The application of rice husk and cabbage market waste for fuel briquette production

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Abstract

The aim of this research was to develop higher calorific value charcoal briquettes from cabbage market waste by adding rice husk through pyrolysis process. To produce briquette, rice husk and cabbage were mixed into 5 ratios including 60:40, 55:45, 50:50, 45:55 and 40:60 using briquette machine (hot compression) at 250-270^{0}C temperature and pyrolysis at 500^{0}C. The results showed that charcoal made from 60% of rice husk and 40% of cabbage market waste was characterized as the most efficient renewable energy resource due to its higher calorific value (5,026.7 cal/g) which is in accordance with TCPS (5,000 cal/g). Results showed that rice husk and cabbage market waste are feasible for charcoal production and are in line with the TCPS requirements, however, briquettes just hot compressed but not gone through pyrolysis could not achieve the TCPS calorific values. The results revealed that in comparison with other parts of processing, Pyrolysis have the major impacts on environment when analyzed for the production of 1 kg charcoal**.**

Keywords: *Solid fuel briquettes, charcoal, rice husk, cabbage market waste, LCA*

1. Introduction

Trends of energy consumption especially petroleum in the past decades has been increasing unceasingly [1]. The volume of petroleum from source that can be restored in Thailand is only 9.94 trillion cubic feet, while it is about 1,574.98 trillion cubic feet in Russia [2]. In 2007, Thailand produced CO_2, one of the greenhouse gases, at a significant amount of 54.6 million ton mainly via the exhaustion of vehicles used in transportation [3]. Consequently, such records have caused Thailand to become more committed in seeking wider ranges of alternative sources of energy that can be utilized within the country in order to reduce energy import in the long term. Currently, there are many types of alternative energy commercially available, such as solar energy, hydro power, wind power, ocean thermal energy conversion and biomass.

Biomass is an organic compound derived from plants, animals or microorganisms as biological material. It also includes products and residues/waste from agriculture, forestry, industry and municipalities [4]. Thailand is one of the countries, rich in agricultural crops hence having many kinds of biomass including corn cobs, bagasse, coconut, cassava and rice husk which can be used to produce renewable energy[5]. These residues from agriculture crops consist of high amounts of celluloses, hemicellulose, lignin which are the major organism components providing energy [6][7][8][9].

Thailand is a major agricultural producer of the world with substantial resources of biomass related to agriculture activities [10]. In Thailand, rice husk, a fibrous material, is being produced, more than 5 million tons annually [11]. Similarly, the vegetable production of Thailand yields more than 2 million tons per year. [12]. The production of vegetable waste is in profusion because of the high biodegradability, thus such waste has been a major concern in municipal landfill. [13]. Cabbage (*Brassica oleracea L. var. capitata L.)* is one of the major vegetables produced in Thailand. The production of cabbage solely yields more than 250,000 tons every year [14]. Waste from cabbage leave from markets commonly disposed in municipal landfill or dumping sites causing environmental pollution [13]. So biomass can be created as briquettes by compression at moderate temperatures and can be used as an alternate/clean energy source.

Srivastava et al [13] studied the production of the briquette from vegetable market waste, it was reported that calorific values of briquette from cabbage leaves and cauliflower were 12.39 MJ/kg. Liu et al [15] measured heating value of rice husk by using oxygen bomb calorimeter with benzoic acid as combustion adjuvant. At a mass ratio 1.2:1 of rice husk and benzoic acid the heating value was found 15.94 MJ/kg. Heating value of biomass is around 12.56 MJ/kg, but pyrolysis process can add high heating value [16]. Pyrolysis is the heating of an organic material, such as biomass, in absence of oxygen. This would enable the material to be thermally decomposed into combustible gases and charcoal. Apirak et al [17] revealed that a production of bar-shaped fuel from rice husk ashes mixed with corn-cob and coconut shell has a heating value of around 21 MJ/kg. And briquette of durian peel has calorific value about 26.27 MJ/kg [16].

