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Simulation of Gamboeng Tea Product Manufacturing Process and Their Role in Reducing Environmental Impact

Teuku Beuna Bardant[1], Arief Ameir Rahman Setiawan[2,5], Muthia Syafika Haq[3], Hafiizh Prasetia[5], Adhi Irianto Mastur[3], Sugeng Harianto[3], Agusta Samodra Putra[4,5], Anny Sulaswatty[1], Edi Iswanto Wiloso[5], Ryozo Noguchi[4]

[1] *Research Center for Chemistry, Indonesian Institute of Sciences (LIPI), Kawasan Puspiptek, Serpong, Tangerang Selatan, Indonesia*
[2] *Graduate School of Sciences and Engineering, University of Tsukuba, Tsukuba, Japan*
[3] *Research Institute for Tea and Cinchona, Mekarsari, Gambung, Bandung, Indonesia*
[4] *Faculty of Life and Environmental Sciences, University of Tsukuba, Tsukuba, Japan*
[5] *Research Center for Policy and Management of Science, Technology and Innovation, Indonesian Institute of Sciences (LIPI), Jl. Gatot Subroto 10, Jakarta Selatan, Indonesia*

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Abstract
This study offers an overview of how changing habits in consuming a cup of tea can contribute to make better environment. As the initial existing scenario, survey for picturing Indonesian consumers in preparing their cup of tea from dried leaves was conducted to urban and sub-urban citizens. According to the survey, both respondent groups were using LPG as the first choice in boiling water for preparing tea, followed by using an electric dispenser as the second choice. This habit causes CO_2 emission from processing a cup of tea by Indonesian consumer was 24 g CO_2-eq per cup of tea, excluding the tea organic waste. The portion of CO_2 emission from boiling water in tea preparation was 41.93% of whole CO_2 emission from plantation to served cup. The emission can be significantly reduced by converting dried tea (initial scenario) into the ready-to-drink product, in the form of powdered tea (second scenario) and boxed tea (third scenario). This study simulated an integrated system of tea product manufacturing system with biogas utilization produced from tea organic waste. Simulation conducted based on daily manufacturing process at the Gamboeng green tea factory. Additional required energies were simulated from the wood pellet, which is the best practice in the Gamboeng Tea factory. By shifting tea consuming habit from dried tea to powdered tea and/or boxed tea, the emission from a cup of tea can be reduced, with range of reduction varied from 8.87 g to 22.13 g CO_2-eq per cup of tea. If the Gamboeng green tea daily production capacity of the factory is fully converted into powdered tea, the potency of CO_2 emission reduction reaches 26.92 metric ton CO_2. However, the factory should pay attention to providing the water for the manufacturing process. The required water was 45.23 m^3 of drinking water if all dried tea converted to powdered tea. Moreover, 11.53 m^3 of water is required as irrigation for the biogas process in converting all tea organic waste into biogas.

Keywords
CO_2 emission, dried tea, powdered tea, boxed tea, consuming habits.

Introduction

As part of global commitment, Indonesia has continuously devised various policies for mitigating climate change, which recently have also been paid off (Chandra and Pratiwi, 2020). One of the concerns by the Indonesian government is to drive sustainable production and consumption toward all sectors (Wiloso *et al.*, 2020). Meanwhile, Indonesia is also known as one of the biggest tea-producing nation in the world. As tea is an important commodity in Indonesia, the government has also encouraged the research and implementation toward good practice to support global efforts to reduce greenhouse gas.

An illustrative example of how much carbon emissions were produced while preparing a cup of tea was published by The Guardian (Berners-Lee and Clark,

***Corresponding author**: Teuku Beuna Bardant, phone: +62 21 756 0929, e-mail: qaismajnum@gmail.com, rc-chem@mail.lipi.go.id*

2019). American tea consumers emitted 21 g CO_2-eq when they boiled the water for tea by an electric heater. Emission increases when the tea was added with milk and/or added with more boiled water. Comparably, if a cup of tea was consumed daily, CO_2 emitted for one year was 30 kg CO_2-eq which is equal to driving 40 miles in an average car. Consuming three large sizes of milk tea daily emits carbon accumulated annually about 600 kg CO_2-eq, or similar with emission for flying half way across Europe. A significant contribution from milk was because cow as ruminant also produces methane into the air. Thus, it was recommended for tea consumers to avoid excessive boiling water and aware of milk addition not only add calories to the body but also CO_2-eq to the air (Berners-Lee and Clark, 2019).

It was reported from several previous studies about tea environmental impact in Taiwan (Chen and Yang, 2011; Hu *et al.*, 2019), Kenya (Azapagic et al., 2016), Sri Lanka (Munasinghe *et al.*, 2017) that the highest contributor of CO_2 emission was in the consumer phase when tea prepared by boiling water. Even in Denmark and Sweden who imported their tea, CO_2 emission from transportation of tea from the country of origin still less than CO_2 emission contributed by consumers. This study was to investigate the Indonesian tea consumer habits, compared to other countries. The data then used as platform for further analysis and production simulation for designing a more-environmentally-friendly way in consuming tea.

Along with the increase of public awareness in environmental sustainability, several research topics became popular nowadays. Topics such as improving the resource utilization efficiency of global supply chains and lessening the manufacturing effects on the environment; the concept of the green supply chain, a novel idea is aiming at minimizing environmental effects and maximizing resource efficiency (i.e., supplying materials and their processing, packaging, storage, transportation, and use) was thus born. The basic philosophy in these topics is the more efficient resources be utilized; the environment will suffer less by the manufacturing process. Many countries and organizations had adopted environmental protection and energy conservation strategies. These strategies were continuously updated, improved, strengthened, and even enforced to be related laws and regulations (Song and Gao, 2018).

