 10 °C, feedwater = 135 °C, and main steam at 510 °C @ 83 barA. The methodology covers characterization of the flue gas, segment-wise HRSG energy balances (superheater/evaporator and economizer), estimation of steam turbine power, and calculation of plant efficiency and specific CO_2 intensity. Results indicate a steam flow rate of 59.97 kg/s (~215.88 t/h), with 122.4 MW_{th} recovered in the evaporator+superheater and 48.6 MW_{th} in the economizer, totaling 171.1 MW_{th}. The predicted stack temperature is ~228 °C, safely above the acid dew point for HSD fuel (~160 °C). The HRSG steam can drive the steam turbine generator to produce 48.42 MW, raising overall plant efficiency from 31.30% (simple cycle) to 48.34% (combined cycle) at the same fuel flow. Furthermore, the combined-cycle integration reduces the electrical CO_2 intensity from 0.852 to 0.552 kg/kWh (≈35% reduction). These findings confirm the technical feasibility of integrating the PLTG Belawan Lot 3 exhaust with the PLTU Belawan Unit 4 to enhance plant efficiency while lowering specific emissions.

Keywords: Gas Turbine (GT); Combined Cycle (CCPP); HRSG; Waste Heat Recovery; Combined-Cycle Integration; Power-Plant Efficiency.

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Introduction

Energy efficiency is one of the key levers in the transition toward the Government of Indonesia's Net Zero Emission (NZE) 2060 target. According to the International Energy Agency (IEA), improving energy efficiency is the fastest and most effective way to curb the growth of carbon emissions in the energy sector [6]. This is especially relevant because, as of October 2024, Indonesia's power system remains dominated by fossil-fueled plants, contributing about 86.6% of national electricity production [14]. This condition underscores the strategic role of enhancing the operational efficiency of existing plants both to reduce emission intensity and to maintain supply reliability.

One widely used fossil-fueled technology in Indonesia is the gas-turbine power plant (GTPP; Indonesian: PLTG). GTPP units have several advantages, including compact design, fast start-up, and high operational flexibility [3], [7]. Their operation follows the Brayton cycle: air is compressed, then mixed with fuel and burned to produce hot, pressurized gas that expands through the gas turbine to generate mechanical energy. This mechanical energy then drives the generator to produce electricity.

Nevertheless, a principal drawback of GTPP is the relatively low thermal efficiency in simple-cycle configuration typically around 30–40% [3], [12], [20] largely due to the discharge of high-temperature flue gas without recovery [1]. For example, the PLTG Belawan Lot 3 (GTPP) vents exhaust gas at approximately 537 °C directly to the atmosphere without further utilization. This indicates a significant opportunity to harness waste heat to improve plant efficiency. Similar energy studies emphasize that utilizing waste/unused heat should be a first-line efficiency strategy prior to capacity expansion [21].

In the literature, waste heat with temperature above 400 °C is categorized as high-temperature waste heat, most suitably utilized via a steam cycle or Heat Recovery Steam Generator (HRSG) technology [1], [9], [13]. An HRSG extracts thermal energy from flue gas to heat water and produce high-pressure steam, which is subsequently expanded in a steam turbine to drive a generator and produce electricity. This technology underpins the combined-cycle power plant (CCPP; Indonesian: PLTGU) configuration, wherein the thermal energy of gas-turbine exhaust is converted into additional electricity rather than released to the atmosphere. Fig. 1 illustrates this arrangement: the gas-turbine exhaust is used to generate steam in the HRSG, which then drives the steam turbine to produce electric power [3].

