A CLOSED MODEL FOR ENERGY INDEPENDENT PRODUCTION SYSTEM IN CACAO PROCESSING INDUSTRY

– Research paper –

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Abstract: The objective of this research was to assess energy independent and develop a model of closed system production process of cocoa butter and cocoa powder. Mass balance analysis and potential energy assessment of by-products were used to develop the closed system of cacao processing industry. The results showed that cacao industry with 4,500 kg of cacao capacity per day has the potential energy of 14,561,290 k cal per day derived from the pod husk and bean shells. This potential energy meets the energy needs for the production process. This study explained that the cacao industry can be developed to be an energy independent industry by using the by-products for energy source.

Keywords: cacao processing industry; energy independent; closed production system

INTRODUCTION

The cacao processing industry produces intermediate products which are cocoa butter and cocoa powder. This process consumes electrical energy of 50 GJ/ton cacao (Barry Callebaut, 2013; Ntiamoah and Afrane, 2008). Similarly, Ogunsina et al. (2017) have observed the total energy used to process cacao beans into powder was 4.61 MJ/kg consists of 2.23 MJ electrical energy and 2.38 MJ diesel engine. In current practice, the energy is taken from public grid of state electricity company (PLN) in which fossil fuel combustion is used to generate the power.

It has been strongly suggested that the cacao processing industry will be growing faster in the future both at national and local (regional) investment levels. Therefore, this industry will increasingly consume more energy (Fakhrurrazi et al., 2018). Meanwhile, the fossil fuels availability has been declining due to excessive exploitation to meet the very massive and fast growing demand. The annual availability of fossil fuel such as oil and gas declines to 4% and 8% (Badan Pusat Statistik, 2015). This conditions will continue and will end up in energy crisis of industrial production in the very near future, so industry should use renewable energy.

Development of a production system shall save the usage of raw materials and energy from the nature to decrease and prevent the future incidence of energy problems and environmental catastrophe (Robert et al., 2002). Utilisation of by-product biomass to produce energy is a promising alternative to cut or even totally replace fossil fuel energy.

The cacao processing industry produces by-products containing lots of energy (Prasertsan et al., 2002) and their percentage is higher when compared with the main product. Fresh cacao fruit will produce 6.7% cacao dried beans (Effendi, 1995) and over 80% by-product in the form of pod husk, pulp, placenta, and bean shells (Patabang, 2011; Uwagboe et al., 2010). Cacao pod husks discarded as waste represent between 70 to 75% of the cacao fruits weight (Alemawor et al., 2009; Cruz et al., 2012) and 8-11% of the wet cacao beans weight is cacao beans shells (Olubamiwa et al., 2006). The by-products are potential alternative energy sources because they have abundant volume and contain much energies.

The pod husk and bean shells may be used as alternative energy sources that containing about 4,063 k cal/kg (Syamsiro et al., 2012) and in bean shells is about 4,116 k cal/kg (Pabisa, 2013; Spilacek et al., 2014). These energies are expected to fulfil the cacao processing industry needs. That large amount of energy has not been used which can

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be converted into direct combustion and steam turbine system. Biomass combustion such as burning of cacao pod husks is to provide power in the form of heat and electricity (Madguni and Singh, 2013).

Wet basis moisture content of the pod husk is between 10–14% (Daud et al., 2013; Hamzat and Adeola, 2011) and cacao beans shell is 4.9–11.2% (Domfeh, 2013), so they can be burned directly in a boiler to produce steam and drive a turbine that produces electricity (Diji, 2013). The energy produced is inputting back to process cacao to form a closed production system. In addition, the closed system application will cut the amount of the generated wastes and finally cutting the cost of waste handling.

