

LIFE CYCLE ASSESSMENT OF BRIQUETTE PRODUCTION FROM RICE STRAW AND ITS UTILIZATION AS A FUEL FOR ELECTRICITY GENERATION

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Abstract

The objective in this research was to study life cycle assessment (LCA) of rice straw briquette production. The comparison of the environmental problem in term of global warming aspect, midpoint impacts, and endpoint impacts of electricity generation using different fuel was also investigated. The environmental problem in term of global warming aspect was examined with IPCC 2013 GWP 100a methods. Meanwhile, midpoint impacts contributing to environmental problem and endpoint impacts or damages, related to human health, ecosystem health, and resource availability, were analyzed by using IMPACT 2002+ method. From the rice straw briquette production, there were two main steps: a raw material acquisition step and a manufacturing step. It revealed that the manufacturing step had a significantly 71.17% greater potential for global warming aspect than the acquiring raw materials step. This was because of the 4 sub-steps found in the manufacturing step, including reducing the size of rice straw, converting rice straw into charcoal, mixing, and drying. They required more energy and chemical compounds. Specifically, the sub-step of converting rice straw into charcoal through thermal decomposition at the temperature of 400°C under air-free condition that needed high energy consumption resulting in the 74.50% greenhouse gas (GHG) emissions, which was the highest amount and inorganic particle formation that caused the damages to human and ecosystem health. In addition, co-firing of rice straw briquettes with lignite coal in 1:1 ratio for generating 1 MW electricity had 16.43% and 49.15% lower possibility of environmental problems: global warming and acidification problem (ADP), respectively than that those firing lignite coal. Those also affect to the damages attributing to climate change, human health, and ecosystem quality.

Keywords: Life cycle assessment (LCA); Rice straw briquette; Lignite coal; Global warming potential; Acidification problem (ADP)

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Introduction

Due to the energy crisis that began in 1970, the environment is being given a major attention by several organizations (Sampattagul, 2012). This has led to the policies focusing on cost-effective and maximally beneficial energy use, emphasizing the promotion, procurement, and utilization of renewable energy sources (Wang *et al.*, 2021). Renewable energy is sustainable energy that meets human needs with low environmental impact. The tool that used to determine the sustainability of renewable energy sources is life cycle assessment (LCA). LCA is a process that has developed to examine the environmental problem and damages typically refer to three areas of protection: human health, ecosystem health and resources throughout the lifecycle of a product, a production process, and service. As a result, the governments of many countries are interested in the principles of LCA and it is continually developed the assessment methodologies to facilitate diverse reporting of assessment results. For instance, the assessment of global warming potential of Thailand based on LCA concept typically report in carbon dioxide (as equivalent) emissions and they perform by comparing with global carbon dioxide emissions (as CO₂ equivalent). Thailand's greenhouse gas emissions in 2022 were to approximately 271 MtCO₂eq, placing the country in the 25th position globally in terms of GHG emissions. (Global carbon atlas, 2022) while the world released a GHG of 37,150 million tons of carbon dioxide equivalent (MtCO₂eq) in the year of 2022. In each year, Thailand has an upward trend of GHG emissions, originating from the industrial, energy, and agricultural sectors. Most GHG emissions in Thailand are primarily coming from the industrial sector, accounting for 78.19% of a total released by the country. This led to an average annual increase of 7.43% in carbon dioxide emissions during the period of the year 1959-2019 (Energy Policy and Planning Office, Ministry of Energy, 2023).

As mentioned about LCA, it can be used for studying and comparing the different environmental problems and damages over a lifecycle of a product, a production process, and service. Presently, LCA is contained in ISO 14040, an environmental management standard, it includes LCA as a part of the evaluation process, covering with raw materials acquisition, manufacturing, transportation, usage, and disposal (Sirichokchaikul, 1999; Sampattagul, 2012). Additionally, the results from LCA might be a guideline for improving any process to minimize environmental problems and damages (Sampattagul, 2012). According to the previous

study, using biomass to generate electricity resulted in a lower greenhouse gas emissions than using coal, with reductions of up to 76% in Europe and the United States. As a result, the environmental problem in the term of global warming was sharply diminished (Beagle and Belmont, 2019).

Thailand is an agricultural country and rice farming is a main agriculture of Thai people. In 2023-2024, Thailand has 75.26 million rai of rice fields. It covers with both in-season rice fields (or annual rice cultivation) and the off-season rice fields (or second season rice cultivation) approximately 63.38 and 11.88 million rai, respectively (Office of Agricultural Economics, 2024). After rice post-harvest season creates a very large volume of residue as rice straw and stubble when compares with other agricultural residues. The largest volume of rice straw and stubble is obtained from the northeast region of Thailand, which produces 13.7 and 9.1 million tons per year, respectively (Foundation for Agricultural and Environmental Conservation, 2023). Meanwhile, the central region and eastern regions of Thailand produce 6.2 and 4.1 million tons of rice straw and stubble annually, respectively. From a large volume of residue after rice post-harvest, it might be indicated that in 1 rai of rice farming, there is a quantity of both rice straw and stubble on average of 650 kg per year (Foundation for Agricultural and Environmental Conservation, 2023). And farmers do not have proper methods to remove after harvest season. The proper methods are the method which be environmentally friendly and lower effect to people. But open-field burning method is mostly selected for removing because it is easily to manage for the next season of rice farming (Safty AMK, 2020). The open-field burning method is a method that causes air pollution that are GHG emission and create toxic substance affecting to both human health and environmental health. These are the reasons that Thailand's agricultural sector is crucial for a high level of GHG emission.