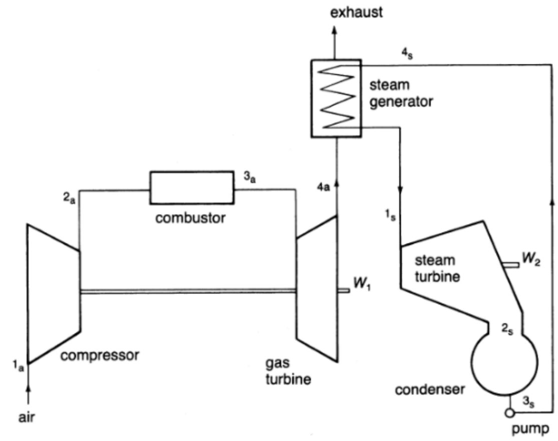

Figure 1. Brayton-Rankine combined-cycle schematic [3]

Combined-cycle efficiency can reach ~60%, much higher than the simple-cycle configuration of GTPP [3], [12]. This concept can be realized, for instance, by integrating PLTG Belawan Lot 3 with PLTU Belawan Unit 4 steam turbine to form a combined-cycle power plant. The GTPP flue gas is directed to an HRSG to produce steam that is then admitted to the Unit 4 steam turbine. Such integration is relatively investment-efficient because it leverages existing infrastructure. Figure 2 ilustrates leveraging co-located infrastructure makes the integration investment-efficient.

Figure 2. Location of PLTG Belawan Lot 3 and PLTU Belawan Unit 4 [11]

Terminology note hereafter we use GTPP, ST, and CCPP for technical terms; Indonesian acronyms (PLTG, PLTU, PLTGU) are retained only in official site names. The concept is therefore worthy of analysis from the perspectives of (i) the steam-turbine power that can be generated, (ii) overall system-efficiency improvement, and (iii) carbon-emissions reduction. Accordingly, this study concentrates on a technical analysis of flue-gas utilization so as to provide more comprehensive recommendations for energy-efficiency strategies in Indonesia's fossil-fueled power plants, with particular emphasis on the PLTG Belawan Lot 3 case.

Aligned with national policy directions that emphasize improving power-system efficiency and optimizing existing assets in the RUPTL 2025–2034 [14], the adoption of combined-cycle technology has progressed rapidly worldwide. However, specific studies on integrating GTPP with existing steam turbine units in Indonesia remain limited. The domestic literature is generally conceptual or simulation-based and preliminary in nature for example, life-cycle assessment of combined-cycle plants in Indonesia by Sinaga et al. [15], and performance evaluations based on modeling or data reconstruction in the Tanjung Priok case by Utami and by Wicaksono et al. [17], [19]. Studies that examine direct PLTG–PLTU integration using real operating data are still scarce. Data-driven approaches have proven effective as a basis for technical decision-making [21], [22]. Therefore, this study focusing on the integration of PLTG Belawan Lot 3 with PLTU Belawan Unit 4 is intended as an empirical contribution to developing energy-efficiency strategies in the domestic context.

Literature Review

2.1 Power-Plant Energy Efficiency

Energy efficiency is a primary indicator of power-plant performance. Improvements in efficiency not only reduce fuel consumption but also directly lower carbon emissions per kWh [6]. Plant efficiency is calculated as the ratio of net electric energy produced to the primary fuel/energy consumed by the plant [26]. In fossil-fueled plants, system efficiency is influenced by thermodynamic cycle design, equipment technology, and operating strategy. In practice, implementing a combined cycle has been shown to increase efficiency to above 50–60%, far higher than the 30–40% typically achieved by simple-cycle configurations [3], [12], [20].

2.2 Gas Turbine Power Plant

A gas-turbine power plant operates on the Brayton cycle: air is compressed in a compressor, mixed and burned with fuel in a combustor, and the resulting hot, pressurized gas is expanded in the turbine to produce mechanical power that drives the generator. Key advantages include operational flexibility and short start-up times features essential for following system load dynamics [3], [7]. The principal drawback in simple-cycle configuration is the relatively low thermal efficiency, only about 30–40% [3], [12], [20], because a large fraction of energy remains in the high-temperature flue gas and is not recovered [1]. This waste energy can be recovered via waste-heat-recovery schemes, particularly a Heat Recovery Steam Generator (HRSG) that converts flue-gas heat into pressurized steam for a steam turbine within a combined-cycle configuration, thereby significantly increasing plant efficiency [1], [3].

