

Korrakot Yaibuathet Tippayawong; Suphanat Panyakom; Chayakorn Suriyanarakorn; Kengkamon Wiratkasem; Nakorn Tippayawong

Article

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Supply chain analysis of smokeless charcoal from maize residues

Korrakot Y. Tippayawong^{a,b,*}, Suphanat Panyakom^b, Chayakorn Suriyanarakorn^b,
Kengkamon Wiratkasem^c, Nakorn Tippayawong^c

^a Excellence Centre in Logistics and Supply Chain Management, Faculty of Engineering, Chiang Mai University, Chiang Mai, 50200, Thailand

^b Department of Industrial Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, 50200, Thailand

^c Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, 50200, Thailand

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Abstract

Open burning of agricultural residues after harvesting season is usually practiced as a disposal means for highland farms. The practice has partially contributed to the haze problem in the northern region of Southeast Asia during February to April every year. This can drastically affect human health in the long run. In this work, alternative means to utilize maize residues as a bio-renewable fuel source is explored. These maize residues can potentially be used as a raw material to substitute or partially replace wood chips in production of smokeless charcoal. Local charcoal producers in Maehongson, northern Thailand have recently looked into alternative raw materials for smokeless charcoal production since the demand for domestic and abroad has shoot up to about 6000 tons this year. Possibility of using maize residues is paramount. According to such requirement, this work focused on cost analysis of transforming maize residues into high-added-value smokeless charcoal. The analysis covered from maize harvesting and residue collection methods, logistics approach to charcoal production site, production cost and product transportation cost. Primary and secondary data collection, site survey, interviews with stakeholders and cost modeling were performed. It was found that the maize farmers could earn up to 15 USD/ton from sales of the maize residues to charcoal production plants, while the plants remain profitable.

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Keywords: Agricultural residues; Smokeless charcoal; Cost analysis; Environmental policy; Sustainable waste management

1. Introduction

Air quality problems have posed a major concern in the northern part of Southeast Asia as the air is found to contain more than the safe limit of PM_{2.5}, especially during the dry season between February to April. One of the main causes of the air pollution problem is thought to be from burning of agricultural residues [1]. Maize grains are

* Corresponding author at: Excellence Centre in Logistics and Supply Chain Management, Faculty of Engineering, Chiang Mai University, Chiang Mai, 50200, Thailand.

E-mail address: korrakot@eng.cmu.ac.th (K.Y. Tippayawong).

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the main ingredient in animal feeds. Over the past decade, rising maize price attracts a great number of small farmers to adopt it. Plantation areas in Thailand expanded by almost 78,000 ha between 2008 and 2015. They are in high demand for domestic and for export. Unfortunately, the crop leaves plenty of residues as an unwanted by-product, most of which is burnt at the end of the harvest season. Managing these agricultural residues can be problematic for farmers. Alternative and sustainable management is needed. Waste-to-energy option is attractive as it turns waste into high value-added product. There have been continual attempts to utilize agricultural and maize residues as energy via physical densification [2–5], torrefaction [6,7], carbonization [8–10], pyrolysis [11–13], gasification [14–16] and combustion [17]. In this work, utilizing maize residues as an alternative raw material to partially substitute woods in production of smokeless charcoal was investigated. Supply chain analysis of the agricultural residues was conducted with the focus on analyzing cost-benefit involved in utilizing maize residues in production of smokeless charcoal from upstream to downstream.

2. Methodology

2.1. Proposed production of smokeless charcoal

A case study of a smokeless charcoal factory is located in Meahongson., a northern border province of Thailand. The in-depth survey was conducted along the maize supply chain from upstream to downstream to investigate cost occurring along the process. The charcoal production considered obtaining maize residue as major input material from five districts of Maehongson which are Muang, Phangmapha, Khunyuam, Maelanoi, and Pai. The study also included the residues from Maejam in Chiang Mai because this area produced the highest amount of maize in northern Thailand and it is located not far. Site selection of the raw material sources was carried out, based on the distance from the factory which should be less than 150 km as constrains from logistics cost and time.

