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Regional Case Study

Environmental Impact Assessment of Co-firing Implementation at X Steam Power Plant, West Java

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Abstract
Co-firing is the activity of adding biomass to the combustion process as a mixed fuel for coal in power plants. In 2021 co-firing has been carried out at 17 PLTUs in Indonesia. The co-firing program at a steam power plant is a form of reducing coal consumption which can reduce carbon emissions while increasing the use of renewable energy without increasing investment in new power plants. PLTU X in West Java, Indonesia has implemented co-firing using sawdust biomass using the direct method without adding or modifying equipment. The use of biomass is obtained from wood-cutting waste, with a ratio of sawdust biomass usage <5%. Assessment of potential environmental impacts is carried out using the Life Cycle Assessment (LCA) method with cradle-to-gate coverage through two scenarios, namely full coal burning, and co-firing. The functional unit uses 1 kWh and the potential impact assessment method used IPCC2021 GWP100 and the CML-IA baseline. The results of the study obtained an assessment of the potential for environmental impact that could reduce the Global Warming Potential (GWP) by 0.13%, acidification by 0.40%, and eutrophication by 0.14%, but there was an increase in ozone layer depletion by 0.72%.

Keywords: Life cycle assessment; co-firing; environmental impact assessment; steam power plant; biomass; sawdust

1. Introduction

An increase in the human population will increase economic conditions and quality of living standards. Increasing human living standards will affect the high use of energy (Seutche et al., 2021). Continuous use of energy will cause an energy crisis (Bhuiyan et al., 2018). Fossil-based energy sources are the main cause of global warming (Hadi & Heidari, 2021). The electricity production sector is the main contributor to 25% of global Greenhouse Gas (GHG) emissions (Thaker et al., 2019). To reduce GHG emissions by reducing the use of fossil energy, steps can be taken by using alternative energy, such as the use of renewable energy (C. Gao et al., 2021). However, the use of renewable energy requires a lot of money and uses a large area of land (L. Gao et al., 2021). Efforts to reduce costs and continue to use renewable energy from combustion are through mixing biomass (Kuznetsov et al., 2021). The use of biomass energy as renewable energy has a significant contribution which can produce less CO_2 than fossil fuel sources (Bhuiyan et al., 2018). Co-firing is a joint combustion process between biomass and coal in a power plant. Burning coal and biomass has a positive impact on reducing emissions, so it can show a synergy between the amount of biomass and the emissions produced (Yang et al., 2021). Currently,62 countries in the world generate electricity from biomass such as America (26%), Germany (15%), Brazil (7%), and Japan (7%) (Bhuiyan et al., 2018).

According to the Press Release of the Ministry of Energy and Mineral Resources of the Republic of Indonesia Number 215.Pers/04/SJI/2021 dated 22 June 2021, co-firing has been carried out in 17 power plant units until June 2021, or 17.7% of the total power plants in Indonesia. The co-firing program at the steam power plant is a form of reducing coal consumption which can reduce carbon emissions while increasing the use of renewable energy without increasing investment in new power plants (Rahayu, 2021). The type of biomass utilization in Indonesia is wood sawdust. The amount of wood sawdust in Indonesia is 679,247 m^3 with a density of 600 kg/m^3 equivalent to 407,548.2 tonnes (Arman & Munira, 2018). However, the amount of mixing biomass in co-firing can only be carried out at a maximum of 10% of the capacity of a coal-fired power plant (Mohd Idris & Hashim, 2021). Biomass has a higher moisture content than coal, so the calorific value of biomass is lower than coal. Biomass has a lower sulfur content and a carbon-to-oxygen (C/O) ratio than coal. Residual biomass has a higher chlorine content than coal. So if not properly managed and maintained it can damage the boiler (Smith et al., 2019).

