Bioenergy power generation improved through biomass co-firing – a viewpoint of Life Cycle Assessment (LCA) method

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Abstract

The coal-fired power plant is the most dominant in the world where it currently fueled about 38% of global electricity. This is due to the relatively cheap price of coal and high calories produced. On the other hand, emissions generated by coal-fired power plants are quite large compared to other types of power plants, while all countries are working to reduce global warming, one of which is by reducing CO_2 emissions. Utilizing renewable energy is one of the solutions in efforts to reduce the use of fossil energy so that there is a decrease in CO_2. Biomass is renewable energy which is currently widely used as fuel for electricity generation, biomass fuel can be used 100% for a plant called biomass power plant and can also be a coal-fired power plant with a certain percentage mix. Many researchers conducted an analysis using the Life Cycle Assessment (LCA) method to determine the emissions produced differences between coal-fired power plants compared to the Biomass co-firing system. This paper collected and analyzed some literature related to the LCA researches on coal-fired power plants compared to the biomass co-firing power plant. The results showed that the biomass co-firing power plant produced lower emission than the coal-fired power plant.

Keywords: *Coal, Biomass, Co-firing, Life Cycle Assessment*

Abstrak

Pembangkit listrik jenis PLTU batu bara, merupakan pembangkit yang paling dominan di dunia. Hal ini disebabkan harga batu bara yang relatif murah dan kalori yang dihasilkan tinggi. Namun disisi lain emisi yang dihasilkan oleh PLTU batu bara cukup besar dibanding pembangkit jenis lainya, sedangkan seluruh negara sedang berupaya dalam mengurangi pemanasan global salah satunya dengan menurunkan emisi CO_2. Pemanfaatan Energi Baru Terbarukan (EBT) menjadi salah satu solusi dalam upaya pengurangan penggunaan energi fosil sehingga terjadi penurunan CO_2. Biomassa adalah EBT yang banyak dimanfaatkan sebagai bahan bakar untuk sektor pembangkit listrik. Bahan bakar Biomassa dapat digunakan 100% untuk pembangkit yang disebut PLTBm dan bisa juga sebagai Co-firing PLTU batu bara dengan persentase campuran tertentu. Oleh karena itu, banyak peneliti yang melakukan analisa dengan metode Life Cycle Assesment (LCA) untuk mengetahui perbedaan emisi yang dihasilkan antara PLTU batu bara dibandingkan dengan sistem co-firing biomassa. Pada paper ini dilakukan pengumpulan dan pengkajian literature terkait uji LCA pada PLTU batu bara dibandingkan PLTU co-firing Biomassa. Hasilnya diperoleh bahwa PLTU dengan sistem co-firing Biomassa menghasilkan emisi yang lebih rendah dibanding kan dengan PLTU batu bara.

Kata Kunci: *Batu bara, Biomassa, Co-firing, Life Cycle Assessment*

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1. INTRODUCTION

The fossil fuel depletion and global warming are two main concerns of industrialization and rapid technological development. Most of the world's energy consumption is fulfilled by fossil energy because of its easy access and low price. However, the production and use of fossil energy are closely related to high greenhouse gas (GHG) and particulate emissions [1].

Power generation and energy consumption often resulting in a high negative environmental impact. The use of coal-fired power plants is the dominant source of electricity generation in almost all countries in the world [2]. This is because of the economical price of the electricity fueled by coal. However, several discussions are debating about the environmental impact of using coal-fired power plants. Also, the considerations regarding the sustainability of coal supply which also continue to thin out certainly will be another threat in the aspect of the world's energy availabilities.

Besides, the main task of the world in tackling climate change and global warming is to reduce the use of fossil energy. In this case by reducing the use of coal which has the greatest impact on CO_2 emissions per unit of energy production [3]. During the combustion process at coal-fired power plants, they released nitrogen oxides (NOx), sulfur dioxides (SO_2), and other particulates. Where the coal-fired power plants are responsible for 93.4% and 80.2% of SO_2 and electricity NOx emissions [4]. Therefore, it is important to find a solution to solve these problems.

