

Baseline Report

Analysis on External-use potential and Utilization of Agro-industrial Waste-based Bioenergy for Power Generation in Indonesia

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Executive Summary

Indonesia has huge potential of agro-industrial waste for energy generation. These resources have not been fully utilized for power supply. On the other hand, biomass and biogas power plant can reduce energy consumption of fossil fuel which results in greenhouse gas emission reduction. Therefore, it is important to prepare a comprehensive and accurate data estimating the potential resources from agro-industrial wastes for electricity generation.

This study had been conducted by KOPETINDO (the Indonesian Renewable Energy Cooperative) for the Ministry of Energy and Mineral Resources (MEMR) under GIZ-ExploRE. This study was based on the concern that some potential agro-industrial waste may be added into the RUPTL of PLN, increasing the potential sources for electricity generation. In this study, the focus of agroindustry is limited to the specific processing mills as follows: palm oil, sugar cane, tapioca, rice, pulp & paper, and wood mills.

In fact, some of the agro-industrial wastes from the processing mills had been used internally for power and heat consumption as in the palm oil, sugar cane, wood, and pulp & paper mills. While most of the rice husks from rice mills had been used for bricks making in Java Island, most of the rice husks at rice mills in other islands have not been utilized yet. While some of tapioca mills had utilized their biobased wastes, some others have not started yet. Unfortunately, the detailed data regarding the internal consumption of these mills is not available. Thus, these numbers had been estimated by expert's method based on their experience in the specific processing mills.

Based on this study (see Chapter 3), the calculated technical potential of agro-industrial waste is achieving 15.6 GW. However, the current installed capacity (as in MEMR Data 2021) is recorded 0.2 GW (on-grid) and 1.7 GW (off-grid) only. Based on available data and few assumptions (see Appendix 1), it has been calculated about 6.4 GW is available as the feedstock for bioenergy power plants to generate electricity (so-called External-use potential). This calculation was based only from the processing mills and not including the on-farm side (i.e., plantations, fields, and forests).

Currently, the PLN's target is adding 0.4 GW electricity from biobased sources (not include biofuel and municipal solid waste) as in the latest RUPTL (2019-2028), which is only 6.2% of the total External-use potential source that was calculated in this study. On the other hand, the Indonesian Government put a higher target for bioenergy development (5.5 GW in 2025). From 6.4 GW of agro-industrial sources from the selected processing mills, 1.3 GW can be used for diesel substitution and using scenario 2, 75% RUPTL target (0.3 GW) is achievable with current regulation framework. Therefore, there are 4.8 GW as the remaining. Thus, there might be additional 4.2 GW can be added into RUPTL (see Chapter 5). Therefore, the RUPTL needs to be revisited adopting the targeted biowaste sources to support the national bioenergy target. Moreover, an adjustment of electricity tariff in specific locations will definitely speed up the bioenergy power plant development in Indonesia.

It is important to synchronize the MEMR and PLN's target, as well as providing supportive regulations that allow boosting up the renewable energy development in Indonesia. In this study, policy recommendations also have been provided (see Chapter 5). It is expected that this comprehensive data will support the Ministry of Energy & Mineral Resources (MEMR) for preparing plans and regulations to achieve the mandated bioenergy's target as part of renewable energy target aiming 23% of energy mix by 2025 and 31% by 2050. Further works will be needed to disseminate the calculated data to PLN and other related stakeholders (e.g., associations, private companies, national & local governments, and academicians).

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Glossary

Agroindustry	industry that processes agriculture materials, which also include forestry, fisheries, and livestock product. (e.g., palm oil, sugar cane, tapioca, and rice, pulp & paper, plywood, veneer, and sawn timber)
Existing Utilization	the existing utilization is based on the installed capacity of bioenergy power plants
External-Use Potential	the fraction of technical potential which is available (after deducted by internal-use potential), which can be used to fulfil external energy demands.
Internal-Use Potential	the fraction of technical potential which is usually used for internal energy demands (as heat and/or as electricity) at the respective agro-industrial mills
Remaining Sources	the fraction of the external-use potential which deducted to meet RUPTL target and for diesel substitution
Technical Potential	power generation capacity that can be generated by utilizing available biomass from agro-industrial waste using current technologies.
Wood Mills	mills that produce plywood and or veneer and or sawn timber

Abbreviation

BPP	<i>Biaya Pokok Penyediaan Tenaga Listrik</i> (Generation Cost of Power Plant)
CAPEX	Capital Expenditure
COGS	Cost of Goods Sold
CPO	Crude Palm Oil
EFB	Empty Fruit Bunch
FEE	Front-end Engineering Design
FiT	Feed in Tariff
GW	Giga Watt
IPP	Independent Power Producer
kW	kilo Watt
kWh	kilo Watt hour
MEMR	Ministry of Energy & Mineral Resources
MW	Mega Watt
MSW	Municipal Solid Waste
OPEX	Operational Expenditure
PKS	Palm Kernel Shell
PLN	<i>Perusahaan Listrik Negara</i> (Electricity State-owned Company)
PLTA	<i>Pembangkit Listrik Tenaga Air</i> (Hydro Power Plant)
PLTB	<i>Pembangkit Listrik Tenaga Bayu</i> (Wind Power Plant)
PLTD	<i>Pembangkit Listrik Tenaga Diesel</i> (Diesel Power Plant)
PLTBio	<i>Pembangkit Listrik Tenaga Bioenergy</i> (Bioenergy Power Plant)
PLTBm	<i>Pembangkit Listrik Tenaga Biomassa</i> (Biomass Power Plant)
PLTP	<i>Pembangkit Listrik Tenaga Panas Bumi</i> (Geothermal Power Plant)
PLTS	<i>Pembangkit Listrik Tenaga Surya</i> (Solar Power Plant)
PLTM	<i>Pembangkit Listrik Tenaga Mini Hidro</i> (Mini Hydro Power Plant)
POME	Palm Oil Mill Effluent
PPA	Power Purchase Agreement
RUPTL	<i>Rencana Usaha Penyediaan Tenaga Listrik</i> (National Electricity Business Plan)
RE	Renewable Energy
TFEC	Total Final Energy Consumption
TPES	Total Primary Energy Supply

1. Background of Study

Indonesia is implementing national policies and legislations to encourage bioenergy production for electricity generation as a means to achieve energy security and self-sufficiency and to reduce reliance on fossil fuel reserves. The growing national and international demand of bioenergy is particular interest to developing countries like Indonesia for seeking opportunities on economic growth and trading. Indonesia has a comparative advantage for bioenergy because of greater availability of land, favorable climatic conditions for agriculture and relatively low-labor costs.

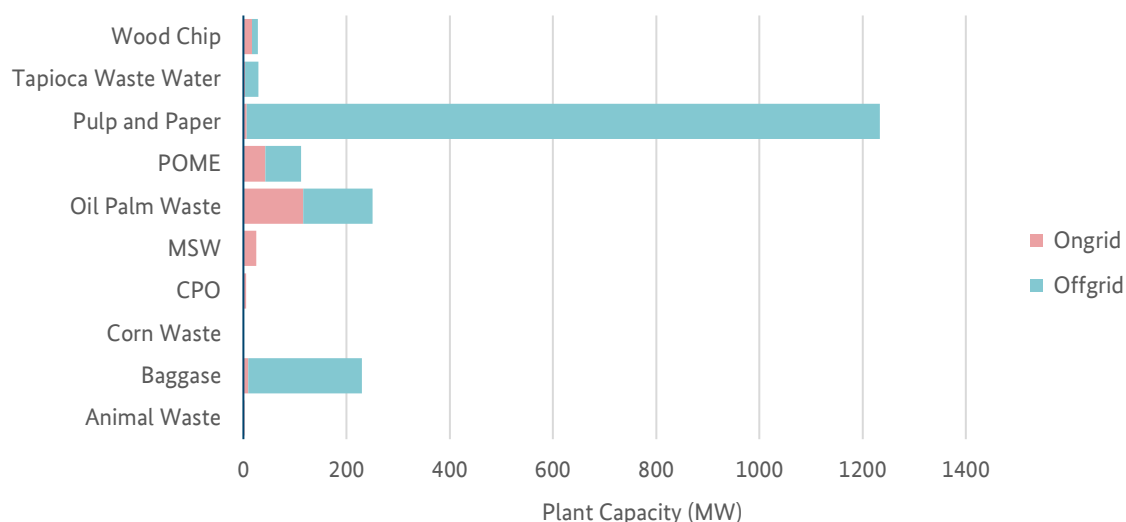
A comprehensive regulation will be required to reduce the negative impacts of large-scale production, as well as ensuring the most cost-effective and highest-energy conversion technologies that will be used. Given the opportunities and risks, criteria for the sustainable development of the bioenergy industry should be clearly established in both international and national regulatory frameworks.

Indonesia has set an overall target to have modern renewables (excluding traditional uses of bioenergy) providing 23% of Total Primary Energy Supply (TPES) by 2025, and 31% by 2050 (Rencana Umum Energi Nasional, 2017). Reference case, which assumes that these targets are met, implies a share for renewable energy of 17% in Total Final Energy Consumption (TFEC) by 2030, beyond 6% as for today (IRENA 2017).

1.1. Bioenergy Development

The Indonesian government has set a target for increasing renewable energy share to 23% in the national energy mix by 2025. Bioenergy is expected to contribute about 12 percent of the total installed capacity target ¹ (Presidential Decree, 2017). Currently, installed capacity of bioenergy power plants in Indonesia is 1.8 GW, in which most of them are developed for meeting internal energy demand of agro-industrial mills. Only smaller capacity is exported to PLN's grid as excess power.

Figure 1. Installed capacity of bioenergy power plants in Indonesia (as of April 2021, source: MEMR 2021)



Following this aim, PLN has also incorporated renewable energy sources in the 10-year electricity supply business plan or *Rencana Usaha Penyediaan Tenaga Listrik PT PLN (Persero)* (RUPTL) 2019-2028. However, compared to other renewable energy sources, bioenergy target within RUPTL is relatively small. Additional 40 MW of Bioenergy power plants (including MSW and biofuel) will be built until 2025 (approximately 5.3 percent from total new RE power plants) (Ministry of Energy and Mineral Resource Regulation, 2019).

¹ In RUEN (*Rencana Umum Energi Nasional*), Bioenergy is targeted to increase to 5.5 GW as part of the total target of 45 GW renewable energy power plants by 2025.



Following this aim, PLN has also incorporated renewable energy sources in the 10-year electricity supply business plan or *Rencana Usaha Penyediaan Tenaga Listrik PT PLN (Persero)* (RUPTL) 2019-2028. However, compared to other renewable energy sources, bioenergy target within RUPTL is relatively small. Additional 40 MW of Bioenergy power plants (including MSW and biofuel) will be built until 2025 (approximately 5.3 percent from total new RE power plants) (Ministry of Energy and Mineral Resource Regulation, 2019).

Table 1. Additional renewable energy power plants in RUPTL (2019 – 2025) (Source: RUPTL 2019 – 2028)

RE Plants	2019	2020	2021	2022	2023	2024	2025	Total
Geothermal	190	151	147	455	245	415	2759	4362
Hydropower	154	326	755	0	182	1484	3047	5948
Mini Hydro	140	238	479	200	168	232	27	1484
Solar PV	63	78	219	129	160	4	250	903
Wind	0	0	30	360	260	50	150	850
Bioenergy (incl. MSW and biofuel)	12	139	60	357	50	103	19	740

1.2. Objectives

The objectives of this report are as follow:

- To identify current utilizations of agro-industrial wastes in Indonesia
- To estimate available agro-industrial waste potential for power generation
- To assess economic aspects of bioenergy power generation from agro-industrial waste

1.3. Paper Structure

This report is structured to various chapters:

- Chapter 1:** Background of Study
- Chapter 2:** Methods & Approaches
- Chapter 3:** Utilizations & Potential Sources
- Chapter 4:** Economic Analysis
- Chapter 5:** Demand Analysis
- Chapter 6:** Conclusions & Recommendations

2. Methods and Approaches

2.1. Scope of study

The focus of this study is limited to the utilizations of agro-industrial wastes from 6 (six) agro-industries: palm oil, sugar, tapioca, rice, pulp & paper, and wood. Specifically, only wastes from the off-farm side (i.e., processing mills) are considered for further analysis. Wastes from the on-farm side (e.g., palm oil plantation, sugar cane plantation, cassava plantation, rice field, and industrial forest) were excluded in this study due to its irregular availability and additional feedstock collection measures.

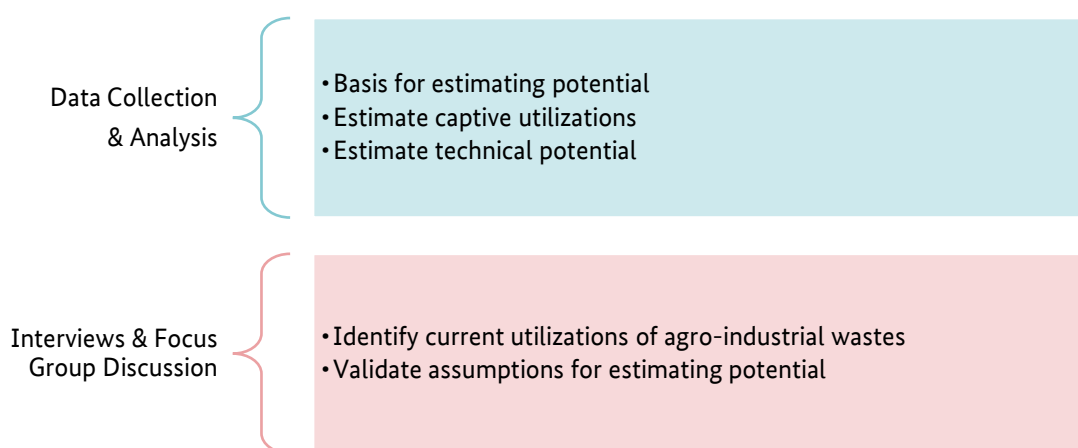
The bioenergy sources from agro-industrial wastes will be evaluated for power generation, using biogas conversion technology using anaerobic digestion (for liquid wastes) and biomass combustion (for solid wastes).

2.2. Methods

The study was carried out using a mix of data collection and analysis, interviews, and focus group discussion. Agro-industrial mill data was collected along with development of Bioenergy Potential Database ² with Directorate of Bioenergy, Ditjen EBTKE. The data sources vary from past study of EBTKE, Ministry of Agriculture, Ministry of Environment and Forestry, association, certification databases (ISPO and RSPO), and other online sources.

Interviews and focus group discussions were organized to identify current utilizations of agro-industrial wastes, validate assumptions for estimating captive utilizations and external-use potential as well as to update mill database. Apart from EBTKE, Ministry of Agriculture, agro-industrial associations, and big holding companies were involved in the process.

Figure 2. Main methods for conducting the study

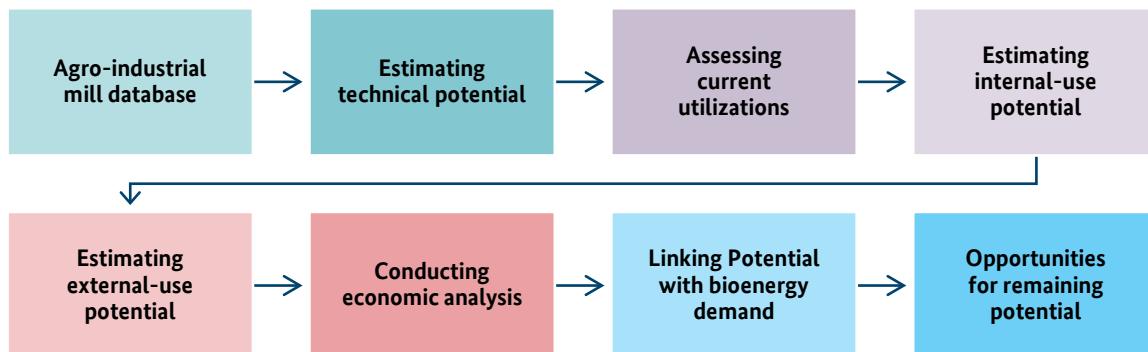


² Bioenergy Potential Database is an activity that has been developed by GIZ and Directorate of Bioenergy, EBTKE to compile bioenergy potential within each agro-industrial mill in Indonesia.

2.3. Frameworks

The study follows below framework to estimate available external-use potential from agro-industrial waste for power generation (see Figure 3).

Figure 3. Framework for estimating bioenergy external-use potential from agro-industrial wastes



Database on agro-industrial mills is used as basis for calculating bioenergy technical potential from agro-industrial waste. Then, based on inputs from industry players during interviews and focus group discussion, a portion of technical potential is deducted for captive use (internal-use potential), including as heat or as power. The other portion left is regarded as external-use potential for external utilizations.

The external-use potential then be compared with bioenergy demand for grid-connected electricity generation. Finally, economic analysis will be developed as the last part considering the nature of regulatory framework which is frequently adapted in Indonesia.

Definition of Bioenergy Potentials

Definition of bioenergy potential within this study might differ from other publications (NREL, FAO) due to special characteristic of agroindustry in Indonesia and specific purposes to evaluate the potential.

Technical potential: Power generation capacity that can be generated by utilizing available biomass from agro-industrial waste using current technologies.

Internal-use potential: The fraction of technical potential which is usually used for internal energy demands (as heat and/or as electricity) at the respective agro-industrial mill.

External-use potential: The fraction of technical potential which is available (after deducted by internal-use potential), which can be used to fulfil external energy demands.

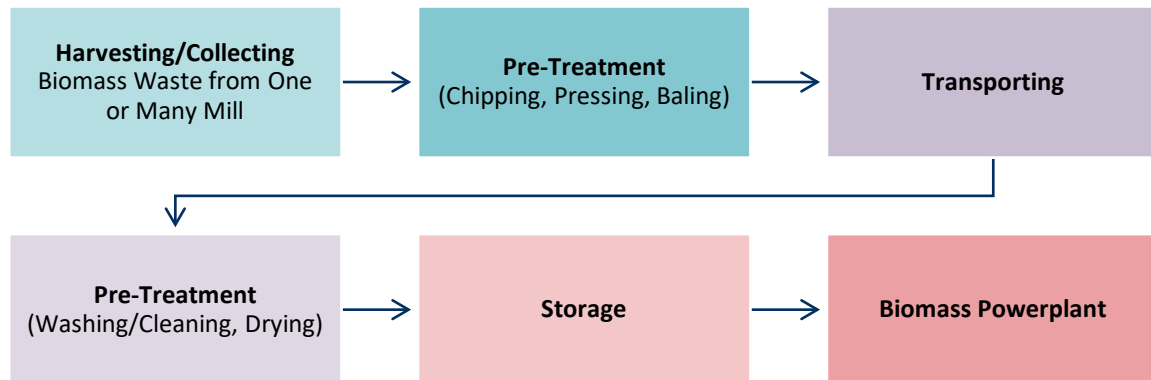
Detailed calculation is provided in Appendix B.

In practice, the assessment of the technical potential considered all wastes on site, while the external-use potential focused on the availability and accessibility of wastes for electricity generation (considering available technologies). In addition, the feasibility of the utilizations of agro-industrial waste will be determined by the actual costs of the waste, collection cost as well as transportation cost to the bioenergy power plant.

Ultimately, the assessment of the bioenergy from agroindustry should also consider actors, such as: the range of institution, geopolitical, and social impacts. These will affect to the implementation of the bioenergy power plant projects in the targeted regions and matching them with the roadmap timeframe. It

is crucial to assess whether the residues had been used currently. Moreover, the bioenergy potential within a region is usually expressed on annual basis, however it is important to consider seasonality and inter-annual variability (especially for palm oil, rice, and sugar mills). It is also necessary to consider the sustainability of each part in the supply chain as well as the complete supply chain (see Figure 4).