Currently, the implementation of co-firing has become a sustainable alternative to reducing fossil fuels (Wander et al., 2020). Based on research Septiani (2021) explained that the implementation of co-firing has been proven to reduce exhaust emissions produced from a power plant, namely it succeeded in reducing SO_2 emissions by 46.82%, NOx by 37.03%, and particulates by 37.28%. Meanwhile, according to research by Kommalapati (2018) the results of co-firing using LCA analysis with Simapro 8.3.0 software at 15% co-firing can reduce CO_2, CO, SO_2, PM2.5, NOx, and VOC emissions by 13.5%, 6.4%, 9, 5%, 9.2%, 11.6%, and 7.7%.

In a previous study, Tsalidis et al., (2014) and Arteaga-Pérez et al., (2015) conducted an assessment of the potential impact of cofiring with the type of burning using torrefaction biomass which uses a type of wood biomass with a ratio of 20% the result can reduce the GWP by 6-12%. Kommalapati et al., (2018) and Morrison & Golden (2017) studies, co-firing was carried out using direct co-firing where a potential impact assessment was not only carried out to measure the GWP but also assessed other impacts such as ozone layer depletion, acidification, and eutrophication using forest residue biomass in Kommalapati et al., (2018) and wood pellets in Morrison & Golden (2017) research. The research implementation of co-firing in Indonesia has been carried out by Wiloso et al.,(2020) using sorghum biomass, but only evaluating the reduction in GWP. In this study, the evaluation will be carried out of the co-firing implementation with sawdust to assess the potential environmental impacts of GWP, ozone layer depletion, acidification, and eutrophication.

In June 2021 X steam power plant in West Java carried out co-firing in its production activities after going through several trials using biomass types from 2020. Co-firing was carried out using sawdust-type biomass. Implementation of co-firing at X steam power plant is direct and without equipment engineering. Co-firing at X steam power plant is carried out with a sawdust biomass usage ratio of <5%. This research was conducted to assess environmental aspects and impacts using the Life Cycle Assessment (LCA) method. Impact assessment is carried out by comparing the existing condition of full coal with the condition of co-firing implementation.

2. Methods

Life cycle assessment or Life Cycle Assessment (LCA) is an assessment method for assessing environmental impacts based on products, and production processes, which are calculated from the use of energy, substances, and the amount of emissions produced (Zhao et al., 2020). LCA can provide an overview of the decision-making process in calculating potential impacts throughout the life cycle (Bianco et al., 2021). This research was conducted in the power generation industry with coal as the main fuel, which is known as a steam power plant located in West Java. X Steam power plant has an installed capacity of 990 MW (3X330 MW) which uses coal fuel, but in June 2021 it will start implementing co-firing using sawdust and environmental potential impact will be evaluated using the LCA method, which refers to SNI ISO 14040:2016 Environmental Management-Life Cycle Assessment-Principles and

Framework, and SNI ISO 14044:2017 Environmental Management-Life Cycle Assessment-Requirements and Guidelines. The research framework is in **Figure 1**.

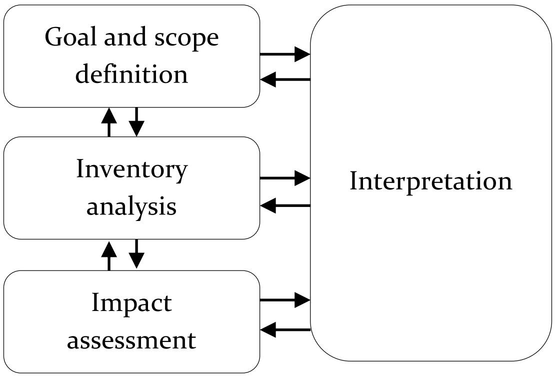


Figure 1. Stages of a LCA

Step 1: Determination of objectives and scope: In this stage, the boundaries of the scope of the product, process, or activity are determined. This research aims to evaluate the potential environmental impact and compare it with full coal burning with an assessment of the potential environmental impact of co-firing using coal and sawdust biomass as fuel. The limitation of this study is in the scope of Cradle to Gate which includes the coal mining process and/or the sawmill industry as well as the electricity production process which consists of production process units namely Circulation Water Pump (CWP)-Condensor Heater-Boiler-Turbine-Generator-Transformer. Function units are used in units of 1 kWh of electricity production.

