

The Comparison of Environmental Impacts of Carbonized Briquettes from Rain Tree Residues and Coffee Grounds/Tea Waste and Traditional Waste Management

Chaisuwan N., Kansai N., Supakata N., and Papong S.

Abstract—The objective of this research was to investigate and compare the cradle-to-grave environmental impacts of five ratios of carbonized briquettes obtained from rain tree (*Samanea saman*) residues and coffee grounds/tea waste and traditional waste management including landfill disposal and composting. The SimaPro 8.0.5.13 software was used for life cycle assessment analysis. The results were grouped into six impact categories: acidification, eutrophication, global warming, ozone layer depletion, human toxicity and photochemical oxidation. The results showed that carbonization and briquetting processes were the main source of global warming, ozone layer depletion and photochemical oxidation due to the pollutants emitted from an electric briquetting machine and the diesel fuel used for carbonization. Composting rain tree residues had the lowest impact on global warming at 0.02%. Conversely, the carbonized briquette obtained from coffee grounds/tea waste had the highest impact on global warming at 21.57%. This impact resulted from the high amount of electricity used for briquetting and the diesel fuel used for carbonization. On the other hand, composting rain tree residues had the highest impact on acidification and eutrophication with 90.01% and 82.85%, respectively, due to utilization of the compost for soil amendment. Thus, carbonized briquettes from rain tree residues and coffee grounds/tea waste were an alternative way to reduce waste to landfill and to add value to biomass residues for use as raw materials for producing fuel products.

Index Terms—Life cycle assessment, carbonized briquette, rain tree, coffee ground/tea waste.

I. INTRODUCTION

Biomass briquettes, made mostly from green waste and other organic materials, are commonly used for cooking and in boilers. The briquette technology is the process of compacting loose biomass to form a compacted and shaped product. According to the Thai Community Product Standard (TCPS), briquettes' characteristics consist of the heating value (> 5000 kcal/kg), the moisture content (< 8%) and the

Manuscript received May 20, 2019; revised November 2, 2019. This project was supported by the Department of Environmental Science, Faculty of Science, Chulalongkorn University and was partially supported by the Research Program: Municipal Solid Waste and Hazardous Waste Management, Center of Excellence on Hazardous Substance Management (HSM-PJ-CT-17-02).

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lack of smoke and scent when ignited by fire [1]. One of the most common variables of the briquette process is the way in which volatile compounds and moisture are dried out of the organic matter called carbonization, the most efficient forms of drying out biomass with a higher proportion of carbon [2]. If this is the case, the carbonization process is applied to increase the fixed carbon and to remove the moisture content and volatile matter from the briquettes [3].

Rain tree residues and coffee grounds/tea waste can be used as raw materials to produce the carbonized briquettes. When cassava starch is used as a binder, the briquettes are a good tool for household cooking because of their transportation convenience and environmental friendliness [4]. The method for carbonized briquettes production can be divided into two steps: the carbonization and the briquetting that improves the fixed carbon content [5].

However, the carbonization process can release carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) [6]. Many tools have analyzed the environmental impacts of different processes [7]. To evaluate the environmental performance of the carbonized briquettes from rain tree residues and coffee grounds/tea waste, the Life Cycle Assessment (LCA) is often used as a comprehensive tool to evaluate the environmental impact of such products or services. The scope of this assessment is the entire life cycle of a product, from the extraction of raw materials to the manufacturing, use and end of life [8]. According to the ISO 14040, the LCA has four steps, including goal and scope, inventory analysis, impact assessment, and interpretation [9]. LCA is used to identify environmental impacts [10] and provide analysis for integrated waste management [11].

Hu *et al.* [12] published an environmental assessment of briquette fuel from agricultural residues using the LCA method. This assessment covered the entire life cycle, from raw material acquisition to disposal (also known as cradle-to-grave). According to this assessment, briquettes from corn stalks had a high environmental impact due to electricity consumption during the briquetting process.