Some researchers already proposed some techniques and methods of reducing the GHG emissions of the coal power plant combustions. But it was found that the technologies and control methods were increased the operational costs. From all the alternative technologies that were introduced at present, the co-firing technologies have gained popularity as it less-expensive costs. Co-firing defined as the renewable fuel combustions (i.e. biomass) blending with the primary fuel (e.g. coal, natural gas, diesel, furnace oil, etc.) in the power plants system [5]. This blending method results a less-expensive fuels and also can mitigate the pollution depending on the kind of biomass blended with coal.

Renewable energy sources are an alternative that can be used to replace fossil energy supplies. Among the available renewable energy sources (e.g. biofuel, geothermal, hydro-electric, wind-power, photovoltaic, and ocean thermal energy conversion) biomass is an energy source that can be directly converted to high-value products, for example, by using thermochemical conversion technology such as pyrolysis, gasification, and liquefaction, it can be converted into bioenergy and biofuel in various forms, solid, gas or liquid [6].

The use of wood and other forms of biomass (e.g. wood-derived, crops, agricultural and agro-industrial by-products, and animal by-products) as fuel to produce electricity, heat, and energy carriers has become the focus of new interest in many parts of the world [7]. Biomass is an inexpensive and especially renewable fuel. The availability increased of biomass can be combined with the recent technological developments to utilize it efficiently and with lower emission levels. Biomass has a unique potential to result in a positive environmental impact as it lowers GHG emissions. Compared to coal, the biomass combustion system is not releasing large quantities of nitrogen oxides (NOx) depends on the combustion conditions and gas cleaning system. Besides, the sulfur dioxide (SO_2) emissions will be reduced because of the low sulfur content of biomass [4]. Therefore, the use of biomass is a promise as a cleaner energy source for electricity generation fuels.

To manage power plants, the determined use of a co-firing system is not only determined by the environmental focus but also in terms of its economic aspect. But in this paper, will only discuss the consideration of the co-firing system utilizing by the determination of its environmental impact. To assess the obtained benefits by the co-firing system at existing power plants, many researchers used the life cycle assessment (LCA) method to evaluate the environmental impact of a biomass co-firing system compared to a coal combustion system. LCA is an analytical tool used to identify the potential environmental impacts of the final product of a process in its entire process cycle. Besides, LCA also evaluates the impact, energy, and material output in producing final products and emissions during the process cycle [6].

The use of biomass co-firing technology in coal power plants has been widely developed in various countries. Indonesia itself through a strategy to increase bioenergy plants PT. The Java-Bali Power Plant presented at the seminar "Efforts to Increase Bioenergy Power Plants in Indonesia" in 2019, has launched three scenarios of plans to increase bioenergy power plants in Indonesia following the potential of bioenergy.

- Wood Pellet Co-firing on PC Boilers Scenario
- Palm-shell Co-firing on CFB Boilers Scenarios
- Palm-shell Co-firing on Stock Boilers Scenarios

The plan to increase bioenergy power plants in Indonesia began with the commitment of Indonesia in meeting the COP 21 Paris Agreement to reduce GHG emissions by 29% by 2030. In addition, also in meeting the target of renewable energy mix (EBT) by 23% in 2025, The Biomass Co-Firing program for coal-fired power plants is a long-term breakthrough program to achieve the target of reducing dependence on fossil fuels and reducing emissions towards the Green Power Plant [8].

Current global average temperatures have risen by 1°C due to human activities. Therefore, it is urgent to apply deep de-carbonization in the industry, especially for the electricity sector; as a major contributor that released 11.5 GT CO_2 in 2017, of which around 70% from coal power plants. Then it is necessary to do further research in developing bioenergy power plants in Indonesia.

Planning for biomass co-firing technology in Indonesia continues to be developed and enters the large-scale research stage. Many laboratory studies have been carried out, but towards a greater stage, there needs to be more emphatic emphasis and commitment from policymakers and the entire Indonesian community. In this case, the use of the LCA methodology is an appropriate step that can be used as a material for evaluating the comparison of the impact of power plants with fossil fuels compared to bioenergy fuels, especially in providing recommendations for policymakers.