Marousek (Maroušek, 2014, 2015) analyzed the possibility of biomass wastes utilization as a biofuel and their potency of being used in buildings and its economical constrain. They analyzed the process parameters robustly to improve them at the market scale. Hašková offered analysis from several different aspects (environment, economy, health and social issues) for guiding the customer to buy novel solid biofuels (Hašková, 2017).

This study analyses and designs a more-environmentally-friendly way of consuming tea. Simulation that integrating biogas production unit with the tea production process and analyzed its carbon emission. In this design, all fuel for supplying heat required by the process was from biogas and pellet. Carbon emission from these biomass-based fuels is then considered as zero. By this approach, a significant reduction of carbon emissions can be achieved compared to self-preparation by tea consumers. This study aimed to quantify the carbon emission reduction for several possible scenarios of production downstream tea product, tea powder, and boxed tea. The simulation used blended tea waste and cow dung as input for the biogas production unit. Thus, there will be a contribution in preventing methane emission from cow dung into the atmosphere. The liquid effluent from biogas production unit was simulated to substitute the utilization of synthetic fertilizer, hence, another contribution in reducing carbon emission can be proposed.

Materials and methods

This study tried to compare the carbon emission from a cup of tea from cradle to grave. Several data were extracted from previous study.

Carbon emission from both of tea plantation (to yield fresh tea leaves) and tea factory (to produce dried tea) refers to energy and exergy analysis from previous studies (Bardant et al., 2018a, 2018b), while carbon emission from RTD factory will be simulated in this study.

The consumption habit evaluated in this study was based on the questionnaire. Emission from waste referred to previous studies for similar type of packages. A brief flow diagram of the product from the cradle to grave can be seen in Fig. 1.

Since the existing dried tea is targeted to the same consumer as the simulated powdered tea and boxed tea, the secondary packages (pallet box), as well as the transportation from the factory to the consumers are also considered equal, and thus, excluded from calculation and analysis of comparison.

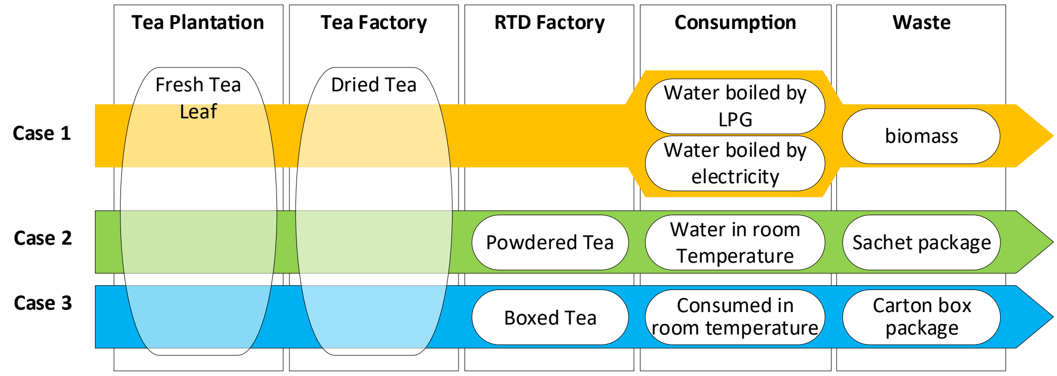

Fig. 1. Brief flow diagram of the product from cradle to grave for a cup of Gamboeng Tea

Energy and carbon emission analysis of Gamboeng tea based on Indonesian consumer habits

Simulation of the energy and carbon emission associated with Gamboeng tea consumption by Indonesian consumer was conducted based on the data collected from questionnaire. The questionnaire respondents were selected randomly and can be classified into two groups. Questionnaires from the first respondent group were distributed in Tangerang Selatan, which can be considered as urban consumer representation, while questionnaires from the second group were obtained from villagers in Desa Mekarsari, Kecamatan Pasir Jambu, Kabupaten Bandung, which can be considered as suburban consumer representation. The gathered data was analyzed based on the assumption that Gamboeng green tea will be treated as the majority habit of Indonesian consumers in urban and suburban.

Collecting operation condition and ambient condition for processing powdered tea and boxed tea from laboratory and field

Calculations of energy utilization are according to theoretical approach using Gamboeng environmental climatology data as basis of the calculation. The ambient air condition as basis for calculation was the average measured value from 15 September 2018 to 15 October 2018, which were 65% relative humidity and 30.5°C of air ambient temperature. The climate data was collected from Automatic Weather Station (AWS) that was placed in Gamboeng. The moisture content of tea leaf along the process was determined based on the weight loss at 103°C, referring to SNI 3945:2016. The data was collected between 8 October to 12 October 2018 and the mean value was used in the calculation. Energy utilization and thermodynamic properties of each stream and heat and workflows for green, powdered and boxed tea were computed based on the process flow diagrams presented in Fig. 2.

Operation condition and yield for processing Gamboeng tea into powdered tea and boxed tea were gathered from the experimental laboratory and used as references for the simulation. The experiment for extraction was conducted in a custom-made batch extractor, which operated in 90°C for 60 minutes with a water to dried tea ratio, was 10. The extract was centrifuged in (Hermle, Z 360 Germany) centrifuge at 6,000 g and then fed to the spray-dryer (Ohkawara Kakahki Twinjetter CNL-3 Japan). Operating conditions of the spray drier were feed rate to the spray drier, 17.6 ml/min. It operated concurrently with the inlet air temperatures of 168°C. Exhaust air and product temperatures were 60°C, and the spraying pressure was 0.1 MPa.