2.3 Thermodynamic Characteristics of Flue Gas

The flue gas produced by combustion in a gas turbine is a multicomponent mixture dominated by nitrogen (N_2), carbon dioxide (CO_2), water vapor (H_2O), and residual oxygen (O_2). Its composition and properties determine key thermodynamic characteristics and affect the estimate of recoverable heat [1].

A key parameter in this study is the flue-gas mass flow rate, which can be obtained (i) directly via instrumentation or (ii) indirectly via a combustion/energy balance. A generic hydrocarbon combustion reaction can be written as:

$$C_xH_y + a(O_2 + 3.76N_2) \rightarrow xCO_2 + \frac{y}{2}H_2O + \left(a - x - \frac{y}{4}\right)O_2 + 3.76aN_2 \quad (1)$$

From the flue-gas composition (e.g., O_2/CO_2), one can determine the excess-air ratio (λ), the air–fuel ratio (AFR), and ultimately the flue-gas mass flow from the mass/energy balance:

$$\dot{m}_{fg} = \dot{m}_{air} + \dot{m}_{fuel} \quad (2)$$

Within gas-turbine performance-test standards, ASME PTC 22-2023 recognizes the indirect energy-balance approach for determining the exhaust-gas mass flow as the sum of air and fuel mass flow [2].

2.4 Heat Recovery Steam Generator (HRSG)

In the literature, waste heat with temperature >400 °C is categorized as high-temperature waste heat and is most suitably utilized via a steam cycle/HRSG [1], [9], [13]. An HRSG is a heat exchanger that uses flue-gas energy to generate pressurized steam, which is then expanded in a steam turbine to produce electric power. An HRSG generally comprises three main sections: superheater, evaporator, and economizer, which illustrate by Fig. 3.

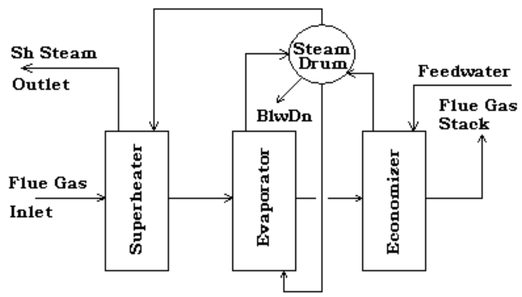

Figure 3. Single-pressure HRSG schematic [4].

The thermal design of an HRSG is governed by the pinch point (PP), defined as the temperature difference between the evaporator outlet flue gas and the drum saturation temperature:

$$PP = T_{fg,evap,out} - T_{sat} \quad (3)$$

A very small PP increases heat-transfer surface area and, consequently, HRSG capital cost. Practical values commonly used are PP = 10–15 °C [1].

In addition, the lower bound of the flue-gas temperature is set by the acid dew point (T_{dp}). For oil fuels (HSD/HSFO), the acid dew point typically ranges from 120–160 °C, whereas for natural gas it is generally 60–70 °C; the stack temperature should be maintained 15–20 °C above the respective dew point to prevent corrosion from acid condensation [9]. In hot-humid climates, controlling surface/stack-gas temperatures in energy equipment shows sensitivity to performance and material degradation justifying a safety margin above the acid dew point for

HRSG operation [23]. Therefore, PP and T_{dp} jointly determine the minimum thermally and materially safe HRSG exit temperature, $T_{fg,out}$.

2.5 Steam Turbine

A steam turbine is an energy-conversion machine that utilizes the thermal energy of high-pressure, high-temperature steam to produce mechanical power through expansion. This mechanical power drives the generator shaft to produce electricity. In a combined-cycle system, the steam turbine functions as the bottoming-cycle component that uses steam produced by the HRSG.