Fig. 1 shows overall process in smokeless charcoal production. Two maize residue harvesting approaches were performed to explore cost and possibility, which were solely labor harvest and labor with harrow attached rotary tillers. The sample harvest area was one rai or 1600 m². The labor only option used five harvesters working 8 h, while the machine integrated option used five labors working 2.5 h. Related cost were 754 and 335 THB/rai for the first and second options, respectively. The maize residues (cob, stover, stem, leaf, root) were reduced in size, blended and briquetted. The milling and briquette machines were set up in each district. The briquettes were transported to the factory, where they were carbonized. Carbonization of the biomass residues was carried out in a locally designed pyrolysis reactor, yielding about 18% mass of original input (5.5 kg residues led to 1.0 kg char).



Fig. 1. Smokeless charcoal production chain.

The char was subsequently milled to powder for easy mixing and forming into shape. The binding agent was tapioca flour, used for strengthening the charcoal briquettes. Weight ratio for char: flour: water was 20:1:7. They were mixed and agitated in a container, prior to densification. The mixture was mechanically compacted into

hollow hexagonal briquettes of 10 mm inner diameter, 50 mm in external diameter and about 100 mm long using an extruding machine. Its capacity was about 1500 kg per 8 h per machine. The charcoal briquettes were then placed in a tray and loaded into a thermal treatment chamber. The charcoal briquettes were thermally treated at about 80–120 °C condition for 12 h. The final products were subsequently packed and sealed for storage.

2.2. Cost analysis

Cost analysis in production of smokeless charcoal briquettes covered three stages; inbound cost, production cost, and outbound cost. Calculation of fixed and variable costs were performed in each stage. Total cost was finally worked out with sensitivity analysis of changed cost assumption. The inbound cost included cost of materials such as maize residue charcoal from each district, tapioca flour, and packing material. The production costs included direct and indirect labor cost, fuel wood cost, machine depreciation cost and facility cost. The outbound cost in this case study was transportation cost from the factory to the Bangkok port approximately 1000 km away with traveling time of around 18 h. Cost calculation was based on actual cost data gathered, together with the most possible assumption where cost could be changed. The total cost in THB/kg was calculated from all these costs with the following conversion (33 THB = 1 USD).

3. Results and discussions

3.1. Cost analysis results

3.1.1. Inbound cost

For direct materials, charcoal was the main ingredient, coming from farmers whose harvesting cost at 335 THB/rai. The average maize residues were amounted to 1120 kg/rai. Cost of harvesting the residues was approximately 0.3 THB/kg. Transportation cost between the factory and the milling/briquette station of each district is shown in Table 1. Each milling/briquette station had moving machine cost, labor cost, electricity and gas cost, whose machine work was on 8 h/day. Average moving machine cost (shown in Table 2) was just over 360 THB, having three men for each milling/briquette machine at 300 THB/man. The milling machine used gasohol, while the briquette machine used electricity. The total cost for milling/briquetting the maize residues is shown in Table 3. The total cost for maize residue importation from each district is shown in Table 4.

Table 1. Transportation cost of the maize residues.

Province	District	Distance: factory-district	Transportation cost	Total transportation cost
Maehongson	Muang	3.9	11.26	0.0113
Maehongson	Pangmapa	72.2	107.04	0.1070
Maehongson	Kunyuam	81.2	190.8	0.1908
Maehongson	Pai	112	260.23	0.2602
Maehongson	Maelanoi	128	297.16	0.2972
Chiang Mai	Maejam	140	325.02	0.3250

From Table 4, the distance between the factory and the milling/briquetting station affected the inbound cost, whose transportation cost for each nearby district was about 0.2 THB/kg. So, the total maize residue charcoal cost was $(0.3 + 0.2 + 0.77) \times 5.5 = 6.985$ THB/kg. The inbound cost calculated in this phase combined all necessary direct materials including charcoal, tapioca flour and water. The case study company consolidated carbonization of biomass from local and remote producers at 8 THB/kg on average. About 20 kg of raw char were grounded with the mixture of tapioca flour (1 kg) and water (7 kg). After briquetting process and heat treatment, 20 kg of smokeless charcoal briquette were usually obtained. The moisture of around 25%–30% was removed from the wet briquettes. List of direct materials to produce the smokeless charcoal briquettes are indicated in Table 5.