Step 2: Inventory analysis: The process of identifying and measuring the energy, water, and other materials used. In this study, the cradle data used the simaPro software database using the USLCI (United States Life Cycle Inventory) database for the process of adding coal which includes the coal production process which consists of the process of coal mining, coal cleaning, and coal transportation as well as data on electricity/fuel consumption, water consumption, and chemical consumption and the resulting emissions. Cradle data for obtaining biomass sources also see the USLCI database contained in the SimaPro software. Meanwhile, gate data was obtained from data from monitoring and measurements carried out by PLTU X.

Step 3: Impact Analysis: The process of identifying aspects and impacts originating from the inventory results that have an impact on humans and ecological conditions. In this study, an environmental impact assessment was carried out using the IPCC2021 GWP 100 and CML IA methods.

Step 4: Interpretation: The process of evaluating the results of the inventory and the impact of the product life cycle

LCA results depend on data processing, databases, impact assessment methods, and models developed and implemented in the LCA study development software (Aparecido et al., 2019). The LCA method can be carried out using the SimaPro software. SimaPro is a software that provides data on environmental impacts by revealing the carbon footprint of various factors and their development (Natarajan et al., 2020).

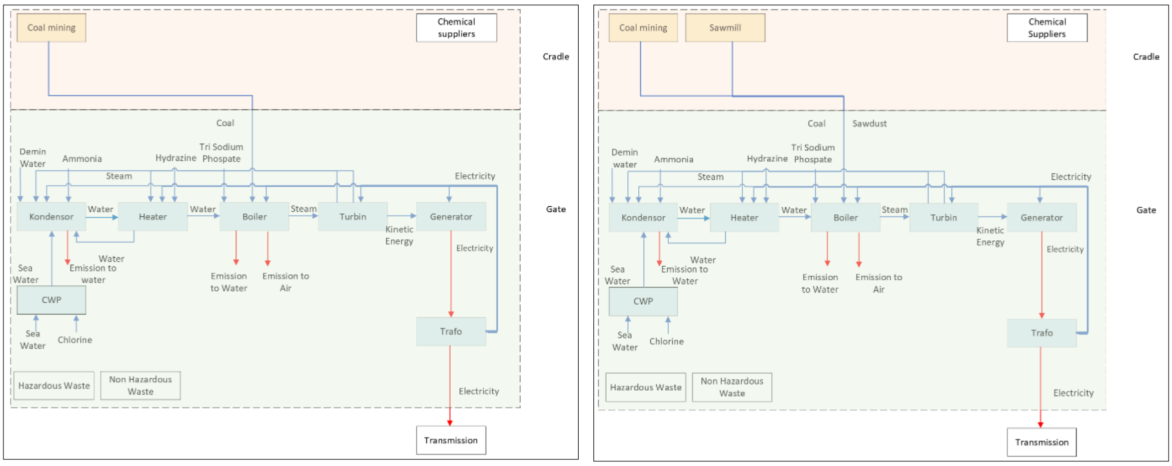
3. Result and Discussion

3.1 Purpose and Scope

The purpose of LCA is to assess the primary environmental impact of the implementation of co-firing using coal and sawdust biomass and compare the environmental impact assessment with the existing condition of full coal. The scope of analysis is carried out in the cradle-to-gate scope starting from the coal mining process, sawdust in the sawmill, a production process that converts thermal energy from coal biomass and/or sawdust into 1 kWh of electricity with the production process unit being Circulation Water Pump (CWP)-Condensor-Heater-Boiler -Turbine-Generator at X steam power plant.

The environmental impact assessment is not divided into each unit. The function of electrical products is used as an energy source to support activities in the industry.

The condition of the machine and equipment is assumed to be in the same reliability condition so that the calculation is not divided for each generating unit. While the limitations in this study are only focused on the production process and have not included the process of production support activities, the assessment period is carried out for 5 months for each scenario, supporting facilities and offices in the production process are ignored, do not take into account losses from one unit to another, have not had transportation data for inspection trips namely the transportation of employees in the management and monitoring of production processes, and has not taken into account related to core infrastructure i.e. construction, reinvestment and decommissioning of energy conversion plant (system) including other buildings, fuel preparation equipment and roads on site.