The steam turbine operates on the Rankine cycle: superheated steam enters the turbine, where its thermal energy is converted into mechanical work during expansion; the exhaust steam then enters the condenser to be cooled back into water, which is subsequently pumped to the boiler/HRSG. Steam-turbine performance is strongly influenced by inlet steam pressure, temperature, and mass flow rate [9].

Water–steam properties in this study are computed using the IAPWS-IF97 formulation, which is the common standard for water and steam-cycle design and evaluation [18].

2.6 Combined-Cycle Power Plant

A combined-cycle power plant integrates the Brayton cycle (GTPP) and the Rankine cycle (SPP) to form what is commonly known in Indonesia as PLTGU [24]. In this configuration, the gas-turbine exhaust is not released directly to the atmosphere; instead, it is utilized by the HRSG to generate steam that is subsequently expanded in the steam turbine (ST). Integrating the two cycles significantly increases plant thermal efficiency from about 30–40% in simple-cycle operation to as high as ~60% in a combined-cycle system [3], [12], [20]. Globally, CCPPs have become the standard for modern gas-fired power generation due to their high efficiency and reduced carbon-emission intensity [10].

2.7 Carbon Emissions from Power Plants

Carbon-dioxide (CO_2) emissions are a primary indicator in environmental analyses of fossil-fueled power plants. The magnitude of CO_2 emissions depends on the amount of fuel consumed and the fuel-specific emission factor. The Intergovernmental Panel on Climate Change (IPCC) provides standard emission-factor (EF) values for various fuel types, expressing the amount of CO_2 released per unit of energy combusted, as summarized in Table 1 [8].

Table 1. CO_2 Emission Factors by Fuel Type

Fuel Type	Emission Factor (kg CO_2/GJ)
Bituminous Coal	94.6
Fuel Oil	77.4
High-speed diesel (HSD)	74.1
Natural Gas	56.1

Research Methodology

This study employs a quantitative approach with thermodynamic analysis. The primary focus is to utilize the waste heat (flue gas) from the Belawan Lot 3 gas-turbine power plant (GTPP; Indonesian: PLTG) to generate steam via a Heat Recovery Steam Generator (HRSG). The produced steam is then admitted to the existing steam turbine at Belawan Unit 4 steam power plant (SPP; Indonesian: PLTU).

The research steps include collecting gas-turbine operating data, calculating the flue-gas mass flow rate, determining the heat that can be absorbed by the HRSG, estimating steam production and steam-turbine power, and computing efficiency as well as emission reductions.

2.1 System Description

This study analyzes a combined-cycle power plant (CCPP) scheme that harnesses the waste-heat (flue-gas) energy from the PLTG Belawan Lot 3. The objective is to assess the potential increase in thermal efficiency and electric-power production by integrating an HRSG with the existing steam turbine (ST), or alternatively with a new ST unit.

As illustrated in **Error! Reference source not found.**, the high-temperature exhaust from the PLTG Belawan Lot 3 is routed to a new single-pressure HRSG that produces high-pressure steam. This steam is then injected into the existing ST of Belawan Unit 4 SPP at a pressure admission point compatible with its design. The scheme leverages existing SPP assets (ST, generator, condenser), which lowers investment cost; however, the achievable capacity and operational flexibility are bounded by the specifications of the installed ST.

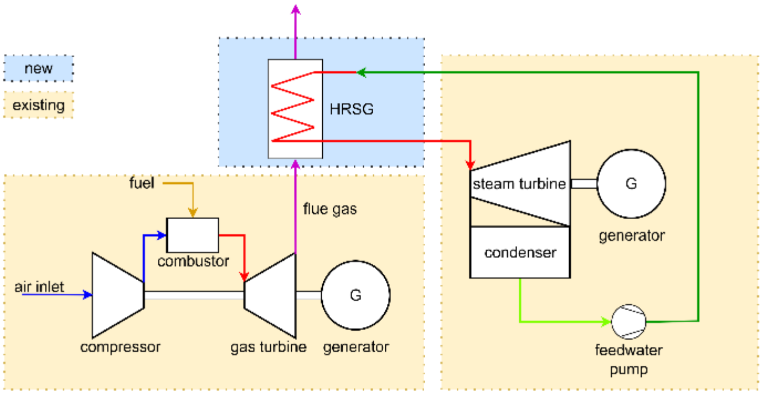

Figure 4. Single pressure combined cycle schematic.