Agroindustry that processing raw material containing energy (carbohydrate, fibre, and oil) is potential to be designed for closed production systems such as crude palm oils (Bantacut and Pasaribu 2015), sugarcane (Bantacut and Novitasari, 2016) and rice (Bantacut and Nurdiansyah, 2017). Development of such systems for cacao processing industry would improve efficiency of the production process and cut generation of the by-product. Analysis of alternative energy sources derived from biomass will help to develop an independent energy of cacao processing industry system. The mass balance model

development is to form a closed system for cacao processing industry.

This research aim was to develop an independent energy production system design in the cacao processing industry with a minimum input and optimum output. For that reason, the main works were: (i) calculating mass flow in the process and constructing the mass balance model of cocoa butter and powder production, (ii) calculating the energy required in production process and the by-products energy content, and (iii) designing the flow process of an independent energy production system with a minimum input and optimum output.

This research was limited to cacao processing industry that produces cocoa butter and cocoa powder by considering only pod husk and bean shells as potential energy sources. Material balance was based on mass transfer flows in and out of the main process stages as to include losses during the production process. The calculation included energy used for the process of production and the by-products potential energy. The model results then compared to the factory actual data to analyse its level of accuracy. Actual data were based on the 4,500 kg cacao fruit per day capacity of cacao processing factory. The closed system of mass flows and energy in cacao processing industry was then established and analysed.

MATERIALS AND METHODS

Data Collection

Primary and secondary data were used in this research. Journals, research papers, thesis, dissertations, and books are main sources of secondary data that addressed process mass balance and resource requirements. Most secondary data were about production of dried cacao beans, cocoa powder and cocoa butter to assess chance to apply an independent energy production system. Meanwhile, the primary data was the real mass balance based on the cacao processing industry in Lampung (Sumatra Indonesia).

System Boundary

Cacao processing industry has a complex production system because it involves many inter-connected factors. The main factors are material and energy (input) required, production process, product and by-product (output), they are inter-connected. To study these factors need a comprehensive approach so an ideal solution to energy used can be identified. Therefore, the systems approach was used to determine the energy needs and mass flow,

including the by-product energy potential that involved in production process of cocoa butter and cocoa powder.

The cacao butter and powder production consists of two main processes, namely upstream (primary) and downstream (secondary) processes. Upstream process is to convert cacao fruits into dried cacao beans, while the downstream processes are to separate dried cacao beans into cocoa butter and cocoa powder. Developed model in this research integrated the upstream and downstream processes. The main processes involve four compartments such as upstream processes, liquefying process, fat or butter separation process, and flouring process. The main input material was 4,500 kg cacao fruits per day and ingredient (potassium carbonate) in the downstream processes (Dyer, 2003). The output is cocoa butter, cocoa powder, and by-product such as pod husk, pulp, placenta, water vapour, and bean shells.

Model Description

The flow process of compartments was used to develop mass balance model that was observed from the real production process. Independent

variables and dependent variables was input and output respectively. The model was built by using the ratio (coefficient or efficiency) of the independent and dependent variables based on the principles of linear equations with a calculation tool of Microsoft Excel.

To evaluate the model accuracy, the calculation results were then compared with real data of production process of cacao processing industry in Lampung. The calculated by-products weight was used to calculate the amount of energy potential as a source of energy to run the production process. This model has a high degree of accuracy and can be used as the basis of analysis of by-products energy potential under the actual production process to generate more calories for energy independent production process.

Mass Balance

The first stage in creating mass balance model was compartments identification that describe the production process. Later, the model was built by creating a mass balance equation that connects the input (cacao fruit and supporting materials) and output (cocoa butter, cocoa powder, and by-products). The mass balance equation was developed according to each step of main process by linking input and output.

Equation coefficients were efficiency factors (the ratio of the variable values) and taken from previous research of the mass flow of cacao processing industry. The equations were then solved by matrix operation to determine dependent variables value.

