Techno Economy Evaluation of Co-firing Method with CFBB Boiler Type in Indonesia

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Abstract. Studies on the use of biomass focus on its effectiveness in producing efficient and clean energy production. Using two treatments, this research tested the joint combustion of coal and biomass in a circulating fluidized type boiler (CFBB). The parameters tested are divided into technical evaluations, namely the performance of the generator and the emissions produced. In contrast, the cost evaluation is an economic study of the co-firing method. The application of co-firing at both plants produces a good efficiency level, as indicated by the generator performance and emissions, as shown by a reduction in SO_2 emissions by -33.8% in plant A. The co-firing method in plant A produces a higher heating value. In contrast, plant B produces a higher level of energy consumption. In the environmental aspect, co-firing in the two plants under review produces better emissions using the co-firing method. Plant B's emission efficiency level is better than that of plant A. With a decrease in CO of 77% in plant A. In terms of economy, adding biomass in the co-firing method shows a reduction in costs in plant A by 0.35% and an increase in the expenses in plant B.

1 Introduction

Renewable energy policies are developing rapidly around the world. Developing and developed countries allocate investment for the application of renewable energy due to a world agreement to involve all countries in reducing greenhouse gas emissions. Renewable energy requires using fuels that can be recovered or are continuously available, such as wind, diesel, geothermal, and biomass [1]. Furthermore, co-firing strategies are anticipated to be adopted by more power plants shortly [2]. The development of biomass use in energy production is estimated to grow 6% between 2021 and 2030 [3].

As a country that emits greenhouse gases, Indonesia also invests in biomass by substituting some of the fuel in steam power plants. PT PLN (Persero) stipulates that energy provider management must combine fuel with biomass. The Indonesian government is targeting the availability of a co-firing power plant with a total capacity of around 18.000 MW and biomass consumption of 9 million tons/year by 2025 [4]. Power plants in Indonesia use fossil fuels, which causes a climate crisis due to greenhouse gas emissions.

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Reducing coal consumption with co-firing technology is starting to be studied at several power plants. The co-firing method has been tested on various types of boilers in power plants. However, the big question regarding the co-firing method is the potential impacts on boiler performance when co-firing wood with coal may be caused by changes in ash deposition on heat transfer surfaces [5][6].

Power plants with a circulating fluidized bed boiler (CFB) are the most widely used type of boiler in power plants in Indonesia. The combustion process in this boiler involves three components called the fire triangle: fuel, oxygen, and temperature. Solid coal is the primary fuel, which is crushed to achieve smoother grains, so the combustion process takes place optimally. The finer the coal grains, the more optimal the combustion process will be due to the perfect interaction between oxygen and the coal surface.[7]. The air element is essential in the combustion process. Air is pumped into the furnace first, increasing its temperature to reach ignition point conditions.

For a CFB boiler, the solid circulation rate is the ash circulation rate, which is an important design parameter and, along with gas velocity, determines the fluidization state in the CFB boiler. The gas-solid flow in furnaces of CFB boilers can reach a fast fluidization state only if the circulation rate exceeds the saturated carrying capacity, and different values of solid circulation rate represent different flow states of fast bed [8]. Bed material is used as an initial medium for heat transfer from high-speed diesel (HSD) combustion to coal combustion through a fluidization process. This process occurs by blowing air from the bottom of the furnace to keep the bed material and coal floating and turning it into fluid material. This process is called the fluidization combustion process, which is a process that converts coal into energy. Next, energy plays a role in the steamer process to produce water vapor. The practical mechanism in boilers is the change of solid coal into liquid and water vapor. Hot water steam is conveyed to rotate the turbine. Next, the rotation becomes a source for the generator to produce electricity.

Combustion with fluidized bed combustion shows flexibility in fuel use. The fluidized bed process is considered to present a lower furnace maintenance risk. The results of previous studies show that using temperatures lower than 850^0C produces NO_x levels in the gas. This condition can avoid the problem of slag formation at the bottom of the furnace. The fluidized bed process also reduces sulfur dioxide (SO_2) levels, usually formed from burning sulfur content in coal. With these characteristics, CFB is seen as enabling the co-firing method to be applied [9].