Rousset *et al.* [13] investigated the LCA of charcoal briquettes using the GaBi 4.3 database software and the Global Warming Potential (100 years). The study included every stage of the production (cradle-to-grave). According to the study, charcoal briquettes from eucalyptus had the most impact due to CO_2 emissions released during the briquetting process.

However, carbonized briquettes from rain tree residues and coffee grounds/tea waste can be an alternative way to add value to residues [4]. No studies have examined the Life Cycle Assessment (LCA) in the field of carbonized briquettes

from rain tree residues and coffee grounds/tea waste.

The purpose of this study was to compare the LCA of the carbonized briquettes produced from rain tree residues and coffee grounds/tea waste with the traditional waste management of these residues. Traditional waste management techniques are associated with environmental impacts such as acidification, eutrophication, global warming, ozone layer depletion, human toxicity and photochemical oxidation. The life cycle stages began with raw materials acquisition and ended with disposal, either of the carbonized briquette or the traditional disposal of biomass. This inclusion of all life cycle stages is called “cradle-to-grave.”

II. METHODS

A. Methods of the LCA of Briquettes

1) Goal and scope

As stated above, the goal of this study was to investigate and compare the environmental life cycle impact of carbonized briquettes made from rain tree residues and coffee grounds/tea waste residues and traditional waste management including landfill disposal and composting. Carbonized briquettes made from rain tree residues and coffee grounds/tea waste were mixed into five ratios including RT100:CT0, RT75:CT25, RT50:CT50, RT25:CT75 and RT0:CT100. These ratios were studied to discover the optimal ratio with the lowest environmental impact. The analysis used in this study followed the cradle-to-grave phases of the LCA (Fig. 1 and Fig. 2). The functional unit was defined as one piece of carbonized briquette (150 g/unit).

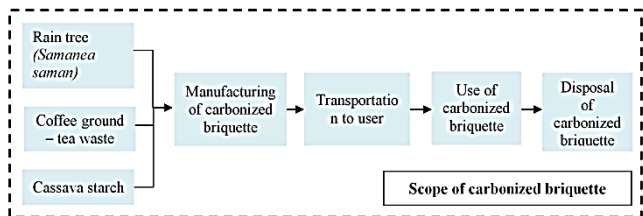


Fig. 1. The system boundaries of study include raw material acquisition to disposal of carbonized briquettes.

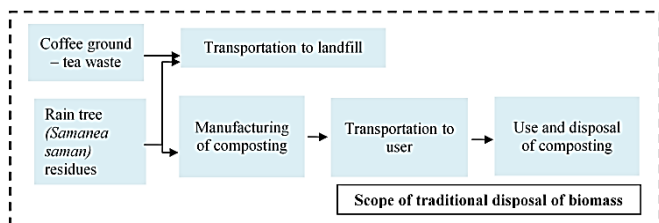


Fig. 2. The system boundaries of the study include raw material acquisition to traditional disposal of biomass.

B. Assumptions

- 1) Vehicles used for LCA calculation in this study were trucks with four wheels and a max payload of seven tons. Diesel was used as fuel.
- 2) The distance used for the LCA calculation in this study (transportation for carbonized briquettes and compost) was 10 km (from Chulalongkorn University to the

consumer).

- 3) The distance used for the LCA calculation in this study (transportation to landfill) was 45 km (from Chulalongkorn University to the landfill at Nongkhaem).
- 4) The raw materials used in the carbonized briquette process were assumed to be residues at Chulalongkorn University that did not cause environmental impact.
- 5) Carbonized briquettes and composting were assumed to be products from Chulalongkorn University that did not cause environmental impact. Thus, environmental impact was calculated only from transportation of the product.
- 6) The raw materials in traditional waste management such as transportation to the landfill were assumed to be residues at Chulalongkorn University which did not cause environmental impact. Thus, environmental impact was calculated only from raw material transportation.

C. Life Cycle Inventory

1) Data preparation

Rain tree residues were collected from Chulalongkorn University, Bangkok. Coffee grounds/tea waste was obtained from a coffee shop in Chulalongkorn University, Bangkok. Cassava starch was purchased from a bakery shop.