3.1.2. Production cost

The production cost in this case study included machine depreciation cost, direct labor cost, utility cost which combined electricity cost, and cost of firewood to generate heat in the thermal treatment process.

(a) Machine depreciation cost

Table 2. Average moving machine cost.

Province	District	Average field (km ²)	Distance for work (km)	Car for lade machine (15 THB/km)
Maehongson	Muang	2483	28	422
Maehongson	Pangmapa	798.4	16	239
Maehongson	Kunyuam	1698	23	349
Maehongson	Pai	2245	27	401
Maehongson	Maelanoi	1457	22	323
Chiang Mai	Maejam	2687	29	439
Average				362.17

Table 3. Total cost milling/briquette maize residue process.

	Milling machine (THB)	Briquetting machine (THB)
Labor cost	300.00	900.00
Electricity cost	113.64	–
Gasohol cost	–	513.80
Total cost for each machine	413.64	1413.80
Total cost per day	1987.44	

Table 4. Total charcoal cost.

Province	District	Harvest price (THB/rai)	Importation cost (THB/kg)	Briquette cost (THB/kg)	Total charcoal powder cost (THB/kg)
Maehongson	Muang	0.3	0.0113	0.77	5.95
Maehongson	Pangmapa	0.3	0.1070	0.77	6.47
Maehongson	Kunyuam	0.3	0.1908	0.77	6.93
Maehongson	Pai	0.3	0.2602	0.77	7.32
Maehongson	Maelanoi	0.3	0.2972	0.77	7.52
Chiang Mai	Maejam	0.3	0.3250	0.77	7.67

Table 5. Direct material cost.

Materials	Amount	Unit cost (THB/unit)	Total cost (THB)
Charcoal (kg)	20	6.985	160
Tapioca flour (kg)	1	20	20
Water (kg)	7	2	14
Total input (kg)	28		194
Output (kg)	20	8.685	

List of initial price and power requirement of all machines is shown in Table 6. The case study had three production lines. Each line encompassed three coarse milling machines with a capacity of 140 kg/h per machine. A mixing tank was able to mix 280 kg (char + tapioca flour + water) in 30 min. Three fine milling machines had a capacity of 187.5 kg/h. Three briquetting machines were capable of forming char briquettes at a rate of 187.5 kg/h per machine.

The total cost of all machines and equipment were estimated at 4,625,000 THB as an initial investment. The cost was assumed to depreciate over 30 months only because the company operated on two shifts for forming process (one shift was 8 h) and 24 h for thermal treatment (one round of thermal treatment was 12 h). One shift of forming process could produce up to 13.5 tons of the wet briquettes which would be 30% less (9450 kg) after 12 h baking process. In total, 18,900 kg of the smokeless charcoal briquettes could be produced in one day from working on 2 shifts. Assuming that the company operated 25 days per month, therefore 30 months × 25 day = 750 days depreciable duration. One day depreciation could be calculated from 4,625,000/750 days = 6167 THB/day,

Table 6. List of available machines and equipment.

Machine	Power (kW/unit)	Amount (unit)	Unit cost (THB/unit)	Total cost (THB)
Coarse milling machine	2.2	10	100,000	1,000,000
Mixing machine	3.7	3	250,000	750,000
Fine milling machine	2.2	10	100,000	1,000,000
Briquette machine	7.75	10	100,000	1,000,000
Thermal treatment chamber		1	200,000	200,000
Incinerator		2	150,000	300,000
Racking		100	3,750	375,000
Total cost				4,625,000

where 18,900 kg of the briquettes were produced. Hence, the machine depreciation cost was 6167 THB/day at 18,900 kg/day = 0.33 THB/kg.

(b) Direct labor cost

Total briquette production process required 15 temporary (daily) laborers and two permanent staff. Daily cost of temporary staff was 350 THB per 8 h and the permanent staff was around 800 THB per 8 h. Total labor cost of 8 h was $(350 \times 15) + (800 \times 2) = 6850$ THB, where 9450 kg of dry briquette were produced. Therefore, labor cost was 6850 THB/9450 kg = 0.72 THB/kg.