The biomass fuels most widely used in co-firing applications in Indonesia are palm oil processing waste, wood pellets, sawdust, and domestic solid waste. The application of co-firing contributes to waste utilization and reduces the volume of coal consumption. However, several studies have shown problems in its implementation, such as the potential for slag at the bottom of the furnace due to increased NO_x emissions (Aditya, Haryadi, and Haryani. 2022) [11]. This research describes two observation points for co-firing with teak sawdust biomass and wood chips. Studies integrating technical and economic aspects will be used for fuel selection decisions.

2 Methods

This research analyzes the test results of applying co-firing to two PLTU (Plant A and Plant B) type Circulating Fluidized Bed (CFB) boilers in Indonesia in 2022. Plant A is in South Sulawesi, and Plant B is in North Sulawesi. The test treatment compares biomass and coal's weight with various parameters in Table 1. Plant A performed three treatments by comparing boiler performance using biomass saw dust with graded compositions (ASD1 and ASD2). Meanwhile, Plant B carried out three treatments using biomass sawdust and wood chips with equal composition (BSD and BWC).

Table 1. Co-firing test parameters.

Parameter	Comparison of Weight Coal: Biomass					
	PLANT A			PLANT B		
	100% Coal	99% Coal: 1% SD	97% Coal: 3% SD	100% Coal	95% Coal: 5% SD	95% Coal: 5% WC
Load (MW)	30	30	30	20	20	20
Test Duration (Hour)	4	4	4	4	4	4
Coal weight (Ton)	96	144	144	76	72.2	72.2
Biomass weight (kg)	0	10.2	3.36	0	3.8	3.8
Total weight (kg)	96	154.2	147.36	76	76	76

The research reviews the efficiency of energy produced, exhaust emissions, and financing. The fuel used is lignite coal, while the biomass used is sawdust and wood chips.

2.1 Energy Efficiency

Energy efficiency is measured by calculating the value of Δ, which compares the difference in boiler performance between co-firing and coal firing divided by the boiler performance during co-firing using formula 1. Meanwhile, the comparison value is the comparison of the fuel's calorific value between co-firing and coal firing divided by the calorific value during co-firing.

$$\%\Delta \text{HHV} = \frac{HHV_{cofiring} - HHV_{coal-firing}}{HHV_{coal-firing}} \text{ x } 100\% \qquad (1)$$

$$\%\Delta \text{FC} = \frac{FC_{cofiring} - FC_{coal-firing}}{FC_{coal-firing}} \text{ x } 100\% \qquad (2)$$

$$\%\Delta \text{MSP} = \frac{MSP_{cofiring} - MSP_{coal-firing}}{MSP_{coal-firing}} \text{ x } 100\% \qquad (3)$$

2.2 Exhaust Gas Efficiency

The efficiency of greenhouse gas emissions is measured by differentiating the emission values when burning pure coal and with co-firing. Emission assessment is based on NO_x and SO_2 parameters.

$$\%\Delta \text{NO}_x = \frac{NOx_{co-firing} - NOx_{coal-firing}}{NOx_{coal-firing}} \qquad (4)$$

$$\%\Delta \text{SO}_x = \frac{SOx_{co-firing} - SOx_{coal-firing}}{SOx_{coal-firing}} \qquad (5)$$

2.3 Economic Efficiency

Economic efficiency is achieved by differentiating the cost value when burning pure coal and burning with co-firing. The cost value assessment is calculated using the formula.

$$\%\Delta\text{Price} = \frac{Price_{cofiring} - Price_{coal-firing}}{Price_{coal-firing}} \text{ x } 100\% \qquad (6)$$

3 Result and Discussion

3.1 Energy Efficiency

The primary evaluation of coal (C) and biomass (B) co-firing was conducted by examining the difference (Δ) value between co-firing and coal firing results with parameters high heating value (HHV), fuel consumption (FC), and main steam pressure (MSP). Boiler performance is seen in the parameter High Heating Value (HHV) or the calorific value produced by the fuel, which is calculated in units of kcal/kg or how many calories are produced when 1 kg of fuel is burned. The second parameter is fuel consumption (FC). The main steam pressure (MSP) is the steam pressure in the boiler that is produced to drive the turbine in the electricity production process, measured in MPa units.

Efficiency analysis of the HHV parameters produces comparative values between biomass and coal co-firing. The ΔHHV value in Figure 1 shows a negative number, or the heat value produced in co-firing is lower than in coal-firing. Of the four treatments, it was found that the best level of efficiency for the HHV parameter was a value close to 0. If ΔHHV=0, the heat value produced in co-firing and coal firing is the same. Researchers found that ASD1 treatment showed the best effectiveness or the use of 1% sawdust, and 99% coal produced an efficiency level of -0.135%. Using 3% sawdust and 97% coal produces an HHV comparison value of -0.004%. Meanwhile, plant B, with a 5% sawdust and 5% wood chip configuration, has HHV comparison values of -0.0054% and -0.0055%.