Energy Content of By-Product

The output of material balance model that describes the real condition of the cocoa processing industry was used to calculate the potential energy of by-product with the equation below:

Potential Energy (k cal) = Mass (kg) × Calorific Value (k cal/kg)

The mass of by-product was obtained from the model calculation, while the caloric values were obtained from the literature. The caloric values of pod husks of 4,063 k cal/kg (Syamsiro et al., 2012) and bean shells of 4,116 k cal/kg (Pabisa, 2013;

Spilacek et al., 2014). In this research, it was assumed that boiler efficiency is 76.8% (Bora and Nakkeeran, 2014) and turbine efficiency is 43.5% (Wolowicz et al., 2012).

Process Flow of Self-Sufficient Energy

The total potential energy contained in the by-product was examined to meet energy needs of the cacao processing industry. Analysis of the energy usage begins with calculation of the mass balance equilibrium through observations of input-output system. Energy needs were analysed from machines specification used in the production process following with calculation of the amount of energy used for operation and sources availability.

The cacao processing industry used electrical energy in the production processes where its mount differs from one to another, depending on applied processing technology. Electrical energy in the cacao processing industry in Lampung used for drying, liquefaction, milling, pressing, and separation processes. Specifications of the engine used in the cacao processing industry with 4,500 – 5,000 kg capacities of cacao fruit per day are presented in Table 1.

The potential energy of by-product ascertain the energy sufficiency level by comparing potential energy generated with the energy consumption. The independent energy level is gained if the energy obtained is greater or equal to the energy needed. Oppositely, dependent energy plant is that if the energy obtained were smaller than the needs.

MASS BALANCE MODEL OF CACAO PROCESSING

Balance Principle

Thermodynamic principle, no mass can neither created nor destroyed, was applied to modeling mass balance. The first step is compartment identification. Each compartment has mass balance equation by subtraction total input with output that to be equal to zero or no accumulation. These equations were identified with secondary data onto the mass flow of cacao processing to determine efficiency values that balancing the mass flows.

Table 1. The machines of cacao processing industry specifications

Process	Engine Spesification		Number of Machines
	Capacity (kg/h)	Energy Consumption (kWh)	
Drying process I	60	20.92	2
Drying process II	80	10.18	1
Liquor process	50	19.15	1
Pressing process	18	669.4	2
Milling process	8	45.44	3
Separation process	30	45.30	1

Outputs of a compartment as the product to be an input of the next compartment, while by-product to be reutilised for creating higher value than treated as a waste. By-products contain fibre, carbohydrate and oil that can be used for energy generation (Bantacut and Novitasari 2016). Mass balances models were used to calculate by-product volume, while the heat values were taken from literatures. The net energy determine energy sufficiency level in the cacao processing industry which was energy produced diminished the energy needs in the production process.

Model assumption was formed into the system for compartments thoroughly without specific flow linking inputs (I), product (P), and by-product (W) (Figure 1). This model used to develop “real model” based on the input and output of the industry of dried cacao beans, cocoa butter and cocoa powder.

Figure 1. Simple and basic mass balance model of production process (Bantacut and Nurdiansyah, 2017)

The simplest mass balance equation is:

$$I = P + W$$

$$\text{Efficiency (a)} = \frac{P}{I}$$

A case study was used with the real capacity of 4,500 kg of cacao fruit per day and additional material of potassium bicarbonate. This was the field observation results.

Mass Balance Model

Mass Balance Model uses compartments detailing into the process unit that has independent input and dependent variables as the output of a process (Figure 2). This Mass Balance Model has 9 unit processes of two independent variables (I_{11} and I_{81}) and 16 dependent variables (X_{11} to X_{91} ; W_{11} to W_{51} ; P_{71} and P_{91}). On dependent variables X_{61} can be ignored because it was only a size reduction process and was a closed flow with no flow coming out of the system. A detailed calculation produces a model with better results and will be able to describe the real conditions that actually occur to the cacao processing industry.