The purpose of this paper is to review the LCA results from the selected literature regarding the environmental profile from co-firing applications and compared it to the coal combustion systems. It also provides some recommendations to the policymakers, regarding the implementation of co-firing coal with biomass to reduce GHG emissions.

2. METHODS

The methodology used in this paper is a literature study using systematic review methods. The systematic review is a research method for identifying, evaluating, and interpreting all relevant research results related to certain research questions, specific topics, or phenomena of concern [9]. In this paper, research done by collecting and reviewing secondary data that is journals/articles related to the LCA evaluation of co-firing biomass compared to coal combustion systems. Then the obtained data are compiled, analyzed, and concluded to obtain the conclusions regarding the study of literature. It also provides outcomes as some recommendations to the policymakers, regarding the implementation of co-firing coal with biomass to reduce GHG emissions

2.1 Life Cycle Assessment (LCA)

Life Cycle Assessment or LCA discusses the environmental aspects and potential environmental impacts throughout the product life cycle from the acquisition of raw materials, production, use, final processing, recycling, and final disposal (i.e. cradle-to-grave).

There are four stages in the LCA study such as shown in figures 1:

- the stage of definition of objectives and scope,
  The objectives and scope, including the LCA boundaries and detail level system, depending on the study subject and purpose. The LCA's depth and breadth can be very different depending on the specific LCA objectives.
- inventory analysis stage,
  The life cycle inventory analysis stage (LCI stage) is the input/output data inventory stage related to the system being studied. Inventory includes the collection of data needed to achieve the objectives of the specified study.
- the impact assessment stage,
  The life cycle impact assessment (LCIA) phase aims to provide another information to assist in assessing the product system results of the LCI so that it can better understand its importance to the environment.
- interpretation phase.
  Life cycle interpretation is the final stage of an LCA procedure, which results from LCI or The LCIA, or both, is summarized and discussed as a basis for drawing conclusions, recommendations and decisions according to the definition of objectives and scope.

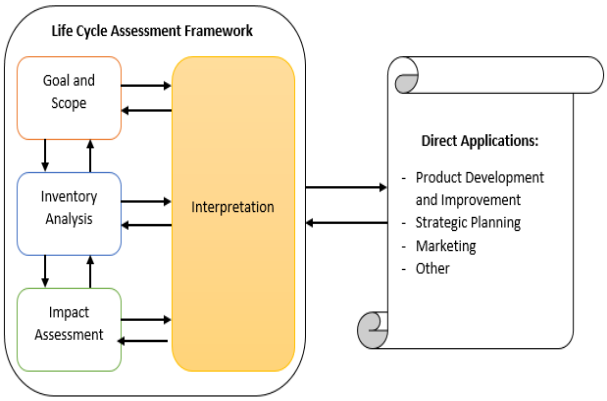

Fig 1. The LCA Framework (*Source: ISO 14040:2006*)[10]

LCA is an instrument to measure all impacts of the entire energy supply chain, e.g. to get cumulative energy demand for electricity generation, carbon cycles, carbon emissions, etc. All facilities are divided into components and subcomponents and all energy and material flow through this is checked. The typical renewable energy system LCI/A is important when comparing it to conventional fuel-based systems as a rational choice of energy sources.

The LCA methodology follows ISO 14040 guidelines. The model was developed using a software program, a tool for Environmental Analysis and Management. LCA is a technique for reviewing aspects associated with product development and its potential impacts from the supply of raw materials, production processes, and final products to their distribution. The scope, assumptions, description of data quality, methodology, and results of LCA studies must be transparent. The LCA methodology must be accepted by incorporating new scientific findings and improvements in the latest technology. The strength of LCA is its approach to holistically studying all products/systems and allowing us to avoid sub-optimization which may be the result of only a few processes being focused on. The results are also related to the use of a product, which allows comparison between alternatives [11].