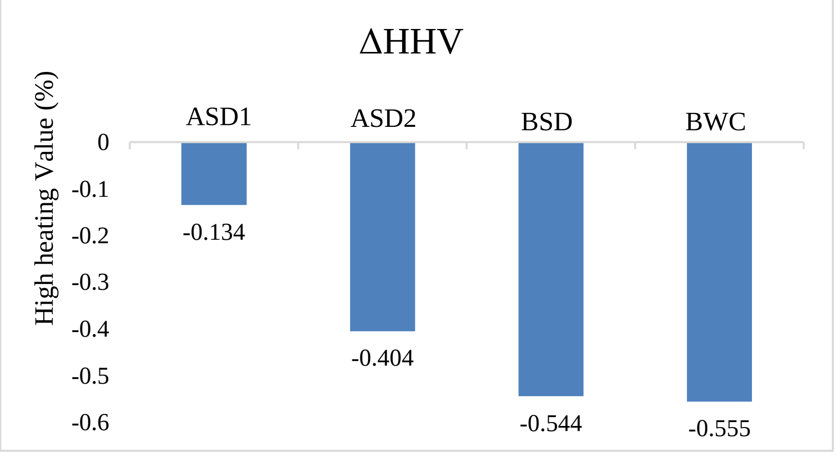

Fig. 1. Efficiency of calorific value of fuel using the co-firing method.

Figure 1 shows that the co-firing method produces a lower heating value than the coal-firing method. The reference explains that the calorific value is related to the carbon content of the fuel used. The carbon content in coal is around 50% higher than the carbon content in biomass [12], [13].

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Efficiency analysis of FC parameters compares fuel consumption values between co-firing biomass and coal. The ΔFC value in Figure 2 shows a positive number at plant A and a negative at plant B. It can be concluded that fuel consumption is more efficient at plant A, especially when using 3% sawdust. Researchers found that ASD 2 treatment showed the best effectiveness or the use of 3% sawdust and 97% coal, resulting in an efficiency level of 60.62%. Using 1% sawdust and 99% coal produces an FC ratio of 53.5%. Meanwhile, plant B, with a 5% sawdust and 5% wood chip configuration, has FC comparison values of -50.78% and -57.94%.

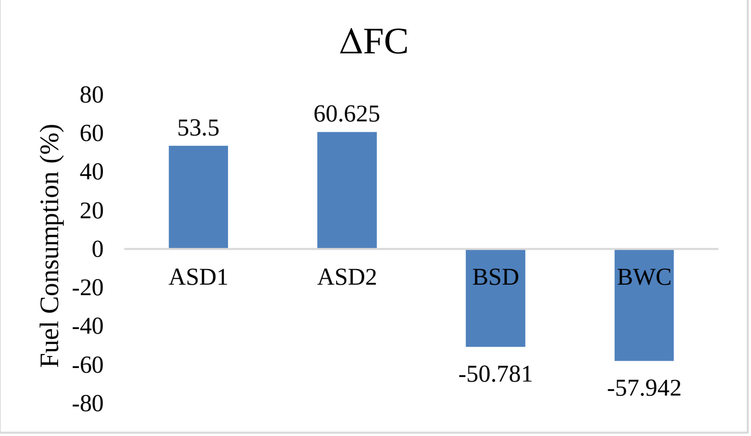

Fig. 2. Fuel consumption efficiency with the co-firing method.

Efficiency analysis the MSP parameter shows the comparative value of combustion work results in the form of steam pressure between co-firing biomass and coal. The ΔMSP value in Figure 3 shows a negative number in plant A or fuel use in the co-firing method is more significant than in the coal firing method. Researchers found that ASD 2 treatment or using 3% sawdust and 99% coal resulted in an efficiency level of 60%. Furthermore, using 1% sawdust and 99% coal produces an MSP comparison value of -0.33%. Meanwhile, plant B, with a 5% sawdust and 5% wood chip configuration, produces MSP comparison values of 9.63% and 1.35%, respectively.