2.2 Plant Parameters

Table 2 summarizes the operating parameters of PLTG Belawan Lot 3 and PLTU Belawan Unit 4 used as the basis for calculating flue-gas mass flow, recoverable heat, and steam production.

Table 2. Operating Parameters

Parameter	Value	Unit
Gas turbine		
Generator active power	89	MW
Fuel flow rate	7.5	kg/s
Fuel heat value	9060	kcal/kg
Flue gas inlet HRSG temp.	537	°C
HRSG & Steam turbine		
Feedwater inlet econ. temp	135	°C
Feedwater inlet econ. press	91	barA
Steam drum press	93	barA
Steam drum temp	306	°C
Main steam inlet temp	510	°C
Main steam inlet press	83	barA
Turbine outlet temp	53	°C
Turbine outlet press	0.14	barA
Generator Efficiency	98	%

2.3 Flue-Gas Characteristics

Flue-gas characteristics are determined using the May 2025 stack-test data for PLTG Belawan Lot 3, particularly the composition listed in Table 3.

Table 3. Flue gas mole fractions

Component	Concentration
H_2O	7,88 %
O_2	15,90 %
CO_2	2,85 %
N_2	73,37 %

The flue-gas mass-flow rate is determined via the energy-balance method consistent with ASME PTC 22-2023, using fuel-consumption rate and measured O_2 in the flue gas, combined with an element balance (C–H–O–N) and the definition of excess-air ratio. The liquid fuel (HSD) is represented by a neat hydrocarbon surrogate C_xH_y. In this study we adopt $C_{12}H_{23}$ as a representative surrogate for diesel (HSD). The fuel molar mass is obtained from atomic masses and stoichiometric indices:

$$M_{fuel} = (M_C\, x) + (M_H\, y) \qquad (4)$$

The molar mass of air is obtained from the sum of the product of each air-component mole fraction (y_i) and its molar mass (M_i):

$$M_{air} = \sum_i y_i\, M_i \qquad (5)$$

with the normal-air composition defined by ISO 2533 (Table 4) [16].

Table 4. Standard Ambient-Air Composition

Component	Concentration
N_2	78,8 %
O_2	20,95 %
Ar	0,93 %
CO_2	0,04 %

Next, the air–fuel ratio (AFR) is determined. From the combustion-reaction relations, the total product moles are:

$$N = \left(4.76\, a - \frac{y}{4}\right) + \frac{y}{2} = 4.76\, a + \frac{y}{4} \qquad (6)$$

The flue-gas O_2 mole fraction is:

$$y_{O_2} = \frac{a - x - \frac{y}{4}}{4.76\, a + \frac{y}{4}} \qquad (7)$$

Hence the required oxidant, in mol O_2 per mol fuel, is:

$$a = \frac{x + \frac{y}{4}(1 + yO_2)}{1 - 4{,}76\, yO_2} \qquad (8)$$

With x, y, and measured y_O2, solve for a, then compute:

$$AFR = \frac{m_{air}}{m_{fuel}} = \frac{4{,}76\, a\, M_{air}}{M_{fuel}} \qquad (9)$$

Finally, the flue-gas mass flow is obtained from fuel mass flow and AFR:

$$\dot{m}_{fg} = \dot{m}_{air} + \dot{m}_{fuel} = \dot{m}_f (AFR + 1) \qquad (10)$$

Table 5. Flue gas parameters

Parameter	Value	Unit

Temperature	537	^{O}C
AFR	63.25	kg_{air}/kg_{fuel}
Mass Flow ($\dot{m}_{fg}$)	481.89	kg/s

2.4 HRSG Heat-Absorption Potential

Given the flue-gas characteristics, the HRSG energy-absorption capability is calculated based on the design parameters for a single-pressure HRSG. The recoverable heat is determined from an energy (heat-balance) approach using the flue-gas mass-flow rate, the mean specific heat of flue gas $(\overline{c_{p,fg}})$, and the temperature difference between HRSG inlet and outlet.