2) Inventory and data calculation

The life cycle inventory (LCI) showed the material and energy flows (input and output) at every stage of the life cycle from raw materials acquisition to disposal (Rousset *et al.*, 2011). This process was divided into two parts: (1) the LCA of raw materials acquisition to the disposal of carbonized briquettes and (2) the LCA of traditional waste management by landfill disposal.

There were five processes for carbonized briquettes: diesel production, carbonized briquetting, the transportation, utilization and landfill disposal (Fig. 3).

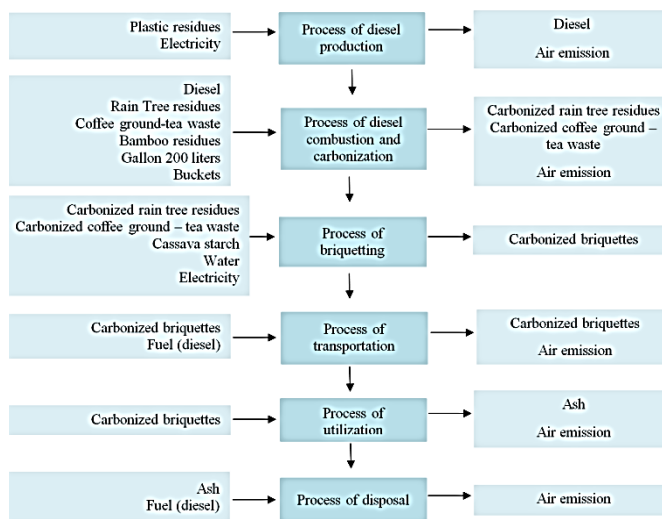
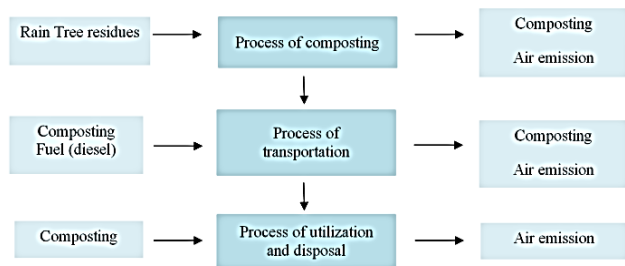


Fig. 3. Life Cycle Inventory (LCI) of carbonized.

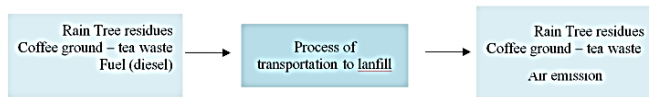
There were three steps in traditional waste management through composting: composting, transportation and utilization and disposal (Fig. 4).

There were two steps in traditional waste management by landfill disposal: transportation and landfill disposal (Fig. 5).



* Air emission = CO₂, CO, NO_x, SO₂, NMVOC, NH₃

Fig. 4. LCI of traditional waste management by composting.



* Air emission = CO₂, CO, NO_x, SO₂, NMVOC, NH₃, CH₄

Fig. 5. LCI of traditional waste management by the disposal of biomass in a landfill.

D. Life Cycle Impact Assessment (LCIA)

1) Classification

The air emission estimation methodology covered exhaust emissions by diesel production, diesel combustion, carbonization, briquetting, transportation, utilization and disposal. These were further categorized into global warming (CO₂), ozone layer depletion (CO, NO_x, NMVOC), acidification (NO_x, SO₂, NH₃), eutrophication (NO_x, NH₃), human toxicity (SO₂, NO_x, CO, Benzo [a] pyrene, Benzo [k] fluoranthene, Benzo [b] fluoranthene) and photochemical oxidation (NMVOC). These were estimated using the IPCC 2007 guidelines [14] and EEA 2016 air emission inventory guidebook [15].