(a) (b)

Figure 2. (a) Scenario 1: Existing full coal (b) Scenario 2: implementation of co-firing

Figure 1 explains that the environmental impact assessment study with the scope of the cradle-to-gate includes the coal mining process, sawdust in the sawmill, and production process, namely converting heat energy from coal into electricity with the production process unit being Circulation Water Pump (CWP)-Condensor Heater-Boiler-Turbine-Generator-Transformers in PLTU X which are not divided into each unit. The difference in pictures (a) and (b) can be seen that in the co-firing scenario, 2 fuels are used, namely coal and sawdust.

3.2 Life Cycle Inventory (LCI)

Inventory analysis includes data collection and procedures to calculate the relevant inputs and outputs of the product system. The inventory data summarized in **Table 1** is the input-output inventory data used in the study. Data that has been collected related to energy production such as operating conditions, fuel combustion, chemical consumption, the input of raw water, and disposal of wastewater is obtained based on operational technical reports issued and managed by PLTU X. Scenarios are carried out without dividing each unit in PLTU X.

Table 1. Inventory of existing condition

Category Inputs	Inventory Data	Amount	Unit
Materials	Sea water	397,051,332	tons
	Demin water	97,720.64	tons
Fuel/Energy	Electricity	151,361,316.67	kWh
	Steam	2,122,856.44	tons
	Coal	1,475,366.89	tons

Category	Inventory Data	Amount	Unit
Inputs			
	HSD	66,436.20	Liter
	Kinetic Energy	10,276,544.48	GJ
Chemical material	Chlorine	416,14	tons
	Ammonia (NH4OH)	1.71	tons
	Hydrazine (N2H4)	2.55	tons
	Tri-Sodium Phosphate	0.01	tons
Transportation	Coal	178,960,351,346.08	tkm
	Chlorine	27465.24	tkm
	Ammonia (NH4OH)	112.86	tkm
	Hydrazine (N2H4)	168.3	tkm
	Tri-Sodium Phosphate	1.16	tkm
Outputs			
Product	Electricity	2,426,406,336	kWh
Emissions to air	Coal CO_2	2,324,949,241.70	kg
	SOx	2,015,862.77	kg
	NOx	2,734,103.40	kg
	Particulate	564,109.93	kg
	Hg	28.83	kg
Emissions to water	Condensate water	397,051,332.00	tons
	Free Chlorine	13.15	tons
	Blowdown boiler	4950	tons
Hazardous waste	Used Lubricating Oil	29,617	tons
	Used Rags	0.6	tons
	Glasswool	3,945	tons
Nonhazardous waste	Fly Ash	61703.03	tons
	Bottom Ash	7709.08	tons
	Metal	1.17	tons
	Shell	2.48	tons

Inventory data which includes input and output data for co-firing implementation in the period August to December 2022 is shown in **Table 2**.

Table 2. Inventory of co-firing implementation

Category	Inventory Data	Amount	Unit
Inputs			
Materials	Sea water	393,633,780	tons
	Demin water	94,231	tons
Fuel/Energy	Electricity	160,018,383	kWh
	Steam	2,568,852	tons
	Coal	1,419,108	tons
	Sawdust	9,270	tons
	HSD	109,796	Liter
	Kinetic Energy	9,673,024.42	GJ