For calculation clarity, the HRSG duty is divided into two segments: Evaporator/Superheater and Economizer. The target outlet temperature of the Evaporator/Superheater segment is set first to evaluate heat absorption. With a pinch point of 10 °C, the evaporator-exit flue-gas temperature is:

$$T_{fg,out,evap} = T_{sat} + PP \quad (11)$$

The heat absorbed in the Evaporator/Superheater segment is:

$$\dot{Q}_{eva,sh} = \dot{m}_{fg}.\overline{c_{p,fg}}\left[T_{fg,in,hrsg} - T_{fg,out,evap}\right] \quad (12)$$

The mean flue-gas specific heat ar{c_p,fg} is computed from the thermodynamic properties of the gas mixture (ideal-gas approach) based on the measured composition, over the operating temperature range:

$$\overline{c_{p,fg}}[kJ/kg.k] = \textstyle\sum_i \omega_i \cdot c_{p,i}\left(T_{avg}\right) \quad (13)$$

with

$$T_{avg} = \frac{T_{fg,in,hrsg} + T_{fg,out,evap}}{2} \quad (14)$$

where ω_i is the mass fraction of each gas component and $c_{p,i}$ is the component specific heat at T_{avg} obtained from tables or the Shomate equation (NIST) providing Cp(T), h(T), and s(T) for species such as CO_2, H_2O, O_2, and N_2 [5]. The mass fraction of each component is computed as

$$\omega_i[\%] = \frac{y_i M_i}{\sum_i y_i M_i} \quad (15)$$

Table 6. Flue-gas mass fractions

Component	Concentration
H_2O	5,01%
O_2	17,97%
CO_2	4,43%
N_2	72,59%

With $\dot{Q}_{eva,sh}$ known, the HRSG steam mass flow is estimated by

$$\dot{m}_{steam}[kg/s] = \frac{Q_{eva,sh}}{h_{out,sh} - h_{in,evap}} \quad (16)$$

Assuming $\dot{m}_{eva,sh} = \dot{m}_{eco}$, the Economizer duty is:

$$Q_{eco}(kW_{th}) = \dot{m}_{steam}\left(h_{in,eva} - h_{fw}\right) \quad (17)$$

Thus, the total HRSG recovered heat is:

$$Q_{rec} = Q_{eva,sh} + Q_{eco} \quad (18)$$

To ensure the HRSG exit temperature remains above the HSD acid dew point, the stack temperature after the Economizer is calculated by:

$$T_{fg,out,eco} = T_{fg,out,evap} - \frac{Q_{eco}}{\dot{m}_{fg} .c_{p,fg}} \quad (19)$$

2.5 Steam-Turbine Power Estimate

The electric power producible by the steam turbine accounts for turbine and generator efficiencies:

$$P_{ST}(MW) = \dot{m}_{steam}\left(h_{steam,in} - h_{steam,out}\right)\eta_{gen} \quad (20)$$

This formulation yields a realistic estimate because it includes thermodynamic, mechanical, and electrical losses in the turbine–generator set.