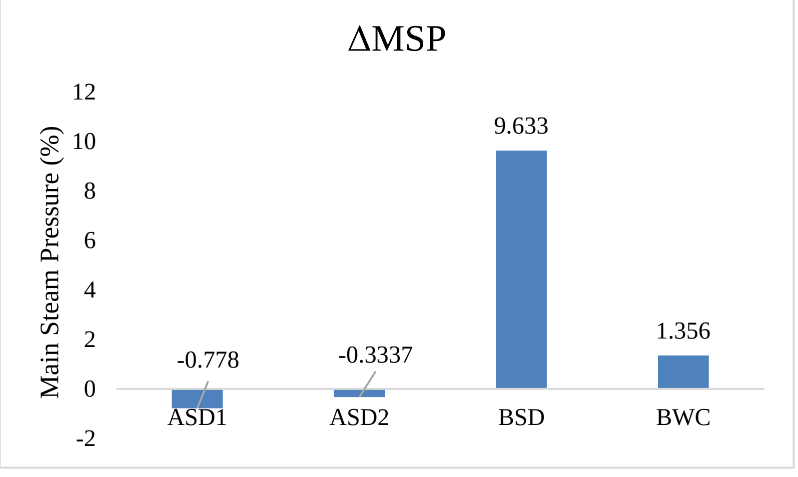

Fig. 3. Analysis of Steam Pressure Efficiency in Boilers.

3.2 Fuel Consumption

Main steam pressure and fuel consumption are essential parameters for the energy generated; changes in steam pressure can affect the electrical efficiency of systems like solid oxide fuel cell–gas turbine hybrids, where a higher pressure ratio can enhance efficiency due to steam injection [14]. Ideally, the higher the fuel consumption, the higher the main steam pressure. However, the limitation of fuel consumption is related to emission risks and production costs. [15].

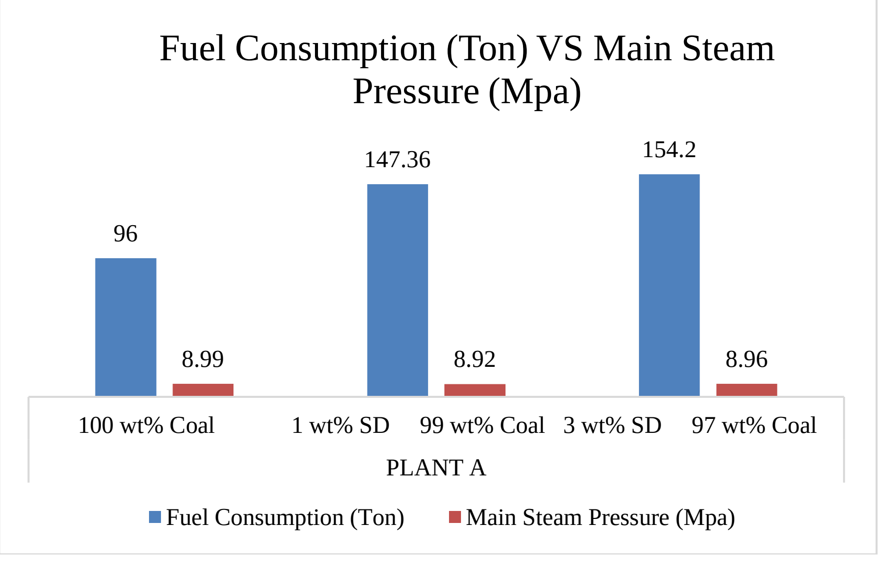

Fig. 4. Relationship between fuel consumption and main steam pressure at plant A.

Figure 4 shows that the findings at plant A illustrate that coal firing with lower fuel consumption produces higher main steam pressure. Meanwhile, both co-firing treatments had lower MSP values even when using a higher fuel volume. Thus, co-firing at plant A could be more efficient in fuel use.