Figure 4. Supply chain of biomass feedstock



3. Utilizations and Potential Sources

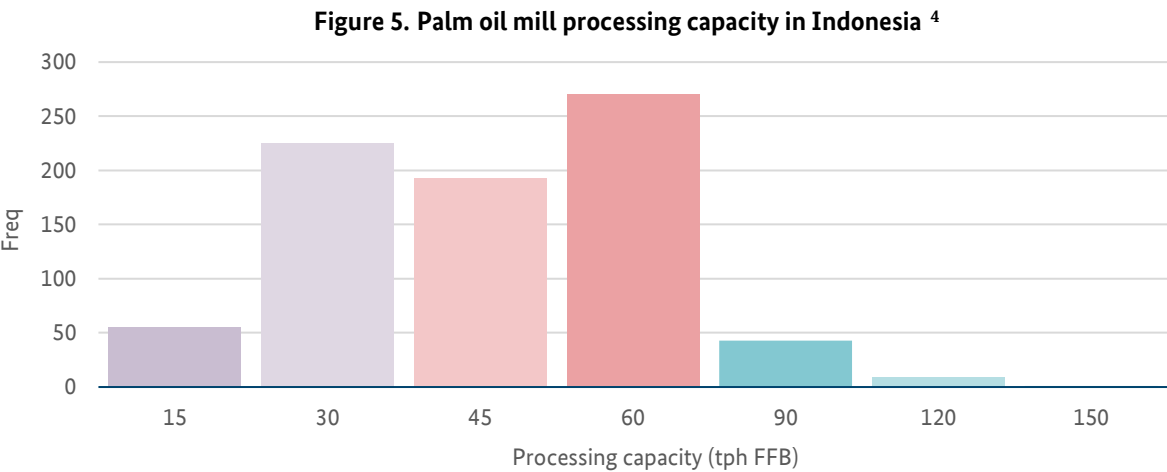
In this chapter, the current utilizations of agro-industrial wastes and the external-use potentials of them were described for each agro-industry, given the characteristic of each industry.

3.1. Palm Oil



“Palm Oil Mill Terantam, PTPN V”, photo by GIZ

Indonesia is the world’s largest palm oil producer with total production of 51.8 million metric tons in 2019 (GAPKI, 2020). Hence, it is clear that palm oil industry plays a significant role in Indonesia’s economic development and contribute to approximately 2.46 percent of the country’s gross domestic products in 2017 (Jakarta Globe, 2019). Based on available data ³ within internal database, there are eight-hundreds-eighty-nine (889) palm oil mills in Indonesia, which are mostly located in Sumatera and Kalimantan. Most palm oil mills have processing capacity between 30, 45 and 60-ton FFB per hour (see Figure 5 below).

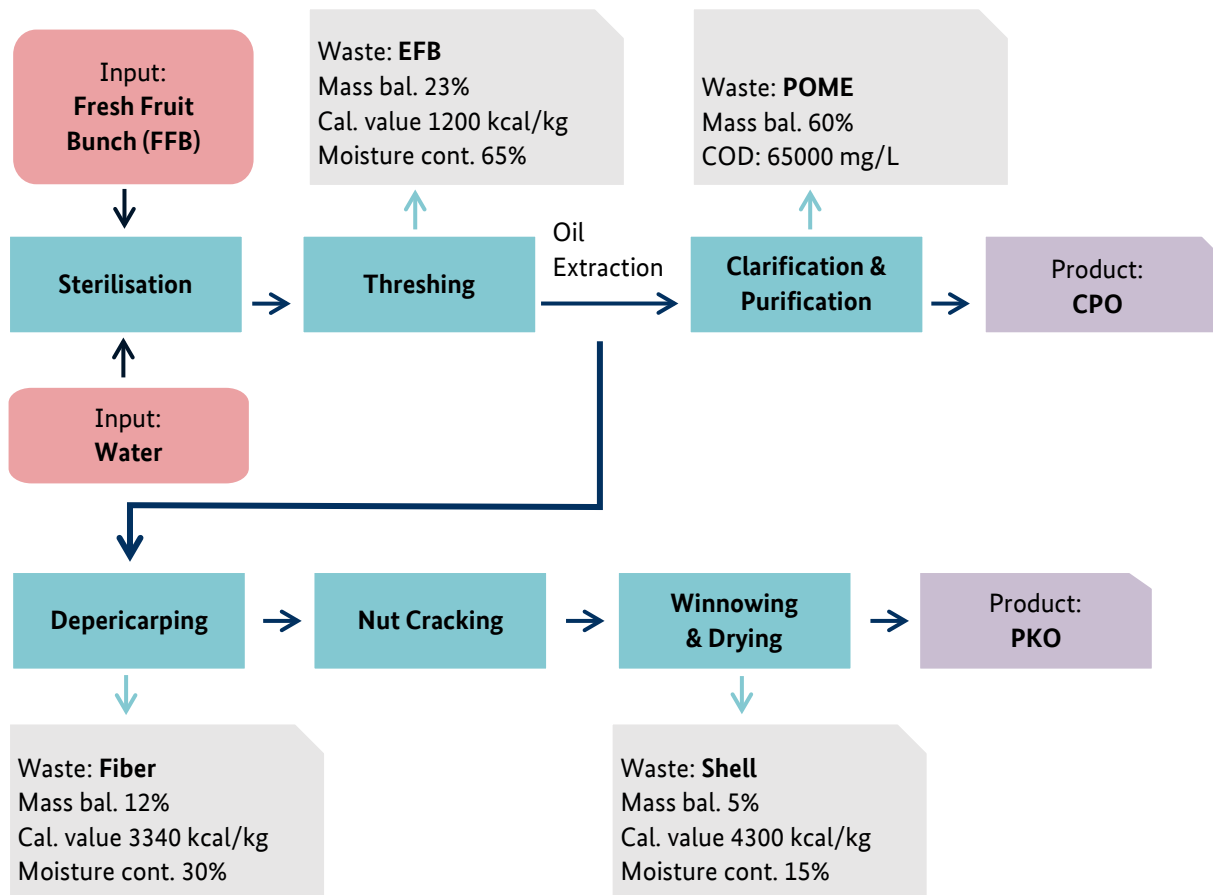


³ Actual number might be larger

⁴ Based on available internal data that was compiled from various sources. Actual number might be different.

Apart from its economic benefit, palm oil industry could potentially harm and pollute the environment (if continue its business as usual) due to its activities as it generates vast amount of wastes. During the conversion process of Fresh Fruit Bunch (FFB) to Crude Palm Oil (CPO), the palm oil mills produce large number of wastes both in solid and liquid forms that consist of Palm Kernel Shell (PKS), Mesocarp Fiber (MF), Empty Fruit Bunch (EFB), and Palm Oil Mill Effluent (POME) as can be seen in the Figure 6 below. Therefore, it is essential to treat wastes to ensure the environment remains protected. To date, the utilization of palm oil mill wastes as the feedstock for bioenergy power plant become the most preferred and attractive because the quality is relatively stable, huge amount in volume, and the transportation cost is also relatively easier to be determined.

Figure 6. Simplified process flow for palm oil mill and its wastes



In practice, all mesocarp fibers and small portion of Palm Kernel Shell (PKS) have been used internally to produce heat (using drier or boiler) and/or electricity. For palm oil mills located near port, PKS has been commonly used as trade commodity for domestic and export market with price ranging from Rp 826 to Rp 998 per kg. In total during 2019, Indonesia has exported 2.8 million tons shell, it was around 22% of total PKS production in Indonesia. Japan is the largest export destination for PKS, in 2019 1.7 million tons PKS or around 60% of total PKS were exported to Japan (BPS 2019). Furthermore, the trends of PKS price was rise in the past few years due to increasing demand in several countries, as it has high energy content ca. 14 – 20 GJ/ton and considered as a cheap source for biomass fuel.

Empty Fruit Bunch (EFB) is commonly used for organic fertilizer through mulching. Co-composting EFB with POME is also possible to minimize the nutrient losses and concentrate all nutrients from POME and EFB into one product. In addition, EFB could be potentially used as feedstock for boiler in the mills. However, because of high water content, chlorine (which could create corrosion) and potassium. Pre-treatments to reduce the impurities are required.

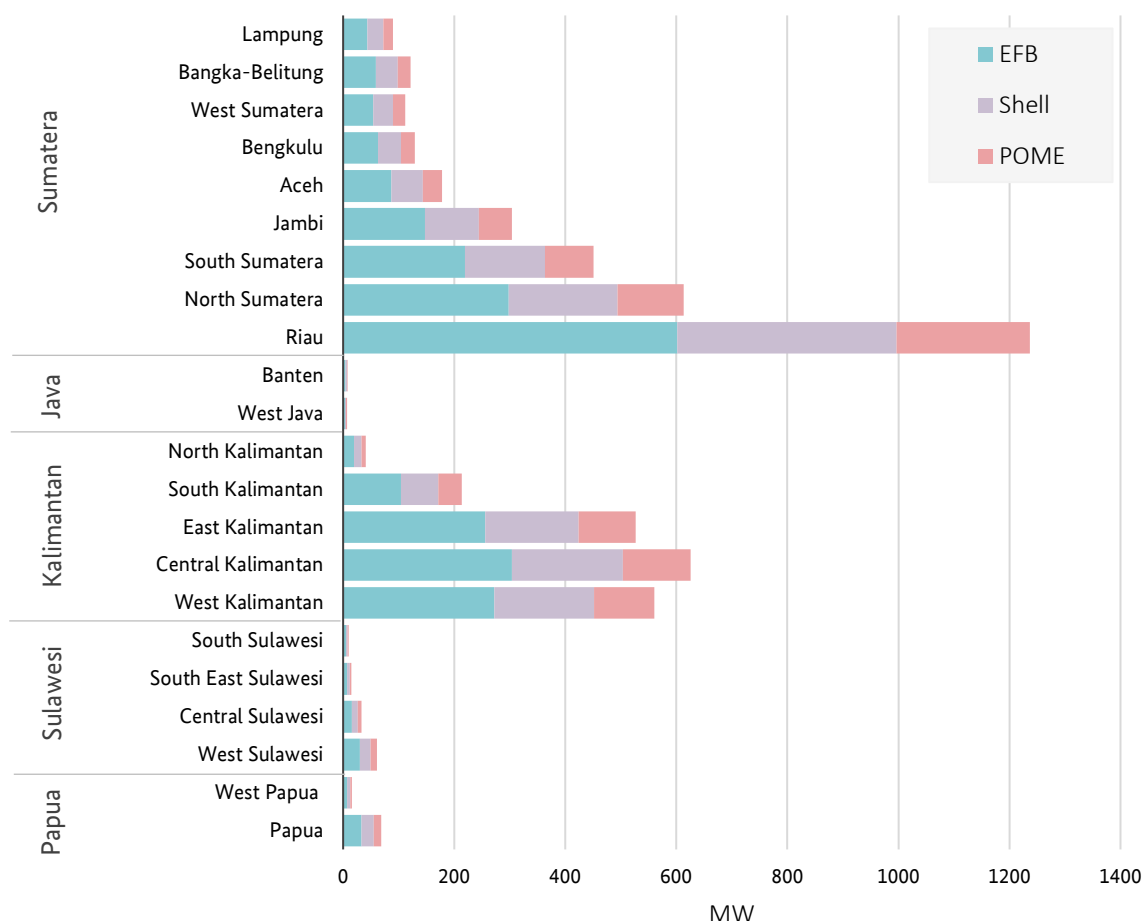
Based on our internal data, currently there are only seventy-three (73) palm oil mills in Indonesia that have utilized POME for biogas production (for heat and/or electricity generation) through anaerobic digester technology, especially in mills which produces CPO for European market. By implementing methane capture, the company will be able to get premium price that is validated through ISCC certification. Between 2000 – 2012, methane capture through POME biogas was also gaining popularity through Clean Development Mechanism (CDM).

Most Indonesian palm oil mills use open composting (*"mulsa"*) due to low investment cost. According to Minister of Environment Decree No. 28/2003, the wastewater utilization for land application must not exceed 5,000 mg/l of BOD₅. In conjunction with that, before it discharges to the land, generally the wastewater passed through several lagoons (aerobic & anaerobic lagoon) in order to reduce its organic content. Therefore, it requires large areas and also release high methane concentration to atmosphere, which is twenty (21) times more powerful greenhouse gas than carbon dioxide.

Based on estimation (detail is provided in Appendix 4 and Appendix 5), palm oil industry has total technical potential of **7.0 GW**. As rough estimate, a typical **60-tph** palm oil mill, has technical potential of **10 MW**, consisting of **1.6 MW** (from POME biogas), **4.1 MW** (from EFB combustion), **1.3 MW** (from MF combustion) and **3.0 MW** (from PKS combustion). However, since all mesocarp fibers and small portion of PKS are assumed to be used for internal consumption, the external-use potential from palm oil mill is estimated to be around **5.9 GW**. This potential consists of **19%** (from POME Biogas), **32%** (from shell combustion), and **49%** (from EFB combustion).

Furthermore, due to market competition (especially for solid biomass sources), biogas generation from POME is recommended to be the first developed. However, in areas where Palm Oil Mill is far from port, shell could also be interesting options for utilizations near the mill area since it is transportable.

Figure 7. External-use potential from palm oil mill wastes



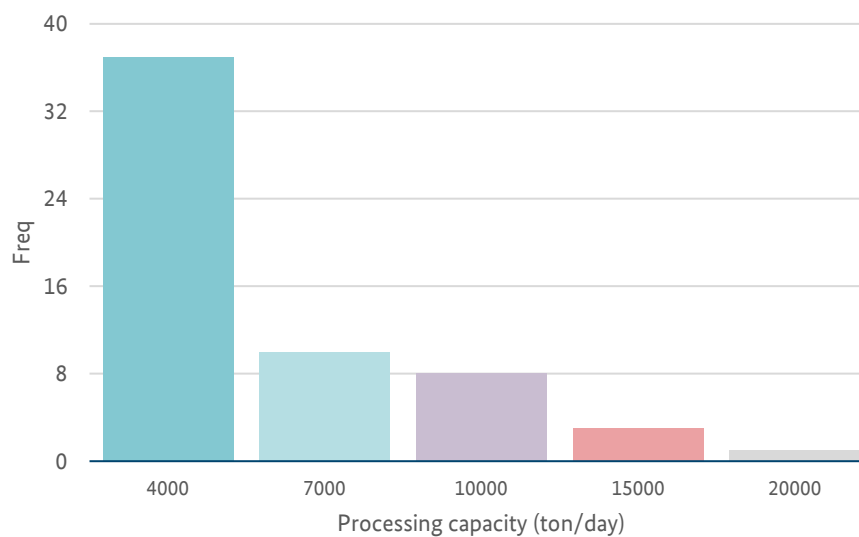
“Sugar Mill Tersana Baru,
PT PG Rajawali II”,
photo by GIZ



3.2. Sugar

Sugar industry has existed since the Dutch colonial period. Based on our database, currently Indonesia has fifty-seven (57) sugar mills which is operated by fourteen (14) companies. About 60% of the sugar mills is owned by PTPN (a state-owned enterprise running plantation business) and 73% are located in Java Island. Sugar mills are mostly located in areas where electricity is considered “cheap”. Sugar mill capacity distribution in Indonesia is illustrated in Figure 8.

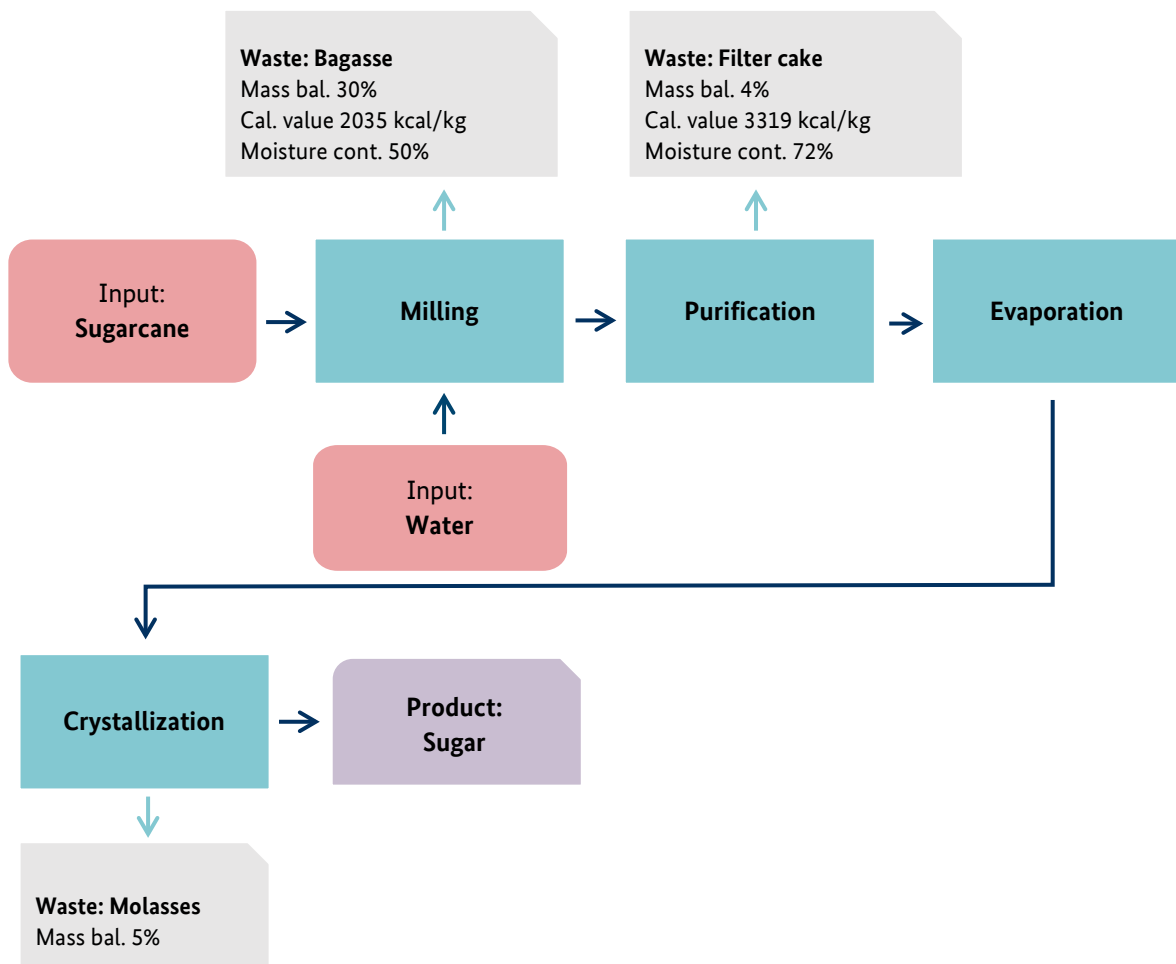
Figure 8. Sugar mill distribution in Indonesia ⁵



⁵ Based on available internal data that was compiled from various sources. Actual number might be different.

Sugar mill wastes consist of bagasse, filter cake, molasses as well as wastewater. Bagasse is the solid waste that comes from mill station (the extraction of sap). It has a mass balance of 30% of total weight of sugarcane. During the focus group discussion, the Chairman of Indonesia Sugar Association mentioned that most of bagasse in several locations have been used internally as feedstock for boiler. Since most of sugar mills are using obsolete technologies, the mill efficiency is significantly low. Thus, only small amount of bagasse is available. However, in new sugar mill with better efficiency, there will be more bagasse available for other utilizations, e.g., excess power. In addition, sugarcane is seasonal plant, thus, bagasse is not available all year long, which might not be applicable for IPP scheme which requires stable and continuous power supply. For simplified process flow in sugar mill, see Figure 9.