Modeling of Gamboeng green tea downstream product

Information about Gamboeng tea was collected by direct observation and measurement from tea plantation and tea factory belong to Research Institute for Tea and Cinchona in Desa Mekarsari Kecamatan Pasir Jambu Kabupaten Bandung. The tea factory was operated in batches for 14–20 hours per batch operated by 46 employees. Research Institute for Tea and Cinchona was also operating a mineral water bottling company with a capacity 15.6 m^3 per day and 418 ha tea plantation which produce 3.5–4 ton of dried tea leaves per day.

The model of Gamboeng Green tea downstream process integrated with the biogas production unit was described in Fig. 2.

As an existing industry studied in this work, Gamboeng green tea factory production capacity per batch

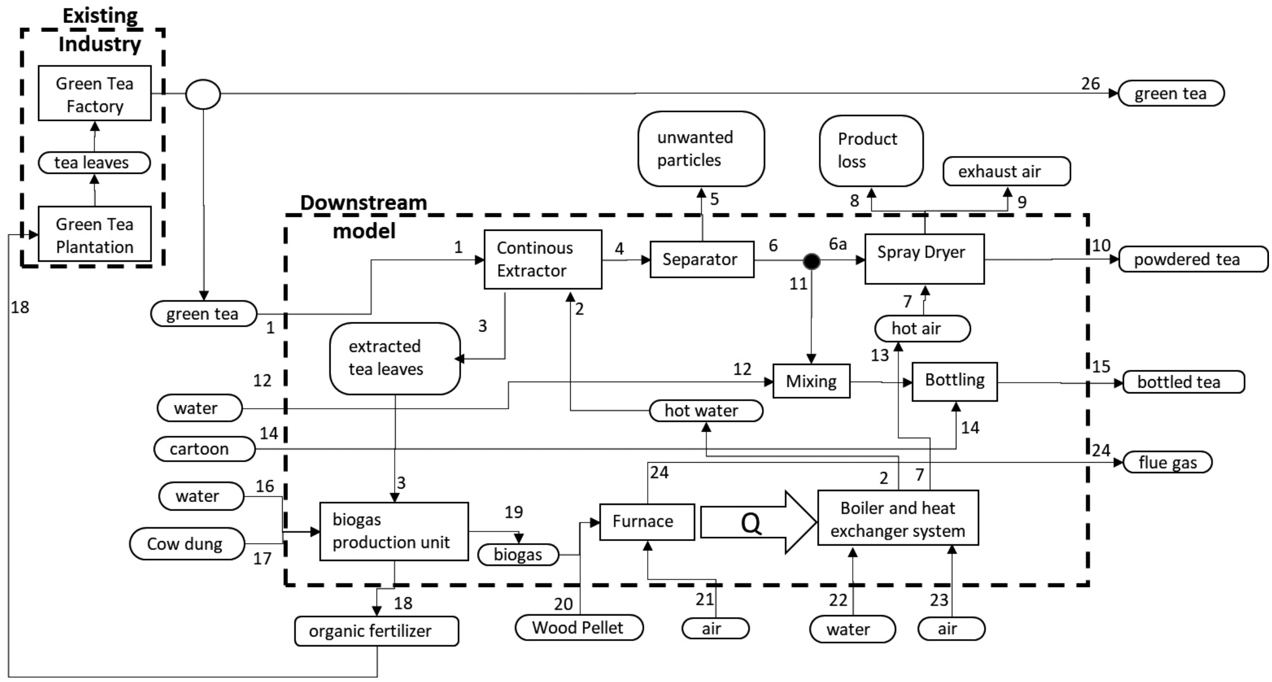

Fig. 2. Modelling scope of tea production system

(20 hours operation) was considered as 4,523.56 kg, referring to average production from 15 September to 15 October 2018 (Bardant et al., 2018a, 2018b). In the downstream model, Gamboeng green tea factory had three options for these products, first, packed their dried green tea and sell them directly to market which shown as line 26 (Fig. 2). This option was the business as usual for Gamboeng green tea. The second option was sending the green tea to downstream process for producing powdered tea and, or, boxed tea which shown 1 (Fig. 2).

Energy and fuel consumptions for the Gamboeng tea downstream process were obtained from a modeled biogas production unit and an additional biomass pellet. The biomass production unit was designed as an integrated unit with the downstream process as shown in Fig. 2. The organic fertilizer was then sent to tea plantation as inorganic fertilizer substitutes, which shown as line 18.

Water and energy analysis

Operation conditions for the biogas production units were adopted from the previous study (Aksay et al., 2018) (Manyuchi et al., 2018). The biogas production was conducted in a water suspension with a solid to water ratio was 10. Tea waste to cow dung ratio was four with moisture content of cow dung was 65%w (Aksay et al., 2018). Gathered biogas from the tea waste of this process was 0.2 m^3/kg with a methane concentration of 65%V and moisture content was 7%V. The resulted biogas had combustion efficiency 0.2, which was relatively low when compared to wood pellet, 0.33, due to low methane concentration. Biogas production process considered as a continuous fermentation process. Tea waste and cow dung mixture as the process feed stays in the fermenter for 14 days. Not all biomass in the feed was fermented into biogas, especially biomass from tea waste. The unfermented biomass went out from the fermenter through the liquid effluent. The unfermented solid fraction in the liquid effluent was 39.4% w (Manyuchi et al., 2018).