In order to reduce the GHG emission of Thailand's agricultural sector, the rice straw management should be treated in the sustainable pathway. Several researchers have studied the methods used to make rice straw briquette for energy source application. The rice straw charcoal briquette with starch, paper, and taro starch as a binder gave a significant amount of CO, NO_x, and SO₂ emission while used as a fuel (Narzary *et al.*, 2023). The 1 kg of wood charcoal briquettes produced from eucalyptus wood strongly affected to the global warming potential with GHG emission of

3.9690 kgCO₂eq. Mostly GHG emission came from the charcoal fines production step (Rousset *et al.*, 2011). The addition of rice bran during the production process was able to improve both physical and thermal property in term of the increased in densification and heating value of the rice straw briquette (Chou *et al.*, 2009). In this research, the rice straw briquettes were prepared under air-free carbonization process before briquette in particular shape to relieve the air pollutions while use. For the guarantee of environmentally friendly of the studied rice straw briquette, the LCA of rice straw briquette production process was investigated based on global warming potential, environmental health and human health. Moreover, the use of rice straw briquette for electricity generation comparing with lignite coal was also included.

Methods

In this study, the experiment can be divided into two parts of briquette production from rice straw (Narzary *et al.*, 2023), and (2) the comparison of the global warming potential, environmental problem, and damage between the use of rice straw briquette and lignite coal as a fuel for an electricity generation. From those two parts, they comprised of four steps, which are goal and scope definition, inventory analysis, impact assessment, and interpretation step. SimaPro 9.0.0.49 version was used, along with IMPACT 2002+ and IPCC 2013 GWP 100a methods. IMPACT 2002+ methods was

used to evaluate 14 issues of midpoint impacts and 4 endpoint impact, indicating environmental problems and damages relying on human health, ecosystem health, and resource, respectively. Meanwhile, IPCC 2013 GWP 100a methods was used to evaluate the environmental problem in term of global warming aspect (Tanompolkrang, 2014).

Goal and Scope Definition

Goal and scope of this study are defined based on research objectives. The first goal was to evaluate the environmental problem in term of global warming aspect, midpoint impacts, and endpoint impacts of 1 kg of rice straw briquette production. It consisted of two main steps, which were raw material acquisition step (consisting of rice straw acquisition and glycerin acquisition) and manufacturing step. The cradle-to-gate system boundary was applied for the assessment of rice the cradle-to-gate system boundary was applied for the assessment of rice straw briquette production (Sirichokchaikul, 1999) (Figure 1). For the second goal was to evaluate the environmental problem in term of global warming aspect, midpoint impacts, and endpoint impacts of the rice straw briquette used as a fuel for 1 kWh electricity generation with gate-to-gate system boundary (Figure 1). Furthermore, the comparison of environmental problem in term of global warming aspect, midpoint impacts, and endpoint impacts between the use of rice straw briquette and lignite as a fuel for generating 1 kWh of electricity was also studied by using gate-to-gate system boundary as shown in Figure 1.

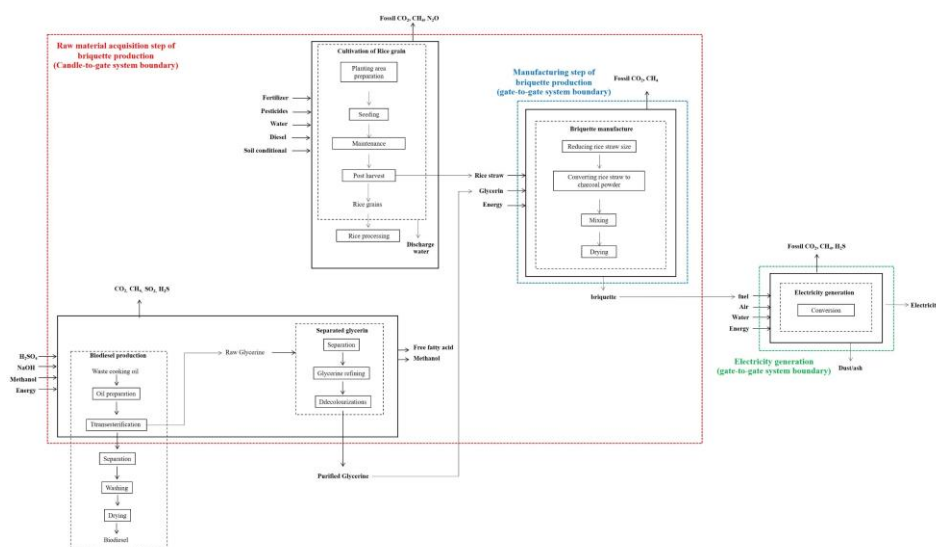


Figure 1. Shows system boundary for rice straw briquette and electricity generation by using different type of fuel