In order to modify briquettes from cabbage market waste to obtain higher calorific value, rice husk was added and pyrolysis process was applied. The aim of this study was to investigate the optimum ratio of cabbage market waste and rice husk to produce solid fuel briquette of high calorific value. Various physical properties of briquette and charcoal were analyzed including heating value, moisture content, ash content, volatile matter, fixed carbon and compressive strength. Further the economic feasibility has also been emphasized in this study.

2. Materials and methods

2.1 The raw material collection and characterization

In this study rice husk was obtained from the Royal Chitralada Project and cabbage market waste was collected from Samrong market, Samutprakan province. Cabbage market waste was sun dried for 10 days until moisture content less than 10% by weight. After sun drying, the total weight of dried cabbage was 16.2 kg (205.4 kg before sun drying). Raw materials were ground by grinding machine (Leshan Dongchuan Machinery, China) and were sieved into the size of 1-2 mm. The physical properties of rice husk and cabbage market waste were analyzed as shown in Table 1.

Table 1 Physical properties

Physical properties	Instrument/Method
Moisture content	Simultaneous Thermal Analyzer(STA) ASTM E1131-08
Ash content	Simultaneous Thermal Analyzer(STA) ASTM E1131-08
Volatile matter	Simultaneous Thermal Analyzer(STA) ASTM E1131-08
Fixed carbon	Simultaneous Thermal Analyzer(STA) ASTM E1131-08
Calorific Values	Automatic Bomb Calorimeter (Ac-500)
Compressive strength *	UTM-1000/RF2 ASTM D 695

* Compressive strength test for briquette and charcoal

2.2 The process of briquetting

The briquettes were formed in cylinder shapes with the inner diameter of 2 cm, the outer diameter of 7 cm, and the length of 12-24 cm (Figure 1). Dried rice husk and cabbage market waste with particle size between 1-2 mm were mixed into a homogenous texture with the ratios of 60:40, 55:45, 50:50, 45:55 and 40:60 without binder. The mixtures of rice husk and cabbage market waste were compacted by hot pressing machine (screw press) at the temperature of 250-270°C and pressure 600 kg/cm^2.

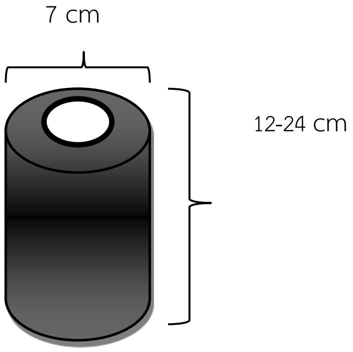

Figure 1 Fuel briquette

a. The process of pyrolysis

Briquettes obtained from 2.2 were pyrolyzed by using the 200 L tank at temperature 500 ºC.

b. Characterization of fuel charcoal made from pyrolyzed cabbage market waste and rice husk

Physical properties of fuel charcoal including moisture content, ash content, volatile matter, fixed carbon, calorific values, compressive strength, thermogravimetric analysis, and differential scanning chromatography were analyzed using instrument/method shown in Table 1.

c. Economical Feasibility

An economics analysis of production of fuel briquettes made from 60% of rice husk and 40% of cabbage market waste was evaluated using following equations.

The break even volume (N*)

$$N* = \frac{F}{P-V} \quad (1)$$

Where:
N* is the break even volume
F is fixed cost, Baht
P is price per unit, Baht/unit
V is variable cost, Baht

The payback period

$$\text{Payback period} = \frac{N*}{N} \quad (2)$$

Where:
N* is the break even volume
N is productivity yield/year
Data of fixed cost and variable cost were shown in Table 2

Table 2 Data of fixed cost and variable cost

Fixed cost (Baht)		Variable cost (Baht)	
1. Grinding machine	2,500	1.Material cost (rice husk and cabbage market waste)	0
2. Hot compressive machine	320,000	2.Transportation cost	24,510
3. 200 liter fuel tank (for pyrolysis)	500	3.Electricity cost*	1,623
4. Labor cost (300 Baht/person/day x 300 days)	90,000		
Total	413,000	Total	26,133

*Electricity (unit) = electricity power (kW) x working hour (hr)