Mass balance equations:

$$I_{11} - X_{11} - W_{11} = 0 \quad \dots\dots\dots(1)$$

$$X_{11} - X_{21} - W_{21} = 0 \quad \dots\dots\dots(2)$$

$$X_{21} - X_{31} - W_{31} = 0 \quad \dots\dots\dots(3)$$

$$X_{31} - X_{41} - W_{41} = 0 \quad \dots\dots\dots(4)$$

$$X_{41} - X_{51} - W_{51} = 0 \quad \dots\dots\dots(5)$$

$$X_{51} - X_{61} = 0 \quad \dots\dots\dots(6)$$

$$X_{61} - X_{71} - P_{71} = 0 \quad \dots\dots\dots(7)$$

$$I_{81} + X_{71} + X_{91} - X_{81} = 0 \quad \dots\dots\dots(8)$$

$$X_{81} - X_{91} - P_{91} = 0 \quad \dots\dots\dots(9)$$

Efficiency coefficient equation:

The production of cacao beans with pulp and placenta (a_1):

$$a_1 = \frac{X_{11}}{I_{11}} = \frac{\text{cacao beans with pulp and placenta}}{\text{cacao fruits}} \quad (10)$$

Cacao beans produced from the process of cracking the fruit has a percentage of 21.7% (Adzimah and Asiam, 2010; Nguyen, 2010; Velayutham et al., 2013), then a_1 is 0.22.

The production of wet cacao beans (a_2):

$$a_2 = \frac{W_{21}}{X_{11}} = \frac{\text{pulp and placenta}}{\text{cacao beans with pulp and placenta}} \quad (11)$$

Percentage of separable pulp and the placenta is 2.38% generated from cacao beans with pulp and placenta (Adzimah and Asiam, 2010; Pusporini, 2013), then a_2 is 0.02.

The production of dried cacao beans (a_3):

$$a_3 = \frac{X_{31}}{X_{21}} = \frac{\text{dried cacao beans}}{\text{wet cacao beans}} \quad \dots\dots\dots(12)$$

As much as 25 kg of wet beans with moisture content of 60% (wet basis) was dried to moisture content of 6.45-7% (Geuhi et al., 2010; Napitupulu and Tua, 2012). Percentage of dried bean up to 43% of the wet beans, then a_3 is 0.43.

The production of roasted cacao bean (a_4):

$$a_4 = \frac{X_{41}}{X_{31}} = \frac{\text{roasted cacao beans}}{\text{dried cacao beans}} \quad \dots\dots\dots(13)$$

Roasted cacao beans resulted from roasting process was 9.77 kg with input (dried cacao beans) of 10.13 kg (Elisabeth et al., 2015). Similarly, Akinnuli *et al.*, (2014) found that a total 20,957.3 kg of roasted cacao beans produced from 21,500 kg dried cacao beans. Therefore, percentage of roasted beans resulted from roasting process were 96.54% (Elisabeth et al., 2015) and 97.48% (Akinnuli et al., 2014), then a_4 is 0.97.

The production of nib (a_5):

$$a_5 = \frac{X_{51}}{X_{41}} = \frac{\text{nib}}{\text{roasted cacao beans}} \quad \dots\dots\dots(14)$$

Nip separated from shells amounting to 82% of the roasted cacao beans (Azizah, 2015; Adzimah and Asiam, 2010), then a_5 is 0.82.

Figure 2. Mass balance model of cacao processing (symbol description in Table 2)

Table 2. Description of mass balance models symbol

Symbol	Explanation
1	cracking process of cacao fruits
2	fermentation process of cacao beans
3	drying process of cacao beans
4	roasting process of cacao beans
5	separation process of beans (nib)
6	grinding process of nib
7	pressing process of cocoa liquor
8	grinding process of cocoa cake
9	separation process of cocoa powder
I ₁₁	Cacao fruits
I ₈₁	Potassium carbonate
X ₁₁	Cacao beans with pulp and placenta
X ₂₁	Wet cacao bean
X ₃₁	Dried cacao bean
X ₄₁	Roasted cacao bean
X ₅₁	Nib
X ₆₁	Cocoa liquor
X ₇₁	Cocoa cake
X ₈₁	Cocoa powder (fine and coarse)
X ₉₁	Cocoa powder (coarse)
W ₁₁	Pod husk
W ₂₁	Pulp and placenta
W ₃₁ and W ₄₁	Water vapour
W ₅₁	Beans shells
P ₇₁	Cocoa butter
P ₉₁	Cocoa powder (fine)