Inventory analysis

Inventory analysis involved the data collecting and calculating procedures to quantify relevant inputs and outputs from the rice straw briquette production and electricity generation process using different type of fuel: rice straw briquette and lignite coal. The inputs data covered with materials, natural resources, energy consumption, and water consumption. As well as the output data were covering with the emissions release into the environment during the production process. The Nong Harn and Muang Len municipalities in Sansai, Chiang Mai, where a total of 30 households were included in surveys for rice straw acquisition in this study. Therefore, all input data of rice straw acquisition were collected as a primary data. An economics allocation based on the price of rice grain per kilogram per rai (13.30 baht/kg) and rice straw per kilogram per rai (50.00 baht/rai) was chosen. The economics allocation for sharing the environmental impact for rice grain and rice straw was 99.63 % and 0.37 %, respectively. The CHN628, 628S instrument with LECO Method was used for identify the elemental composition of rice straw, rice straw briquette, and lignite coal, as shown in Table 1 in order to further estimate the amount and type of the substances that might be released when they are burned while generating the electricity. The high heating value (HHV) of rice straw briquette and lignite coal was analyzed by calorimeter IKA/5000 PKG. The HHV of rice straw briquette and lignite coal in MJ/kg unit was performed in Table 3.

Table 1. Shows the elemental composition of rice straw, rice straw briquette, and lignite coal

Material	Content (% by weight)				
	C	H	N	S	O
Rice straw	37.53	6.83	0.11	¹ N.D.	55.52
Rice straw briquette	49.31	6.54	0.13	¹ N.D.	44.03
Lignite coal	70.47	4.57	1.69	4.24	19.03

Note: ¹not detect

Impact Assessment

Impact assessment included the conversion of all input and output data in rice straw briquette production and the electricity generation using different type of fuel into environmental problem indicators and damage indicators (Tanompolkrang, 2014), by using SimaPro 9.0.0.49 version software. For the environmental problem in term of global warming aspect, the IPCC 2013 GWP 100a method was chosen, while IMPACT 2002+ method was selected to assess the midpoint impacts, which are

categorized into 14 issues, and to further align those 14 issues of midpoint impact with the endpoint impacts as mention in the previous study (Tanompolkrang, 2014; Kucharoen, 2016).

Interpretation

The interpretation is to analyze the results, to reach the conclusion, to explain limitation, and to provide recommendations based on the finding of the preceding phases of the life cycle inventory (LCI) study and to report a result of the life cycle interpretation in a transparent manner. It might entail improving certain production procedures, eliminating stages that lead to the impact on the environment, or limit effects on people's quality of life.

Results and Discussions

A life cycle assessment of rice straw briquette production

1) Environmental problem in term of global warming aspect

The environmental problem in term of global warming aspect of rice straw briquette production was conducted with IPCC 2013 GWP 100a method. This rice straw briquette production could be divided into two main steps, which were the raw material acquisition step and the manufacturing step. And 2 mains raw materials for producing the studied briquette were rice straw and glycerin. Rice straw was a primary component, whereas glycerin used as a binder for increasing in the strength of briquette during transportation. Under the raw material acquisition step, it was found the significant gaseous substances released into the atmosphere were carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O), that are classified as GHG (López *et al.*, 2013). The GHG have a significant potential to cause the environmental problem as global warming or a greenhouse effect. From the study, it was investigated that the GHGs emission of 1 kg of rice straw acquisition was 0.000632 time lower than those of 1 kg of glycerin acquisition (GHG emission of 1 kg of glycerin acquisition was 0.778 kgCO₂eq reported by Thai National LCI Databased, TIIS-MTEC-NSTDA (with TGO electricity 2016-2018)). It can be suggested that rice straw is residues from rice cultivation that there is the extensive use of chemical fertilizers (especially, nitrogen-based fertilizer), pesticides, and herbicide in order to obtain a high quality of rice grains in term of high fresh weight. According to the excessive use of chemical compound and chemical fertilizers, they are going to accumulate and eventually ferment in