The product yield of briquette was 28,500 kg/year as the production of briquette for 1 hour was 125 units, thus in one year 300,000 units (125 units x 8 hr x 300 days) briquettes were produced. The weight of briquette per unit was 0.095 kg, therefore the product yield of briquettes per year was 28,500 kg. This study determined the price of briquette 5 Baht/kg.

d. Life Cycle Assessment (LCA) of fuel briquette made from durian peel and used cooking oil

Life cycle assessment (LCA) is an approach to evaluate and improve the environmental impact of products [18]. According to ISO 14042, there are 4 steps of LCA including goal and scope definition, inventory analysis, impact assessment, and interpretation. In the present study, the life cycle assessment (LCA) methodology was implemented in the briquette and charcoal production in laboratory in term of cradle-to-gate. The scopes of cradle-to-gate were studied and collected information in 2 processes including raw material acquisition and manufacturing using Sima Pro 7.1 program from National Metal and Materials Technology Center for calculation. Five impact categories were considered: global warming, ozone layer depletion, human toxicity, acidification, and eutrophication.

Table 3 showed the LCI (life cycle inventory) of raw material acquisition.

Table 3 LCI of raw material acquisition

Input	Data	Output	Data
Gasohol 91 (kg)	8.57×10^{-2}	Carbon dioxide (kg)	0.214
		Methane (kg)	6.29×10^{-3}
		Nitrous Oxide (kg)	9.90×10^{-6}

Table 4 showed the LCI of manufacturing including preparation, briquetting and pyrolysis.

Table 4 LCI of manufacturing including preparation, briquetting and pyrolysis

Input	Data	Output	Data
Preparation			
Electricity (kWh)	0.45	Carbon dioxide eq (kg)	0.28
Briquetting			
Gasohol 91 (kg)	0.26	Carbon dioxide (kg)	0.65
		Methane (kg)	1.91×10^{-2}
		Nitrous Oxide (kg)	3.01×10^{-5}
Electricity (kWh)	0.48	Carbon dioxide eq (kg)	0.29
Pyrolysis			
Gasohol 91 (kg)	0.43	Carbon dioxide (kg)	1.07
		Methane (kg)	3.14×10^{-2}
		Nitrous Oxide (kg)	4.94×10^{-5}
Wood (kg)	14	Carbon dioxide eq (kg)	0.11

The summary of this research experiment was shown in Figure 2.