2.2 Data Collection

Based on the type of biomass resource used in the LCA analysis, the environmental impact results can be variated. The origin and characteristics of the vegetative resource as fuel (e.g. water content and particle size

mainly) are directly related to the various processes that will be needed to obtain, transport, and convert it into electricity. To include the most common cases, three types of biomass resources have been assessed (basic information is shown in Table 1):

Table 1. Characteristics of Mixed Coal and Biomass Resources

Characteristics	**Coal**	**HARB**	**WARB**	**EC**
HHV (odt) (kJ/kg)	23.200	18.900	19.800	18.900
Ultimate Analysis (odt)				
C (%)	54,9	46,6	50,3	46,6
H (%)	3,5	5,2	6,1	5,2
Moisture Content (w.b) (%)	5	25	40	25

Source: Sebastian, et al., 2009 [12]

Where,

- HARB (*Herbaceous Agricultural Residual Biomass*): straw, corn stalks, and husks, etc.
- WARB (*Woody Agricultural Residual Biomass*): remaining pieces of fruit trees.
- EC (*Energy Crops*): all including wood plant or tree pieces. The most important characteristic of this group when compared to the previous one is that all land products are considered as fuel and not just residual fractions.

3. RESULT AND DISCUSSIONS

Tahara et al. (1997) [13] study about the renewable energy power plants CO_2 payback time in the future compared to commercial fossil fuel power plants (coal, oil, and LNG) to estimate the renewable energy CO_2 reduction potential. The estimation of CO_2 emissions based on an analysis measurement of clean energy derived from operational systems and design studies. the research evaluated and compared the CO_2 payback times of PV (photovoltaic cell power plant) and OTEC (ocean thermal energy conversion) as alternative energy resources, and coal (coal-fired power plant), oil (oil-fired power plant), LNG (LNG-fired power plant) and hydroelectric. The results show that the hydroelectric and OTEC (100 MW) have a very short CO_2 payback time, which is caused by the smaller CO_2 emissions during its construction than the PV power plants. The researcher also suggested that the evaluation of all the renewable power plants CO_2 payback times in the present paper were shorter than their operational lifetimes.

Hartmann and Kaltsschmitt (1999) [14] studied the environmental impact of electricity production from different biomass through co-firing using the LCA method. Their study used 10% straw and wood waste mixture with coal in power plants in southern GermanyThe global warming impact of electricity from biomass is much lower compared to that from hard coal.

Rafaschieri et al. (1999) [15] analyze the environmental impact of electricity production through a combined combustion gasification cycle (IGCC) mixed special vegetative energy sources (poplar short rotation forestry (SRF)) by LCA method. These results are compared with alternative options for generating power with conventional fossil fuel power plants. Impact assessment using the "Eco-indicator" method. Biomass is used as fuel in gas/steam cycle power plants. Biomass production produces 7330 kg-CO_2 emissions per ha per year for 16 dry Mg/ha/year biomass.

Corti and Lombardi (2004) [16] performed life cycle assessment an integrated gasification combined cycle (IGCC) with biomass fuel. In the simulation, the atmosphere gasifier has been modeled, given input with a biomass mass flow of 31 kg / s. The results were compared with IGCC with de-CO_2 using CO_2 chemical absorption where the reduction of CO_2 on the stack was obtained by amine solution. The LCA result under the scheme of coal IGCC co-firing biomass and CO_2 sequestration system is 167 kg-CO_2 / MWh, whereas under the scheme of conventional IGCC are 700-800 kg-CO_2 / MWh, and conventional NGCC is 380 kg-CO_2 / MWh, respectively.

Carpentieri et al. (2005) [17] study the life cycle assessment of a combined cycle of integrated biomass gasification (IBGCC) with CO_2 removal by chemical absorption. In this case, the LCA is carried out by presenting the results based on the Eco-indicator 95 impact assessment methodology. The simulation results from this specific IBGCC is 178 kg-CO_2 / MWh. Table 2 shows an overview of the CO_2 analysis of biomass systems.