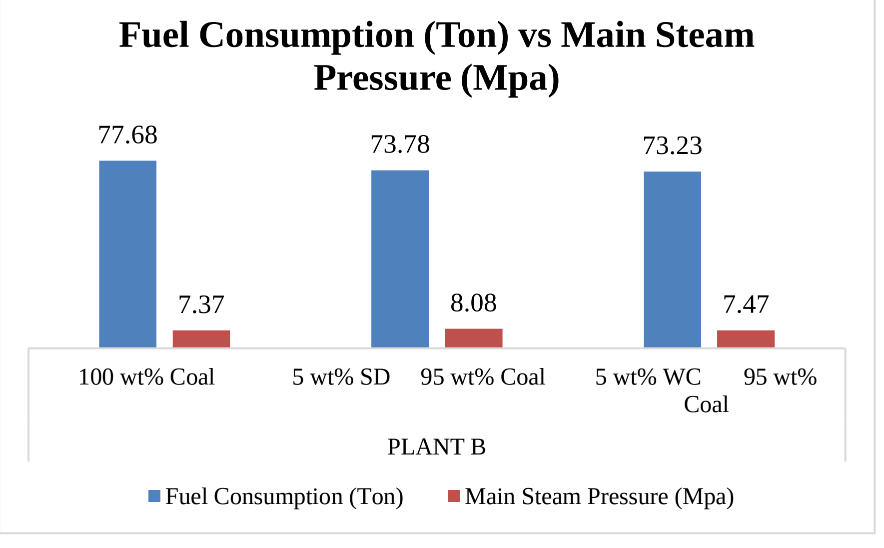

Fig. 5. Relationship between fuel consumption and main steam pressure at plant B.

Figure 5 shows that the coal-firing method at Plant B is a process with a lower fuel efficiency level than the co-firing method. Using 73.78 tons of fuel containing 5% sawdust and 95% coal produces a main steam pressure of 8.08 MPa. The energy value produced in this treatment is greater than that of the coal firing method, even with lower fuel consumption. The co-firing method uses wood chips containing 5% and 95% coal, which produces similarly.

Differences in proximate test results cause the difference in efficiency between Plant A and Plant B. The moisture content value of biomass in Plant A is higher than the two types of biomass in Plant B. This results in differences in fuel quality due to the fuel's water content. This finding relates to previous studies showing that dry fuel produces a higher heating value than wet [16].

3.3 Emission Efficiency

Based on Minister of Environment and Forestry Regulation No. 15 of 2019 concerning PLTU Emission Quality Standards, the maximum emission levels for SO_2 and NO_x are 550 mg/Nm^3—emission results at plants A and B in both configurations.

Table 2. Emission Test Result at Plan A.

Parameter	PLANT A		
	100 wt% Coal	**1 wt% SD 99 wt% Coal**	**3 wt% SD 97 wt% Coal**
CO (ppm)	17	3.8	3.8
NO_x (mg/Nm^3)	158.7	296.4	279.7
SO_2 (mg/Nm^3)	313	206.9	258.7

Table 2 shows plant A results for CO, NO_x, and SO_2 emission values, which are still below the specified standard. The lowest NO_x emissions were at 100% coal firing, and the lowest SO_2 value was at 1% sawdust.

Table 3. Emission Test Result at Plan B.

Parameter	PLANT B		
	100 wt% Coal	**1 wt% SD 99 wt% Coal**	**3 wt% SD 97 wt% Coal**
CO (ppm)	17	5.7	4.8
NO_x (mg/Nm^3)	158.7	123.0	71.5
SO_2 (mg/Nm^3)	313	277.8	222.4

Table 3 shows plant B results for CO, NO_x, and SO_2 emission values, which are still below the specified standard. The lowest NO_x emissions were at 3% sawdust firing, and the lowest SO_2 value was at 3% sawdust. The co-firing method applied at plant A reduced CO and SO_2 emissions. At the same time, NO_x emissions in co-firing are higher than in coal firing. This differs from the application of co-firing at plant B, contributing to the three emission parameters. The analysis of the efficiency level of the co-firing method is continued by calculating the comparison (Δ) between co-firing and coal firing. Figures 6, 7, and 8 present the level of efficiency. A small comparison value indicates a significant level of efficiency.

The results of the ΔCO analysis showed negative values in all four treatments (Figure 6). Thus, all these treatments produce low emissions. The best emission efficiency values were demonstrated in the ASD1 and ASD2 treatments or when using 1 & 3% sawdust. The ΔCO value between co-firing biomass and coal shows negative numbers in all four treatments. Plant A produces a better efficiency than Plant B for CO emission parameters. Researchers found that ASD1 and ASD2 treatments showed a CO efficiency level of 77%. Plant B produces an efficiency level of 66% when using sawdust and 71% when using wood chips.