planting areas leading to the source of N element. Once it contacts with moisture in soil or oxygen in the air, it turning to N_2O , which is a GHG that a 298 times higher potential to global warming than CO_2 (Said *et al.*, 2020). Moreover, the flooded rice fields activity could be the one of GHG emission. The flooded rice fields had to be present throughout the entire cultivation period. How much and how long to flood depend on season, land type, and rice variety/cultivar (AgLEDx resource platform, 2023). When the rice fields are under water (approximately 5 cm below the water surface), a gas exchange between soil and atmosphere was severely inhibited. An anaerobic area is developed, where anaerobic bacteria including methanogenic bacteria, could grow and survive resulting in the rice fields could be a direct source of CH_4 that has a 28 times higher potential to global warming than CO_2 (Vanichsan and Kwanyuen, 2013 ; Wongchina, 2019). While, glycerin is a byproduct of biodiesel production through the chemical reaction known as transesterification (Kosamia *et al.*, 2020; Xu *et al.*, 2022). Under the production process of biodiesel from vegetable oil, the separation of glycerin was necessary for obtaining biodiesel product with a very high level of purification (Rodrigues *et al.*, 2017). As a result, the gases that generated during the separation process are CO_2 and CH_4 from energy usage (Bansod *et al.*, 2024). Figure 2 show the total GHG emission during raw material acquisition step and manufacturing step of rice straw briquette. It can be indicated that the rice straw acquisition also had a potential to environment problem particularly global warming aspect as well as rice grains product (Parry *et al.*, 2008). Therefore, the total amount of the CH_4 and N_2O emissions for rice straw acquisition and glycerin acquisition were calculated in term of the total GHG emission in kilograms of carbon dioxide equivalent unit ($kgCO_2eq/unit$). From the calculating, it was found that the GHG emission of acquiring all raw materials had 71.17% lower than the manufacturing step, as shown in Figure 2a (the GHG emission of raw material acquisition step was 0.911 $kgCO_2eq$, which will be discussed in the next).

In the manufacturing step of rice straw briquette production, it was discovered that there were four additional sub-steps: reducing the size of the rice straw, turning rice straw into charcoal, mixing, and drying (Figure 2b). Among these four additional sub-steps, turning rice straw into charcoal gave the highest GHG emission because it required heat as an energy source for letting all carbon-based components in rice straw (such as lignin, cellulose and hemicellulose) slowly and completely decompose to charcoal in an air-free environment at the temperature of $400^\circ C$ with heating rate of

$5^\circ C/min$, indicating that turning rice straw into charcoal sub-step might take time (Suttibak and Loengbudnark, 2018). Thus, during the procedure of turning rice straw into charcoal, the CO_2 and CH_4 were mostly released to the atmosphere (Parry *et al.*, 2008). This contributed to the amount of GHG emission of turning rice straw into charcoal was 1.796 $kgCO_2eq$, showing in Figure 2b, (which was 74.50 % of a total released in manufacturing step). For, the reducing the size of the rice straw procedure and mixing procedure, they showed the minimized GHG emissions. The GHG emission of 2.2190 $kgCO_2eq$ found in the mixing procedure is significant (Figure 2b), due to the glycerin acquisition has been employed. The drying procedure did not emit the GHG, because rice straw briquettes were applied under the sun light for 7 days. It can be concluded that the raw material acquisition step of rice straw briquette production gave a lesser environmental problem particularly global warming aspect than the manufacturing step (Figure 2a). Compared to other the production processes of briquette from rice straw, the total GHG emissions from this studied rice straw briquette production were 4.973 times greater while the energy content was 76.45 % higher (Alengebawy *et al.*, 2022) (Table 2). Similar to earlier studies by Shafie *et al.* (2014), which found the GHG emissions was 3.644 times higher (Table 2) whereas the energy content of rice straw briquette was 36.67 % higher. These resulted from the rice straw was not being carbonized in a free of air condition to turn it into charcoal before briquetting. The un-carbonized rice straw might cause a low quality of briquette fuel. Low energy content of produced briquettes makes them a poor fuel property for producing electricity due to high consumption and low productivity, as shown in Table 2 (Adams *et al.*, 2015).

To minimize the global warming problem, it may be possible to cover with the reduction of the GHG emission of overall rice straw briquette production process. The possibility ways to reduced GHG emission are finding other raw materials to replace and those might be also slightly affected to the briquette properties. In this research work, the replacement of the rice straw might not be feasible because of the quantity limitations and ‘STOP BURNING’ campaign in Thailand (Singh and Kumar Arya, 2021). Therefore, the raw material as a binder might be considerable, which was glycerin. The material that be suitable for glycerin replacement should be viscous and high carbon content. Because a good property of fuel can be immediately causing by a binder property. Regarding its properties, molasses was a material to employ as a binder instead of glycerin. (Deniz,

2013). Molasses is a byproduct of the sugar refining process. The crystallization and centrifugating steps are only used to separate the molasses from sugar. The sugar refining process does not require any chemical additives, it needed only heat for boiling (Cui *et al.*, 2017). Therefore, the GHG emission of 1 kg of 1 kg of molasses acquisition was 84.06% lower than 1 kg of glycerin acquisition (the GHG emission of 1 kg of molasses acquisition was 0.124 kgCO₂eq calculated by using IPCC 2007 GWP 100a method of Ecoinvent 2.2 under gate-to-gate boundary system of sugar refinery process, as shown in Figure 3a), causing the use of molasses as a binder to produce rice straw briquette was more environmentally friendly in term of 1.073 time lower GHG emission (the GHG emission of rice straw briquette by using molasses as a binder was 8.989 kgCO₂eq, as shown in Figure 3b). Consequently, using molasses might be feasible to produce rice straw briquettes with a lesser global warming issue.