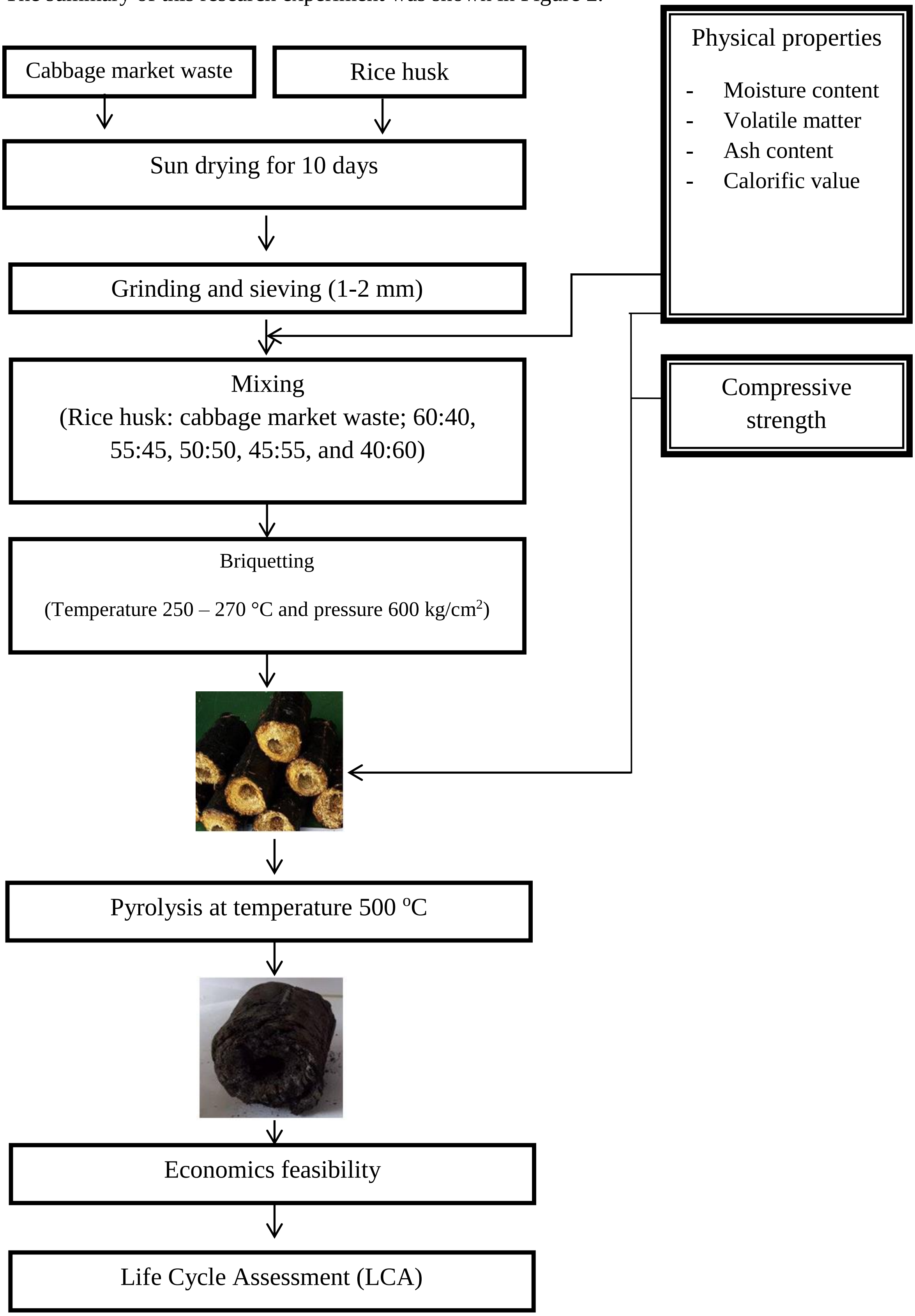

Figure 2 Summary of research experiment

3. Results

3.1 Characteristics of rice husk and cabbage market waste

The calorific values of rice husk and cabbage market waste were 3,650.4 cal/g and 3,470.5 cal/g respectively as shown in Table 5. For the production of solid fuel, calorific value is the major quality index [19]. These values shows that rice husk and cabbage market waste are feasible raw materials for production of briquettes.

Table 5 Analysis of rice husk and cabbage market waste sample

Sample	Moisture content (%)	Volatile matter (%)	Fixed carbon (%)	Ash content (%)	Calorific value (cal/g)
rice husk	12.0	62.70[20]	17.40[20]	20.00[20]	3,650.4
cabbage	9.18	69.64[13]	12.21[13]	18.15[13]	3,470.5

3.2 The characterization of briquette

3.2.1 Appearance of briquette

The appearances of all the lots of briquettes (formed with different mixing ratios) were basically cylindrical in shape as shown in Figure 3. The results found that the size and the shape of briquettes from all lots were not much different from the designed length (12 to 24 cm) and the diameter (7 cm), however small cracks were found on the surface of briquettes.

[A] R60:C40 **[B]** R55:C45 **[C]** R50:C50 **[D]** R45:C55 **[E]** R40:C60

Figure 3 The appearance of briquette [A] briquette with 60% of rice husk and 40% of cabbage market waste. [B] Briquette with 55% of rice husk and 45% of cabbage market waste. [C] Briquette with 50% of rice husk and 50% of cabbage market waste. [D] Briquette with 45% of rice husk and 55% of cabbage market waste. [E] Briquette with 40% of rice husk and 60% of cabbage market waste.