(c) Utility cost

The utility cost for the briquette production involved two main parts; (1) electricity cost for the briquette forming process, and (2) wood cost for the thermal treatment process. The electricity cost was derived from the maximum usage of four machine types; coarse milling, fine milling, mixing and briquetting machines. The machines were fully utilized in 2 shifts (16 h) per day and the company ran 25 days per month. The power requirement for each machine is shown in Table 2. The electricity charge was from the Provincial Electricity Authority of Thailand in the sector of medium general service applied to industries with a maximum 15-min integrate demand from 30 to 999 kW. The monthly electricity charge was approximately 145,000 THB or 5800 THB/day, where 18,900 kg of briquettes were produced. Hence, the electricity cost was 0.31 THB/kg.

Wood cost was dependent on amount of wood consumed to provide heat for the thermal treatment process. The condition required was 80–120 °C for 12 h in a chamber of $4 \times 8 \times 2.4$ m³ capable of handling 40 racks. The rack size was $0.6 \times 0.9 \times 2$ m³, containing 15 trays. Each tray could load 96 briquettes (6 briquettes/kg). Therefore, one rack carried approximately 240 kg of the wet briquettes to the thermal treatment chamber. In one 12 h thermal treatment, 40 racks were loaded, accounting for $40 \times 240 = 9600$ kg of the wet briquettes. On average about 2.9 tons of firewood was consumed to generate heat required by the thermal treatment, resulting in the smokeless char briquettes of about 6.8 tons. The wood cost was 600 THB/ton \times 2.9 tons = 1740 THB, translating into 0.26 THB/kg briquette treated. So the wood or fuel cost was $0.26 \times 0.2 = 0.052$ THB/kg.

3.1.3. Outbound cost

The outbound cost covered the packaging and the transportation cost. The packaging requirements were requested specifically from customers which were usually in customized sack with moisture protection. This packaging was needed to comply with international shipping standards, because they were mainly shipped to customers in Korea and Japan. About 50 kg of the smokeless charcoal briquettes were loaded in one sack, yielding the packaging cost at 10 THB/sack of 50 kg = 0.20 THB/kg. The transportation was required from the factory at Maehongson to the main Bangkok port, whose distance is 880 km with a traveling time from 12–20 h depending on traffic condition. The transportation cost was derived from the charging rate per one container which could carry up to 24 tons of dry charcoal briquettes. The cost was approximately 40,000 THB/24 tons, or 1.67 THB/kg.

3.1.4. Total cost and profit estimation

Table 7 lists all components of the total cost considered in this work. The raw materials were obviously the main cost, as anticipated. Saving in the raw material cost would largely affect the total cost. The selling price offered from the Korean and Japanese customers was 17 THB/kg which was Freight on Board (FOB) price. The demand was approximately 5000 tons a year. After the calculation, it was shown that the factory could get profit up to

Table 7. Total costs from inbound, production, through outbound process.

Stage	Category	Cost (THB/kg)
Inbound	Raw material (raw char + tapioca + water)	8.685
Production	Machine depreciation	0.330
	Labor cost	0.720
	Electricity cost	0.310
	Wood cost	0.052
Outbound	Packaging	0.200
	Transportation	1.670
	Total cost	11.97
	Selling price (FOB)	17.00
	Profit	29.6%

Table 8. Total costs from inbound, production, through outbound process.

Residue price from farmer (THB/kg)	Charcoal price (THB/kg)	Total cost (THB/kg)	Profit (%)
0.50	9.74	12.97	31%
0.60	10.29	13.52	26%
0.70	10.84	14.07	21%
0.80	11.39	14.62	16%
0.90	11.94	15.17	12%

almost 30%. Changes in price from farmers would affect the livelihood of farmers as well as the charcoal producer. An example is shown in Table 8, on corn residue price sensitivity analysis. Charcoal producer could offer farmer the price of residue up to 0.70 THB/kg to maintain 20% profit. This offer could stop farmers from burning after corn harvest season.