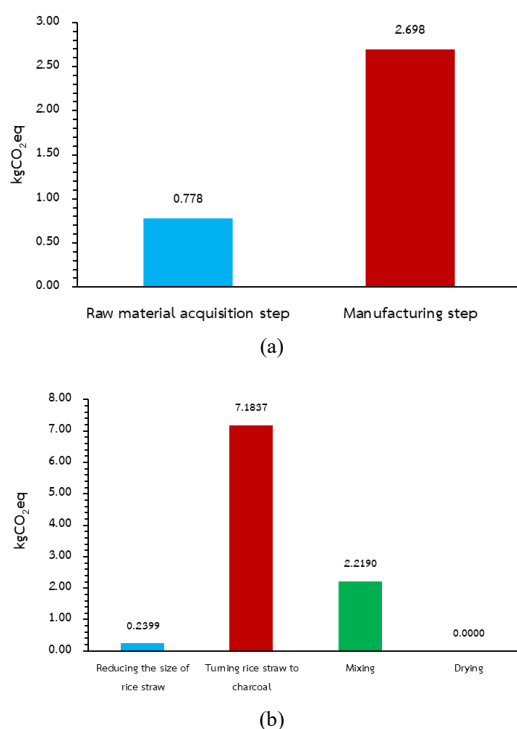


Figure 2. Shows total greenhouse gas emissions (GHG) per kg dried rice straw in (a) raw material acquisition step and manufacturing step of rice straw briquette, and (b) the four additional sub-steps of manufacturing step

Table 2. Comparative GHG emission of briquette production from rice straw and the electrical generation by using rice straw briquette

Ref.	This study	Alengebawy <i>et al.</i> , 2022	Shafie <i>et al.</i> , 2014
High heating value, HHV (MJ/kg)	22.25	12.61	16.28
GHG emission (kgCO ₂ eq/kg)	3.476	0.699	0.954
GHG emission of electricity generation (kgCO ₂ eq/20 kWh)	48.61	-	16.90
Briquette usage for 20 kWh electricity generation (kg)	3.23	5.71	4.42
Electricity generation by using 1 kg of rice straw briquette (kWh)	6.181	3.504	4.523

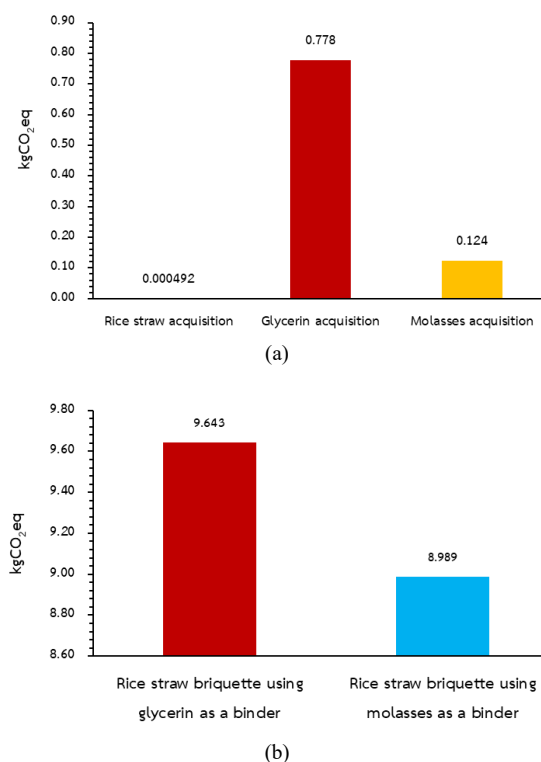


Figure 3. Shows GHG emission of (a) 1 kg rice straw acquisition, 1 kg glycerol acquisition, and 1 kg molasses acquisition and (b) rice straw briquette with different type of binder in kgCO₂eq/kg rice straw unit

2) Midpoint and endpoint impacts

Beside the assessment of environmental problem in term of global warming aspect was analyzed by using the IPCC 2013 GWP 100a method, the midpoint and endpoint impacts were also investigated by using IMPACT 2002+ method. The midpoint impacts are contributing to an environmental problem, whereas endpoint impacts (or damages) typically refer to human health, ecosystem health and resources. Figure 4 shows the midpoint and endpoint impact of raw material acquisition and manufacturing steps in rice straw briquette production. From Figure 4, each midpoint impact and endpoint impact were compared under normalization units in order to easily to understanding and comparing. The significant midpoint impacts of raw material acquisition step and manufacturing step are GHG emissions, the formation of inorganic compounds referring to particulate matter emissions, land use, and the use of fossil fuels. Those significant midpoint impacts continuously contributed to endpoint impacts that are damages to the environment, ecosystem quality, human health, and resources known as climate change, extinction of species, human diseases covering with cancer and respiratory disease, and the reduction of resources, respectively. To diminish and/or discard environmental problems and damages, the GHG removal principle by using CO₂ as a source of carbon minerals to draw it into the ground may be used. The utilization of chemical absorption and/or CO₂ capture and storage (CCS) technology is required to remove GHG from the environment (Marcelo Ketzer *et al.*, 2016). For the inorganic dust particles that adversely affect to human health, such as particulate matter or smog, could be removed by electrostatic collector (Cui *et al.*, 2017). Moreover, the use of heat losses in steam generation systems as an alternation could be an approach to reduce the use of energy from fossil fuels (Fevzi Savaş and Kocabaş, 2022).