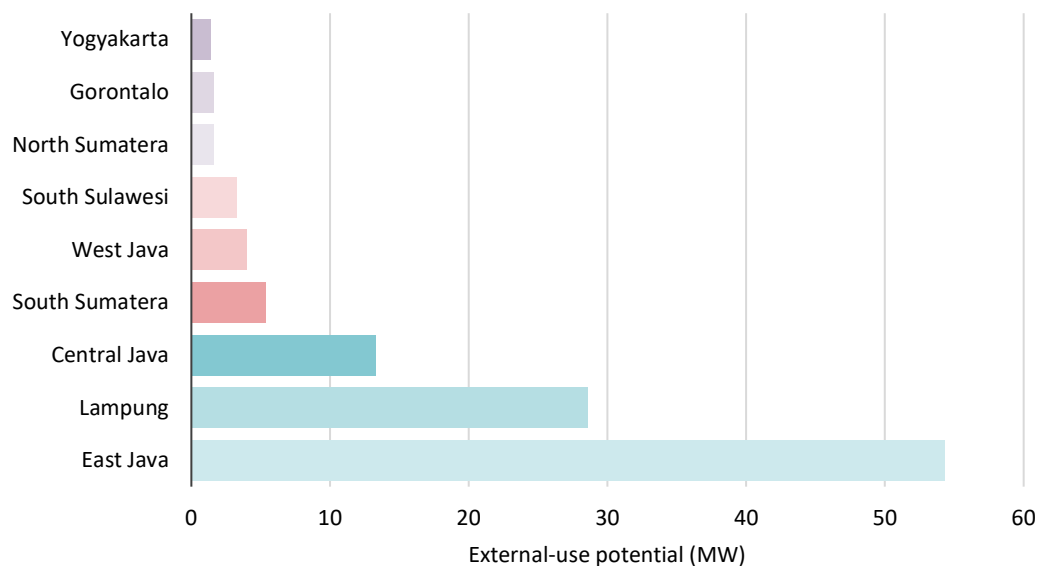
Figure 9. Simplified process flow for sugar mill and its wastes



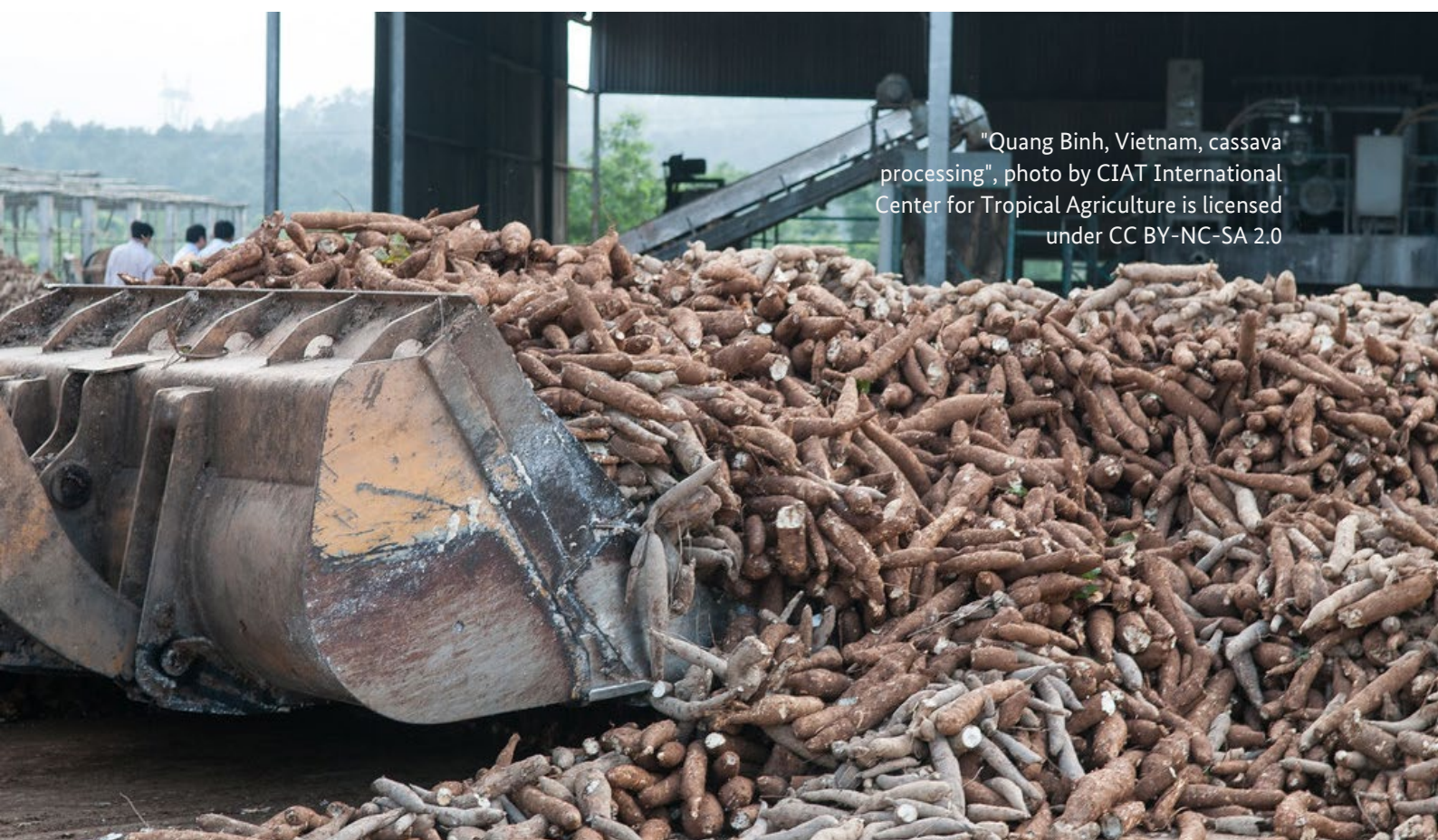
Filter cake (also called “*blotong*”) is solid waste that comes from the screening process (filtration). Currently, filter cake is mostly used by local community for cattle feed or raw material for organic fertilizer (composting). The molasses had been utilized for other products and some of them had been exported. But still significantly can be utilized for biogas generation and converted into electricity. Surprisingly, only few of the sugar mills had been utilized the wastewater for electricity generation.

In this study, only bagasse is considered as bioenergy potential due to its characteristic (calorific value) and availability. From fifty-seven (57) mills, it is estimated that total technical potential from sugar mill waste is around **452 MW**. Out of this amount, around **74%** has been used internally for boiler. Thus, external-use potential is calculated to be around **117 MW**. Since most of sugar mills are mostly located in areas where electricity is considered “cheap” (i.e., Java, Lampung, South Sumatera), with current regulatory framework, it might not economically attractive to sell the excess power to the grid. See Figure 10 for the electricity generation potential from sugar mill wastes distribution.

Figure 10. Electricity generation potential from sugar mill wastes

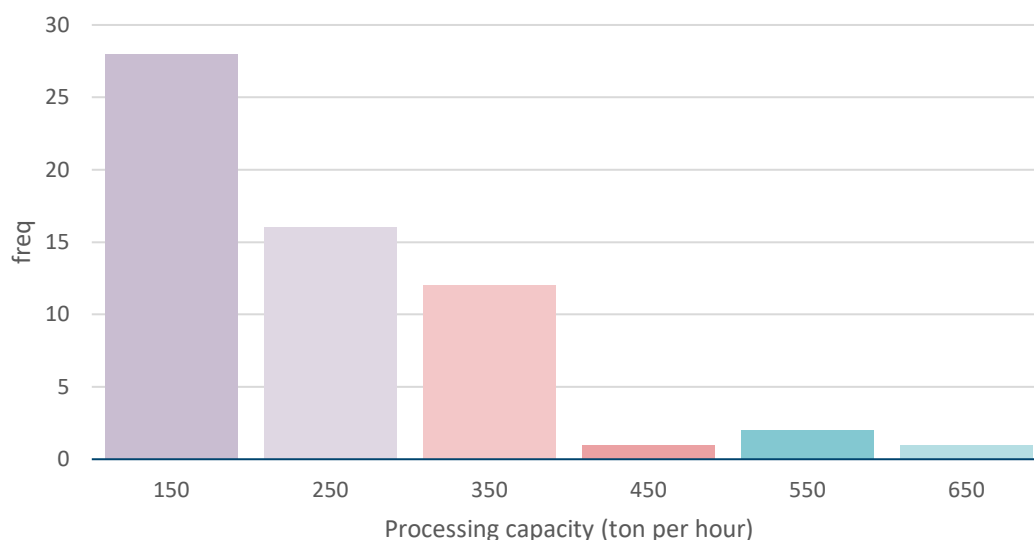


3.3. Tapioca



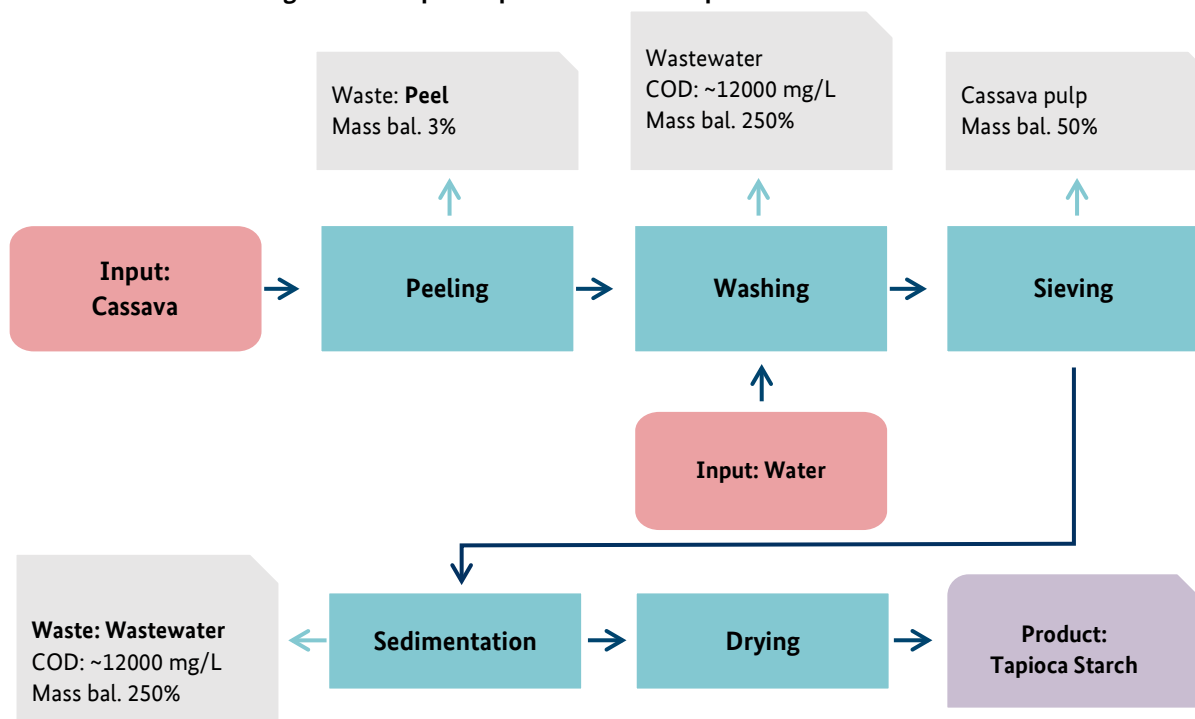
Indonesia is the world's fourth largest producer of tapioca. According to Bank of Indonesia's data in 2009, the production of tapioca starch in Indonesia is about 15 – 16 million tons every year. Most of tapioca mills are concentrated in Sumatra Island, particularly in Lampung Province where 78% of overall Indonesia's tapioca mills take place. To date, there are sixty (60) tapioca mills in Indonesia with the capacity above 45 tons tapioca starch/day (see Figure 11 for its capacity distribution).

Figure 11. Tapioca mill distribution in Indonesia ⁶



There are several main steps to produce tapioca starch (as shown in the Figure 12 below). During the process, large amount of liquid and solid waste cannot be avoided. Tapioca starch industries utilize extensive amount of water in washing and starch extraction process.

Figure 12. Simplified process flow for tapioca mill and its wastes



It is estimated that approximately 5 - 11 m³ of water required to produce one ton of tapioca starch and as much as 40 - 60 m³ of wastewater will be produced or around 5 times of cassava that being processed to produce tapioca. Moreover, peels and cassava pulp (or so-called "*onggok*"), that mostly consist of fiber and nutrient, are considered as solid waste generated.

Solid waste is not the case in the tapioca starch industry as it has been used by both industry and community. Take for instance cassava pulp, that has a mass balance of about 50% of the weight of cassava, it

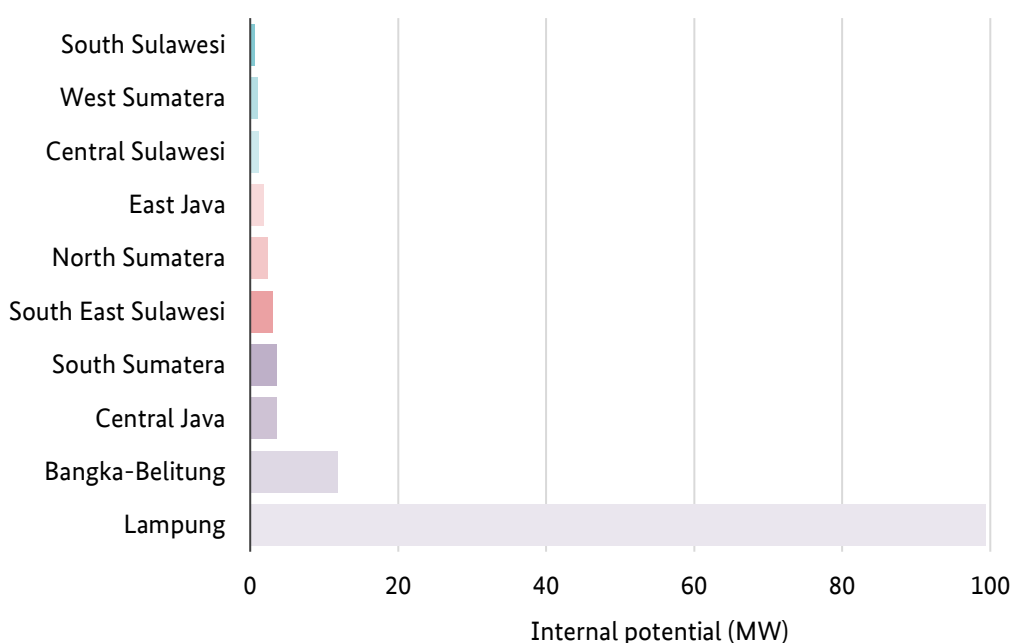
⁶ Based on available internal data that was compiled from various sources. Actual number might be different.

is commonly used as organic fertilizer, animal feed, and wheat flour substitute. In addition, mixing cassava pulp with wastewater through co-digestion is possible to produce higher amount of biogas, but it has not been applied yet in Indonesia.

Whereas large amount of wastewater does create environmental concerns since many of tapioca mills discharge their wastewater directly to the river. The fact that tapioca starch wastewater still having a high organic content (approximately between 10,000 to 12,000 mg/L of COD) make it becomes potential source for electricity generation through biogas power plant. In Lampung, there are already ten (10) projects utilizing wastewater as the feedstock to generate biogas to fulfil internal energy demand.

Unlike palm oil mill, tapioca starch mill is not energy self-sufficient, because the internal energy demand is higher than energy potential from its waste. Therefore, it is assumed that all wastewater that is processed to generate biogas is used to fulfil most of internal energy demand (internal-use potential), which results in zero external-use potential. The electricity generation potential from tapioca mill wastes can be seen in the Figure 13.

Figure 13. Electricity generation potential from tapioca mill wastes





“Rice Field in Bogor”, photo by GIZ

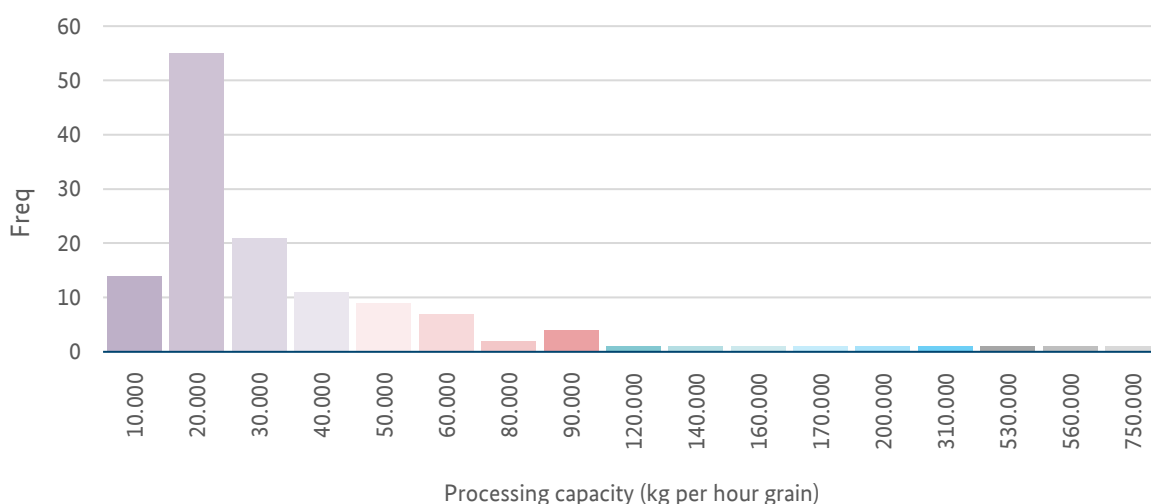
3.4. Rice

Indonesia is the third largest milled rice producer in the world according to United States Department of Agriculture (USDA) from 2018 - 2019 data, following India and China. In 2019 the production of milled dry grain reaches 54.6 million or it is equal to 31.3 million ton of rice. According to PERPADI (Indonesia Rice Association) data in Indonesia there are total 182,000 unit of rice mill with 2,000 large-scale mills, 8,000 medium-scale mills, and 172,000 small-scale mills. The classification of rice mills scale based on Ministry of Agriculture’s are as follows:

- (1) Small-scale mills (capacity < 1.5 ton/hour)
- (2) Medium-scale mills (capacity 1.5 - 3 ton/hour)
- (3) Large-scale mills (capacity > 3 ton/hour)

The above classifications provide further detail on in the following projection. Only large-scale mills with the capacity above 6.5 ton/hour had been estimated based on sufficient production capacity and working capital in managing the mill wastes for electricity generation prior to year 2025. Based on our database, currently Indonesia has a hundred and thirty-two (132) rice mills with the capacity above 6.5 ton/hour and most of them located in Java. The majority of rice mill capacity is ranging from 10 to 20 ton/hour. See Figure 14 for its capacity distribution.