The required electricity was still from a national provider. The amount of electricity required for pump, compressor, screw conveyor, and belt conveyor were adopted from the previous study (Pelvan and Özilgen, 2017). For the packaging unit, required electricity was adopted from LCA for Tetra Pak Final Report (Markwardt et al., 2017).

Unit operations were simulated to have the flexibility for changing capacity. Drinking water availability became the limiting factor for simulation, which is 15.6 m^3 per day. The maximum capacity for each unit was simulated based on the scenario if all available drinking water was used for producing powdered tea or all of them for producing boxed tea. Duration of operation for these unit operations will depend on decided production capacity, with maximum capacity were obtain if they run for 24 hours and able to process all available drinking water from Gamboeng mineral water factory. Required electricity was then calculated based on the capacity of unit operation and working duration.

Results

Analyzing tea consumer habits in Indonesia

The data collection from the questionnaire was about picturing the habit of Indonesian tea consumers and its relation with their citizenship. The consumers not specifically consumed Gamboeng tea, but tea in general. Since the Gamboeng green tea marketing mostly in local market, then it can be assumed that Gamboeng green tea consumed by the end user in the similar habit with the other type of tea that consumed by the respondents.

From the data collection, no significant difference in consuming habit between Indonesian urban citizen and the suburban ones. The 76.5% of respondents used LPG for preparing hot water for a cup of tea and the other 23.5% used electric dispenser. This is very reasonable since LPG was one of the subsidized fuels in Indonesia. This consuming habit was the main reason of consumer use phase in Indonesia become the highest used of energy in tea boundary system from cradle to grave. Similar reason of what happened in other countries. In subtropical countries where tea was consumed in winter, this similar habit can be considered more efficient since the excess energy in preparing tea was contributed to heat room. However, compared to other tea life cycle phase in tea boundary system from cradle to grave, still the highest.

This study used the greenhouse gas emission factor released by the Ministry of Energy and Mineral Resources, Directorate General of Electricity. The emission factor for electricity in Java, Madura and Bali islands was 0.862 kg CO_2-eq/kWh. The emission factor for LPG used in this study was 0.172 kg CO_2-eq/kWh. Energy required for heating a liter of water is 0.0721 kWh. The average time required for preparing hot water and cup's volume were not in the questionnaire. It was then assumed that the average cup's volume was 200 ml and the average time for preparation was 10 minutes. Based on the percentage of LPG and electricity used by Indonesian consumers it was concluded that the average carbon emission in preparing hot water for a cup of tea was 24 g CO_2 equivalent. If hot water was prepared more than a cup in preparation and/or if preparation time was shortened, energy consumption became more inefficient and more carbon was emitted.

The summary of comparison of tea environmental impact from cradle to grave from several previous studies (Table 1). Most previous studies sug-

Table 1
The summary of comparison of tea environmental impact from cradle to grave

Country	Method	Results	Reference
Taiwan (organic tea)	PAS 2050	Fertilizer use in raw material phase and energy use in consumer use phase were hotspots.	(Chen and Yang, 2011)
Taiwan (Dongshan tea)	IPCC	Consumer use gave the highest contribution to carbon emission (climate change impact), farming gave the highest contribution on human health impact.	(Hu et al., 2019)
Iran	CML-IA	Most pollutant inputs were machinery and diesel fuel.	(Farshad et al., 2018)
Kenyan	IPCC 100	CO_2 emission was highest in the consumer use phase	(Azapagic et al., 2016)
Sri Lanka	LCA	Energy use was the highest in the consumer use phase, the CO_2 emission was highest in the packaging phase.	(Munasinghe et al., 2017)
Denmark	Carbon footprint	Kettle boiling gave the highest contribution (49%) of CO_2 Emission	(Pukka, 2018)
Sweden	LCA	Consumer use gave the highest contribution (68%) of environmental impact.	(Swedish Lifecycle Center, 2019)

gested that consumers use the more efficient stove and avoid using electricity to boil the water for preparing tea (Prasetia et al., 2020). This study gave different approach in facing the considerable energy used in the consumer phase by providing ready-to-drink tea product.

Water and energy analysis for Gamboeng green tea downstream model

Unit operations that simulated in this study were designed to process all available drinking water into powdered tea or boxed tea. The list of unit operations and their power consumption were in Table 2. The required electricity for simulation then will be calculated based on the duration of these unit operations running for processing a scenario of productions.

There are several scenarios for a fraction of Gamboeng tea to be processed into powdered tea and boxed tea that suitable for the total drinking water available. The first extreme point was when all 15.6 m^3 of available drinking water was used for the powdered tea production process. In this case, 34.5% of the average batch Gamboeng green tea production capacity processed into 67,500 sachets of powdered tea. On the other extreme point, all available drinking water was used for producing boxed tea. In this case only 7.5% of the average batch Gamboeng green tea production capacity that used for producing 41,212 boxed tea packed in a 330 ml Tetrapack carton box. Other scenarios lie between the aforementioned two extreme points (Fig. 3). The first extreme point was on the most left of the figure and the second extreme point was on the most right.