2.6 Efficiency Calculation

Plant efficiency is evaluated before (simple cycle) and after integration (combined cycle).

$$\eta[\%] = \frac{P}{\dot{m}_{fuel} \times GHV} \times 100\% \quad (21)$$

2.7 Emission-Reduction Estimate

Carbon-emission intensity is evaluated before and after integration. The electrical CO_2-intensity factor is:

$$EF_{elec}\left[kg\,\frac{CO_2}{kWh}\right] = \frac{\dot{m}_{fuel}.GHV.EF_{CO2}}{P_{out}} \quad (22)$$

where EF_CO2 is the fuel-specific emission factor. For HSD, EF_{CO2} = 74.1 kg/GJ is used to assess CO_2 intensity per kWh.

2.8 Sensitivity Study Method

To evaluate the influence of gas-turbine operating conditions on combined-cycle performance, a sensitivity analysis is performed on the HRSG inlet flue-gas temperature ($T_{gas,in}$) while maintaining the gas-turbine power and fuel-consumption rate at the reference values. The three performance indicators are steam-turbine power (P_{ST}), combined-cycle efficiency (η_{CC}), and CO_2 emission intensity per kWh (EF_{elec}). Other HRSG design parameters pinch point, drum saturation temperature, and HRSG exit temperature are held at baseline values so that the effect of $T_{gas,in}$ can be isolated.

Results

This section presents calculation results based on the plant operating data and HRSG design parameters described in Section III. The results are organized from the heat source (flue gas), HRSG heat balance, steam production, and steam-turbine power to the impacts on efficiency and emissions. With the flue-gas characteristics known and given the plant operating parameters, the analysis proceeds as follows. Table 7 presents the results of calculations.

Table 7. HRSG heat balance, steam production, and steam-turbine power

Parameter	Description	Value	Unit
$T_{fg,out,evap}$	Flue-gas temperature at evaporator outlet	316	°C
$T_{fg,out,eco}$	Flue-gas temperature at economizer outlet	228.3	°C
$\dot{Q}_{eva,sh}$	Energy recovery at evaporator + superheater	122 438	kW_{th}
Q_{eco}	Energy recovery at economizer	48 635	kW_{th}
Q_{rec}	HRSG Total energy recovery	171 073	kW_{th}
$\dot{m}_{steam}$	Main-steam mass flow	59.97	kg/s
P_{ST}	Steam-turbine power	48.42	MW

The HRSG exit temperature after the Economizer is above the HSD acid dew point (~160 °C), indicating acceptable corrosion margin for HRSG materials.

Plant performance is compared for two configurations before integration (simple cycle) and after integration (combined cycle) to highlight the effect of heat recovery on efficiency and emission intensity. The summary is given in Table 8.

Table 8. Comparison Before and After Combined-Cycle Integration

Parameter	Description	Unit	Before	After
$\dot{m}_{fuel}$	Fuel Consumption	kg/s	7.5	7.5
P_{out}	Plant Power	MW	89	137.42
η	Efficiency	%	31.30	48.34
EF_{elec}	Emission Intensity	$kgCO_2/kWh$	0.852	0.552

The efficiency gain in the combined-cycle configuration is primarily driven by converting flue-gas enthalpy into steam power, thereby increasing total output without increasing fuel consumption. Consequently, the specific emissions per kWh decrease significantly. The overall efficiency rises from 31.30% to 48.34% because plant output increases with constant fuel input, while the specific CO_2 intensity drops to 0.552 kg/kWh a 35.23% reduction from 0.852 kg/kWh.

To assess sensitivity to operating conditions, a parametric analysis varies the HRSG inlet flue-gas temperature ($T_{gas,in}$) while keeping the gas-turbine power and fuel rate constant. The impacts on steam-turbine power, combined-cycle efficiency, and emission intensity are summarized in Table 9.