Category	Inventory Data	Amount	Unit
Inputs			
Chemical material	Chlorine	409.08	tons
	Ammonia (NH_4OH)	1.175	tons
	Hydrazine (N_2H_4)	2.55	tons
	Tri-Sodium Phosphate	0.005	tons
Transportation	Coal	144,085,625,583.24	tkm
	Sawdust	169180620.8	tkm
	Chlorine	26999.28	tkm
	Ammonia (NH_4OH)	77.55	tkm
	Hydrazine (N_2H_4)	168.3	tkm
	Tri-Sodium Phosphate	0.58	tkm
Outputs			
Product	Electricity	2,283,906,544	kWh
Emissions to air	Coal CO_2	2,236,293,962.44	kg
	SOx	2,055,402.69	kg
	NOx	1,989,348.56	kg
	Particulate	540,414.04	kg
	Hg	12.24	kg
Emissions to water	Condensate water	393,633,780.00	tons
	Free Chlorine	18.04	tons
	Blowdown boiler	4950	tons
Hazardous waste	Used Lubricating Oil	29.2542	tons
	Used Rags	0.46	tons
	Glasswool	3,838	tons
Nonhazardous waste	Fly Ash	73545,038	tons
	Bottom Ash	3959,681	tons
	Metal	1.11	tons
	Shell	2.4	tons

3.3 Life Cycle Impact Assessment (LCIA)

LCIA is an environmental impact assessment using methods appropriate to the place and material to be studied. The LCIA stage will be processed by SimaPro 9.4.0.2 software and produce output category impacts along with characterization values using the IPCC2021 GWP100 impact assessment method for assessing potential GWP impacts while the CML-IA baseline impact assessment method is used to assess potential impacts of ozone layer depletion, the potential for acid rain, and eutrophication. The results of the impact assessment (Characterization) are shown in **Table 3**:

Table 3. Impact assessment (characterization)

Potential Impact	Unit	Method	Existing	Co-firing	Decrease Percentage
Global Warming Potential (GWP)	kg CO_2 eq	IPCC 2021 GWP100	7.65E+10	7.64E+10	0.13%
Ozone layer depletion	kg CFC-11 eq	CML IA-Baseline	7929,0678	7986,2804	-0.72%
Acidification	kg SO_2 eq	CML IA-Baseline	5.06E+08	5.04E+08	0.40%
Eutrophication	kg PO_4 eq	CML IA-Baseline	91992996	91868491	0.14%

In **Table 3** the potential impact assessment was carried out using 2 methods, namely the GWP using the IPCC 2021 GWP 100 method while the three other potential impacts namely Ozone layer depletion, Acidification, and Eutrophication used the CML IA-Baseline impact assessment. The results show that there is a decrease in the impact on the potential impact of GWP, acidification, and eutrophication but an increase in the ozone layer depletion.

Table 4. Impact assessment (damage assessment)

Potential Impact	Unit	Method	Existing	Co-firing
Global Warming Potential (GWP)	kg CO_2 eq	IPCC 2021 GWP100	7.66E+10	7.65E+10

In addition to characterization, an impact assessment (Damage Assessment) was carried out on the GWP potential impact which showed the same value as the characterization value shown in **Table 4**. **Table 4** shows an assessment of the GWP potential impact during the study period. Meanwhile, the results of the impact assessment (Normalization) are shown in **Table 5** for the three potential impacts using the CML IA-Baseline method.

Table 5. Impact assessment (normalization)

Potential Impact	Unit	Method	Existing	Co-firing
Ozone layer depletion	kg CFC-11 eq	CML IA-Baseline	8.88E-05	8.94E-05
Acidification	kg SO_2 eq	CML IA-Baseline	0.017956838	0.017901332
Eutrophication	kg PO_4 eq	CML IA-Baseline	0.006973069	0.006963632

Meanwhile, the impact assessment comparison chart of the Damage assessment is illustrated in **Figure 3**.