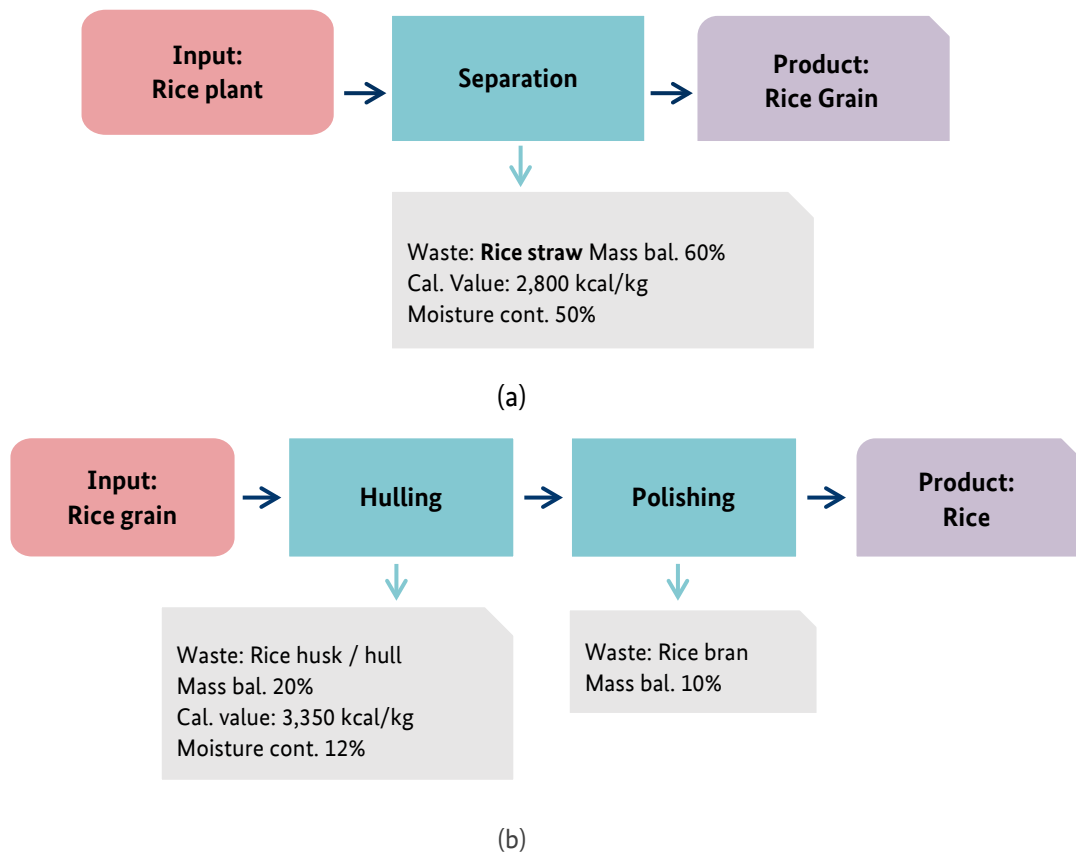
Figure 14. Rice mill processing capacity in Indonesia ⁷



⁷ Based on available internal data that was compiled from various sources. Actual number might be different.

Rice production resulted several by-products or wastes which can be utilized for energy and non-energy use. Rice straw is a by-product resulted from separation of rice plant and rice grain (see 1.1.1. Figure 1). It had been used mostly for animal feed and fertilizer. Rice husk is a by-product resulted from husking/hulling the rice grain which the main product of that process is head-rice and broken-rice (so-called “*beras kepala*” and “*beras patah*”). Rice husk had been sold to local community for heating up the brick workshops (especially in Java Islands), cattle bed lining, feed mixture materials, and the feedstock for boiler in industries. Rice bran is a by-product resulted from polishing the head and broken rice to produce white rice. Rice bran had been sold as food supplement as it is a good source of vitamin B, rich in mineral like magnesium and potassium, and it also can be sold as rice bran oil.

Figure 15. Simplified process flow for rice mill wastes

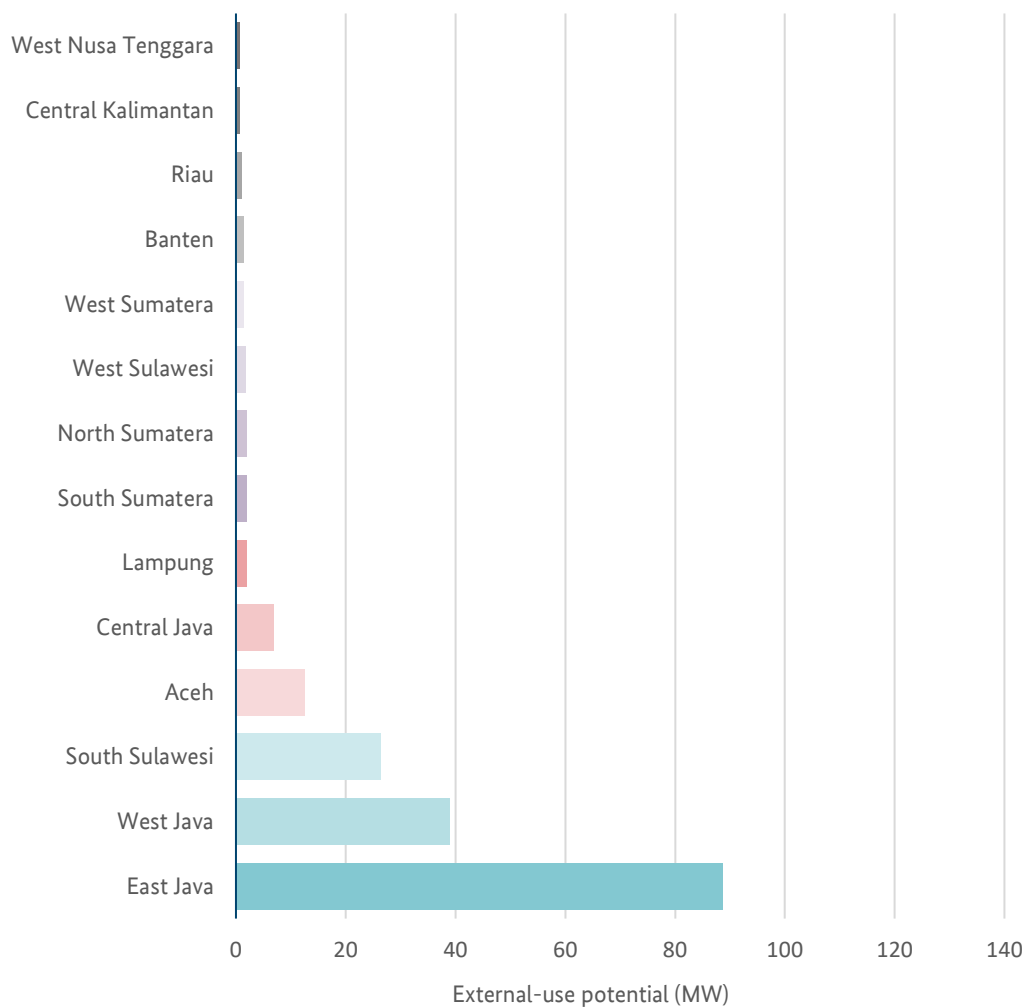


Although rice straw has the highest amount of volume compared with other by-product at the location source of rice straw made, it is not feasible as the source of electricity as it has to be transported from the paddy field to the power plant. Besides that, it has a lower calorific value and a higher amount of water content compared with rice husk. Higher water content made it needs further pre-treatment before entering the boiler. Therefore, rice husk is more suitable to be used as the energy source.

The result of the external-use potential of electricity generation coming from rice husk (see Figure 15). External-use potential is coming from technical potential deducted by internal rice mill electricity needs. Technical potential for rice mill is **284 MW** and for internal-use potential is **98 MW**. Heat is not considered in internal consumption calculation as there is no need for heat in rice milling process with the assumption rice grain already in dried form. In total, the electricity generation potential after deducted with internal consumption is relatively low, around **186 MW**.

The main contributor of this potential is coming from East and West Java province as those provinces has a high number of large-scale rice mills (see Figure 16).

Figure 16. External-use potential from rice mill wastes



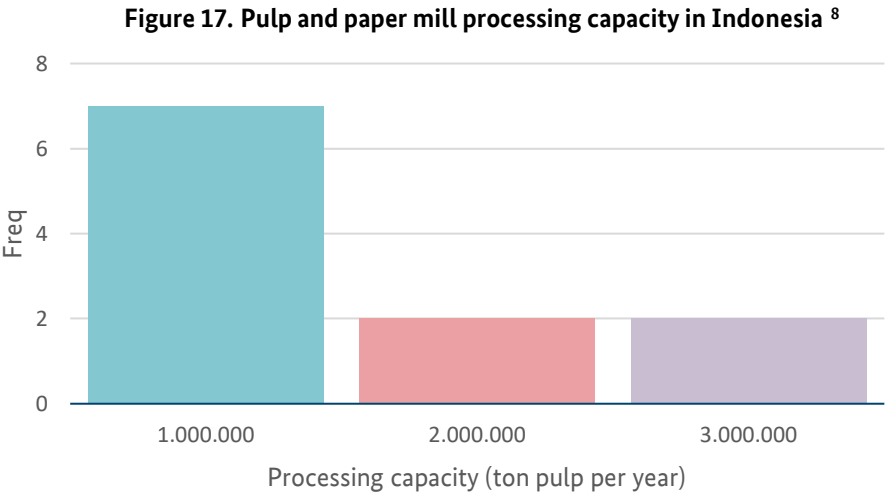


"J.D. Irving Pulp & Paper Factory 408 Mill Road Saint John New Brunswick (Canada) September 2017", photo by Ron Cogswell is licensed under CC BY 2.0

3.5. Pulp & Paper

Pulp & Paper Mill is one of energy intensive agroindustry with the average energy cost is around 16% of their production cost, in some cases might up to 30% depends on each factory efficiency itself (Roth et al., 2016). In 2019, pulp production Indonesia reaches 11 million ton per year and paper production reaches 16 million ton per year. It made Indonesia the ninth largest pulp producer and sixth largest pulp producer in the world. In 2018, pulp and paper industry contribute quite significant for national economic, it contributed 17.6% to the non-oil and gas processing industry and 6.3% to GDP of national processing industry.

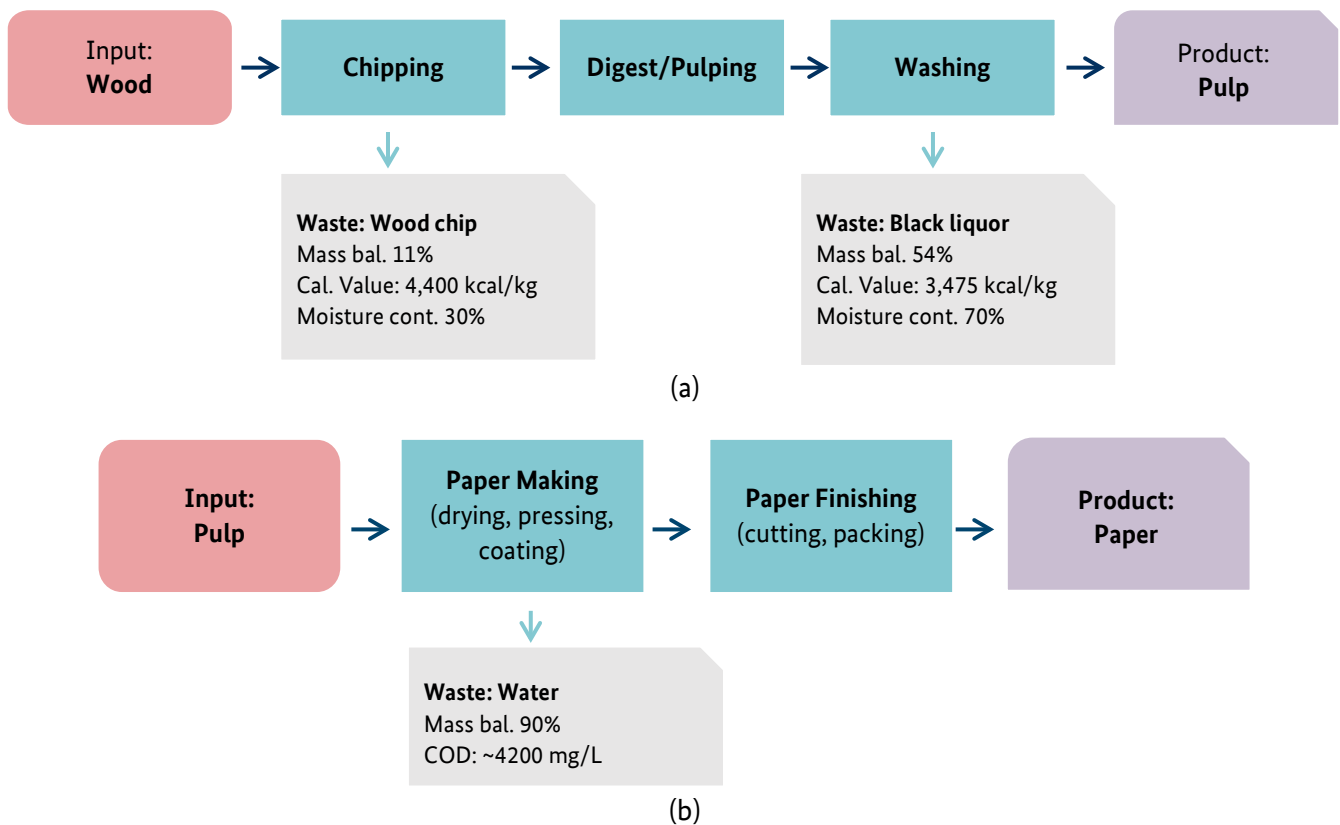
Based on our database, currently Indonesia has eleven (11) pulp & paper mills which most of them is located in Sumatra Island, while others are located in Java and Kalimantan. The capacity of every mill is different with each other ranging from 16,000 tons pulp/year capacity for mill located in West Java to around 2.5 million tons pulp/year capacity for mill located in Riau. The majority of pulp and paper mill capacity is ranging from 16,000 to 1,000,000-ton pulps per year (see Figure 17).



⁸ Based on available internal data that was compiled from various sources. Actual number might be different.

Pulp and paper production resulted several by-products or wastes which can be utilized for energy and non-energy use. Wood waste is a residue coming from chipping the wood log (see Figure 18), the ratio of wood waste and pulp are approximately 300 kg/ton pulp or 11% from the input. Wood waste had been used for making fiberboard, particle board, and use internally for producing heat (with drier or boiler) and/or producing electricity.

Figure 18. Simplified process flow for pulp and paper mill and its wastes



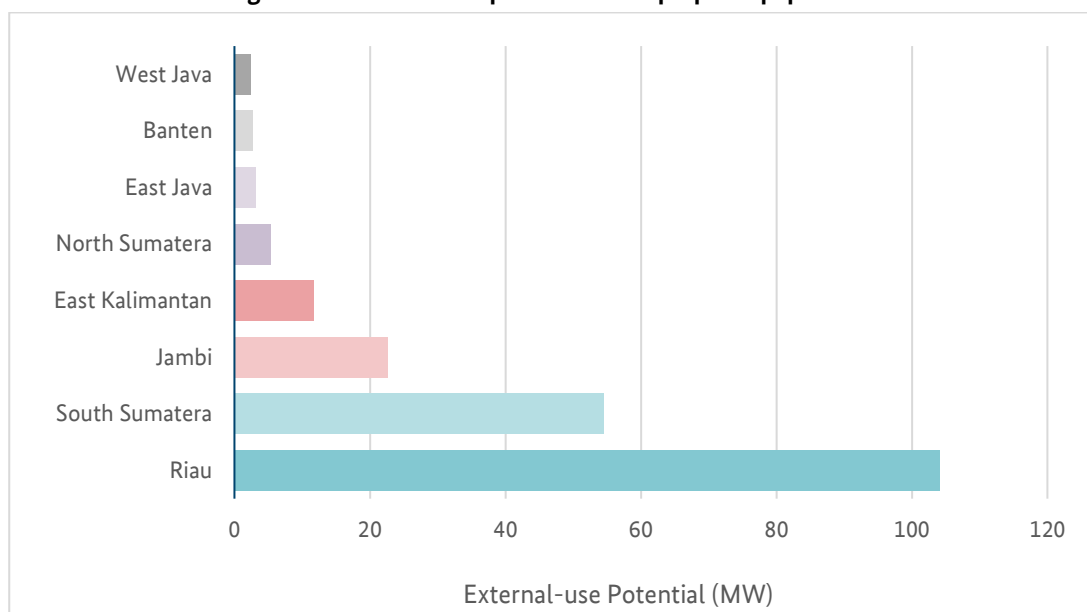
Pulp and paper production resulted several by-products or wastes which can be utilized for energy and non-energy use. Wood waste is a residue coming from chipping the wood log, the ratio of wood waste and pulp are approximately 300 kg/ton pulp or 11% from the input. Wood waste had been used for making fiberboard, particle board, and use internally for producing heat (with drier or boiler) and/or producing electricity.

Black liquor is a by-product resulted from digesting process converting wood into wood pulp, washing aims to separate pulp and black liquor. Black liquor has been used internally for producing heat (using a special gasifier engine) and/or producing electricity as it has high calorific value and high amount of black liquor can be generated in one production cycle, the ratio of black liquor and pulp produced are approximately 1,500 kg/ton pulp or 54% from the input.

The result external-use potential of electricity generation coming from pulp and paper mills wastes can be seen in Figure 19 below. External-use potential is coming from technical potential deducted by internal heat and electricity needs. In total, although the technical potential from pulp and paper mill wastes is high which is around **7.5 GW**, however the internal needs also very high which is around **7.3 GW**. Therefore, the electricity generation potential after deducted with internal consumption is relatively low which is around **207 MW**.

The main contributor of this potential is coming from Riau province as in Riau there are two big pulp and paper mill with the capacity each of them is above 2 million tons pulp per year (see Figure 17).