Table 9. Sensitivity Analysis

Gas Turbine flue-gas temperature, T_gas.in (°C)	Steam turbine power, P_ST (MW)	Combined cycle efficiency, η_CC (%)	Emission factor, EF_elec ($kgCO_2/kWh$)
527	46.14	47.53	0.561
532	47.28	47.93	0.557
537	48.42	48.34	0.552
542	49.56	48.74	0.547
547	50.71	49.14	0.543

The results show an approximately linear trend: every 5 °C increase in $T_{gas,in}$ raises steam-turbine power by about 1.1 MW and increases η_{CC} by ~0.40 percentage point, while improving emission intensity proportionally. Physically, hotter exhaust carries greater enthalpy, enabling higher HRSG heat absorption especially in the evaporator/superheater so steam production and ST output increase accordingly. Figure 5 visualizes the relationships of $T_{gas,in}$ versus P_{ST} and $T_{gas,in}$ versus η_{CC}.

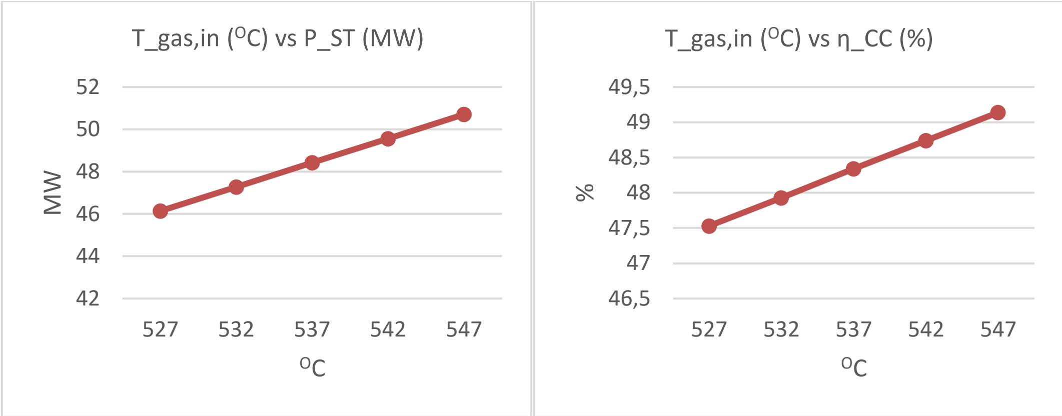

Figure 5. Effect of $T_{gas,in}$ on P_{ST} and on η_{CC}.

Conclusion

In this study we evaluated the technical feasibility of utilizing the PLTG Belawan Lot 3 exhaust through a single-pressure HRSG (pinch point 10 °C) to raise plant performance. The HRSG can recover about 171 MW_{th} of heat (≈122 MW_{th} in the evaporator+superheater and ≈49 MW_{th} in the economizer) while keeping the stack temperature at ≈228 °C, safely above the HSD acid dew point. Under the reference operating conditions, the HRSG produces 59.97 kg/s of steam at 510 °C and 83 barA, enabling an additional 48.42 MW of steam-turbine power. Consequently, overall efficiency increases from 31.30% (simple cycle) to 48.34% (combined cycle) at the same fuel flow, and the specific CO_2 intensity declines from 0.852 to 0.552 kg/kWh (−35.23%). A sensitivity sweep (527–547 °C) further shows that every 5 °C rise in HRSG inlet temperature increases steam-turbine power by ~1.1 MW and combined-cycle efficiency by ~0.40 percentage point. These results collectively answer the research question raised in the Introduction: integrating a single-pressure HRSG with the existing steam turbine is a technically viable pathway to improve efficiency and reduce emission intensity without increasing fuel consumption.

The findings support asset-optimization strategies for Indonesia's fossil-fueled power plant, indicating that brownfield PLTG–PLTU integration can deliver meaningful efficiency gains and emission-intensity reductions aligned with RUPTL 2025–2034. Future work should (i) examine multi-pressure (HP–LP) and/or reheat HRSG configurations to capture a larger fraction of exhaust enthalpy, and (ii) undertake a life-cycle cost assessment (CAPEX/OPEX) with sensitivity to fuel prices and annual operating hours to quantify economic viability and investment risk. Operational studies on admission-point constraints and part-load behavior of the existing steam turbine would also help translate the technical potential into reliable long-term performance.

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