The comparison of electricity generation by using different type of fuel: rice straw briquette and lignite coal

1) Environmental problem in term of global warming aspect

The assessment of electricity generation by using various types of fuel considered under gate-to-gate system boundary starting with introducing air or oxygen into the combustion chamber in order to allow complete combustion until release the gaseous compounds and solid particles during the combustion (Beér, 2000). When the rice straw briquette and lignite coal were burned, the different type of gaseous compounds were released depending on their elemental composition (as

mentioned in Table 1). The possibility of gaseous compounds that could be emitted was CO₂, CH₄, carbon monoxide (CO), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), nitrous oxide (N₂O), and hydrogen sulfide (H₂S) as well as the inorganic solid particles that could be spreaded throughout the atmosphere known as particular matter or dust. From the assessment, it revealed that firing rice straw briquettes had a 32.86% lower global warming potential than firing lignite coal on average (the GHG emission by firing rice straw briquette for steam generation was 15.025 kgCO₂eq/kg_{briquette}, as shown in Figure 5). The electricity generation using this studied rice straw briquette showed a 65.23 % higher GHG emission than that the previous study of Shafie *et al.*, 2014. Although the GHG emissions were greater, the acidification problem (ADP) was 16.34 times lower. This result was the same as Silalertruksa and Gheewala, 2013. The ADP was 1.50 time higher, while the GHG emission was 13.21 time higher. The ADP had a negatively affected to aquatic ecosystems because it included a harmful component in freshwater and further impacts to the aquatic life. Moreover, ADP would affect to soil quality and further reduces the crop yield because of nutrient depletion in soils.

Under the consideration of 20 MWh electricity, it was examined that the amount of rice straw briquette used for generating 20 MWh electricity was 3.23kg, which was 8.67% larger amount than the use of lignite coal (Table 3). Even though the amount of rice straw briquette use was greater, but it gave a lesser impact on global warming issue by 32.86% lower level of GHG emission. Similarly, 1 kg of rice straw briquette could generate 6.181 kWh electricity, which was 8.62% lower than that of using 1 kg of lignite coal (Table 3). Not only the amount and type of GHG emission during combustion was estimated based on the elemental composition of each fuel, but also the amount of oxygen consumption can be indicated. In this work, the studied rice straw briquette contained both carbon element (C) and nitrogen element (N) and those C and N content were 11.47% and 92.54% lower than those found in lignite coal, respectively shown in Table 1. The different content of C and N could be related to the amount of CO₂, CH₄, and N₂O released to the atmosphere when it is burnt. The combustion of 1 kg rice straw briquette produced 1.8079kgCO₂ and 0.00044 kgN₂O which was lower than those of 1 kg lignite coal combustion by 0.882 and 0.075 time, respectively (AgLEDx resource platform, 2023). In contrast, firing 1 kg of the rice straw briquettes produced 0.2614kg of CH₄, which was 1.431 times higher than that of firing 1kg of lignite coal. This can be explained by the fact that rice straw briquette contained a high level of H

element (Table 1). The H content in rice straw briquette was 30.12% higher than that in lignite coal resulting in a high level of CH_4 because the formation of methane gas is the reaction between CO_2 and H_2O in the combustion chamber. From the estimated gaseous compound carried out in electricity generation process by using different type of fuel, the GHG emission by using 1 kg of the rice straw briquettes was $9.26 \text{ kgCO}_2\text{eq}$ which was 2.14% lower than that of using 1 kg of lignite coal due to lower C and N content in rice straw briquettes. The lower C and N content, the formation of CO_2 and N_2O was diminished. Along with global warming potential, an ADP in electricity generation process also could be a concern. The ADP causes by the emission of SO_2 , NO_2 , and NH_3 to the atmosphere (Stanners and Bourdeau, 2000). In this work, there were 2 possible substances that referred to ADP, which were SO_2 and NO_2 . The formation of SO_2 and NO_2 was observed when firing lignite coal. Both SO_2 and NO_2 were calculated and obtained the value at 0.08488 kgSO_2 and 0.05553 kgNO_2 , respectively. Meanwhile, the firing of rice straw briquette might create only NO_2 at the value of 0.00414 kgNO_2 without SO_2 formation. The content of NO_2 was equivalent to SO_2 content in order to estimate the level of ADP issue. It was examined that the 0.00414 kgNO_2 of firing rice straw briquette and 0.05553 kgNO_2 of firing lignite coal could be referred to the 0.00291 and $0.03887 \text{ kgSO}_2\text{eq}$, respectively. It can be suggested that the SO_2 and NO_2 content released from a lignite coal power plant were a very higher than those from the rice straw briquette power plant. It can be concluded that the use of lignite coal as a fuel for an electricity generation produced $0.1238 \text{ kgSO}_2\text{eq}$, which was 42.44 times greater than that using the rice straw briquette as a fuel because of no S composition and containing low N content in this rice straw briquette (Table 1). It might be attributed to lignite coal power plant causes a severe environment problem in the term of both global warming issue and ADP. However, using the biomass fuel instead of coal is not currently popular, because the quantity of biomass residue (and/or agricultural waste) is not be enough. The 1 MW of electricity capacity, the quantity of biomass use is about 7.45 time larger than the quantity of coal use. The 2,381 ton/MW/year of coal is used for producing 1 MW of electricity (Academic Services Consulting Center, 2022). Although, the quantity of biomass use is larger, the C, H and N contents of biomass are much lower resulting in the reduction of GHG, SO_2 , and NO_2 emission. In order to environmentally friendly concern and to meet the demand, co-firing of briquettes with lignite coal in a proper ratio might be applied, rather than solely relying on lignite coal