Heller et al. (2004) [18] conducted electricity under the co-firing of coal with willow biomass in the US which the co-firing cycle system scheme is shown in figure 2. Two scenarios are given and applied in Dunkirk, 1) 5% willow and 5% the remaining wood residue; 2) 10% willow. Both are then compared to power plants with coal fuel (conventional).

The results show that coal-fired power plants consume 11,496 MJ / MWh through the entire full cycle, of which 93% of coal is used directly in the plant. After substitution with willow biomass, the upstream energy consumption for the no-co-fire case is reduced to 273 MJ / MWh, while the residue/mixture of willow and all co-fire is 320 and 304 MJ / MWh. The net energy ratio for the no-co-fire case is 0.313 energy ratio. This increased to 0.341 energy ratio with 10% workmanship, by very little difference in the net energy ratio between the two co-firing scenarios. The comparison of total gas emissions produced is shown in table 3.

Willow biomass is planted specifically for electricity generation because the willow tree production is considered the potential to fulfill the power generation system fuel needs. As a result, power plants with willow biomass are almost unproduced Green House Gaseous (GHG) emissions, it just about 40 – 50 kg-CO_2 eq. / MWh.

Table 2. The Overview of CO_2 Biomass System Analysis

No.	Year of Study	Process	Electricity Capacity	Emissions (kg-CO_2/MWh)
1	2004	Coal IGCC + co-firing biomass and CO_2 sequestration System	457 MWh	167
		Conventional IGCC		747–789
		Conventional Coal NGCC		377
2	2005	Conventional Coal ICGCC	204,5 MWh	725
		IBGCC + CO_2 Remover (Chemical Absorption)		178
		ICGCC + CO_2 Remover (Chemical Absorption)		130
3	1999	90% Coal and 10% Straw	509 MWh	37
		90% Coal and 10% Wood		35
		100% Hard Coal		931
4	1999	Biomass Fuels System (IGCC)	1 MWh	110
		Coal Fuels System		930

Source: Carpentieri et al, 2005 [17]*; Corti and Lombardi, 2004* [16]*; Hartmann and Kaltsschmitt, 1999* [14]*; Rafaschieri et al., 1999* [15]

Table 3. Greenhouse gas emissions (kg CO_2 eq. / MWh) with 10% co-firing and with residues/willow mixture scenarios.

	Total System	Transportation	Disposal of avoided residues	Power Plant Emissions
Cumulative Total	909,6 (0,4%)	0,8 (80,7%)	-76,8 (8,8%)	948,4 (1,0%)
CO_2 (Biomass)	865,1 (23,8%)	0,0 (80,7%)	-17,9 (-27,5%)	109,5 (9,9%)
CO_2 (Fossil)	852,6 (0,0%)	0,7 (80,7%)	0,7 (-41,0%)	838,9 (0,0%)
CH_4	-29,9 (71,1%)	0,0 (80,7%)	-59,6 (26,4%)	0 (0,0%)

Source: Heller et al., 2004 [18]