2) Data calculation and characteristics

Calculation of environmental impact potential used the following equations (1):

Emission of exhaust pollutants

$$\text{Emission} = \sum[\text{Fuel} \times \text{EF}] \quad (1)$$

where:

Emission = emission in kg
 Fuel = fuel consumed (TJ)
 EF = emission factor (kg/TJ)

The life cycle assessment study was carried out using the SimaPro 8.0.5.13 software from National Metal and Materials Technology Center (MTEC). Results were expressed in six categories of impact, including global warming, ozone layer depletion, acidification, eutrophication, human toxicity and photochemical oxidation.

5. Interpretation

In this step, the data were analyzed. The results from the SimaPro 8.0.5.13 software calculation were collected to show the environmental impacts of carbonized briquettes, landfill disposal and composting.

III. RESULTS AND DISCUSSION

The LCA was carried out with the SimaPro 8.0.5.13

software, using the CML2 baseline 2000 V2.05/World 1995 method from National Metal and Materials Technology Center (MTEC). Results were grouped into the six previously mentioned categories of impact: acidification, eutrophication, global warming, ozone layer depletion, human toxicity and photochemical oxidation.

A. Carbonized Briquettes Made from Rain Tree Residues (RT100:CT0)

SO₂ emissions resulting from the use of diesel fuel for carbonizing rain tree residues were the main cause of acidification and photochemical oxidation, with the values of 59.70% and 96.01%, respectively. The briquetting process caused eutrophication, global warming, ozone layer depletion and human toxicity with the values of 60.44%, 73.64%, 98.87% and 97.02%, respectively (Fig. 6). This was the result of using a high amount of electricity for the briquetting machine.

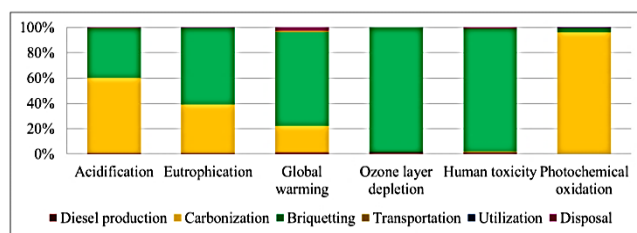


Fig. 6. Distribution of the environmental impact of carbonized briquettes made from 100% rain tree residues) RT100:CT0.

B. Carbonized Briquettes Made from 75% Rain Tree Residues and 25% Coffee Grounds/tea Waste (RT75:CT25)

The main cause of six environmental impacts—acidification, eutrophication, ozone layer depletion, human toxicity and photochemical oxidation—was the briquetting process, with the values of 96.96%, 97.93%, 94.80%, 98.82%, 97.94% and 87.74%, respectively (Fig. 7). These impacts resulted from using a high amount of electricity for the briquetting machine.

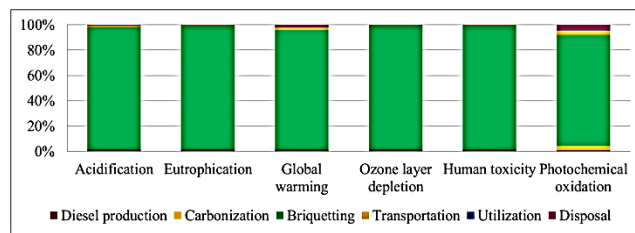


Fig. 7. Distribution of the environmental impact of carbonized briquettes made from 75% rain tree residues and 25% coffee grounds/tea waste (RT75:CT25).

C. Carbonized Briquettes Made from 50% Rain Tree Residues and 50% Coffee Grounds/Tea Waste (RT50:CT50)

The main cause of the six environmental impacts (acidification, eutrophication, ozone layer depletion, human toxicity and photochemical oxidation) was the briquetting process, with the values of 96.96%, 98.22%, 94.81%, 98.82%, 98.11% and 88.03%, respectively (Fig. 8). This resulted from the electricity consumption of the briquetting machine.

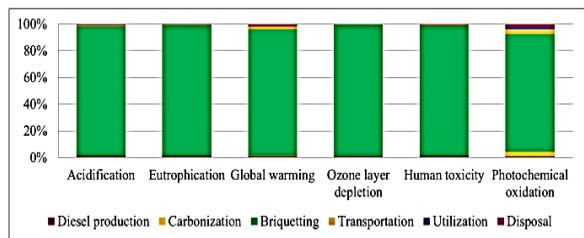


Fig. 8. Distribution of the environmental impact of carbonized briquettes made from 50% rain tree residues and 50% coffee grounds/tea waste (RT50:CT50).