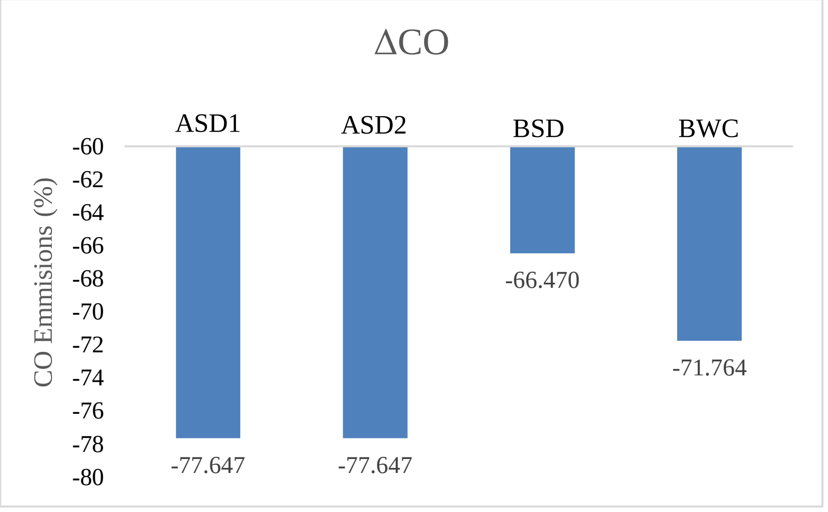

Fig. 6. Efficiency of Co-firing Application on CO Emissions.

CO emissions were measured during joint combustion in two power plants for four hours at plants A and B. Data was measured at the same load demand and operating mode for both locations. In the NO_x parameter, a positive delta value was found in plant A and a negative value in plant B. A positive value indicates NO_x emissions in co-firing are higher than in coal firing (Figure 7). The best emission efficiency value was shown in the BWC or co-firing treatment with 5% wood chip or a NO_x delta of -54.9%.

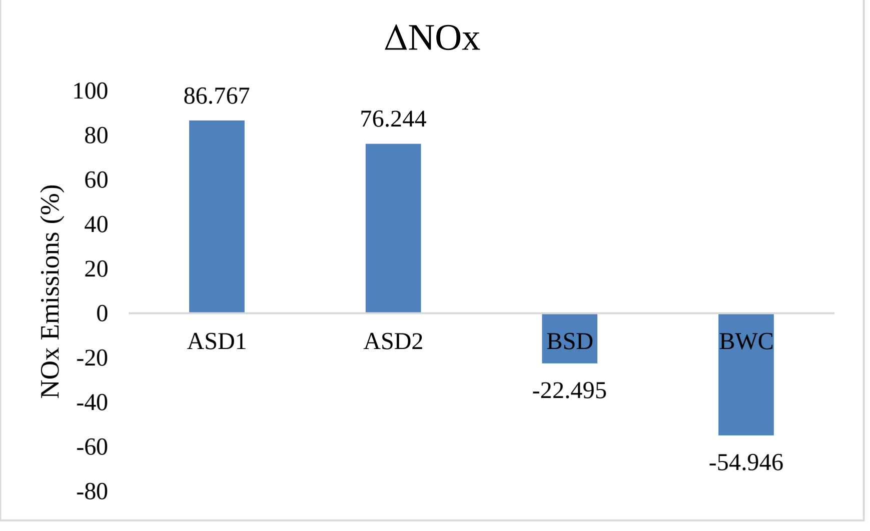

Fig. 7. Efficiency of Co-firing Application on NO_x Emissions.

In the SO_2 emission parameter analysis, negative delta values were found in all treatments. A negative value indicates SO_x emissions in co-firing are lower than in coal firing (Figure 8). The best SO_2 emission efficiency value was shown in the ASD1 or co-firing treatment with 1% sawdust in plant A or delta SO_2 of -33.8%.

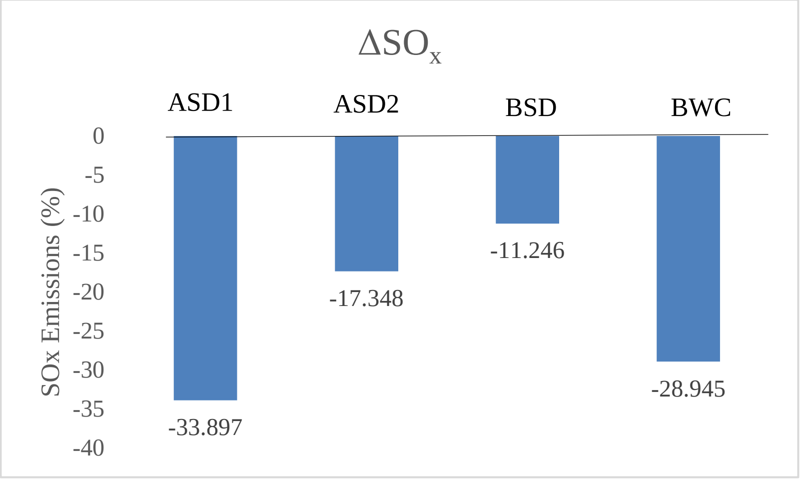

Fig. 8. Efficiency of Co-firing Application on SO_x Emissions.