The production of cocoa butter (a_6):

$$a_6 = \frac{P_{71}}{X_{61}} = \frac{\text{cocoa butter}}{\text{cocoa powder}} \dots\dots\dots(15)$$

Cocoa butter produced from the processing of cocoa liquor is about 39% (Indarti, 2007; Sudibyo, 2006), then a_6 is 0.39.

The production of cocoa powder (fine) (a_7):

$$a_7 = \frac{P_{91}}{X_{81}} = \frac{\text{cocoa powder (fine)}}{\text{cocoa powder (fine and coarse)}} \dots\dots\dots(16)$$

Cocoa powder (fine) resulted from the grinding process and separation process was 4.77 kg from cacao beans (coarse and fine) of 5 kg (Elisabeth et al., 2015). Percentage of cocoa powder produced from the milling process and separation process was 95.4% (Elisabeth et al., 2015; Joel et al., 2013), then a_7 is 0.95.

Table 3 summarises efficiency coefficient values that used to build matrix of the material balance.

Table 3. Mass balance model efficiency coefficient

Symbol	The Value of Coefficient of Efficiency	Reference
a_1	0.22	Adzimah and Asiam, 2010; Nguyen, 2014, Velayutham et al., 2013
a_2	0.02	Adzimah and Asiam, 2010; Pusporini, 2013
a_3	0.43	Guehi et al., 2010; Napitupulu and Tua, 2012
a_4	0.97	Elisabeth et al., 2007; Akinnuli et al., 2014
a_5	0.82	Azizah 2005; Pusporini, 2013
a_6	0.39	Indarti 2007; Sudibyo 2006
a_7	0.95	Elisabeth et al., 2007; Joel et al., 2013

RESULTS AND DISCUSSIONS

Mass Balance Model Output

Mass Balance Model calculated the yield of cocoa butter and cocoa powder as shown in Table 4 (detailed result of each variable in Appendix 1). There is a difference to actual data of factory in the cocoa powder yield. Figure 3 shows the mass flows of cacao butter and powder production processes. The model output of cocoa butter was very close to, while the cocoa powders was higher than factory's actual data. The difference was due to the factory that still incurred loss of 5–8% on the liquor processing and pressing process. The production system in factory also does not re-mill (cycle) cocoa powders that were still coarse, then the final yield of fine cocoa powders were lower. An improvement may be made to increase the yield of cocoa butters through re-milling the coarse powder. Taking the factory data into account, a simple way to improve the yields of cocoa butter and cocoa

powder is by improving the machine performance in optimal conditions and re-milling rough powder. Potential yields improvement can be increased to the cocoa powder product by 7.5% (Table 4). Increasing cocoa powder yields can be done by not washing excessively the cacao beans after fermentation. Washing will remove the bean shells thereby reducing the yield of cocoa cake and then cocoa powders to yield. Moisture content of cacao beans also affects the yield of cocoa powder produced. The loss and change volume were associated with the cacao beans moisture contents, which can reduce the cacao mass (Asiedu, 1989; Gereke and Niemz, 2010). The increase rate of 4% of moisture content will increase the linear dimensions of 3%, sphericity values of 2%, and deformation linearly of 57% (Plange, 2012).