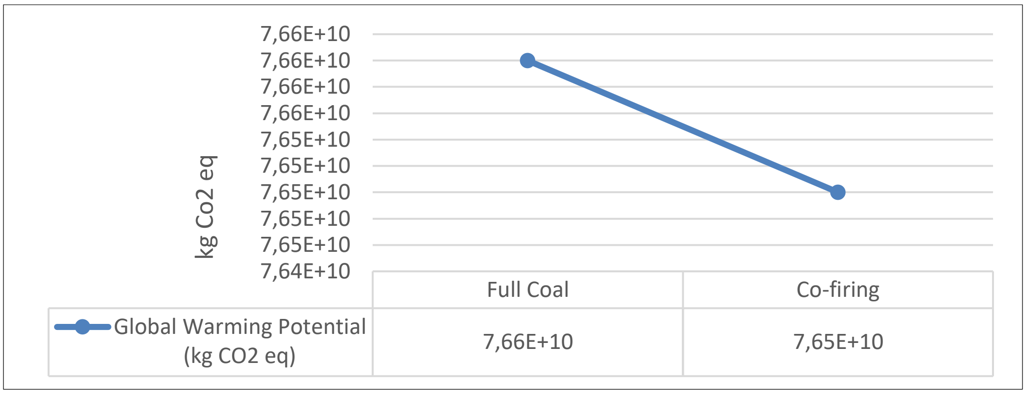


Figure 3. Impact assessment comparison chart of damage assessment

Figure 2 shows that the co-firing scenario can reduce the potential impact, especially on the Global Warming Potential. The impact assessment comparison chart of Impact Assessment (Normalization) is illustrated in **Figure 4**.

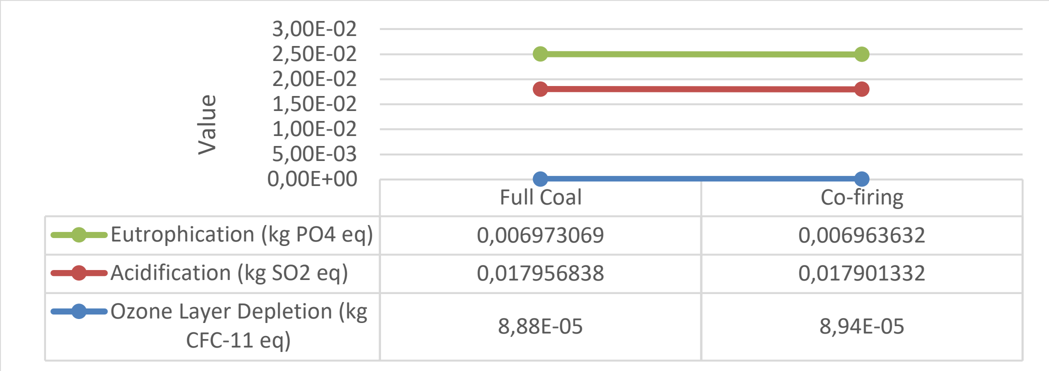


Figure 4. Impact assessment comparison chart of impact assessment (normalization)

Figure 4 shows that the highest potential impact value is eutrophication, followed by the potential for acid rain and the lowest is ozone depletion. The assessment of the impact of eutrophication and the potential for acid rain decreased during the implementation of co-firing but increased ozone depletion. Of the three environmental impact assessments carried out between full coal combustion and co-firing implementation did not show a significant decrease or increase.

3.4 Interpretation

The potential impact assessment carried out in this study is divided into 4 impacts, the following describes an explanation of each category as follows:

i. Global Warming Potential (GWP)

Global warming is an imbalance in the ecosystem on Earth due to the increasing temperature of the Earth's atmosphere, sea, and land on earth (Forest et al., 2017). GHG emissions cause global warming, namely the increase in the earth's temperature due to the trapping of solar energy in the earth's atmosphere as a result of the emissions produced (Muhammad F. Mahmud, 2022). On implementation of co-firing there is a reduction in CO_2, SOx, and NOx in fossil fuels, this is because biomass is included in zero CO_2 so it does not cause accumulation of CO_2 in the atmosphere (Fadli et al., 2019). In addition, the sulphur content in biomass is lower than in coal (Ilham et al., 2022). This makes one of the advantages of the implementation of co-firing, the higher the ratio of biomass burned, the lower the greenhouse gas produced (Tanbar et al., 2021). The calculation method uses a 100-year GWP and is based on the solar radiation absorbed over a fixed period, usually 100 years (Yang et al., 2019). The results of this study indicate that there is global warming which causes greenhouse gases such as CO_2, CH_4, and N_2O in burning coal, but the most dominant is at the transportation stage. Value characterization of global warming on implementation of co-firing is 7.64 x 10^{10} or there is a decrease of 0.13%. The greatest reduction in global warming potential is achieved when biomass is co-burned, but most of the methane is produced during coal production (Tsalidis et al., 2014).