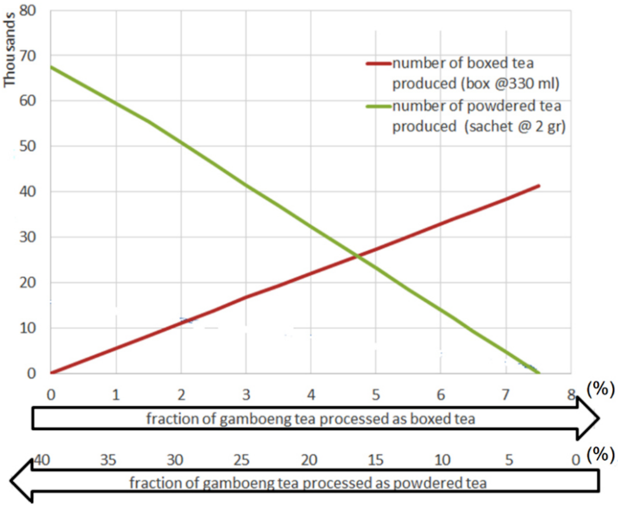

Fig. 3. Number of each product pack obtained for each distinctive combination. The fraction was the percentage of Gamboeng green tea average batch production capacity that used to produce the referred product. Double horizontal axis were used in the figure, with the aligned numbers were the combination fraction of boxed tea and fraction of powdered tea that can be produced with 15.6 m^3 of drinking water. The vertical axis was indicating the number of pack

Table 2
The list of unit operation, maximum capacity, operating capacity and its power consumption that assumed to be used in simulation of boxed tea and powdered tea production process from Gamboeng green tea

Electricity-powered unit operation	Maximum capacity	Operating capacity	Electricity (W)
Screw conveyor for dried tea to extractor (kg)	75	65	350
Centrifuge (l)	300	271	750
Spray drier (l)	300	271	750
Mixer pump (l)	600	567	350
Tetrapack packaging unit (ml) (box 330 ml)	600	567	750
Sachets packaging unit (kg) (2 gr per sachet)	10	6	750
Screw conveyor for tea waste and cow dung to biogas generator A (kg)	500	447	750
Water pump for biogas (l)	600	560	350
Belt conveyor for pellet to furnace (kg)	50	31	350
Hot water pump to heat exchanger and extractor (l)	1200	650	750
Air compressor to heat exchanger and spray drier (l)	2500	2365	1200
Air compressor for furnace (l)	2500	2283	1200

Simulation at full utilization of available drinking water

The simulation started by using available drinking water as the limiting factor. The fraction of Gamboeng green tea that can be used for producing boxed tea and powdered tea was adjusted to the limiting factor. The amount of energy required for the production process was shown in Fig. 3. Producing powdered tea was more efficient in water utilization but required more energy. As aforementioned, by using 15.6 m^3 of drinking water, as much as 34.5% of Gamboeng green tea can be processed into powdered tea, compared to only 7.5% of Gamboeng green tea that used for producing boxed tea. However, producing powdered tea required more heat energy, especially in the spray drying step. As much as 15150.19 MJ of heat were required for processing 1550.6 kg of Gamboeng green tea (34.5% of daily production) plus 618.8 MJ of electricity (172 kWh). This is almost fifteen-fold of required energy for processing 7.5% of Gamboeng tea into boxed tea which only used 1003 MJ of heat and 155 MJ (43 kWh) of electricity.

For reducing carbon emission purposes, more Gamboeng tea can be processed was preferred. This simulation using pellet and biogas as fuel for heat energy required. The portion of pellet and biogas utilization to supply the total energy required was shown in Fig. 4. Another advantage of processing more green tea into ready-to-drink product was the potency of tea waste valorization. In this simulation, the tea waste was used as feed for the biogas production unit. The more tea can be processed, the more biogas can contribute to supply the required energy. The carbon emission from the combustion of biomass-based fuel will be counted as zero. Thus, the only carbon emission that counted was from electricity.

The brewing process conducted by Indonesian consumers were using LPG and electricity, which made the emission counted. Moreover, brewing process contributes to overall carbon emission for a cup of tea up to 48%. Thus, for 51 g of CO_2 emission from a cup of tea, as much as 24 g came from the brewing process by the consumer. On average, consumers used 2 g of dried tea for a cup of tea. Then for 1550.6 g of Gamboeng green tea (34,5% of daily production), the potency of carbon emission caused by the brewing process was 19,100 kg of CO_2 equivalent per day. The simulation gave carbon emission 160.3 kg CO_2 equivalent per day at the highest when all available water was used for processing Gamboeng tea into powdered tea. It can be concluded that the emission of powdered tea is not significant compared to carbon emission if the same amount of Gamboeng tea was sold as dried green tea to the consumer. For other scenarios, the potency of emission reduction was calculated based on the potency of carbon emission caused in the brewing process by the consumer subtracted with the carbon emission caused by the simulated process and were viewed in Fig. 5.

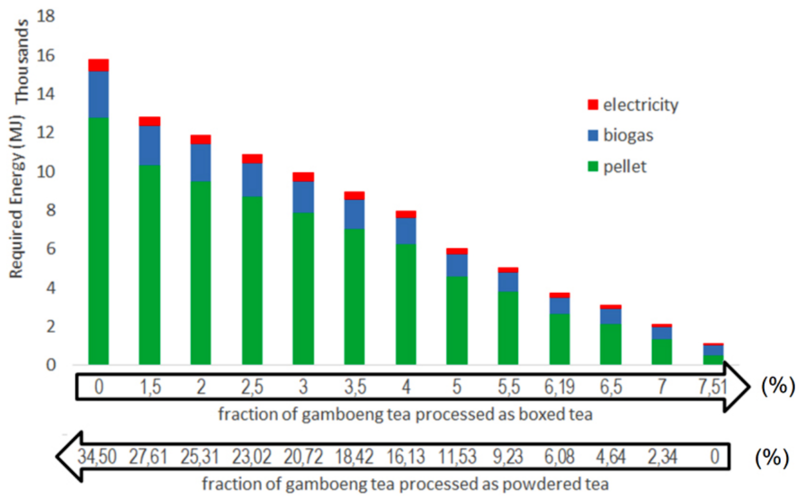

Fig. 4. Amount of required energy (in thousands MJ) for producing several combination boxed tea and powdered tea. The fraction was the percentage of Gamboeng green tea average batch production capacity that used to produce the referred product. Double horizontal axis was used in the figure, with the aligned numbers were the combination fraction of boxed tea and fraction of powdered tea that can be produced with 15.6 m^3 of drinking water. The required energy indicated by the bars, which scaled to the vertical axis. The bar was composed of three different energy sources which indicated by three different colors. All required energy for heat came from pellet and biogas combustion (green and blue). All required energy for working motors came from electricity