(Beagle and Belmont, 2019). The co-firing of briquettes with lignite coal in a ratio of 1:1 for generating 1 MW electricity, the ADP was diminished to $0.06295 \text{ kgSO}_2\text{eq}$, which was 49.15 % lower than that firing of lignite coal alone (Figure 6). Similarly, the global warming issue from co-firing of briquettes with lignite coal in a ratio of 1:1 was to be 16.43 % lower than that of firing lignite coal alone.

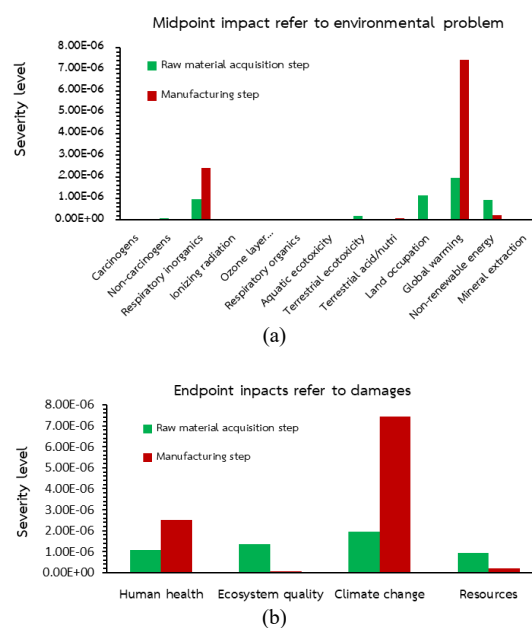


Figure 4. Shows GHG emission of (a) 1 kg rice straw acquisition, 1 kg glycerol acquisition, and 1 kg molasses acquisition and (b) rice straw briquette with different type of binder in $\text{kgCO}_2\text{eq/kg}$ rice straw unit

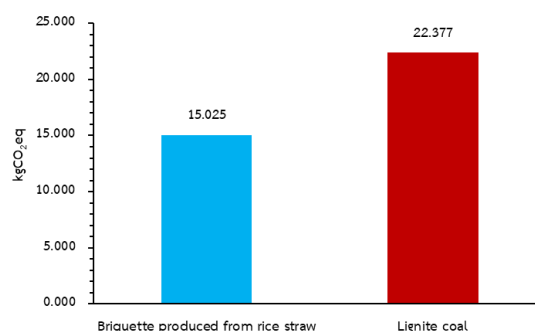


Figure 5. Shows GHG emission of electricity generation in $\text{kgCO}_2\text{eq/kg}$ fuel unit by using 1 kg of rice straw briquette and 1 kg of lignite coal

2) Midpoint impacts and endpoint impacts

Similarly with midpoint and endpoint impacts of rice straw briquette production, the IMPACT 2002+ method also be used to studied both midpoint impacts and endpoint impacts of an electricity generation by using different types of fuel. The midpoint impacts and endpoint impacts can be classified into 14 and 4 issues, respectively (Tanompolkrang, 2014). To make it easier to comprehend and compare, the degree of each impact on every issue will be presented in a normalized unit under the gate-to-gate system boundary. The significant environmental problems being found in rice straw briquette power plant and lignite coal power plant were the formation of inorganic substances resulting in dust/smog spread in the atmosphere and GHG emission associated with global warming issue. In addition, the rain acidification issue was an another severe environmental problem (Figure 7a). Those midpoint impacts caused the damages to human health as a respiratory disease from dust/smog spread in the atmosphere, climate change from a high level of GHG emission to the atmosphere, and ecosystem health as an the formation of acid rain from the formation of SO_2 and NO_2 .