Figure 19. External-use potential from pulp and paper mill wastes



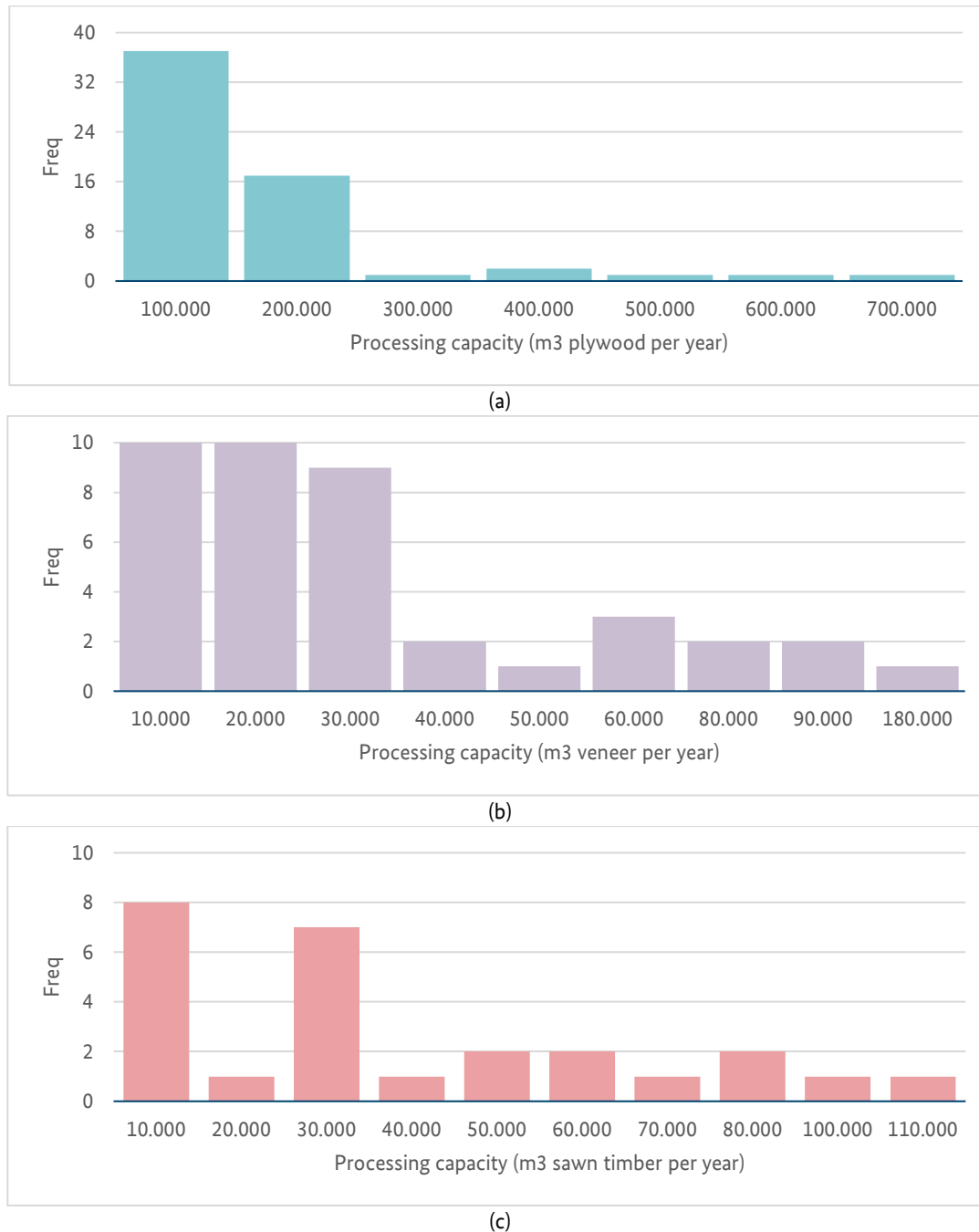
3.6. Wood

Indonesia wood processing industry holds important role in world wood product as in 2018 Indonesia is the third biggest plywood exporter in the world following China and Russia (Global Trade Magazine, 2019). The major destination country of Indonesia wood processed products is China, Japan, USA, European Union countries, and Korea. The total export value of Indonesia wood product reach 11.6 billion USD in 2019, contribute to around 7% of total Indonesia export value (Kontan, 2020).



"Wood Factory Mill, Hong Kong", photo by cesarharada.com is licensed under CC BY-NC-SA 2.0

Figure 20. Wood mill processing capacity in Indonesia: plywood (a), veneer (b), sawn timber (c) ⁹



Based on our database currently Indonesia has sixty-four (64) wood mills which produce plywood and/or sawn timber, some of them also produce veneer (see Figure 20 for the complete distribution). About 28% of them is located in East Kalimantan, about 13% in East Java, and about 11% in South Kalimantan. The remaining mills are distributed from North Sumatra till Papua. These mills are processing wood logs and wood barks from the surrounding industrial forests and private-ownership lands (a land with the “APL” certificate). The wood mill capacity for each product (plywood/veneer/sawn timber) are ranging. The majority of plywood production capacity is ranging from 2,000 to 100,000 m³ plywood/year, for veneer is ranging from 400 to 10,000 and 10,001 to 20,000 m³ veneer/year, for sawn timber is ranging from 1,000 to 10,000 m³ sawn timber per year.

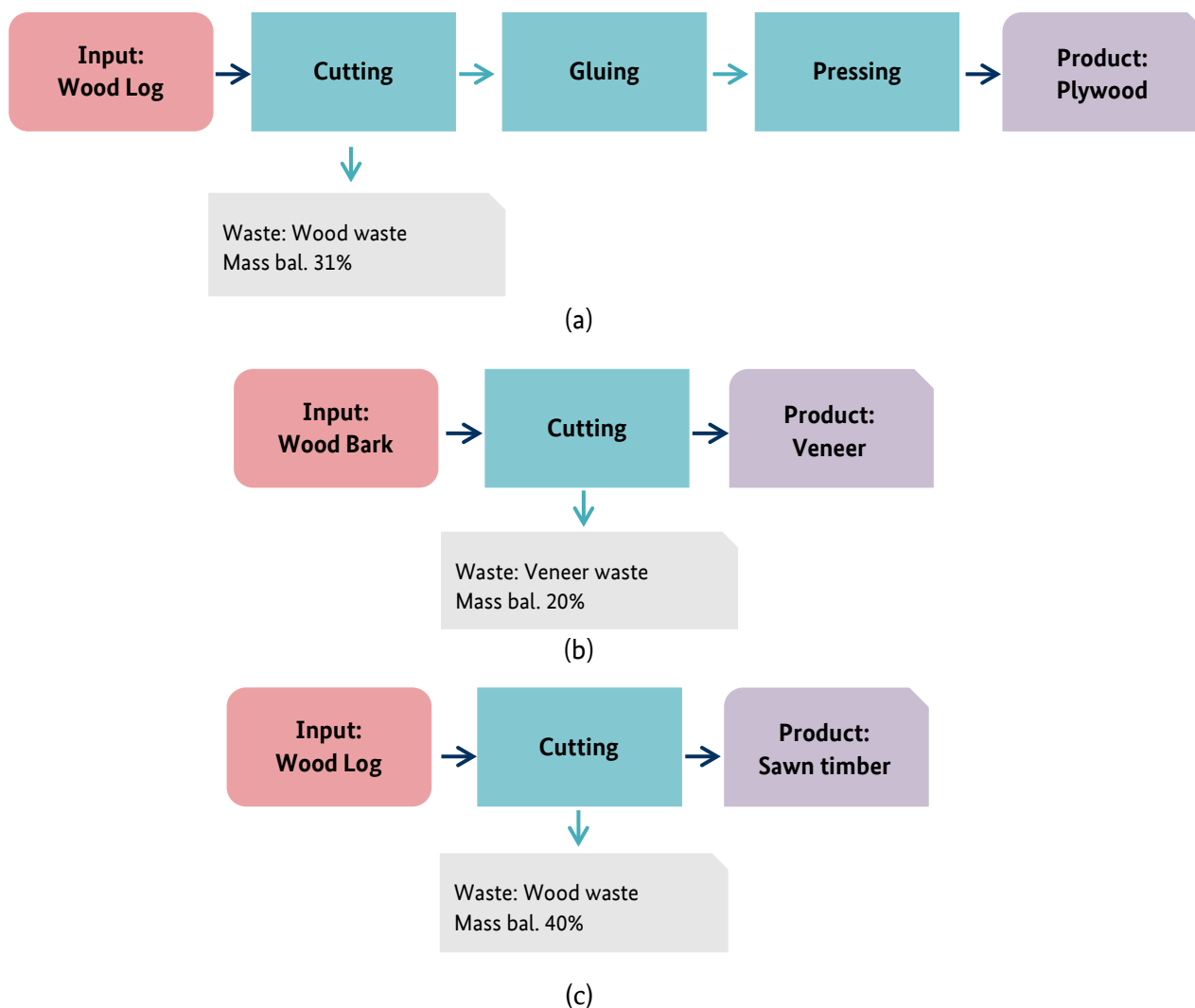
The main by-product of wood processing industry is wood waste itself, approximately 31% wood waste from plywood production, 20% veneer waste from veneer production, and 40% wood waste from sawn timber

⁹ Based on available internal data that was compiled from various sources. Actual number might be different.

production (see Figure 21 for the complete process flow). This number might be less accurate as every mill might have their own way to process their waste, some had been used it for their production as well, such as producing fiberboard, particle board, home furniture and goods (e.g. chair, trash bin, etc.).

Some industries who purchase the wood in wet form use the wood waste to heat up the boiler to dry the wood log, others also processed the wood waste to become wood pellet that also can be used as a feedstock for boiler. However, in this study the assumption is wood log that used is already in dried form, therefore almost no internal need allocation for heat.

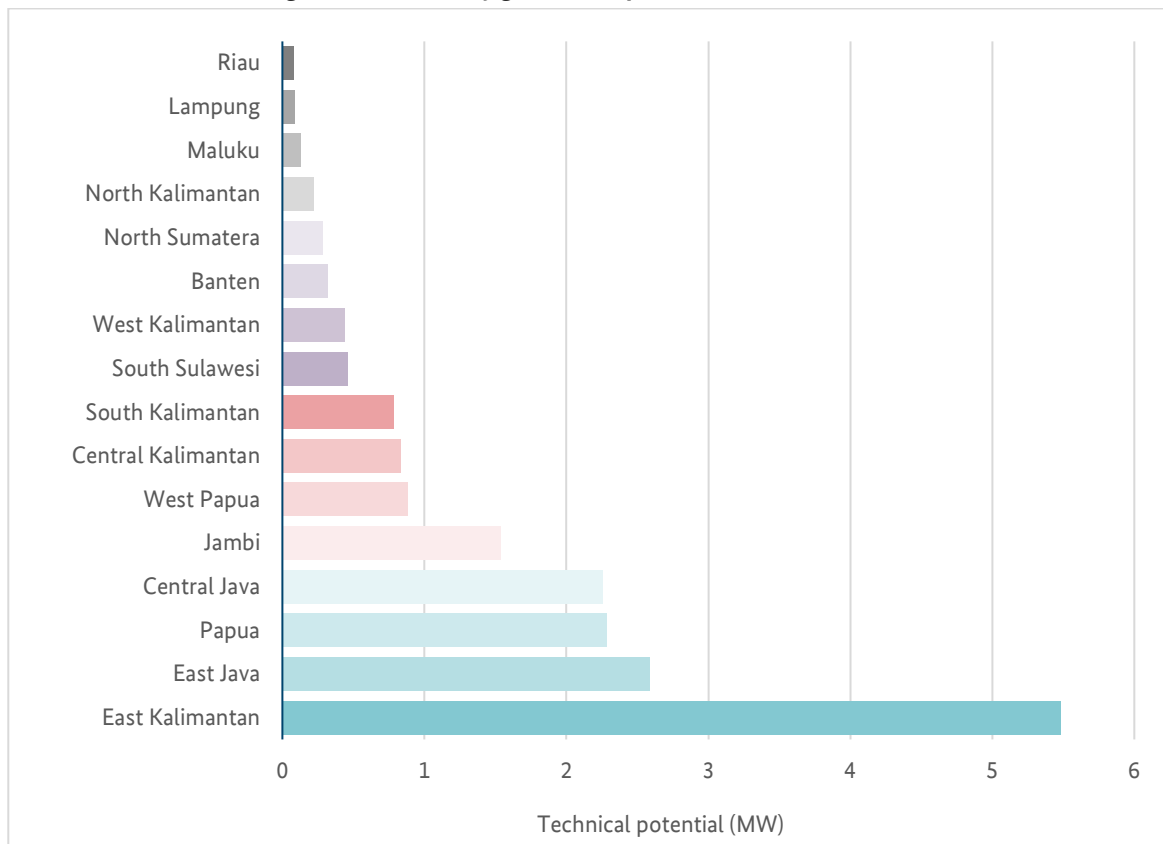
Figure 21. Simplified process flow for wood mills and its wastes: plywood (a), veneer (b), sawn timber (c)



Note: All waste has calorific value at 4400 kcal/kg and moisture content level at 15%

The result of external-use potential of electricity generation coming from wood mills waste can be seen in Figure 22. External-use potential is coming from technical potential deducted by internal electricity needs, for the internal potential in this study only consider electricity needs as not all wood industry purchase wood in wet form and not all wood industry has boiler and drier to dry the wood log. In total, although the technical potential from wood mill waste is quite high which is around **169 MW**, however the internal needs also very high which is around **150 MW** (nearly 90% for internal electricity). Therefore, the electricity generation potential after deducted with internal consumption is very low which is only around **19 MW**.

Figure 22. Electricity generation potential from wood mill wastes



3.7. Summary of Bioenergy Potential

Considering the number of mills, common utilizations as well as technology conversion, it is estimated that the overall bioenergy technical potential from agro-industrial wastes is around **15.6 GW**. Most of this number is considered as internal potential for captive use (around **9.2 GW**). Thus, it results in **6.4 GW** bioenergy external-use potential available for external utilizations (see Table 2).

In total, pulp and paper waste have the highest bioenergy technical potential. However, most of the potential is commonly utilized for meeting internal energy demand (approximately **97%**). Similar trends can be seen in wood, sugar, and tapioca industry where most or all bioenergy potential is used for meeting internal energy demand. In contrary, it is estimated that there is still a considerable amount of bioenergy external-use potential in palm oil industry, even though there are already competing markets (domestic and export), especially for shell.

Table 2. Summary of bioenergy potential by agro-industries (in MW)

Sources	Technical potential (MW)	Internal-use potential (MW)	External-use potential (MW)
Palm Oil	7046.7	1121.0	5925.7
EFB	2895.9	0.0	2895.9
Fiber	934.9	934.9	0.0
POME	1130.5	0.0	1130.5
Shell	2085.4	186.1	1899.3
Pulp and Paper	7563.8	7357.1	206.7
Pulp and Paper Waste	7563.8	7357.1	206.7
Rice	283.6	97.9	185.7
Rice Husk	283.6	97.9	185.7
Sugar	451.5	334.4	117.1
Bagasse	451.5	334.4	117.1
Tapioca	127.6	127.6	0.0
Wastewater Tapioca	127.6	127.6	0.0
Wood	168.5	149.7	18.8
Wood waste	168.5	149.7	18.8
Total	15,642	9,188	6,454

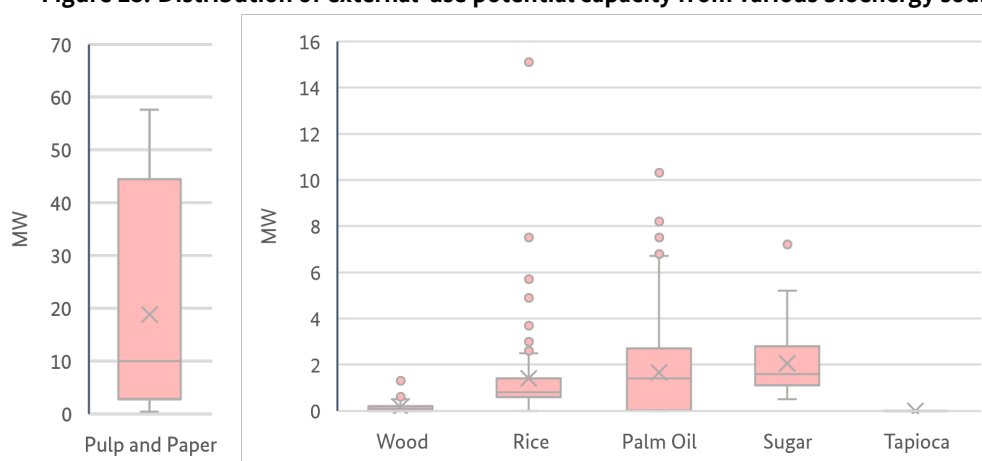
*Note: Based on internal available data, actual number might be different

The range of external-use potential:

- (1) **Palm oil:** there are many mills but relatively small electricity generation potential (mostly between 1 to 14 MW per mill). Feasible for dedicated power supply to the grid with a Long-term PPA Contract between IPP and PLN, using palm kernel shell and EFB or POME.
- (2) **Pulp and paper:** there are few mills but relatively huge electricity generation potential (mostly between 1 to 50 MW per mill). Single type of waste and it has been commonly used for internal. Feasible for additional power supply to the grid with an Excess Power PPA Contract to PLN.

- (3) **Sugar:** there are several mills but relatively small electricity generation potential (between 500kW to 5 MW). The only remaining wastes is bagasse. Feasible for additional power supply to the grid with an Excess Power PPA Contract to PLN.
- (4) **Rice:** there are many mills but relatively small electricity generation potential (between 500 kW to 2 MW per mill). Feasible for dedicated power supply to the grid with a Long-term PPA Contract between IPP and PLN, using rice husk.
- (5) **Wood:** there are several mills but relatively small electricity generation potential (between 100 kW to 1 MW per mill). Feasible for dedicated power supply to the grid with a Long-term PPA Contract between IPP and PLN, if mix with other biomass sources.
- (6) **Tapioca:** there are several mills, but all of the wastes assumed to be used internally. Thus, there is no electricity generation potential from tapioca mills.

Figure 23. Distribution of external-use potential capacity from various bioenergy sources



Bioenergy external-use potential (see Figure 23 for its distribution by source) is available across Indonesia which provides opportunity to utilize it for external energy demand. Sumatera is the region with the highest bioenergy external-use potential (approximately **4.0 GW**) and mainly contributed by palm oil and pulp and paper industries. Jawa-Bali region has about **238 MW** bioenergy external-use potential mainly from sugar and rice industries. Kalimantan region is the second largest bioenergy resources with external-use potential about **1.99 GW**, mainly consists of palm oil industry. Sulawesi has **145 MW** bioenergy external-use potential, mainly from palm oil and rice industries. Finally, Nusa Tenggara, Maluku and Papua have bioenergy external-use potential about **99 MW**, mainly from palm oil and wood industry. The summary of bioenergy external-use potential by provinces & its agro-industry source are shown in Table 3.

Table 3. Summary of bioenergy external-use potential by provinces & agro-industries (in MW)

Province	Palm Oil	Pulp & Paper	Rice	Sugar	Tapioca	Wood	Total
Sumatera	3746.8	186.5	20.9	35.4	-	2	3991.6
Aceh	175.3	-	12.5	-	-	-	187.8
Bangka-Belitung	121.5	-	-	-	-	-	121.5
Bengkulu	128.8	-	-	-	-	-	128.8
Jambi	303.6	22.7	-	-	-	1.5	327.8
Lampung	90	-	2	28.5	-	0.1	120.6
North Sumatera	627.5	5.3	2	1.6	-	0.3	636.7
Riau	1737.9	104	1.1	-	-	0.1	1843.1

4. Economic Analysis

In this chapter, the bioenergy power generation from agro-industrial wastes was evaluated from economic point of view. The economic aspects of two main technologies: biogas anaerobic digestion and biomass combustion using various feedstocks as described in Chapter 3 had been discussed. The analysis is based on generation cost calculation method of PLN.

4.1. Calculating Generation Cost

Generation cost of bioenergy power plants is calculated using the PLN's method, which consists of five (5) main components: Component A (Capital Cost), Component B (Fixed cost for Operation and Maintenance), Component C (Feedstock or Fuel Cost), Component D (Variable Cost for Operation & Maintenance) and Component E (Transmission Cost - optional if the power plant location is far away from the PLN' electrical substation).

4.1.1. Component A

Capital cost is the total investment cost for the power plant, starts from project development until construction. It consists of land purchase, pre-treatment facilities, bioreactor (for biogas), boiler (for biomass), gasifier (for biomass), and engines (gas engine for biogas, and syngas engine or steam engine for biomass). The engineering cost since planning phase and also interest rate during construction are included in the Component A.

Based on our expert's experience, conventional boiler system-steam turbine could be used for solid agro-industrial wastes. The investment value for this system is approximately at USD 1.6 million/MW. For EFB, however, it needs a special boiler design (to avoid corrosion and clogging issues) which increased the investment value to a minimum at USD 2 million/MW (including the steam turbine unit). For liquid agro-industrial wastes, biogas system would cost around USD 2.2 million/MW.

4.1.2. Component B

Some of the Operation & Maintenance (O&M) values are fixed costs. No matter how much power being generated, it depends only on the type of fuel, capacity of powerplant and the applied technology. The fixed O&M costs are management cost, employee & operator salary, administration cost, and maintenance cost.

Maintenance cost can be fixed cost and variable cost. It is a fixed cost if the calculation is based on the machinery's component, the equipment's lifetime, or operating hour. Then the value of total fixed cost for O&M divided by the annual amount of generated power (in kWh).