4. Conclusions

A cost analysis of smokeless charcoal briquette production has been performed to assess the feasibility of utilizing maize residues as raw materials in Mae Hong Son, Thailand. Converting agricultural residues into high value charcoal briquettes has been shown to be cost effective and attractive option for management of agricultural waste. It was observed that the costs of the raw material and briquetting process were the major factors, critically affecting the production profitability. The price range of this raw material should be carefully monitored and controlled (between 5 to 11.5 THB/kg) to ensure acceptable inbound quality and prevent negative return on investment. Consolidation model of the raw charcoal and alternative biomass sourcing should also be further considered in securing cost and supply for future charcoal briquette production.

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References

- [1] Moran J, Nasuwan C, Poocharoen O. The haze problem in northern Thailand and policies to combat it: a review. *Environ Sci Policy* 2019;97:1–15.
- [2] Piboon P, Tippayawong N, Wongsiriamnuay T. Densification of corncobs using algae as a binder. *Chiang Mai Univ J Natur Sci* 2017;16(3):175–82.
- [3] Wongsiriamnuay T, Tippayawong N. Effect of densification parameters on property of maize residue pellets. *Biosystems Eng* 2015;139:111–20.
- [4] Tippayawong N, Jaipa C, Kwanseng K. Biomass pellets from densification of tree leaf waste with algae. *Agric Eng Int : CIGR J* 2018a;20(4):119–25.
- [5] Auprakul U, Promwungkwa A, Tippayawong N, Chaiklangmueng S. Densified fuels from mixed plastic wastes and corn stover. *Adv Mater Res* 2014;931–932:1117–21.
- [6] Onsree T, Tippayawong T, Williams E, Barrow R, Pokagu J, Lauterbach N. Torrefaction of pelletized corn residues with wet flue gas. *Bioresour Technol* 2019;285. 121330.

- [7] Homdoun N, Dussadee N, Sasujit K, Kiatsiriroat T, Tippayawong N. Performance investigation of a gasifier and gas engine system operated on municipal solid waste briquettes. *Int J Renew Energy Dev* 2019;8(2):179–84.
- [8] Tippayawong KY, Santiteerakul S, Ramingwong S, Tippayawong N. Cost analysis of community scale smokeless charcoal briquette production from agricultural and forest residues. *Energy Procedia* 2019;16:310–6.
- [9] Tippayawong N, Rerkkriangkrai P, Aggarangsi P, Pattiya A. Characterization of biochar from pyrolysis of corn residues in a semi-continuous carbonizer. *Chem Eng Trans* 2018b;70:1387–92.
- [10] Tippayawong N, Rerkkriangkrai P, Aggarangsi P, Pattiya A. Biochar production from cassava rhizome in a semi-continuous carbonization system. *Energy Procedia* 2017;141:109–13.
- [11] Onsree T, Tippayawong N, Zeng A, Li H. Pyrolysis behaviors and kinetics of corn residue pellets and eucalyptus woodchips in a macro-thermogravimetric analyzer. *Case Stud Therm Eng* 2018;12:546–56.
- [12] Jaroenkhasemmesuk C, Tippayawong N. Technical and economic analysis of a biomass pyrolysis plant. *Energy Procedia* 2015;79:950–5.
- [13] Jaroenkhasemmesuk C, Tippayawong N. Thermal degradation kinetics of sawdust at intermediate heating rates. *Appl Therm Eng* 2016;103:170–6.
- [14] Homdoun N, Sasujit K, Uttaruan J, Wongsiriamnuay T, Tippayawong N. Influence of torrefaction temperature and time on yields and properties of torrefied biomass. *Eng Appl Sci Res* 2019;46(2):170–5.
- [15] Punnarapong P, Promwungkwa A, Tippayawong N. Development and performance evaluation of a biomass gasification system for ceramic firing process. *Energy Procedia* 2017;110:53–8.
- [16] Wongsiriamnuay T, Kunnang N, Tippayawong N. Effect of operating conditions on catalytic gasification of bamboo in a fluidized bed. *Int J Chem Eng* 2013;1–9, Article ID 297941.
- [17] Sittisun P, Tippayawong N, Wattanasiriwech D. Thermal degradation characteristics and kinetics of oxy combustion of corn residues. *Adv Mater Sci Eng* 2015;2015. 304395.