3.2.2 Physical properties of briquette

Measured parameters of physical properties for all test specimens have been shown in Table 6. The results showed that moisture content for all lots was within the TCPS defined limit (i.e less than 8%). The volatile matter of briquette of all specimens ranged from 64.25 to 69.81 wt%. The fixed carbon of briquette of all specimens ranged from 17.96 to 20.84 wt%. The ash content of briquette of all specimens ranged from 6.76 to 10.97 wt%. For calorific value, all treatment was not compliant with TCPS value (5,000 cal/g). In the study, the compressive strength of all specimens ranged from 0.37 to 1.84 kgf/mm^2. Among all lots, briquette made from 55% of rice husk and 45% of cabbage and briquette made from 50% of rice husk and 50% of cabbage provided the highest calorific value (3,876.80 cal/g and 3,857.00 cal/g respectively).

Table 6 The characterization of briquette made from rice husk and cabbage market waste

Rice husk : Cabbage market waste	Moisture content (%)	Volatile matter (%)	Fixed carbon (%)	Ash content (%)	Compressive strength (kgf/mm^2)	Calorific value (cal/g)
60 : 40	4.05	67.02	17.96	10.97	0.3717	3716.1^{b*}
55 : 45	4.60	64.25	20.47	10.69	1.3899	3876.8^{a}
50 : 50	3.38	69.81	20.05	6.76	1.8389	3857.0^{a}
45 : 55	3.13	68.40	20.01	8.46	0.1161	3756.9^{b}
40 : 60	2.70	66.96	20.84	9.50	0.7272	3734.4^{b*}
TCPS	≤ 8%					≥ 5,000

TCPS standard: Thai community Product Standard, $P < 0.05$

3.3 Characterization of charcoal

3.3.1 Appearance of charcoal

The appearance of all the processed briquettes was again cylindrical and the sizes were almost in agreement with the design, as shown in figure 4. Cracks and ash were found on the surface of charcoal.

[A] R60:C40 **[B]** R55:C45 **[C]** R50:C50 **[D]** R45:C55 **[E]** R40:C60

Figure 4 The appearance of charcoal [A] Charcoal with 60% of rice husk and 40% of cabbage market waste [B] Charcoal with 55% of rice husk and 45% of cabbage market waste [C] Charcoal with 50% of rice husk and 50% of cabbage market waste [D] Charcoal with 45% of rice husk and 55% of cabbage market waste [E] Charcoal with 40% of rice husk and 60% of cabbage market waste

3.3.2 Physical properties of charcoal

Measured parameters of physical properties for all test specimens have been shown in Table 7. The results showed that moisture content for all lots was within the TCPS defined limit (i.e less than 8%). The volatile matter of charcoal of all specimens ranged from 24.17 to 44.26 wt%. The fixed carbon of charcoal of all specimens ranged from 17.49 to 29.27 wt%. The ash content of charcoal of all specimens ranged from 22.41 to 53.92 wt%. Charcoal made from 60% of rice husk and 40% of cabbage market waste had the highest calorific value (5,026.7 cal/g).

Table 7 The characterization of charcoal made from rice husk and cabbage market waste

Rice husk : Cabbage market waste	Moisture content (%)	Volatile matter (%)	Fixed carbon (%)	Ash content (%)	Calorific value (cal/g)
60 : 40	3.57	37.54	17.49	41.30	5026.7^{a*}
55 : 45	1.94	24.17	19.99	53.92	4466.0^{b}
50 : 50	4.53	41.30	19.70	34.48	4450.9^{b}
45 : 55	4.07	44.26	29.27	22.41	4766.1^{a}
40 : 60	3.64	39.06	17.75	39.54	4910.1^{a*}
TCPS	≤ 8%				≥ 5,000

TCPS standard: Thai community Product Standard, $P < 0.05$

According to the result from Strandberg et al [21], as the temperature increased, the concentration of fixed carbon increased. On the other hand, in this experiment with the temperature rise, the amount of fixed carbon decreased, due to uncontrollable time, temperature and leakage of oxygen from pyrolysis chamber (200 liter tank) which served to partially combust the biomass and turned it to ash rather than fixed carbon causing increased ash content and fixed carbon reduction.