4.1.3. Component C

Feedstock supply is one of the key success factors for bioenergy power plant. In general, the liquid waste is used on-site or just located next to the mill location. On the other hand, the solid waste is transportable and most of the time needs a pre-treatment. Fuel cost is categorized as variable cost, which always related to the generated power. The influence factors to be considered are: (1) The consumption rate; (2) characteristic of feedstock; and (3) the price per unit of feedstock. Each kind of fuel has a different caloric value and heat rate. The combination of heat rate and feedstock (or fuel price) will generate the final feedstock (or fuel value).

There are several options to ensure sustainable feedstock supply, such as establishing long-term feedstock supply contract which ensure price, quality and delivery; sourcing alternative feedstock supplier; negotiating with utility regarding seasonality of the feedstock; as well as inviting mill owner to be one of the shareholders of project developer.

Therefore, following factors will be considered when assessing component C:

- (1) Location of feedstock (need for transport), only if power plant is not located on or near agroindustry mill.

- (2) Feedstock availability, especially for seasonal agroindustry, such as sugar
- (3) Feedstock quality, in terms of water content, calorific value, and the need for pre-treatments, and
- (4) Feedstock price, only if mill owner is not or not shareholder of project developer.

The Component C of the biomass and biogas power plants which have significant distance (>50 km) with their mills can be calculated as follows in Table 4.

Table 4. Cost breakdown of Component C in biomass and biogas power plants (feedstock cost)

Feedstock	Phase	Energy content*	Details of Component C (Rp / kWh)					Total with transport	Total without transport
			Unit Price	Transport	Material Handling	Pre-Treatment	Storage	(Rp / kWh)	(Rp / kWh)
Tapioca Liquid Waste	Liquid	4.800 - 6.700	-	-	-	-	25	25	25
POME	Liquid	4.800 - 6.700	-	-	-	-	25	25	25
Bagasse	Solid	3,441	105	70	28	21	14	238	168
Rice Husk	Solid	3,568	105	70	42	49	14	280	210
Wood Waste	Solid	4,400	220	44	33	6	11	314	270
Pulp & Paper Waste	Solid	3,568	220	44	33	6	11	314	270
Fiber	Solid	2,710	180	54	54	18	18	324	270
EFB	Solid	1,441	80	96	96	160	32	464	368
Shell	Solid	4,502	330	33	22	11	11	407	374

*Note: Solid waste in kcal/kg and liquid waste in kcal/m³

4.1.4. Component D

Variable cost for Operation & Maintenance (O&M) is the production related costs which vary to (or related to) the generated power, such as: raw water, industrial water, lubricants, consumable materials, and supplies.

4.1.5. Component E

Most of agro-industrial mills are located far away from the main grid line. Thus, if a bioenergy power plant will be built in these locations, the 20 kV grid line to connect to PLN's grid need to be developed. The responsibility for developing this grid line, is decided on Business-to-Business (B2B) basis between project developer and PLN.

As rough estimate, If the distance to main grid line is more than ten (10) km, the bioenergy power plant is not feasible anymore, since:

- (1) Investment for the 20 kV grid will be very high; Estimated additional cost of USD 30,000/km, thus 10 km x USD 30,000/km = USD 300,000.
- (2) Huge losses of energy at the 20 kV grid line (due to the long distance).

4.2. Cost of Goods Sold (COGS)

In this calculation, the Cost of Goods Sold (COGS) is the sum of Component A, Component B, Component C, and Component D. While the Component E (Transmission Cost) may be neglected since most of the proposed sites that will be near to the grid (at least less than 5 km).

The COGS of the produced electricity can be calculated as can be seen in Table 5 below. The COGS (in Rp/kWh) using boiler system-steam turbine and biogas system-biogas engine are competitive compared to PLN's tariff. Between the two systems, the cost of electricity produced by biogas system is cheaper than by boiler system for commodities: EFB, PKS, Fiber, and wood waste. Especially for bagasse and rice husk, the cost for electricity generation by boiler system is cheaper than by biogas system.

COGS is calculated using following assumptions:

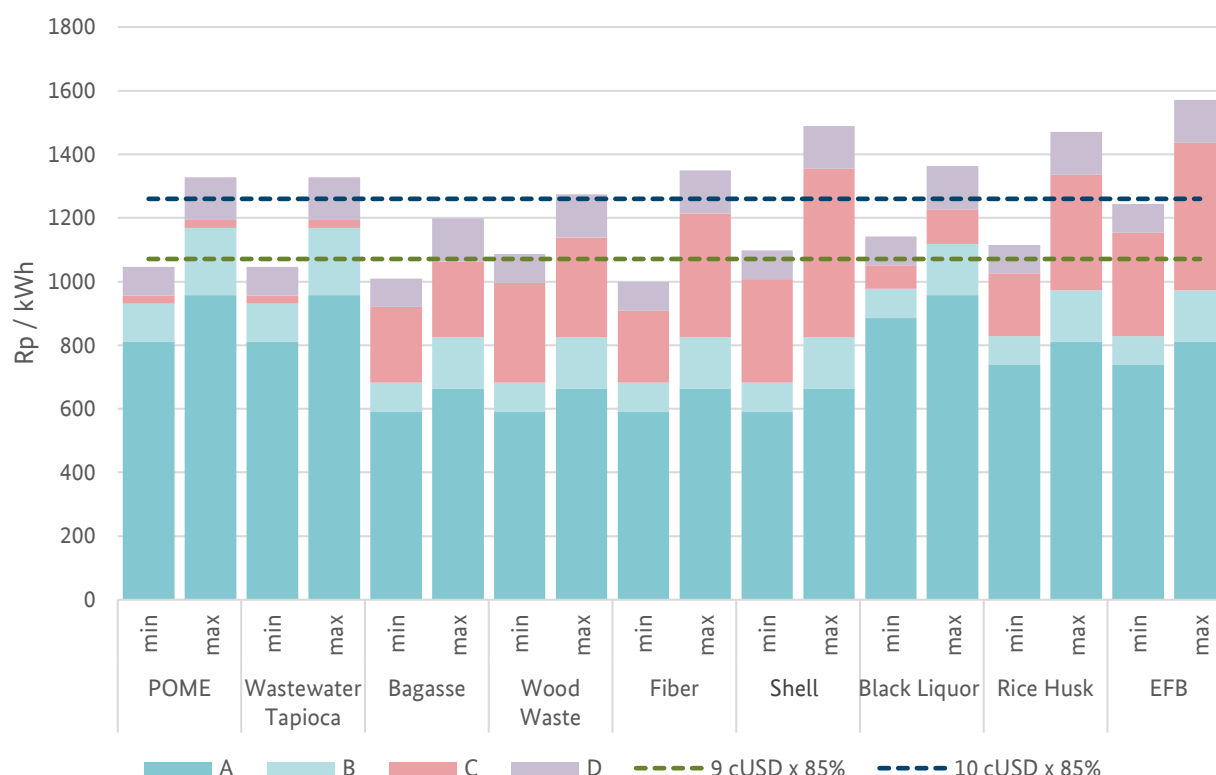
- (1) The investment value for biomass is USD 1.6 million/MW
- (2) The investment value for biogas is USD 2.2 million/MW
- (3) The calculation is fixed with the interest rate of 10%
- (4) The COGS is not including profit
- (5) The currency rate is Rp 13,500/USD

Table 5. Projected (min & max) of COGS for each feedstock

Feedstock		Component				COGS	
		A	B	C	D	(Rp/kWh)	(USD/kWh)
POME	min	811	120	25	90	1,046	0.075
	max	958	210	25	135	1,328	0.095
Wastewater Tapioca	min	811	120	25	90	1,046	0.075
	max	958	210	25	135	1,328	0.095
Bagasse	min	590	92	238	90	1,010	0.072
	max	664	161	238	135	1,198	0.086
Wood Waste	min	590	92	314	90	1,086	0.078
	max	664	161	314	135	1,274	0.091
Fiber	min	590	92	227	90	999	0.071
	max	664	161	389	135	1,348	0.096
Shell	min	590	92	326	90	1,098	0.078
	max	664	161	529	135	1,489	0.106
Black Liquor	min	885	92	74	90	1,140	0.081
	max	958	161	109	135	1,364	0.097
Rice Husk	min	737	92	196	90	1,115	0.080

Feedstock		Component				COGS	
		A	B	C	D	(Rp/kWh)	(USD/kWh)
	max	811	161	364	135	1,471	0.105
EFB	min	737	92	325	90	1,244	0.089
	max	811	161	464	135	1,571	0.112

Figure 24. Cost of Goods Sold (COGS) components of bioenergy power plants compared with 85% BPP



Based on the latest relevant regulation (MEMR Regulation No. 4/2020, replacing MEMR Regulation No. 50/2017 and No. 53/2018) and PLN's generation cost (MEMR Decree No. 55/2019), development of biogas and biomass power plants using IPP scheme will only be economically feasible for a province which has the BPP around USD 9 cent / kWh (for bagasse & fiber, see Figure 24) and around USD 10 cent/kWh (for Palm Kernel Shell, wood waste and Tapioca or POME biogas power plant as in Figure 24).

Thus, based on this scheme, most of external-use potential will not be realized. Contrary to this, biogas and biomass power plants provide additional economic benefit for mill owners, in the efforts of cost saving, increasing efficiency as well as contribution to CO₂ reduction.

4.3. Sensitivity Analysis

The COGS of biomass power plant is sensitive to:

- (1) **Component A:** which depends on interest rate and currency rate (mostly in USD).
- (2) **Component C:** which can vary based on a specific value of Component A (using specific technology for biomass with high alkali content), distance from the biomass power plant's location to the feedstock, and based on fluctuate price of the agro-industrial wastes (e.g. Palm Kernel Shell, that difficult to control in these decades)

While the COGS of Biogas power plant is sensitive to Component A that influenced by interest rate and currency rate (mostly in USD). As it can be seen in Table 6, the calculation of Component A (Rp/kWh) is presented as the function of investment values (USD/MW) and interest rates (%). Some assumptions are listed as follows:

- For boiler, Component A: USD 1.6 million/MW (except for EFB)
- For biogas, Component A: USD 2.2 million / MW
- Interest rate: between 8 – 12%

Table 6. Variation of interest rates of Component A (in IDR/kWh)

Investment Value (USD)	Interest Rate				
	8%	9%	10%	11%	12%
3,200,000	1,106.03	1,142.55	1,179.59	1,217.13	1,255.19
3,000,000	1,036.91	1,071.15	1,105.86	1,141.06	1,176.74
2,800,000	967.78	999.74	1,032.14	1,064.99	1,098.29
2,600,000	898.65	928.33	958.41	988.92	1,019.84
2,400,000	829.53	856.92	884.69	912.85	941.39
2,200,000	760.40	785.51	810.97	836.78	862.94
2,000,000	691.27	714.10	737.24	760.71	784.49
1,800,000	622.14	642.69	663.52	684.64	706.04
1,600,000	553.02	571.28	589.79	608.57	627.59

5. Demand Analysis

5.1. Meeting Bioenergy Demand in RUPTL

As described in Chapter 3, most of the bioenergy potentials are realised as captive utilizations. From **1.8 GW** existing bioenergy power plants, **80%** are captive power utilizations using operational permit (so-called “*Izin Operasi*”) scheme. However, there are still a huge amount of untapped bioenergy potential. Thus, exporting the excess energy to utility’s grid is one of the most feasible options, which gives additional economic benefits to mill owners, provides CO₂ saving potential as well as help government increase renewable energy’ share in the energy mix.

PLN has planned to add **460 MW** of bioenergy power plants (excluding municipal waste and biofuel power plants) until 2028. Most of the bioenergy power plants are planned in Aceh (**150 MW**), West Kalimantan (**69 MW**), East Java (**50 MW**) and Maluku (**46 MW**). By 2019, these provinces have local generation cost of **Rp 1,673 /kWh**, **Rp 1,525 /kWh**, **Rp 989 /kWh**, and **Rp 2,971 /kWh**, respectively. Thus, bioenergy power plants will be more economically attractive to be developed outside Java island, where generation cost is relatively higher.

Specifically, bioenergy sources, which are not used for meeting internal electricity demand (e.g. palm kernel shell, POME, EFB, pulp and paper waste, and rice husk), can be encouraged for dedicated bioenergy power plants using IPP scheme. While bioenergy sources which are commonly used to fulfil internal electricity demand (wood waste, bagasse, and tapioca wastewater), excess power scheme is encouraged, which gives flexibility for mill owners as well as utility.

“PLTBm Terantam, PTPN V”,
photo by GIZ



Overall, planned bioenergy power plant until 2028 could be fulfilled by bioenergy external-use potential ¹⁰ (6.4 GW). However, since bioenergy external-use potential and bioenergy demand are site specific, the analysis should respect the geographical aspect (see Table 7). For example, several areas, where there is abundant bioenergy external-use potential (such as Riau and North Sumatera), should be encouraged for more ambitious bioenergy capacity while respecting future energy demand and existing electricity infrastructure planning.

On the other hand, there is also a case in Maluku where external-use potential (0.2 MW) is far less than planned bioenergy power plant (46 MW). Thus, PLN should revisit bioenergy target in this area or reconsider other renewable energy sources when they are available. There are also provinces in Indonesia such as Bali, East Nusa Tenggara, North Maluku, Riau Island, and North Sulawesi that doesn't have agro-industrial based bioenergy source. Thus, in those location other bioenergy source such as energy forest, corn waste, or domestic waste should be considered to fulfil bioenergy target. The complete detail of the comparison between external use potential with RUPTL Target is shown in Table 7.

Meeting Bioenergy Demand

At this point, bioenergy infrastructure planning is directly compared to bioenergy external-use potential from agro-industrial waste. Economic feasibility, which is highly dependent on renewable energy tariff, is not yet considered because of uncertain political framework ¹¹.

Table 7. Comparing external-use potential with RUPTL target

Province	Technical potential (MW)	Internal-use potential (MW)	External-use potential (MW)	RUPTL 2019-2028 Target (MW)*	Fulfil RUPTL Target
Jawa Bali	852.8	615.2	237.6	55.9	Yes
Bali	0.0	0.0	0.0	0.9	No
Banten	129.3	116.5	12.8	0.0	Yes
Central Java	84.4	61.8	22.6	0.0	Yes
D.I Yogyakarta	5.4	4	1.4	0.0	Yes
DKI Jakarta	0.0	0.0	0.0	0.0	Yes
East Java	466.2	317.8	148.4	50.0	Yes
West Java	167.5	115.1	52.4	5.0	Yes
Papua, Maluku, Nusa Tenggara	150	50.9	99.1	95.0	Yes
East Nusa Tenggara	0.0	0.0	0.0	20.0	No
Maluku	1.5	1.3	0.2	46.0	No
North Maluku	0.0	0.0	0.0	29.0	No
Papua	100	22.4	77.6	0.0	Yes
West Nusa Tenggara	16.2	11.5	4.7	0.0	Yes

¹⁰ Bioenergy technical potential is assumed to be constant, ignoring agro-industry growth.

¹¹ As of May 2020, there is possibility of potential changes in regulatory framework in near future.

Province	Technical potential (MW)	Internal-use potential (MW)	External-use potential (MW)	RUPTL 2019-2028 Target (MW)*	Fulfil RUPTL Target
West Papua	32.3	15.7	16.6	0.0	Yes
Sumatera	11589.3	7597.7	3991.6	176.4	Yes
Aceh	223.4	35.6	187.8	147.6	Yes
Bangka Belitung	156.3	34.8	121.5	13.0	Yes
Bengkulu	153.2	24.4	128.8	0.0	Yes
Jambi	1205.1	877.3	327.8	0.0	Yes
Lampung	320.4	199.8	120.6	0.0	Yes
North Sumatera	957.5	320.8	636.7	9.8	Yes
Riau	5878.9	4035.8	1843.1	0.0	Yes
Riau Island	0.0	0.0	0.0	6.0	No
South Sumatera	2558.5	2046.4	512.1	0.0	Yes
West Sumatera	136	22.8	113.2	0.0	Yes
Sulawesi	216.2	71.1	145.1	30.0	Yes
Central Sulawesi	40.5	7.5	33	10.0	Yes
Gorontalo	6.1	4.5	1.6	0.0	Yes
North Sulawesi	0.0	0.0	0.0	10.0	No
South East Sulawesi	20.8	5.9	14.9	10.0	Yes
South Sulawesi	82.5	42.6	39.9	0.0	Yes
West Sulawesi	66.3	10.6	55.7	0.0	Yes
Kalimantan	2843.7	853.3	1989.4	102.2	Yes
Central Kalimantan	765.6	126.3	639.3	0.0	Yes
East Kalimantan	1092.9	549.9	543.0	13.0	Yes
North Kalimantan	52.5	11.5	41	10.0	Yes
South Kalimantan	268.8	55.2	213.6	10.0	Yes
West Kalimantan	653.7	109.8	543.9	69.2	Yes
Grand Total	15,642	9,188	6,454	460	

* only include planning, not in phase of construction and PPA

5.2. Evaluating Economic Feasibility

In practical, it should be noted that these bioenergy external-use potentials from agro-industrial waste can only be realized if economic feasibility is met. Thus, biogas and biomass generation costs described in Chapter 4 should be incorporated when designing policies for promoting bioenergy.

Referring to existing regulatory framework (MEMR Regulation No. 4/2020, and previously MEMR Regulation No. 50/2017 and No. 53/2018), in which the tariff is based on local utility's generation cost (BPP), bioenergy power plants could only be economically feasible in areas where generation cost is high (Ministry of Energy and Mineral Resource Regulation, 2020). However, these areas usually have lower energy demand. Thus, the abundance of bioenergy potential might be difficult to realize with current regulation.

In contrary, Feed-in-Tariff could be an alternative for early adopter bioenergy market, such as Indonesia. FiT could promote bioenergy in areas where there is big bioenergy potential. As principal motives, bioenergy from agro-industrial waste could provide baseload electricity supply, provide big opportunity for methane capture (CO₂ saving), increase energy security, as well as contribute to national renewable energy targets.

In this sub-section, bioenergy external-use potential for meeting bioenergy target within RUPTL is further examined using economic analysis. COGS at USD 8.5 cent / kWh is used as reference price which is related to the area having maximum electricity price USD 10 cent / kWh (see Chapter 4).