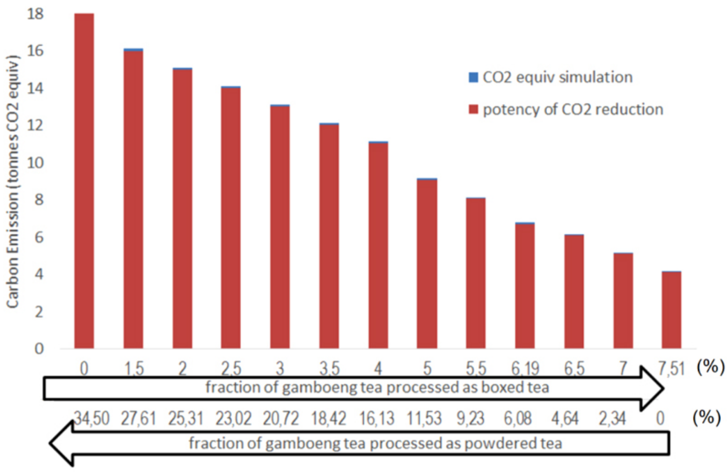

Fig. 5. Potency of carbon emission of simulated process and the potency for emission reduction if Indonesian consumers brewed Gamboeng tea individually. The fraction was the percentage of Gamboeng green tea average production capacity that used to produce the referred product. Double horizontal axis was used in the figure, with the aligned numbers were the combination fraction of boxed tea and fraction of powdered tea that can be produced with 15.6 m^3 of drinking water. Carbon emission is indicated by the bars, which are scaled to the vertical axis

Simulation at balanced wood pellet and drinking water consumption in producing powdered tea and boxed tea

Resources consumption for a process needs to be well identified for calculating environmental impact. In this study, the concerned resources were water and energy. The simulation then calculated the combination of fractions that gave balance consumption of wood pellet and drinking water. The term "balance" means fraction's combination that gave most efficient utilization in both pellet and drinking water. Simulation results can be seen in Fig. 6. Both areas were intercepted at the ratio of fraction for powdered tea to fraction for boxed tea almost equal to 1. If all Gamboeng green tea were transformed into powdered tea and boxed tea (100% was processed), then the balanced fraction's combinations were 49.5% for producing

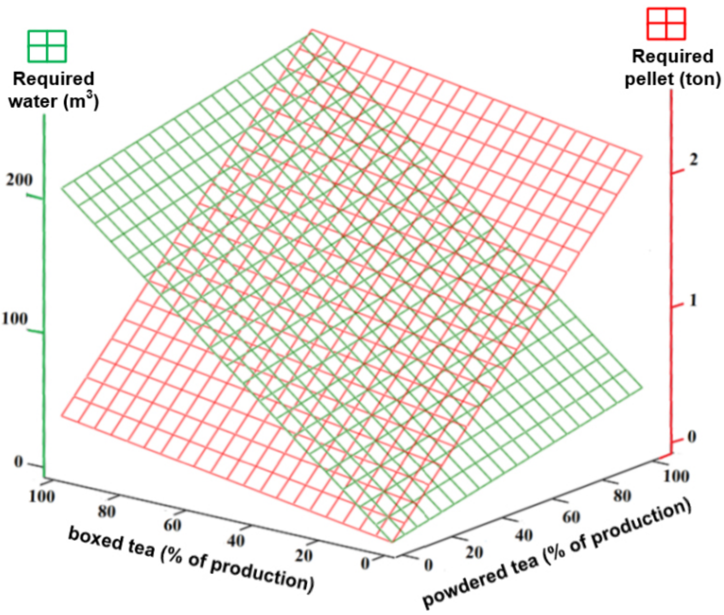

Fig. 6. Simulation result in calculating required drinking water and biomass pellet for boxed tea and powdered tea production process from Gamboeng green tea. The green area indicating the amount of water required (in m^3) for each fraction's combination of powdered tea and boxed tea and the red area was for wood pellet required (in $\times 10$ kg)

boxed tea and 50.5% for powdered tea. In these combinations, the amount of water required 127.16 m^3 and wood pellet required 1,271.63 kg. The number of boxed teas with volume 330 ml each that can be produced at the combination were 270,850 boxes and 98,240 sachets of powdered tea. If more fraction of powdered tea was produced, more wood pellet was required and on the otherwise, more water was required if more fraction of boxed tea was produced.

In the case of full utilization of available drinking water, 15.6 m^3 per day, thus the balance wood pellet required was 156.1 kg per day at afraction of Gamboeng tea processed into powdered tea 6.08% and 6.18% was processed into boxed tea. The number of boxed teas 330 ml that can be produced at the combination were 33,248 boxes and 12,405 sachets of powdered tea. In analyzing the wood pellet availability in Gamboeng, it was more available for supporting the production process compared to drinking water availability.