From Figure 5, the results showed that charcoal from pyrolysis process increased the calorific value of all samples of briquettes approximately 24.70% because the thermal activity of pyrolysis process degraded the organic matter such as lignocellulose, hemicellulose or lignin affecting the higher heating value [22].

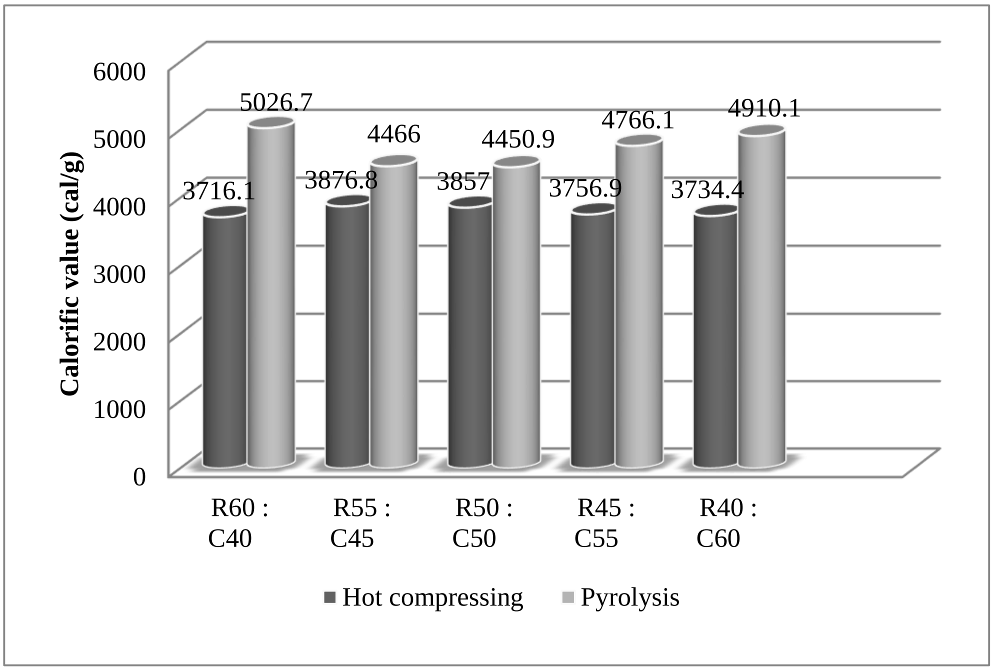

Figure 5 Comparison of calorific value between briquette from hot compressing and charcoal from pyrolysis

3.4 Economic feasibility

An economic analysis of production of briquettes from rice husk and cabbage market waste was done focusing only on charcoal produced from 60% of rice husk and 40% of cabbage market waste with the highest calorific value. The economic analysis was divided into 2 parts including fixed costs (machine cost and labor cost) and variable cost (material cost, transportation cost and electricity cost). The cost of charcoal from rice husk and cabbage market waste was 0.87 Baht/unit (1 unit = 0.095 kg) to compare the cost of wood available at market rate, as 5 Baht/kg and the payback period was 3.5 years.

3.5 The environmental impacts of the production of 1 kg of charcoal made from rice husk and cabbage market waste using Life Cycle Assessment (LCA)

Figure 6 shows the distribution of environmental impact in producing 1 kg of charcoal from rice husk and cabbage market waste. The results showed that the main cause of global warming impact was air emission of CO_2, CH_4, and N_2O from fuel combustion from transportation and electricity usage in the process of pyrolysis, briquetting, raw material acquisition and preparing, which had the global warming impact value at 63.24%, 31.62%, 3.12%, 2.02% respectively. The main causes of the impacts of ozone layer depletion, human toxicity, acidification, and eutrofhication were from pyrolysis process at the value of 81.95%, 87.53%, 79.80%, and 74.66% respectively.