Table 4. Comparison of mass balance model output and actual (factory data)^a

Materials	Model Output	Factory Actual Data
Cocoa butter (%)	32	32.8
Cocoa powder (%)	50	42.5

^aper amount of dried cacao beans

Figure 3. Mass flows in the cacao butter and powder (symbol description in Table 2)

Energy Self-Sufficiency in Cacao Processing Industry

The cocoa processing industry produces semi-finished products namely cocoa butter and cocoa powder. The products made from cocoa liquor through several processing stages with the initial input is the dried cacao beans. In addition to producing these products, cacao processing industry also produces by-product in the form of beans shell. This shell contains certain amounts of energy that can be used as an energy source, but the energy produced is not enough to run the production process. The fulfillment of energy for production can be met from by-product generated in upstream process of the cacao processing. The upstream processes generate more than 75% by-product in the form of pod husk, pulp, placenta and water vapour that is still not used (Patabang, 2011). The number of by-product is bigger than the product. Whereas the by-product still contains plentiful amounts of energy to supply the energy requirement of the

production sector. Pod husk contains energy amounting to 4,063 k cal/kg (Syamsiro et al., 2012) and bean shells of 4,116 k cal/kg (Pabisa, 2013; Spilacek, 2014).

The cacao processing industry requires electrical energy to run the production process. The main processing applied by the cacao processing industry are the upstream process, liquor process, pressing process (separation of cocoa butter), and the milling process. In each major process there are some machines that use electrical energy (Table 1), based on which industry with the capacity of 4,500 kg per day needs electrical energy of 14,436 kWh (Table 5).

A closed system model of the cacao processing industry is an energy independent production model that is able to meet the needs of energy without input from outside of the production systems. The calculation of potential energy of the pod husk and the beans shell are the heating value multiplied by the mass weight.

Table 5. Cacao processing industry energy needs

Process	Input	Engine Specification		Number of Machine	Operation time	Energy Consumed
	(kg)	(kg/h)	(kW)		(hours)	(kWh)
Drying I	970.2	60	20.92	2	8.1	338
Drying II	417.2	80	10.18	1	5.2	53
Separation I	404.7	80	20.74	1	5.1	105
Grinding	331.8	50	19.15	1	6.6	127
Pressing	331.8	18	669.40	2	9.2	12,341
Milling	202.4	8	45.44	3	8.4	1,150
Separation II	213.0	30	45.30	1	7.1	322
Total						14,436.0

Source: Hamdani (2009)

Certain amount of energy obtained from the by-product is utilised to supply the electric energy requirement during the process of production. Biomass of by-product is converted into electrical energy by steam turbine system. Pod husk and beans shell are burned directly to produce steam used in the turbine to produce electrical energy. In the theoretical calculations, the electrical energy generated from the pod husk and beans shell is 27,555 kWh per day. The conversion to electrical energy calculations is presented in Table 6 and the production model (Figure 4) explains that energy needs for production process can be self-sufficient and still have a surplus as much as 91%.

The use of cacao pod husk and bean shells as the fuel of power generator (mini plant) for the production process to replace the electrical energy from coal power plants of public networks. A total of 8.1 tons of coal are needed to generate electricity of 24,000 kWh (Sulistiyono, 2012). About 0.6 ton of coal is needed to meet the demand for electricity in

the production process as much as 14,436 kWh. Therefore, the use of cacao pod husk and bean can save coal as much as 4.8 tons per day. Cacao pod husk and bean shell of 1 ton can save the coal consumption as much as 1.3 tons.

Emissions from cacao shells combustion is very much less of SO₂ around 90 mg/m³, but NO are mostly between 1,000-1,400 mg/m³ (Spilacek et al., 2014). With no use, decomposition of cacao pod husk and bean shells will still release C, H, N, O, and S at certain level.