Gamboeng tea factory had already used wood pellet as fuel for factory heat consumption. However, wood pellet only supplied 13% of total heat required by the factory. The rest still came from LPG. Researcher from Research Institute for Tea and Cinchona had already studied the possibility for utilization of biomass from pruning session in tea plantation as pellet raw material. Pruning was conducted once every four years. It was identified that there was 23.75 ton of biomass per hectare of tea plantation from every pruning session. The study found out that the best pellet can be obtained from tea pruning biomass was having a heating value of 4.4 kcal/g or 16.7 kJ/g. This value was comparable with pellet from other biomass such as *Pinus halepenis*, *Pinus pinaster*, and biomass from olive pruning which have the heating value 4.37 kcal/g, 4.23 kcal/g, and 3.94 kcal/g, respectively (Haryanto, 2019).

Other Indonesian researcher had also developed cyclone furnace which using direct fuel powder. In this case, biomass powder no need to be pelletized. The cyclone furnace showed satisfactory performance in using coal powder. Extended researches are required to adjust the condition in order to use biomass powder.

Extended analysis for CO_2 emission calculation, including packaging and brief economic overview

CO_2 emissions were increased when the CO_2 carried by the packaging container was included in calculation when they disposed. The packaging container for boxed tea and powdered tea (Fig. 7).

CO_2 emission for a Tetrapack box with straw was 15 g CO_2-eq per box. Emission for sachet bag was 270 g CO_2 per square meter (Evers et al., 2009). Then a sachet with size 50 square centimeters has CO_2 emission 1.35 g CO_2-eq per sachet. The extended analysis of CO_2 emission from cradle to grave for boxed tea and powdered tea, then compared to the direct sell of dried green tea to the consumer (Fig. 8).

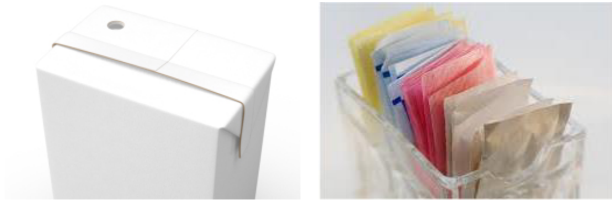

Fig. 7. Example of box and sachet package that used in simulation of boxed tea and powdered tea production process from Gamboeng green tea

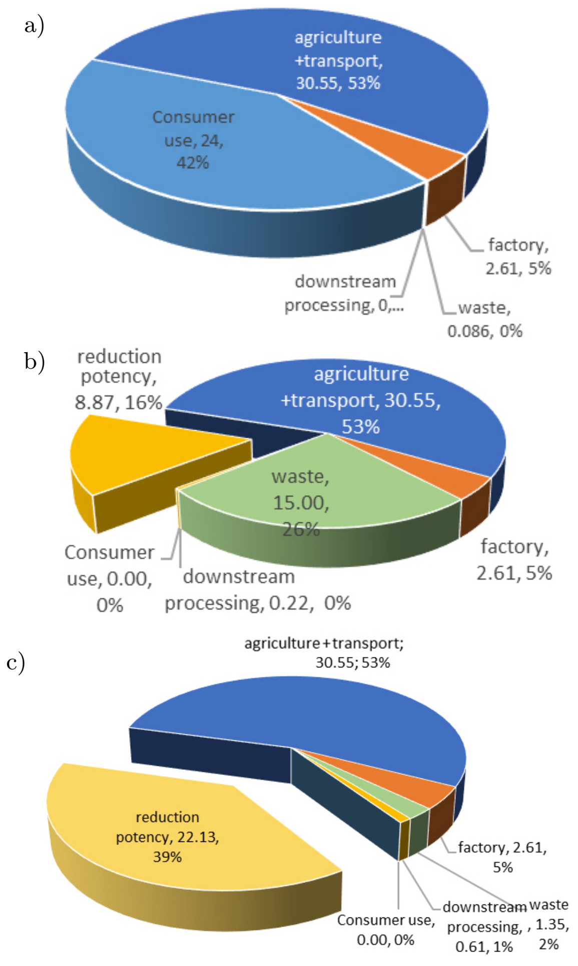

Fig. 8. Reduction potency of carbon emission if consumer (a) self-prepared their tea, (b) consuming boxed tea or (c) consuming powdered tea. Basic assumption for calculating carbon emission for boxed tea and powdered tea is, products were served in room temperature. Serving them with ice or prior refrigeration will increase the total carbon emission and beyond the scope of this study

Based on data gathered by Warta Ekonomi, promising consumption growth of ready-to-drink tea product was recorded since 2005 which all above 8% per year (Table 3). In 2016, total ready-to-drink tea product that sold in Indonesia was 2,080 billion liters per year or 5.8 billion liters per day. In this simulation (Fig. 1), the maximum production of powdered tea was 68,000 sachets of 2 g each and the maximum production of boxed tea was 13,600 liters packed in 41,000 boxes of 330 ml each. The maximum production capacity was less than 0.00025% of total Indonesian consumption. Thus, from the economic point of view, market opportunity was widely opened. Even if the growth was decline in 2017, the market for ready-to-drink tea product is still promising due to many new foreign investors started to captive Indonesian market.