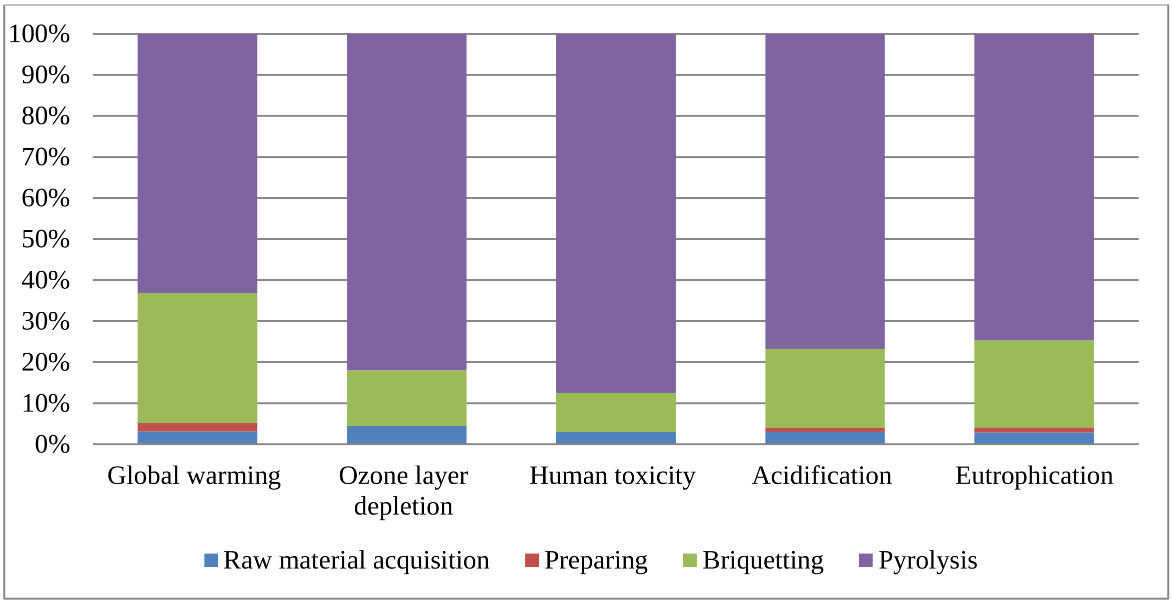

Figure 6 Distribution of environmental impact in producing1 kg of charcoal (pyrolysis) from cabbage market waste and rice husk

The results of environmental impacts in term of global warming from other researches were shown in Table 8. The result of present study (3.42 kg CO_2 eq) was higher than result of Jaikeaw (2.85 kg CO_2 eq) but lower than Rousset et al (3.97 kg CO_2 eq) because of long-distance transportation on raw material acquisition stage and manufacturing stage and more use the electricity in the pyrolysis process.

Table 8 The results of environmental impact in term of global warming from other research

References	The impact value from other researches in global warming (kg CO_2 eq)
Jaikeaw [23]	2.85 (kg CO_2 eq)
Present study	3.42 (1kg of charcoal)
Rousset et al [24]	3.97kg CO_2 eq)

4. Conclusion

The present work examined the physical properties of compressed briquettes/charcoal made from a mixture of cabbage market waste and rice husk in different ratios. It was found that the more rice husk added, the more calorific value increased. Calorific value is considered as the major quality index for solid fuels. Charcoal made from 60% of rice husk and 40% of cabbage market waste was selected as the most efficient renewable energy source because it had a calorific value (5,026.7 cal/g) conforming with the TCPS (5,000 cal/g). It has been established from the results that, rice husk and cabbage market waste are feasible for charcoal briquette production of required quality by TCPS.

The results of environmental impact for production of 1 kg charcoal reveal that, pyrolysis process mainly affects the environment. Briquette and charcoal from cabbage market waste and rice husk uses simple technology, is inexpensive and suitable to be managed by small communities especially in Thailand. Even though, the calorific value of briquette from cabbage market waste and rice husk in this study is not compliant to the TCPS standard, but its production cost is lower than the market price, and its production is friendly to the environment. Thus, to develop these wastes for useful applications in communities by producing briquettes and charcoal, further research is needed to improve its quality.

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