D. Carbonized Briquettes Made from 25% Rain Tree Residues and 75% Coffee Grounds/Tea Waste (RT25:CT75)

The values of the six impacts (acidification, eutrophication, ozone layer depletion, human toxicity and photochemical oxidation) were 90.72%, 95.66%, 81.11%, 98.82%, 94.69%, and 88.03%, respectively (Fig. 9). This was again due to the electricity usage of the briquetting machine.

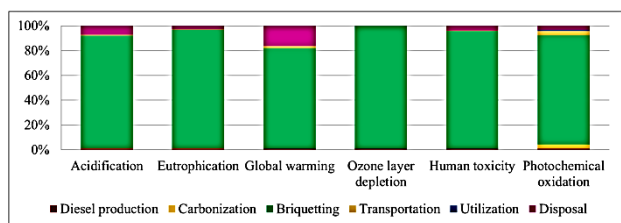


Fig. 9. Distribution of the environmental impact of carbonized briquettes made from 25% rain tree residues and 75% coffee grounds/tea waste (RT25:CT75).

E. Carbonized Briquettes Made from 100% Coffee Grounds/Tea Waste (RT0:CT100)

The main cause of eutrophication, global warming, ozone layer depletion and human toxicity was the high amount of electricity usage of the briquetting machine. The values of these impacts during the briquetting process were 61.99%, 68.87%, 98.82% and 97.44%, respectively. In the carbonization process, the environmental impacts were caused by the use of diesel fuel. This generated SO₂ emissions that caused acidification and photochemical oxidation, with the values of 58.27% and 95.83%, respectively (Fig. 10).

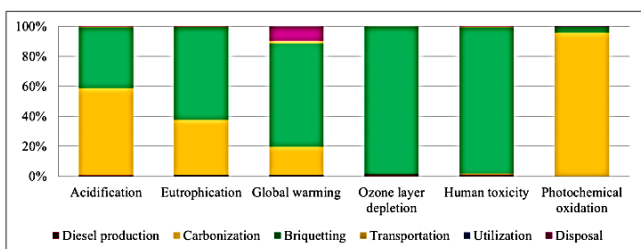


Fig. 10. Distribution of the environmental impact of carbonized briquettes made from 100% coffee grounds/tea waste (RT0:CT100).

F. Traditional Waste Management by Composting

Composting released pollutants such as NO_x and NH₃. The composting process caused acidification, eutrophication and human toxicity with values of 99.95%, 100% and 99.86%, respectively. The main cause of global warming and

photochemical oxidation in this process was transportation of the compost from Chulalongkorn University to the consumer (20 km), both with values of 100% resulting from the combustion and pollutants emissions of diesel fuel (Fig. 11).

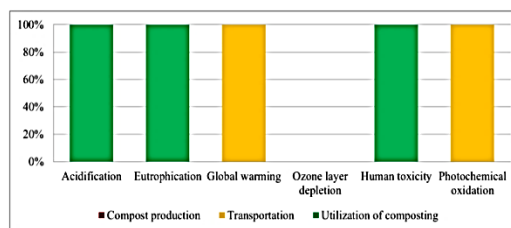


Fig. 11. Distribution of the environmental impact of traditional waste management of rain tree residues by composting.

G. Traditional Waste Management by Landfill Disposal

The main cause of six impacts—acidification, eutrophication, ozone layer depletion, human toxicity and photochemical oxidation—was transportation, with the value of 100% resulting from diesel fuel combustion and pollutants emissions resulting from transportation from Chulalongkorn University to the landfill (90 km) (Fig. 12).