Table 3. Shows the comparison of the amount of fuel and the electrical capacity

Functional unit	Rice straw briquette	Lignite coal
1 kg of fuel (electricity, kWh)	6.181	6.764
20 kWh (amount of fuel, kg)	3.23	2.95
High heating value, HHV (MJ/kg)	22.25	24.35

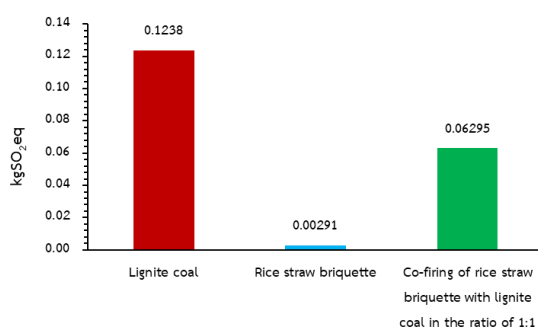


Figure 6. Shows acidification problem in kgSO₂eq unit of 1 MW electricity generation by using different fuel

The use of lignite coal for the electricity generation performed a greater midpoint and endpoint impacts. There are the complicated procedures for lignite coal power plant that are covering with mining process and treatment process. They must be operated carefully and precisely because after mining process, the lignite coal initially had to be reduced the size in order to increase in the surface area, that could be contacted with air and allow to fully complete combustion in the combustion chamber. The procedure of reducing the size of the lignite coal might be the source of inorganic particles as dust and smog that directly affected to humans and causes the respiratory conditions in human (Figure 7). Another important midpoint impact from lignite coal power plant was contributed to the global warming issue (Figure 7a). The cause of global warming issue carried out from the firing lignite coal for producing steam to drive the generator. Interestingly, an attractive midpoint impact as terrestrial acidification issue was found in lignite coal power plant showing in Figure 7a. The terrestrial acidification issue was noticeably observed due to the mining process (Goswami, 2015). Under the mining process, the layers of rock and earth above the coal are removed and those contained heavy metals in a small amount known as traces elements, for example iron, manganese, and aluminum and other heavy metals. These metals can be dissolved from mining sites or can be washed into streams as sediment resulting in the toxicity to fish and other aquatic organisms when they are present in high dissolved concentrations (Gaikwad and Gupta, 2008). This phenomenon is referred to acid mine drainage (AMD) that is often lower water quality. The characteristics of AMD are low pH (or high acidity), high metal concentrations, elevated sulfate level, and excessive suspended solids and/or siltation (Gaikwad and Gupta, 2008). From the AMD phenomenon, it could be a potential to be harmful to human and ecosystem. In addition, when the heavy metals were washed with rain or other source of water, they could be contaminated into soil and water causing soil degradation and deteriorated water resources. Both soil degradation and deteriorated water resources additionally showed a negatively affect to the agricultural cultivation and letting a low-quality agricultural products and further affected to the reduction of the country exportating rate. For treatment process of coal, it must be first chemically cleaned to remove or reduce the sulfur content before feeding to the electricity generation process (Hazan Caglayan and Ipek, 2021). After a chemical cleaning process, coal

sludge is obtained as a hazardous waste. The coal sludge could be contaminated with a ground water and must be directly affected to human and aquatic animals.

This was due to the different contents of elemental composition. Moreover, in the same amount of fuels, there was a very slightly difference in the power capacity.

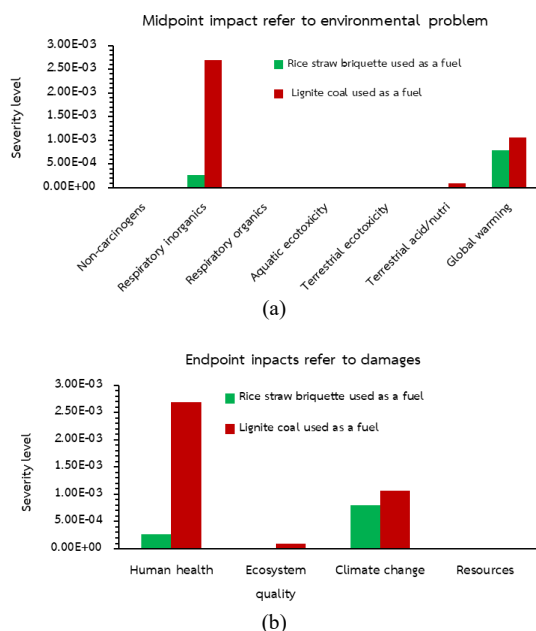


Figure 7. Shows (a) midpoint impacts and (b) endpoint impacts of electricity generation by using different types of fuel: 1 kg of rice straw briquette and 1 kg of lignite coal

Conclusions

This research studied the life cycle assessment of briquette production from rice straw and its utilization for an electricity generation comparing with the use of lignite coal as a fuel for generating electricity. The SimaPro 9.0.0.49 software was used in this studied. The global warming potential was investigated by using an IPCC 2013 GWP 100a V.1.03 method, whereas midpoint and endpoint impacts were used the IMPACT 2002+ method. From the briquette production, it was examined that the manufacturing step performed a significantly global warming potential comparing to a raw material acquisition step. Under consideration of the manufacturing step, the global warming had been the biggest issue in the all categories of midpoint impacts. It contributed to the endpoint impact in the term of climate change. For electricity generation, using the studied rice straw briquette as a fuel had a lower global warming potential, midpoint impact, and endpoint impact than those of using lignite coal.

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