ii. Ozone Layer Depletion

The depletion of the ozone layer in the stratosphere is the depletion of the ozone layer in the atmosphere (Yang et al., 2019). Ozone depletion is caused by reduced levels of ozone in the stratosphere due to the formation of reactive chemicals due to reactions with sunlight with methane, nitrogen oxides, carbon monoxide, and sulphur dioxide (KLHK, 2021). The use of diesel fuel in the transport of biomass and the use of herbicides during the management of forestry resources, the use of biomass produces a greater potential for ozone depletion than the use of coal (Morrison & Golden, 2017). The characterization value for co-firing was 7,986.28 or an increase of 0.72%.

iii. Acidification

Acidification is an increase in acidity in the environment caused by the entry of acids into the environment. Emissions from the steam power plant in the form of SOx and NO produce acid when reacted with water (Mahmud, Muhammad 2022). The increased potential for acid rain from power generation activities is the result of burning fossil fuels and biomass such as Sulphur dioxide (SO_2), Nitrogen oxides (NOx), NH_3, HC, and HF (Yang et al., 2019). The characterization value in the implementation of co-firing is 5.04×10^8 or a decrease of 0.40%. The value of potential acid rain decreases as more biomass is burned due to the low sulphur and nitrogen properties of the biomass (Yang et al., 2019). A significant reduction in the potential value of acid rain was observed as more biomass was co-fired in the power plant, mainly due to its low sulphur and low nitrogen properties (Yang et al., 2019). In addition, the process of distributing coal also produces acidification/acidification emissions such as SO_2 and NOx which can cause environmental conditions to become acidic resulting in a decrease in soil and water quality which can damage ecosystems (Mahmud, Muhammad 2022).

iv. Eutrophication

Eutrophication is caused by the release of phosphorus compounds or compounds (Yang et al., 2019). Eutrophication can also be caused by the emergence of excessive nutrients in aquatic ecosystems which results in the uncontrolled growth of aquatic plants (Simbolon, 2012). The eutrophication impact comes from the biomass source in shared burning. Eutrophication is a type of pollution in the environment where plants grow very fast in water bodies. The cause of eutrophication is the ingress of excess substances into water bodies. N and P substances that cause eutrophication come from coal and boiler water (Wibawa, 2020). The characterization value in the implementation of co-firing was 91.868.491 or there was a decrease of 0.14%. In the implementation of co-firing the plant shows that the potential for eutrophication is caused by the acquisition or origin of the biomass used (Yang et al., 2019). The results of the impact analysis of PLTU X when compared with the implementation of co-firing from other studies are shown in **Table 6**:

Table 6. The comparison of potential impact with similar generators

	X steam power plant, Indonesia	**Steam power plant in the Greater Houston, US***	**Steam power plant in the southeastern United States****
Biomass	sawdust	forest residue	wood pellet
Ratio Co-firing	0.65%	5%	10%
Capacity of Steam power plant	990 MW	300 MW	-
Function units	1 kWh	1 kWh	1 kWh
Impact assessment method	IPCC 2021 and CML IA baseline	Impact 2002+	Traci
GWP reduction	0.13%	3.21%	9.39%
Ozon layer depletion reduction	-0.72%	-4.43%	-0.12%
Acidification reduction	0.40%	3.21%	9.19%
Eutrophication reduction	0.14%	-7.69%	8.13%

*Kommalapati et al., (2018)

**Morrison & Golden (2017)

4. Conclusion

In this study, an environmental impact assessment using the Life Cycle Assessment (LCA) method was used to compare the environmental impact assessment with the existing condition of full coal and the implementation of co-firing using sawdust biomass. The results show that co-firing coal with sawdust biomass has potential positive and negative environmental impacts. The results of this study indicate that co-firing coal with sawdust biomass can lead to important reductions in impact categories such as GWP (0.13%), acidification (0.40%), and eutrophication (0.14%) but increases in ozone depletion potential (0.72%).

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