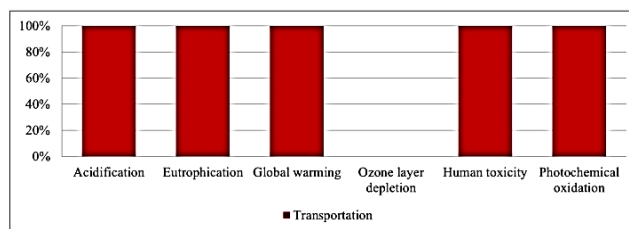


Fig. 12. Distribution of the environmental impact of traditional waste management of rain tree residues and coffee grounds/tea waste by landfill disposal.

H. Comparison of the Environmental Impacts of Carbonized Briquettes and Traditional Waste Management

The impacts from each process among the five different ratios of carbonized briquettes as well as traditional waste management processes were grouped into six categories, as shown in Fig. 13. Composting rain tree residues had the lowest impact on global warming, 0.02%. Conversely, carbonized briquettes made from 100% coffee grounds/tea waste (RT0:CT100) had the highest impact on global warming resulting from the use of electricity and diesel fuel, a value of 21.57%. In addition, the comparison of acidification and eutrophication among the five ratios of carbonized briquettes as well as traditional waste management processes showed that composting rain tree residues had the highest impact on acidification and eutrophication (90.01% and 82.85%, respectively), due to the pollutants NO_x and NH₃ that were released into the atmosphere. Thus, carbonized briquetting had less impact on acidification and eutrophication than composting. Furthermore, carbonized briquettes with the optimal ratio of RT50:CT50 impacted human toxicity with a value of 15.36% resulting from electricity and diesel fuel consumption. This was lower than landfill disposal, which had a value of 17.76%. Fig. 13. presents the comparison of the environmental impacts among the five ratios of carbonized briquettes and traditional waste management processes.

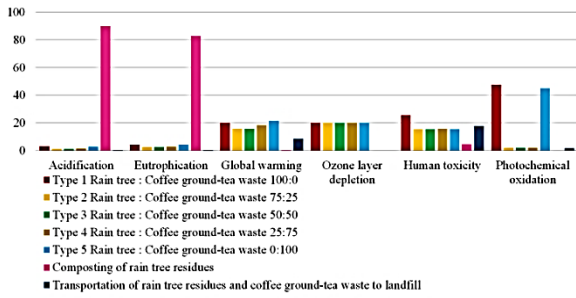


Fig. 13. Distribution of the environmental impacts among the five ratios of carbonized briquettes from rain tree residues and coffee grounds/tea waste and traditional waste management.

I. Comparison with Other Researchers

No previous research existed concerning the LCA over the cradle-to-grave life cycles of carbonized briquettes made from rain tree residues. However, some studies examined the LCA of briquettes or charcoal made with other residues, as shown in Table 1.

Wang *et al.* [16] investigated the environmental impact of the cradle-to-grave life cycle of cornstalk briquettes, a fuel in China. The results showed that briquettes made from cornstalks had global warming impacts of 11 g CO₂ eq/MJ, which was higher than the global warming impacts of carbonized briquettes with the ratio of RT0:CT100. The highest impact of these briquettes was 0.0212 kg CO₂ eq or 7.02 g CO₂ eq/MJ.

Additionally, the results showed that cornstalk briquettes had the impact of 0.39 g SO₂ eq/MJ on human toxicity, which was higher than the human toxicity impacts from the carbonized briquettes with the ratio of RT25:CT75. The highest impact of the carbonized briquettes was 0.00603 kg SO₂ eq or 0.052 g SO₂ eq/MJ. The impact from using electricity in the production of cornstalk briquettes was a major cause of global warming and human toxicity.

Adams, Shirley and McManus [17] published the environmental impacts of the cradle-to-grave life cycle of wood pallet production. The results showed that the wood pallet had the global warming impact value of 17.50 g CO₂ eq/MJ resulting from the grinding process. This was higher than the global warming impact of carbonized briquettes made from 100% coffee grounds/tea waste, which had the highest impact value of 7.02 g CO₂ eq/MJ.