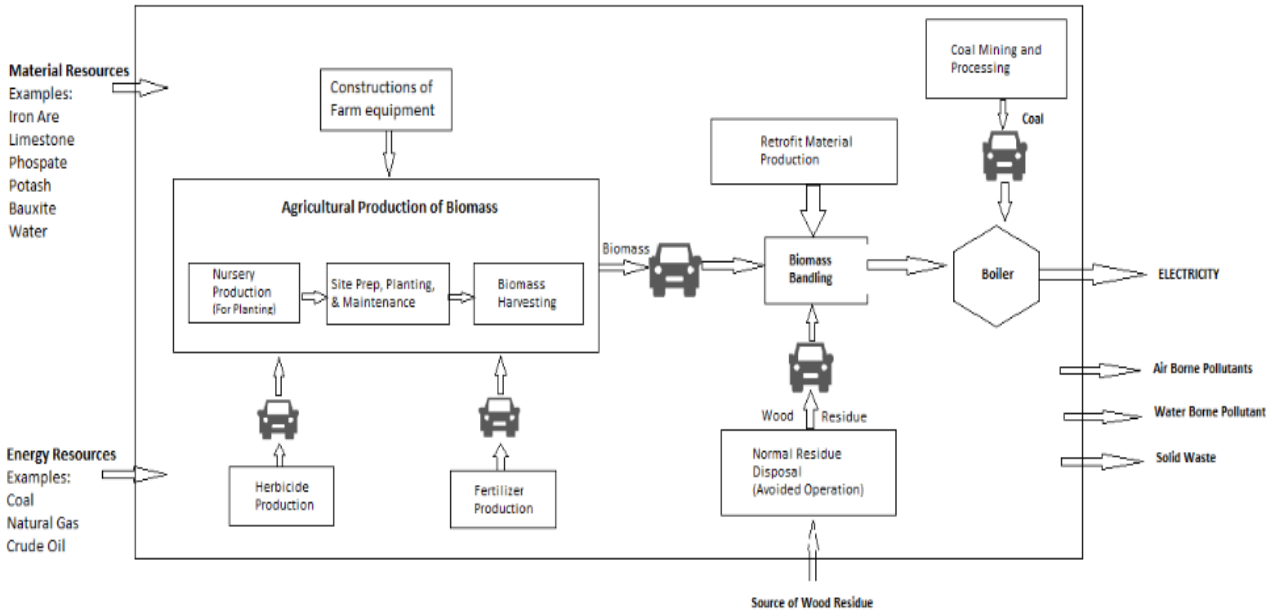

Fig 2. the biomass co-firing cycle system scheme (*source: Heller et al., 2004*) [18]

Table 4. CO_2 Emissions, Global Warming Potential and Carbon Closure Comparison

	Biomass IGCC	Coal Average	15% co-firing	5% co-firing	0% co-firing
Carbon Closure	95,1%	0%	15,1%	5,1%	0%
Net GWP (g CO_2 eq./kWh)	49	1042	816	981	1052
Net CO_2 (g/kWh)	46	1022	927	1004	1031

Source: Mann and Spath, 1999 [19]

Table 5. Energy Results

	Biomass IGCC	**Coal Average**	**15% co-firing**	**5% co-firing**	**0% co-firing**
Power Plants Efficiency	37%	32%	31,1%	31,5%	32%
Process Cycle Efficiency	35%	-76%	-60%	-70%	-74%
External Energy Efficiency	35%	24%	25,5%	25,4%	25,6%
Net Energy Ratio	15,6	0,29	0,31	0,31	0,30
External Energy Ratio	15,6	5,0	5,6	5,1	5,0

Source: Mann and Spath, 1999 [19]

Mann and Spath (1999) [19] conducted a study to determine the implications of co-firing applications from waste biomass and coal using the LCA method. Each assessment is carried out in a cradle-to-grave manner to cover all processes needed for power plant operations, including raw material extraction, material preparation, transportation, and waste disposal, and recycling. Each study is carried out independently, the resulting emissions, resource consumption, and energy requirements of each system are compared. Table 4 shows the results of their study.

Given that the system being studied exists to generate electricity, the clean energy balance is carefully checked. Besides, the efficiency of a standard power plant, which is the energy sent to the network divided by the energy in raw materials to the power plant. Four other efficiency measures are defined in Table 5. The net energy ratio describes the amount of energy produced per unit of energy consumed.

Because the energy contained in coal is greater than the energy sent as electricity, the life cycle efficiency of the coal system is negative. This is because the non-renewable resources such as coal systems are consumed more energy than they produce.

Shafie et al. (2013) [20] investigated the LCA of rice straw co-firing in coal-fired power plants in Malaysia. Co-firing rice straw in existing coal power plants is a technique that can reduce CO_2 emissions and reduce Malaysia's dependence on coal resources. The LCA for rice straw as a whole is presented to analyze the environmental, energy, and economic aspects of rice straw co-firing in coal-fired power plants. The study was conducted in two power plants namely Manjung Power Plant (MP) and Kapar Power Plant (KP) with the results are shown in Table 6.