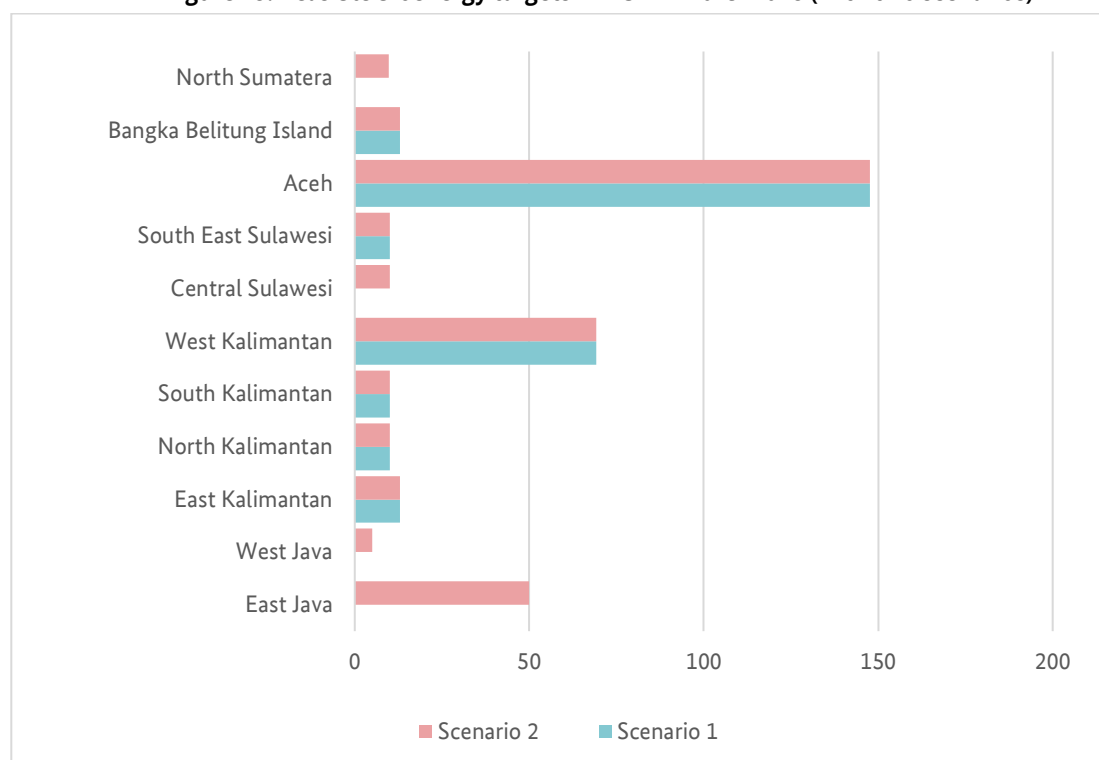
There are two scenarios:

- (1) COGS is compared with 85% of local generation cost (following current regulation)
- (2) Minimum Feed-in-Tariff is decided at COGS level, thus allowing bioenergy potential in any location to be economically feasible wherever the demand exists.

Feed-in-Tariff could unlock huge bioenergy potential in Indonesia. Using **Scenario 1** (benchmarking COGS with 85% of BPP), only **59% (272.8 MW)** of bioenergy target within RUPTL could be fulfilled by bioenergy external-use potential. Several provinces with total bioenergy potentials of **870 MW**, including North Sumatera (**637 MW**), Central Sulawesi (**33 MW**), West Java (**52 MW**) and East Java (**148 MW**) are not economically feasible for bioenergy power plants due to low tariff.

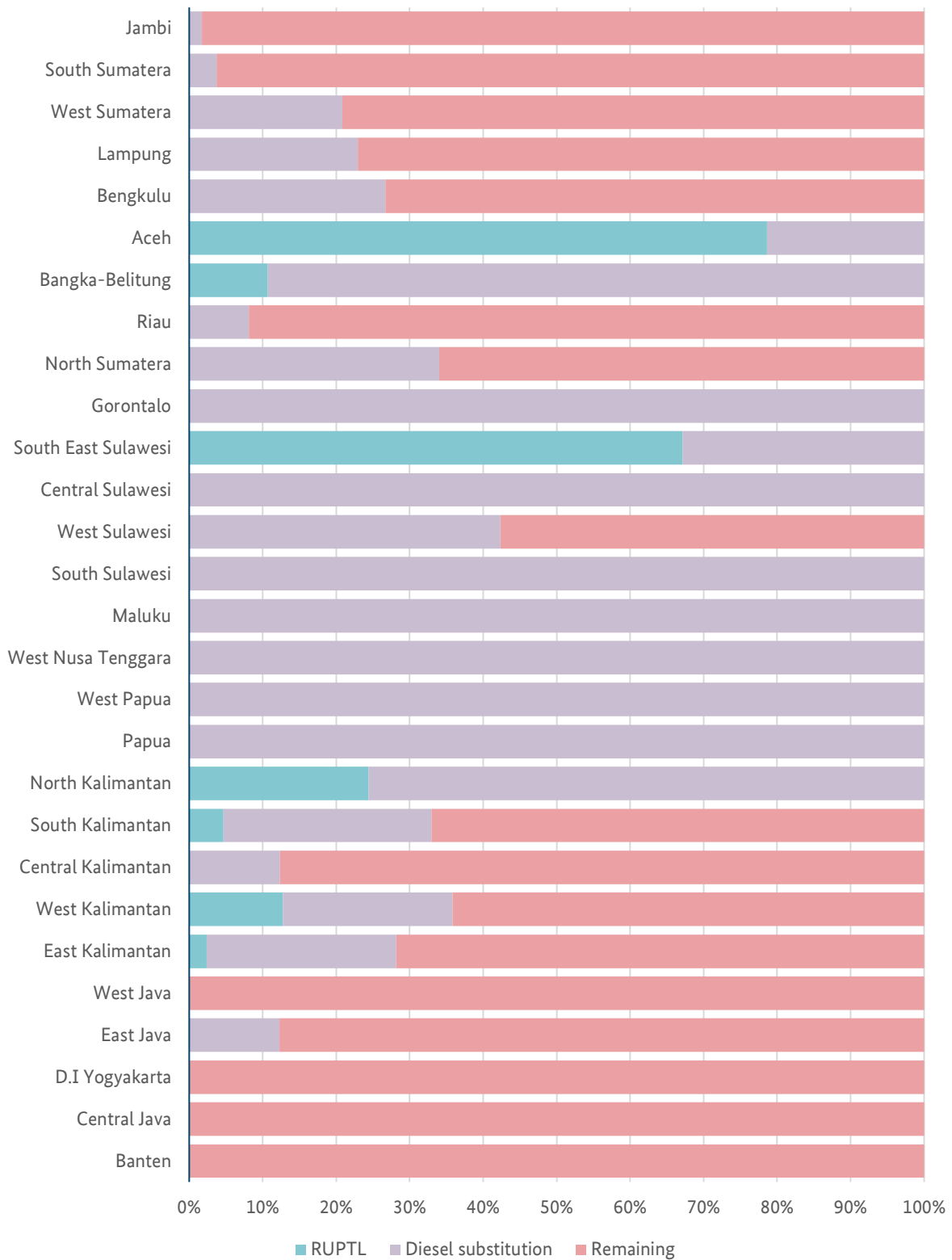
On the other hand, using **Scenario 2** (feed-in-tariff at COGS level), approximately **75% (347.6 MW)** of bioenergy target could be fulfilled (except if the biomass power plant will be built in isolated area / small island in that province). Bioenergy target in Maluku (**46 MW**) could not be fulfilled due to the absence of agroindustry there (except if the biomass powerplant will use agriculture waste or wood from plantation).

Figure 25. Feasible bioenergy targets in RUPTL 2019-2028 (with two scenarios)



5.3. Planning for More Ambitious Targets

Figure 26. Replacing old diesel power plant scenario



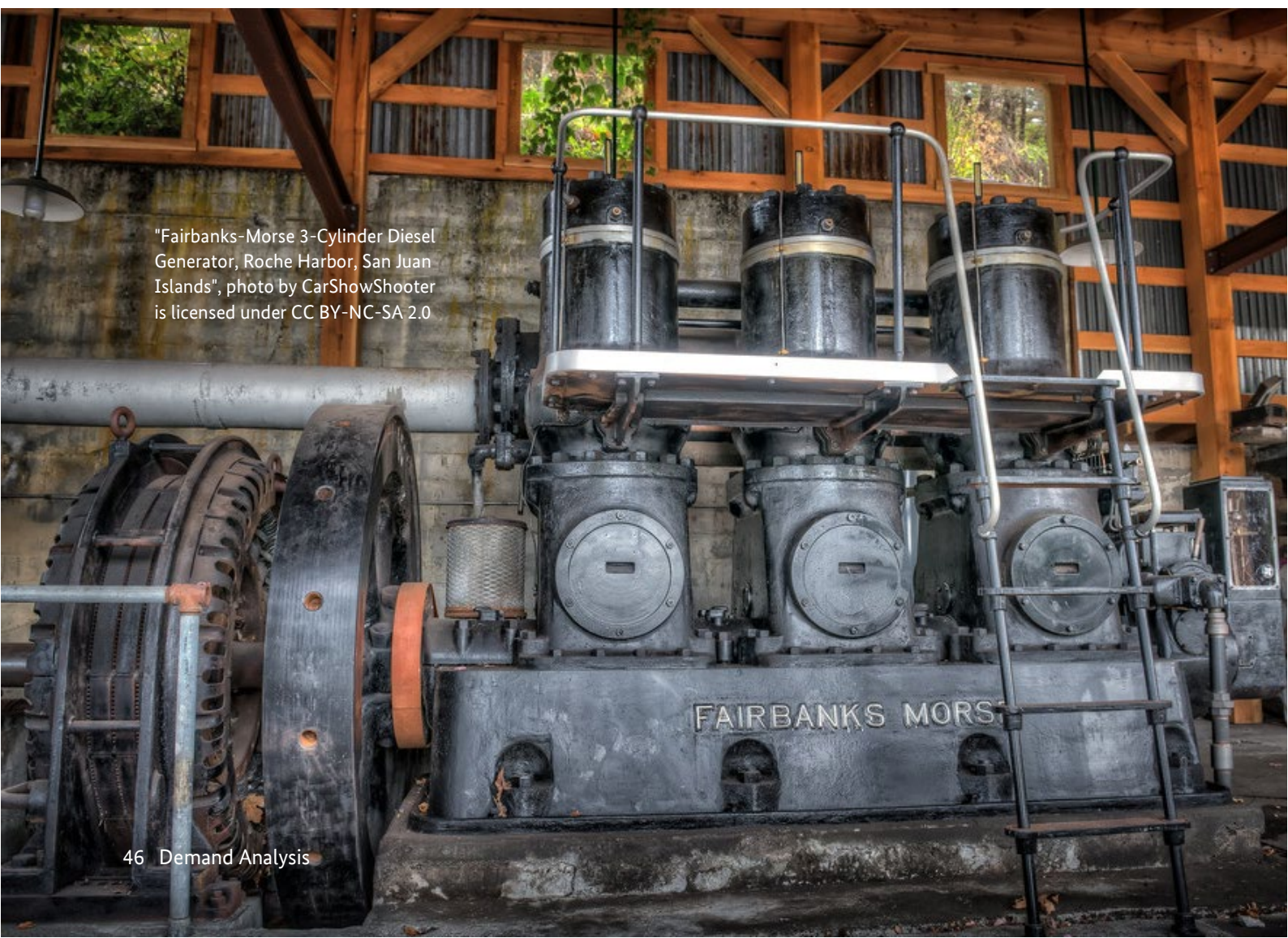
There are some ambitious targets that can be explored:

- (1) Considering more ambitious bioenergy targets in RUPTL (more bioenergy, less fossil based power plants). The provided external-use potential data in this study can be used as the basis for the adjustment of the existing RUPTL. See Figure 26 for the complete illustration.

- (2) Replacing old diesel power plants (a complete replacement or using bioenergy feedstocks, e.g. Bio-CNG). About 1,262.3 MW could be replaced (around 60%) in North Sumatera, Riau, East Kalimantan, West Kalimantan, and Bangka-Belitung. Since the feedstock is transportable, biomass technologies can be proposed. However, this setting is only feasible for wood wastes, rice husks, Palm Kernel Shell (PKS), and Empty Fruit Bunch (EFB).
- (3) Making a hybrid system that integrating a village's generator set with a biomass combustion or a biogas fermentation or, proposing a small biomass gasifier for a stand-alone operation that distributed at several villages.

Based on PLN's RUPTL, there are about 2 GW of the existing installed diesel power plants. It is interesting to see the possible allocation of the excess to replace the existing diesel power plants, use to feasibly meet RUPTL target using scenario 1 (only 59% of RUPTL target), and its remaining (see Figure 26). Since the agro-industrial wastes are distributed in several locations, the existing PLTD cannot be replaced directly based on the excess potential. In some provinces that have plenty of agro-industrial wastes (like Riau Province for example), only have few numbers of PLTD to be replaced. On the other hand, other provinces with high numbers of PLTD do not have agro-industrial wastes as the feedstock. Thus, the availability and the distribution of the feedstock in a specific location is the key.

In general, only **1.3 GW** (about **60%**) of the total existing PLTD can be replaced. Considering the scenario 2 of feasibly meet RUPTL target, there are still **4.8 GW** remaining. It may suggest more bioenergy power plants can be built in Sumatra (i.e. Riau and North Sumatra) and Kalimantan (i.e. Central Kalimantan, East Kalimantan, West Kalimantan, and South Kalimantan).



"Fairbanks-Morse 3-Cylinder Diesel Generator, Roche Harbor, San Juan Islands", photo by CarShowShooter is licensed under CC BY-NC-SA 2.0

6. Conclusions & Recommendations

6.1. Conclusions

Based on the biomass potential data per province, the BPP price, sensitivity analysis , and COGS simulation, we could set up a priority list for the bioenergy power plant to be developed with the following agro-industrial wastes (sequentially from the highest priority to the lowest one):

- (1) Palm Oil Mill Effluent (POME): based on the lowest production cost and lest complexity in construction and operation, the POME is the best waste source to start with. It has a lower risk in investment and operational, and the electricity price of it still under the electricity sales price from PLN. It is suggested the Biogas-POME power plant can be developed for internal electricity consumption (if the Palm Oil Mill has a Palm Kernel Mill or other demand) or selling the electricity to the PLN's grid.
- (2) Wood waste: based on the availability, sustainability, and volume, the wood waste will be the second target for project development. The wood waste may be converted with biomass combustion technology (e.g. boiler or gasifier). To ensure the sustainability of the feedstock, a proper re-plantation plan needs to be considered. It is suggested to secure a Long-term PPA Contract with PLN and injected the generated power to the grid line.
- (3) Black liquor: the black liquor can be utilized for boiler fuel in pulp and paper industries. Worldwide, it has been used since 1930s at most of kraft pulp mills in other countries. Steam and recovering the cooking chemicals. The sodium hydroxide and sodium sulphide had been used to separate lignin from cellulose Fibers. Another option is utilizing black liquor for gasification (so-called Black Liquor Gasification Combined Cycle/BLGCC). Since the pulp and paper industries also require high electricity demand, it is suggested the bioenergy power plant with black liquor source signs an Excess Power PPA Contract with PLN.
- (4) Bagasse: electricity can be generated from bagasse with a lower production cost. However, most of the sugar mills only operate in ten (10) months per annum. The total capacity of the bioenergy power plant can be set at 80% of the available feedstock. The proposed contract will be an Excess Power PPA Contract with PLN.
- (5) Empty Fruit Bunch (EFB): the volume potential of EFB is the highest among others and it will be continuously available. Nowadays, there are several technologies can convert EFB to electricity that can manage the high alkali and chloric contents in it (e.g. dual chamber boiler). However, the Component A will increase due to high investment cost on the boiler. On the other hand, there is a high demand for exporting the EFB pellets for bioenergy power plants in overseas countries (e.g. to Japan and Korea).
- (6) Rice husk: based on the feedstock price, actually the rice husk is placed in the 4th rank. However, the rice mill could not work continuously in twelve (12) months per annum. The operational of the rice mill depends on the harvesting time. Furthermore, most of the rice husks in Java Island have been utilized for heating process in brick production facilities or for cement industries.
- (7) Palm Kernel Shell (PKS): nowadays, the PKS has the highest demand for agro-industrial wastes to be exported abroad. Thus, it will impact on a lower availability and a higher feedstock price. Few of them had been utilized in the Palm Oil Mills due to remote locations of the mills. If the radius of mill location is less than about 50 km from the seaport, the PKS' trader will open a stock-pile near to the seaport and export them to overseas countries. Thus, it will be a high risk to propose a bioenergy power plant based on PKS.

- (8) Tapioca wastewater: the tapioca wastewater can be converted for biogas power plant. However, there are only few tapioca mills in Indonesia, only in five (5) provinces. And from further discussion with the association, this waste source already been utilized for farmers.

6.2. Policy Recommendations

The bioenergy power plant issues are not only related to the bioenergy sources but also related to a fair electricity tariff (for both, investor, and PLN) and supportive policies in developing bioenergy power plants. It would be interesting if PLN's RUPTL can be revisited based on the determined Feasible Sources and fair electricity tariffs for specific locations should be considered (based on the specific COGS at a specific location).

Supporting the Indonesian bioenergy target, either within the RUPTL target (around **460 MW**) and the national renewable energy target (around **5.50 GW** by 2025), several policy recommendations may be proposed as follows:

(1) Feedstock Sustainability

- a. Collaborate with related stakeholders to develop dedicated supply of energy from agroindustry.
- b. Long-term agreement with waste owner or make a joint venture with the waste owner.
- c. Expand bioenergy projects in Sumatra and Kalimantan that have additional excess of potential agro-industrial wastes.

(2) Market Creation

- a. Give task from PLN to local state-owned company (BUMD) for purchasing electricity from renewable energy sources.
- b. Open opportunity for electricity business permits at specific locations/areas can be owned for a certain period by private company or local state-owned company that bring prudent investment within a full control from PLN in grid distribution.
- c. Simplify bidding procedure for renewable energy power plants that will be built by private investors with a full control from PLN for the bidding process.

(3) Pricing Policy

- a. Provide fair chance and certainty to (prospective) investors by revisiting supportive pricing regulations & procedures.
- b. Encourage the development of renewable energy to the eastern part of Indonesia with higher electricity generation cost.
- c. Encourage reverse auction for the electricity tariff.
- d. Add specific correction factor for remote locations to accommodate a higher price due to access road availability and accessibility.

(4) Incentive Strategy

- a. Encourage the investment in bioenergy development by providing incentives, both fiscal and non-fiscal.
- b. Give incentive for custom free of technologies related to renewable energy.
- c. Give incentive for bioenergy development in rural area since some of bioenergy sources are located in rural area.

(5) National Research & Standardization

- a. Collaborate with related stakeholders in conducting R&D for non-conventional feedstock.
- b. Establish national standard and specifications to ensure quality and safety of bioenergy conversion.

(6) Utilization of Agro-Industrial Wastes

- a. The government need to encourage agroindustry to utilized their organic wastes to produce electricity from on-farm and off-farm.

- b. Develop CPO based power plant and or converting existing diesel power plant to CPO based power plant.
- c. Develop biorefinery near to the CPO mills to be able to maximize the utilization of agro-industrial sources.

(7) Project Road Map

- a. Carry out potential mapping and study with related stakeholder to develop bioenergy based on local potential.
- b. Develop project-based road map for bioenergy power plant.
- c. PLN needs to focus more on biomass and biogas projects for the next (five) 5 years, since Indonesia has plenty of bioenergy sources variation.

(8) RUPTL Commitment

- a. Ensure all parties involved to implement the commitment in developing bioenergy power plant as stated in RUPTL 2019-2028.
- b. Revisit the bioenergy target based on the available bioenergy sources in specific locations.
- c. Revisit the electricity tariff for bioenergy power plant at specific locations.