The analysis results show that the co-firing method at both locations effectively reduces exhaust emissions. The mechanism for reducing carbon emissions using the co-firing method was revealed by [17] as increasing the biomass composition of the fuel, which results in a decrease in the volume of unburned carbon. Or the carbon content is not released into the air. The oxygen content influences NO_x and SO_2 emissions in the excreta water and bed temperature [18]. The increase in NO_x values in plant A is caused by the high excretion of water required for complete combustion.

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3.4 Cost Efficiency

In this research, the cost parameters are assumed to be the same as coal and biomass prices for both generators. Generation costs are calculated based on the weight and type of fuel (coal, sawdust, and wood chip) used in the electricity production. The delta fuel price value is positive at plant A and negative at plant B. Figure 9 shows that the minimum cost is shown at plant B with a value of -4.25%. The maximum price comparison value is displayed at plant A with a 3% sawdust co-firing configuration with a value of 1.06 %. The results explain that the cost of electricity production per kWh using co-firing is higher than in plant A and lower in plant B than in coal firing. Fuel price analysis at plant A produces a good level of efficiency. In contrast, at plant B, the difference in cost efficiency is caused by differences in the energy produced, where the power generated at plant A is 30 MW. In contrast, at plant B it produces 20 MW. The working mechanisms in the production process can cause significant costs for power plants. The additional costs at plant B are related to the difference in energy levels between the two observation locations, with relatively the exact total costs due to differences in boiler performance, especially at bed temperature. Still, this condition contributes to an increase in emission quality.

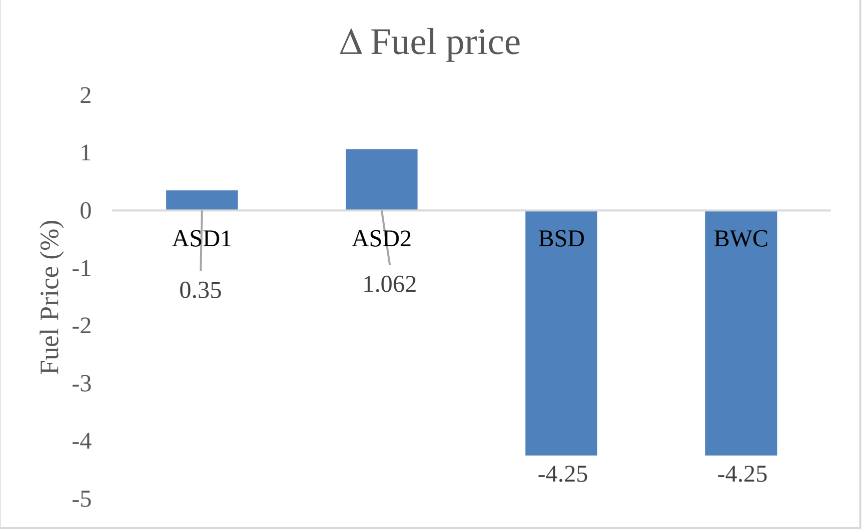

Fig. 9. Cost Efficiency in Implementing Co-firing

4 Conclusion

The results of the analysis of the efficiency of co-firing in two electrical installations show differences in technical performance in various indicators. The co-firing method in both plants produces a good level of efficiency. The energy efficiency produced in the two plants differs in two parameters. The co-firing method in plant A produces a higher calorific value of -0.004%, while plant B produces a higher energy consumption rate of 60.62%.

In terms of the environment, the application of co-firing in the two plants reviewed produced better emissions using the co-firing method. The best emission efficiency value was shown in BWC treatment or co-firing with 5% wood chip or delta NO_x of -54.9%. The emission efficiency level at plant B is better than that of plant A. In the economic aspect, adding biomass to the co-firing method showed a decrease in costs in plant A by 1.06% and an increase in plant B by 4.25%.

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