Coal power has the highest impact in all categories. Co-firing can reduce all impact categories by 73.22% (human toxicity), 92.54% (acidification), and 94.97% (climate change) and 98.83% (eutrophication). Reducing climate change is related to reducing CO_2 emissions. For all impact categories, the use of combustion with rice straw in existing coal power plants provides better environmental impacts than coal-based power plants.

Transporting rice straw contributes to the highest impact in the preparation of rice straw. A summary of the environmental impacts associated with burning rice straw is listed in Table 6. The results are based on the MP power plant which is 700 MWh. To identify each component involved, rice production output was set to 4,322,259 kg of straw in the field. The straw collection output is 9605 bale straw. The amount CO_2 emission of rice straw is 0.0742 kg-CO_2 / kg-rice straw which is equivalent to 296.38 kg-CO_2 / per ha rice straw.

. Table 6. LC Emission in MP and KP Comparisons

Power Plant	**Emission (k.ton)**	**CO_2**	**CH_4**	**N_2O**	**SO_x**	**CO**	**NO_x**
MP	Coal	138837,40	15,39	0,29	46,13	167,61	1664,33
	5% Rice Straw	6950,22	12,37	0,17	17,15	0,79	19,09
	Reduction (%)	94,99	19,60	42,16	62,83	99,53	98,85
KP	Coal	59501,75	6,59	0,13	19,77	71,83	713,28
	5% Rice Straw	2980,42	5,29	0,07	7,38	0,35	8,27
	Reduction (%)	94,99	19,71	42,24	62,66	99,52	98,84

Source: Shafie, et al., 2013 [20]

Table 7. The Environmental Impacts of the Rice Straw Supply for MP (700 MWh)

Environmental system	**Category (Unit)**			
	Acidification (kg SO2-Eq)	**Climate change (kg CO2-Eq)**	**Eutrophication (kg NOx-Eq)**	**Human Toxicity Level (kg 1,4-DCB-Eq)**
Rice Production	8,22 E3	3,21 E5	1,63 E4	7,65 E3
Rice Straw Collection	3,74 E2	2,78 E4	6,42 E2	1,72 E4
Transportation 1 (TPP -> CC)	1,82 E2	4,05 E4	3,13 E2	3,2 E2
Transportation 2 (TCC -> MP)	3,81 E2	9,84 E4	6,53 E2	6,66 E2
Rice Straw Combustion	1,37 E5	1,05 E7	2,44 E5	2,06 E5

Source: Shafie, et al., 2013 [20]

4. CONCLUSION

Considering some research results based on the LCA methodology for biomass co-firing, the implications of reducing actual GHG emissions have been obtained. Based on the paper that has been reviewed were found that the use of biomass for power plants can reduce the GHG emissions to 94,99% by 5% rice straw co-firing, 9,3% by 10% waste biomass co-firing, and 87% by 100% willow biomass. The efficiency of biomass-fueled power plants is the most important parameter that ultimately affects the performance of GHG emission savings. LCA shows that power plants with coal co-firing or biomass power plants produce significant reductions in many of the negative environmental impacts of coal-based electricity production. Consumption of non-renewable resources (coal) is reduced, so are clean greenhouse gas emissions and air pollution criteria including SO_2, Hg, and possibly, NOx. Co-firing biomass offers the opportunity to reduce the net GHG from coal-fired systems.

The basis of innovative comparisons between co-firing biomass and coal-fired power plants has been compared through several studies, by the viewpoint of greenhouse gas emissions, from both alternative electricity production systems with biomass resources and coal fuel. Although much remains to be done, the main conclusion that can be highlighted is that when GHG emissions are taken into account. Successful implementation of co-firing biomass requires full support from the government and various stakeholders. The use of the LCA methodology is the right step that can be used as a comparative evaluation of the impact of power plants with fossil power compared with bioenergy fuels in this case co-firing biomass technology, especially in providing consideration of recommendations to policymakers. The subsidy policy suggested can support the development and implementation of this co-firing technology. Besides, the awareness of global warming issues also can be a primary factor in encouraging renewable energy consumption to reduce GHG emissions.

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