Table 3
Total production of Ready-to-drink tea product in Indonesia (in billion liters

Year	Total production (billion l)	Production growth
2005	892	11%
2006	1000	12%
2007	1098	13%
2008	1126	15%
2009	1181	14%
2010	1276	8%
2011	1375	11%
2012	1402	8%
2013	1620	14%
2014	1783	10%
2015	2000	12%
2016	2080	4%
2017	1976	–5%

Discussion

Carbon emission for agriculture and transport was calculated based on exergy analysis in the previous study (Bardant et al., 2018a) and a similar approach for calculating carbon emission from the green tea factory process (Bardant et al., 2018b). Carbon emission from the downstream process were simulated in this study with main assumption that Carbon emissions from biomass-based fuel were neglected. Thus, the average emission for the contained tea solution and tea powder between the observed scenarios, which use all the available drinking water were 0.22 g CO_2-eq and 0.61 g CO_2-eq, respectively. Significant amount of carbon emission that can be cut off by converting product from dried green tea into ready to drink product through the process designed as simulated in this study, integrated with biogas production unit and using biomass pellet.

One of the technical constrain for this simulation was assumption for combustion efficiency. It was assumed that combustion reaction was complete and all carbons were converted into CO_2. Heat loss was assumed only from the heat transfer process. The combustion efficiency for wood pellet was relied on calculated value in Gamboeng tea processing plant, which is 0.33 (Haryanto, 2019). Combustion efficency for biogas was set at 0.2 due to its low methane content according to previous study (Manyuchi et al., 2018). No further research about the flue gas, especially particulate matter in term of PM 2,5 and/or PM 10. Biomass pellet utilization was suspected to produce more particulate matter than the previous utilized fuel, LPG. The combustion product in term of particulate matter could reduce the efficiency and overestimated CO_2 emission calculation. Simulation which considering combustion with particulate matter will be an interesting new research subject and beyond the scope of this study. This new research can be incorporated with the potential application of green tea downstream production process which discussed in this paper. Many technical option available in dealing with particulate matter in flue gas such as filtering and catalytic converter.

The amount of carbon emission reduction potency by converting product into boxed tea was 10.78 g CO_2-eq/pack. The amount of reduction potency was much higher for powdered tea, 24.04 g CO_2-eq/pack, which was more than emission from self-prepared tea process by consumer, 24 g CO_2-eq/pack. The reduction potency was also coming from waste reduction. Waste of powdered tea was only from sachet package, which is lesser than biomass waste from self-prepared dried tea.

Powdered tea and boxed tea in this simulation were considered as ready-to-drink product. Thus, no emission that counts when the consumer used them. Serving them with ice or prior refrigeration was beyond this simulation scope. The reduction potencies were calculated by using consumer-self-brewed green tea product as a benchmark. Boxed tea used less energy in downstream processing but gave carbon emission through its boxed package, contributing up to 25% of total boxed tea carbon emission.

Large amounts of synthetic fertilizer introduced to plantation compensate for high carbon emission in agricultural step in the tea life cycle.

The carbon emission from Gamboeng tea agriculture was 463.5 kg/ton fresh tea leaves (129.9 kg/ton, 273.5 kg/ton, 59.13 kg/ton were emitted for phosphor, nitrogen, and potassium fertilizer, respectively), and 509.1 kg/ton when transportation from plantation to factory were counted. This simulation offered biogas liquid effluent as organic fertilizer. According to previous study, the effluent was rich in nitrogen (4.5%), phosphorous (0.6%), and potassium (4.6%) (Manyuchi et al., 2018). Wide opportunities for further study of biomass effluent potency as synthetic fertilizer substitute in tea plantation were available. No reliable data of performance comparability between synthetic fertilizer and organic fertilizer from tea waste.

Increasing public awareness of environmental sustainability had already changed the lifestyle of citizen in developed countries. Eco-label had already familiar and become a concern of citizen in selecting product, including tea products. Government in developed countries also gave attractive incentive for industries and products that categorized as eco-friendly. This awareness slowly adopted by citizen in developing countries. There will be capital profit for eco-friendly product and process and increase their competitiveness in market (Setiawan et al., 2019). This simulation and its analytical results gave an example of defining a product or process as an ecofriendly product.

Conclusions

Simulation of Gamboeng green tea downstream process was conducted to show how changing habits in consuming a cup of tea could contribute to make better environment. CO_2 emission from processing a cup of tea by Indonesian consumer was 51 gr CO_2 per cup of tea, excluding the tea organic waste. For reducing carbon emission purposes, more Gamboeng tea was preferred to process. This simulation using pellet and biogas as fuel for heat energy required. The more tea can be processed, the more biogas can contribute to supply the required energy. The carbon emission from combustion of biomass-based fuel will be counted as zero. Thus, the only carbon emission that counted was from electricity. In case of fully utilizing available drinking water, i.e., 15.6 m^3 per day, the balance of wood pellet required was 156.1 kg per day at the fraction of Gamboeng tea processed into powdered tea and boxed tea are 6.08% and 6.18%, respectively. The number of 330ml boxed tea that can be produced at the combination was 33,248 boxes and 12,405 sachets of powdered tea. The amount of carbon emission reduction potency by converting the product into boxed tea and powdered tea was 10.78 g CO_2 eq/pack and 24.04 g CO_2-eq/pack, respectively. The potencies were calculated by using consumer-self-brewed green tea product as a benchmark. Boxed tea used less energy in downstream processing but gave carbon emission through its boxed package, contributing up to 25% of total boxed tea carbon emission.

This simulation was conducted based on operation conditions from laboratory scale and capacity based on Gamboeng tea factory and plantation daily practice. Assumptions related to material and technology resources were chosen closely related to Gamboeng specifically and Indonesia in general. This simulation report could give a valuable forecast or benchmark for any tea industrialist and professionals. This result is expected to inspire further work for other strategic commodities in various countries, such as coffee and cocoa.

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