TABLE I COMPARISON OF THE ENVIRONMENTAL IMPACTS AMONG THE FIVE RATIOS OF CARBONIZED BRIQUETTES AND TRADITIONAL WASTE MANAGEMENT PROCESSES WITH OTHER RESEARCH

Impact categories	Units	Ratios of rain tree residue and coffee grounds/tea waste		Cornstalk briquettes (Wang <i>et al.</i> , 2017)	Wood pallet production (Adams, Shirley and Mcmanus, 2015)
		RT25:CT75	RT0:CT100		
Global warming	g CO ₂ eq	1.80E-02	2.12E-02	1.1E+01	1.75E+01
Human toxicity	g SO ₂ eq	6.03E-03	5.86E-03	3.9E-01	-

Carbonized briquettes from rain tree residues and coffee grounds/tea waste were environmentally friendly products because they decreased waste to landfill and reduced needs for employing natural resources as raw materials. This study

showed that using rain tree residues and coffee grounds/tea waste could be an alternative way to add value to biomass residues that are of good quality and are environmentally friendly. Carbonized briquettes could provide renewable energy for household cooking.

IV. CONCLUSIONS

This study used the LCA to carry out an environmental evaluation of carbonized briquettes, from raw material acquisition to disposal. Environmental impacts of carbonized briquettes depended on carbonization and briquetting processes. Most of the emissions of these processes were attributed to exhausted pollutants from fuel used for carbonization and electricity used for the briquetting machine. The combustion of this fuel and electricity produced large amounts of air pollutants like carbon monoxide and nitrogen oxide.

Comparative results showed that carbonized briquette made from rain tree residues and coffee grounds/tea waste with the ratio of RT0:CT100 had a greater impact on global warming than the other four types of carbonized briquette and traditional disposal processes. This was due to the amount of electricity consumed by the briquetting machine, which led to a greater amount of atmospheric pollutants. However, this impact could be reduced by using different methods to replace electricity, such as a solar cell, or using other machines which require less power. Conversely, composting rain tree residues had the greatest impact on acidification and eutrophication due to the utilization of the compost for soil amendment, even though composting was an alternative way of adding value to the biomass residues.

Carbonized briquettes made from rain tree residues and coffee grounds/tea waste with the optimal ratio of RT50:CT50 had a greater impact on human toxicity than traditional disposal of these residues due to electricity consumption. Additionally, this ratio had less impact on global warming than the other ratios of carbonized briquettes, including RT100:CT0, RT25:CT75 and RT0:CT100.

Consequently, carbonized briquettes from rain tree residues and coffee grounds/tea waste could be an alternative way to reduce and to add value to biomass residues for use as raw materials for producing fuel products used in household cooking that are environmentally friendly.

APPENDIX

Appendixes, if needed, appear before the acknowledgment.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Nuta Supakata conducted, the research and wrote the paper; Nichakorn Chaisuwan and Nattakarn Kansai performed the experiments, analyzed and interpreted the data; Seksan Parpong contributed analysis tools and data; all authors had approved the final version.

ACKNOWLEDGMENT

This project was supported by the Department of Environmental Science, Faculty of Science, Chulalongkorn University and was partially supported by the Research Program: Municipal Solid Waste and Hazardous Waste Management, the S&T Postgraduate Education and Research Development Office, the Office of Higher Education Commission (HSM-PJ-CT-17-02). The authors gratefully acknowledge Prof. Dr. Tharapong Vitidsant (Chief of Fuels and Energy from Biomass Center), Mr. Sirichai Ratanawaraha (instructor and manager of Fuels and Energy from Biomass Center), Fuels and Energy from Biomass Center, *Physical Resources Management*, and the faculty of Engineering at Chulalongkorn University for providing mechanical equipment. The authors also would like to thank Dr. Sujitra Vassanadamrongdee (PI of Chula Zero Waste Project) for encouragement; METC for providing the software and database; Asst.Prof. Dr. Sarawut Srithongouthai, Asst.Prof. Dr. Vorapot Kanokantapong and Asst.Prof. Dr. Pantana Tor-ngern for their kindly suggestions.

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