Closed System Production of Cacao Processing Industry

In forming a closed system production, the main idea is to include by-product reuse, reprocess or recycle into intergrated production system. The production system of cacao processing produces by-product in many forms such as water vapour, pulp and placenta, cacao pod husks and bean shells. The by-product, except water vapour, contains amount

The water vapour produced from the drying process and the roasting process may be collected and condensed that can be used for many purposes such as equipment cleansing. The pulp and placenta

Figure 4. Self-sufficient energy production process model of cacao processing industry (4,500 kg/day)

Table 6. The calculation of conversion biomass into electrical energy

Parameter	Unit	Amount
Plant capacity	kg cacao/day	4,500.0
Pod husk	kg/day	3,510.0
Bean shells	kg/day	73
Energy Content		
Pod husk	k cal/kg	4,063 ^c
Bean shells	k cal/kg	4,116 ^d .0
Total Energy of Biomass		
Pod husk	k cal	14,261,481.0
Bean shells	k cal	299,812
Total Steam		
Heat required to produce steam (derived from the steam table for saturated conditions 30 bar)	kcal/kg	670
Boiler efficiency	%	76.8 ^c
Steam from pod husk	kg/day	16,356
Steam from bean shells	kg/day	343
Total generated steam	kg/day	16,699
Total generated steam	kg/s	0.5
Total Electrical Energy		
Conversion of steam in the turbine	kg/s	61 ^f .0
Turbine efficiency	%	43.5 ^f
The power from turbine	kWh	833,000 ^f .0
Electrical energy generated	kWh/day	27,555
The plant's energy needs	kWh/day	14,436.0
Ratio total energy may be generated to energy needs		191%

Sources: ^e (Syamsiro et al., 2012); ^d (Pabisa, 2013; Spilacek et al., 2014); ^e (Bora and Nakkeeran, 2014); ^f (Wolowicz et al., 2012)

Figure 5. Closed system production of cacao processing industry

CONCLUSIONS AND PERSPECTIVES

Conclusions

The cacao processing is an industry that can be self-sufficient in energy by integrating the processing from the very beginning stage of upstream (cacao fruit). The upstream process produces by-products that contain more energy than with those of downstream processes. The by-product with high moisture content can not be used to generate energy. The pulp and placenta can be used as bioherbicide for the cacao plantation, while the water vapour can be used for equipment cleansing and cocoa groves activity. The potential biomass for generating energy are cacao pod husk and beans shells. Cacao processing industry of 4,500 kg capacity of fruit per day generates cacao pod husk of 3,510 kg and cacao

beans shell of 72.8 kg that potential to generate energy as much as 27,555 kWh per day more than the needs for production of 14,436 kWh. Therefore, the cacao processing industry can be seen to be energy independent and still surplus of electricity as much as 91% of the needs. Cacao pod husk and bean shell of 1 tons can save the coal consumption as much as 1.3 tons.

Perspectives

Further research in applying this system needs to be done to adjust energy calculation. This adjustment is to critically check the conversion rate of biomass to energy from engineering perspective. For that reason, a bigger scale of cacao processing industry may be taken as a case study.

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Appendix 1. Calculation Results of the mass balance model

Symbol	Explanation	Result	Ratio (%)
X ₁₁	Beans with pulp and placenta	990.0	22.00 ^a
X ₂₁	Wet beans	970.2	21.56 ^a
X ₃₁	Half-dried beans	417.2	9.27 ^a
X ₄₁	Dried beans	404.7	8.99 ^a
X ₅₁	Beans	331.8	82.00 ^a
X ₆₁	Cocoa liquor	331.8	82.00 ^a
X ₇₁	Cocoa cake	202.4	50.02 ^a
X ₈₁	Cocoa powder (fine and coarse)	213.0	52.64 ^a
X ₉₁	Cocoa powder (coarse)	10.7	2.63 ^a
W ₁₁	Pod husk	3510.0	78.00 ^a
W ₂₁	Pulp and placenta	19.8	0.44 ^a
W ₃₁	Water vapour	553.0	12.29 ^a
W ₄₁	Water vapour	12.5	0.28 ^a
W ₅₁	Bean shells	72.8	18 ^a
P ₃₁	Cocoa powder	129.0	32 ^a
P ₄₁	Cocoa butter	202.4	50 ^a

^aPer dried cacao bean