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Appendix A

Bioenergy Regulations

The bioenergy regulations in Indonesia may be listed as follows:

- (1) Presidential Decree No. 37/1992; related to electricity provision by private sector.
- (9) Presidential Instruction No. 1/2006; related to utilization of renewable energy in Indonesia:
- (10) Optimizing the utilization of renewable energy in Indonesia.
- (11) The target of national energy mix in 2025, where the utilization of renewable energy has been targeted at 17% where the contribution of bioenergy is 5%.
- (12) The target of energy elasticity which should be less than 1 in 2020.
- (13) Law Act No. 30/2007; related to the priority of developing and utilizing renewable energy, one of which is bioenergy.
- (14) Law Act No. 30/2009; related to electricity provision for general public.
- (15) Government Regulation No. 14/2012; related to upstream & downstream for electricity business regarding integrated electricity provision works.
- (16) MEMR Regulation No. 28/2012, this regulation replaced by MEMR Regulation No. 7/2016; related to the procedure for the issuance of the area permit of electricity generation and distribution.
- (17) MEMR Regulation No. 4/2012, No. 19/2013, and No. 27/2014; related to Feed-in Tariff (FiT) for the bioenergy power plant:
- (18) The electricity price set by government and no need negotiation with PLN.
- (19) Using the standard PPA (power purchase agreement).
- (20) Can be IPP or excess power.
- (21) For the off-grid bioenergy powerplant, the electricity price will be decided by Head of District ("Bupati").
- (22) Government Regulation No. 79/2014; related to the national energy policy.
- (23) MEMR Regulation No. 38/2016; related to the acceleration of rural electrification through small scale project.
- (24) MEMR Regulation No. 50/2017; related to the utilization of renewable energy resources for electricity.
- (25) MEMR Regulation No. 10/2017; related to key points of PPA (Power Purchase Agreement).
- (26) MEMR Regulation No. 47/2018; related to electricity tariff procedure.
- (27) MEMR Regulation No. 53/2018, revision of MEMR Regulation No. 50/2017
- (28) MEMR Regulation No. 04/2020; related to revised regulations as in MEMR Regulation No. 50/2017 and 53/2018.

There are several other regulations in Indonesia expected to be issued soon, such as: the Indonesian Renewable Energy Law Act (including subsidies, incentives, etc.) and Presidential Decree (specific for renewable energy tariff). It has been predicted, with both regulations will boost up renewable energy development in Indonesia including bioenergy.

Appendix B

Calculation Assumption

Table 8. Palm Oil Mill

Parameter	Description	Value	Unit	Reference
General Parameter				
Working hour	Hour	5000	hour/year	[10]
	Day	300	day/year	[10]
Internal energy consumption	Electricity needed	19	kWh/ton FFB	[7]
	Head needed	527.78	kg steam/ton FFB	[12]
POME				
POME production	POME conversion ratio	0.65	m ³ POME/ton FFB	[13]
COD concentration	COD	62500	mg/L	[16]
	kg to mg	1000000	mg/kg	
	m ³ to L	1000	L/m ³	
CH ₄ production	COD to CH ₄ conversion efficiency	0.8		[10]
	CH ₄ conversion ratio	0.35	Nm ³ CH ₄ /kgCOD	[10]
EFB				
EFB production	EFB conversion ratio	0.23	ton EFB/ton FFB	[23]
Energy potency	Calorific Value (water content 65%)	1200	kcal/kg	[21]
	kcal to MJ	0.004169	MJ/kcal	
Fiber				
Fiber production	Fiber conversion ratio	0.12	ton Fiber/ton FFB	[23]
Energy potency	Calorific Value (water content 30%)	3340	kcal/kg	[21]
	kcal to MJ	0.004169	MJ/kcal	
Shell				
Shell production	Shell conversion ratio	0.06	ton Shell/ton FFB	[17]
Energy potency	Calorific Value (water content 15%)	4300	kcal/kg	[21]
	kcal to MJ	0.004169	MJ/kcal	
External use Boiler and Turbine				
Energy produced	Annual working hour	7000	hour/year	[21]
	Boiler + turbine efficiency	0.3		[7]
	kWh to MJ	3.6	MJ/kWh	
Internal Boiler Co-Generation				
Energy produced	Actual Steam Ratio (turbine)	24.5	kg/kWh	[12]
	Boiler delta enthalpy (<i>output: superheated 2.1MPa, 237°C; input 2.1 MPa, 95°C</i>)	2459.48	kJ/kg	[12]
	Boiler efficiency	0.806		[12]
	Turbine Entalphy Output (<i>3.1 barg 144.6°C 0.9 dryness</i>)	2510.37	kJ/kg	[27]

Parameter	Description	Value	Unit	Reference
Multiplier factor	Multiplier factor	0.825		Internal
Gas Engine				
Energy produced	Methane energy value	35.7	MJ/Nm ³ CH ₄	[10]
	Gas engine efficiency	0.35		[10]
	Day to second	86400	second/day	[10]

Table 9. Sugar Mill

Parameter	Description	Value	Unit	Reference
General Parameter				
Working hour	Hour	22	hour/day	Internal
	Day	125	day/year	Internal
Internal energy consumption	Electricity needed	25	kWh/ton sugar	[9]
	Head needed	200	kg steam/ton sugar	Internal
Bagasse				
Bagasse production	Bagasse conversion value	0.3	ton bagasse/ton sugar	[18]
Energy potency	Calorific Value (water content 50%)	2035	kkal/kg	[9]
	kkal to MJ	0.004169	MJ/kkal	
Boiler Co-Generation				
Energy produced	Actual Steam Ratio (turbine)	24.5	kg/kWh	[12]
	Boiler delta enthalpy (<i>output: superheated 2.1MPa, 237°C; input 2.1 MPa, 95°C</i>)	2459.48	kJ/kg	[12]
	Boiler efficiency	0.8		[12]
	Turbine Enthalpy Output (<i>3.02 barg 144.6°C 0.9 dryness</i>)	2737	kJ/kg	[12]

Table 10. Tapioca Mill

Parameter	Description	Value	Unit	Reference
General Parameter				
Working hour	Hour	20	hour/day	Internal
Internal energy consumption	Electricity needed	25	kWh/ton tapioca	[15]
	Head needed	5563	MJ/ton tapioca	[19] & [32] (calculated)
Wastewater				
Wastewater production	Wastewater conversion value	25	m ³ wastewater/ton tapioca	[24]
COD concentration	COD	12000	mg/L	[24],[25],[26] (averaged)
	kg to mg	1000000	mg/kg	
	m ³ to L	1000	L/m ³	
CH ₄ production	COD to CH ₄ conversion efficiency	0.8		[10]
	CH ₄ conversion ratio	0.35	Nm ³ CH ₄ /kgCOD	[10]
Gas Engine				

Parameter	Description	Value	Unit	Reference
Energy produced	Methane Energy Value	35.7	MJ/Nm ³ CH ₄	[10]
	Gas engine efficiency	0.35		[10]
	Day to second	86400	second/day	[10]

Table 11. Rice Mill

Parameter	Description	Value	Unit	Reference
General Parameter				
Working hour	Hour	8	hour/day	Internal
	Day	312	day/year	Internal
Internal energy consumption	Electricity needed	18.4	kWh/ton grain	[22]
Rice Husk				
Husk production	Husk conversion ratio	0.2	kg husk/kg grain	[8]
Energy potency	Husk Calorific Value (water content 12%)	3350	kkal/kg	[33]
	kkal to kWh	0.001163	kWh/kkal	
Boiler + Turbine				
Energy produced	Annual working hour	7500	hour/year	[20]
	Boiler + turbine efficiency	0.3		[7]

Table 12. Pulp & Paper Mill

Parameter	Description	Value	Unit	Reference
General Parameter				
Internal energy consumption	Electricity needed	1650	kWh/ton pulp	[31]
	Heat needed	14	GJ/ton pulp	[31]
Black Liquor and Wood				
Black liquor production	Black liquor conversion value	1500	kg/ton pulp	[29]
Wood waste production	Wood waste conversion value	300	kg/ton pulp	[30]
Energy potency	Calorific Value Black Liquor (water content 70%)	3475	kkal/kg	[33]
	Calorific Value Kayu (water content 30%)	4400	kkal/kg	[33]
	kkal to kWh	0.001163	kWh/kkal	
	kkal to MJ	0.004169	MJ/kkal	
Boiler + Turbine				
Energy produced	Annual working hour	7500	hour/year	[20]
	Heat allocation	0.7		Internal
	Electric turbine allocation	0.3		Internal
	Boiler efficiency	0.8		[33]
	GJ to MWh	0.28	MWh/GJ	

Table 13. Wood Mill

Parameter	Description	Value	Unit	Reference
General Parameter				
Working hour	Hour	20	Hour/day	Internal
	Day	300	Day/year	Internal
Internal energy consumption	Electricity needed	108.8249	kWh/m³ plywood	[14]
		57.20904	kWh/m³ veneer	[14]
		77	kWh/m³ sawn timber	[11]
Plywood Waste				
Plywood waste production	Plywood waste coversion ratio	0.3111	m³ plywood /m³ wood	[6]
Energy potency	Wood Calorific Value (water content 15%)	4400	kcal/kg	[33]
	kcal to kWh	0.001163	kWh/kcal	
	densitas kayu	297	kg/m³	[34]
Veneer Waste				
Veneer waste production	Rasio Limbah Veneer dengan Veneer	0.2	m³ veneer/m³ wood	[6]
Energy potency	Wood Calorific Value (water content 15%)	4400	kcal/kg	[33]
	kcal to kWh	0.001163	kWh/kcal	
	Wood density	297	kg/m³	[34]
Sawn Timber Waste				
Sawn timber production	Rasio Limbah Kayu Gergajian dengan Kayu	0.4048	m³ sawn timber /m3 wood	[6]
Energy potency	Wood Calorific Value (water content 15%)	4400	kcal/kg	[33]
	kcal to kWh	0.001163	kWh/kcal	
	Wood density	297	kg/m³	[34]
Boiler + Turbin				
Energy produced	Jam kerja tahunan	7500	hour/year	[20]
	Boiler + turbine efficiency	0.3		[7]

Appendix C

Bioenergy in RUPTL

Table 14. Bioenergy Power Plant Planning in RUPTL 2019-2028

Provinces	2020	2021	2022	2023	2024	2025	2026	2027	2028	Total
Aceh		3	50		89.6		5			147.6
Bali			0.9							0.9
Bangka Belitung	6				3	4				13
Central Sulawesi				10						10
East Java			50							50
East Kalimantan	13									13
East Nusa Tenggara	1	2	2	5		5		5		20
Maluku			6		10			10	20	46
North Kalimantan	10									10
North Maluku			14						15	29
North Sulawesi				10						10
North Sumatera				9.8						9.8
Riau Island	6									6
Southeast Sulawesi				10						10
South Kalimantan	10									10
West Java				5						5
West Kalimantan	17	52.2								69.2
Grand Total	63	57.2	122.9	49.8	102.6	9	5	15	35	459.5

Appendix D

Biomass Calculation

Table 15. Biomass Power Plant - Empty Fruit Bunch

Components		Min Investment			Max Investment		
		IDR	USD	%	IDR	USD	%
I	LAND PREPARATION	1,500,000,000	107,143	0.4%	1,500,000,000	107,143	0.4%
1	Land Indemnification	1,500,000,000			1,500,000,000		
II	PRE-PROJECT EXPENSE	8,662,590,000	618,756	2.5%	8,662,590,000	618,756	2.3%
1	Pre-FS	596,340,000			596,340,000		
2	Permit	1,500,000,000			1,500,000,000		
3	DFS	4,550,000,000			4,550,000,000		
4	DED	2,016,250,000			2,016,250,000		
5	Other Development Cost						
III	POWER PLANT EQUIPMENT	227,453,000,000	16,246,643	66.5%	260,738,370,000	18,624,169	69.5%
1	Boiler Island (Package)	120,000,000,000			138,750,000,000		
2	Turbine Island	29,351,300,000			40,024,500,000		
3	Make Up Water Island and Water Treatment	12,100,000,000			12,100,000,000		
4	Cooling Water System	4,950,000,000			4,950,000,000		
5	Deaerator System	1,750,000,000			1,750,000,000		
6	Air Compressor and Weighing Bridge	950,000,000			950,000,000		
7	Power Plant Electrical System	38,621,700,000			42,483,870,000		
8	Instrumentation and Automation	8,100,000,000			8,100,000,000		
9	Utilities and Interface Infrastructure	5,150,000,000			5,150,000,000		
10	River raw water line + clarifier and pond	3,315,000,000			3,315,000,000		
11	Essential Diesel Generator + Diesel Fire Pump	3,165,000,000			3,165,000,000		
IV	CIVIL BUILDING WORK	55,570,000,000	3,969,286	16.3%	55,570,000,000	3,969,286	14.8%
1	Civil Work and Building	52,020,000,000			52,020,000,000		
2	Cut, Excavation, Compacting Land	3,550,000,000			3,550,000,000		
V	INFRASTRUCTURE	10,430,000,000	745,000	3.1%	10,430,000,000	745,000	2.8%
1	Road & Drainage	9,480,000,000			9,480,000,000		
2	Fencing	950,000,000			950,000,000		
VI	EPC	18,672,350,000	1,333,739	5.5%	18,672,350,000	1,333,739	5.0%
1	Site Construction and Consumable Material	10,500,000,000			10,500,000,000		

Components		Min Investment			Max Investment		
		IDR	USD	%	IDR	USD	%
2	Freight and Custom Clearance	6,100,000,000			6,100,000,000		
3	Insurance	2,072,350,000			2,072,350,000		
VII	OPERATING CAPITAL	8,061,644,224	575,832	2.4%	8,061,644,224	575,832	2.1%
VIII	FUEL PREPARATION	9,120,300,857	651,450	2.7%	9,120,300,857	651,450	2.4%
IX	MAINTENANCE TOOLS	433,000,000	30,929	0.1%	433,000,000	30,929	0.1%
X	CONTINGENCY	2,011,000,000	143,643	0.6%	2,011,000,000	143,643	0.5%
Total Investment		672,263,469,305	24,422,420	100.0%	738,834,209,305	26,799,947	100.0%
Investment index			2.04	USD / MW		2.23	USD / MW

Table 16. Biomass Power Plant – Wood Waste

Components		Min Investment			Max Investment		
		IDR	USD	%	IDR	USD	%
I	LAND PREPARATION	1,500,000,000	107,143	0.6%	1,500,000,000	107,143	0.5%
1	Land Indemnification	1,500,000,000			1,500,000,000		
II	PRE-PROJECT EXPENSE	8,662,590,000	618,756	3.2%	8,662,590,000	618,756	2.9%
1	Pre-FS	596,340,000			596,340,000		
2	Permit	1,500,000,000			1,500,000,000		
3	DFS	4,550,000,000			4,550,000,000		
4	DED	2,016,250,000			2,016,250,000		
5	Other Development Cost						
III	POWER PLANT EQUIPMENT	148,703,000,000	10,621,643	55.2%	181,988,370,000	12,999,169	60.2%
1	Boiler Island (Package)	41,250,000,000			60,000,000,000		
2	Turbine Island	29,351,300,000			40,024,500,000		
3	Make Up Water Island and Water Treatment	12,100,000,000			12,100,000,000		
4	Cooling Water System	4,950,000,000			4,950,000,000		
5	Deaerator System	1,750,000,000			1,750,000,000		
6	Air Compressor and Weighing Bridge	950,000,000			950,000,000		
7	Power Plant Electrical System	38,621,700,000			42,483,870,000		
8	Instrumentation and Automation	8,100,000,000			8,100,000,000		
9	Utilities and Interface Infrastructure	5,150,000,000			5,150,000,000		
10	River raw water line + clarifier and pond	3,315,000,000			3,315,000,000		
11	Essential Diesel Generator + Diesel Fire Pump	3,165,000,000			3,165,000,000		
IV	CIVIL BUILDING WORK	55,570,000,000	3,969,286	20.6%	55,570,000,000	3,969,286	18.4%

Components		Min Investment			Max Investment		
		IDR	USD	%	IDR	USD	%
1	Civil Work and Building	52,020,000,000			52,020,000,000		
2	Cut, Excavation, Compacting Land	3,550,000,000			3,550,000,000		
V	INFRASTRUCTURE	10,430,000,000	745,000	3.9%	10,430,000,000	745,000	3.4%
1	Road & Drainage	9,480,000,000			9,480,000,000		
2	Fencing	950,000,000			950,000,000		
VI	EPC	18,672,350,000	1,333,739	6.9%	18,672,350,000	1,333,739	6.2%
1	Site Construction and Consumable Material	10,500,000,000			10,500,000,000		
2	Freight and Custom Clearance	6,100,000,000			6,100,000,000		
3	Insurance	2,072,350,000			2,072,350,000		
VII	OPERATING CAPITAL	8,061,644,224	575,832	3.0%	8,061,644,224	575,832	2.7%
VIII	FUEL PREPARATION	15,200,501,429	1,085,750	5.6%	15,200,501,429	1,085,750	5.0%
IX	MAINTENANCE TOOLS	433,000,000	30,929	0.2%	433,000,000	30,929	0.1%
X	CONTINGENCY	2,011,000,000	143,643	0.7%	2,011,000,000	143,643	0.7%
Total Investment		520,843,669,877	19,231,720	100.0%	587,414,409,877	21,609,247	100.0%
Investment index			1.60	USD / MW		1.80	USD / MW

Appendix E

Biogas Calculation

Table 17. POME Biogas Powerplant

No.	Components	Min Investment		Max Investment	
		IDR	USD	IDR	USD
I	PRE-DEVELOPMENT PHASE	1,253,000,000	89,500	1,253,000,000	89,500
1	SPV Establishment	112,000,000	8,000	112,000,000	8,000
2	Principal and Location License	70,000,000	5,000	70,000,000	5,000
3	UKL - UPL & Environmental permit	196,000,000	14,000	196,000,000	14,000
4	Building Construction Permit (IMB)	35,000,000	2,500	35,000,000	2,500
5	Feasibility Study	266,000,000	19,000	266,000,000	19,000
6	Interconnection Study	182,000,000	13,000	182,000,000	13,000
7	Local Security	112,000,000	8,000	112,000,000	8,000
8	PPA Consultant Fee	280,000,000	20,000	280,000,000	20,000
II	PRE-CONSTRUCTION PHASE	437,500,000	31,250	437,500,000	31,250
III	DESIGN ENGINEERING PHASE	805,000,000	57,500	805,000,000	57,500
IV	PROCUREMENT PHASE	55,062,000,000	3,933,000	67,746,000,000	4,839,000
1	SKID 1A - Biogas Utility & Flare Station	4,725,000,000	337,500	4,987,500,000	356,250
2	SKID 1B - Biogas Distribution Station	6,237,000,000	445,500	6,583,500,000	470,250
3	SKID 2 - POME Feeder Station	472,500,000	33,750	498,750,000	35,625
4	SKID 3 - Treated POME & Sludge Handling Station	850,500,000	60,750	897,750,000	64,125
5	Biogas Open Flare	1,417,500,000	101,250	1,496,250,000	106,875
6	Biogas Biological Scrubber	4,914,000,000	351,000	5,187,000,000	370,500
V	CONSTRUCTION PHASE	20,166,300,000	1,440,450	21,286,650,000	1,520,475
1	Preparation	226,800,000	16,200	239,400,000	17,100
2	Biogas Plant Civil Construction				
	Anaerobic Pond Reactor Earth	3,402,000,000	243,000	3,591,000,000	256,500
	Open Channel	378,000,000	27,000	399,000,000	28,500
	Sump Pit	283,500,000	20,250	299,250,000	21,375
	Concrete Slab Foundations & Pipe Support Footings	945,000,000	67,500	997,500,000	71,250
	Miscellaneous	1,890,000,000	135,000	1,995,000,000	142,500
3	Biogas Plant Mechanical				

No.	Components	Min Investment		Max Investment	
		IDR	USD	IDR	USD
	Reactor Nozzles, Pipe and Header Installation	1,512,000,000	108,000	1,596,000,000	114,000
	Pipe and Header Supports	378,000,000	27,000	399,000,000	28,500
	HDPE Sheet Supply & Installation	3,402,000,000	243,000	3,591,000,000	256,500
	Equipment Set Up	283,500,000	20,250	299,250,000	21,375
4	Pond Upfilling for Start Up Purposes	94,500,000	6,750	99,750,000	7,125
5	Biogas Plant Electrical	756,000,000	54,000	798,000,000	57,000
6	Biogas Plant Electrical - Grid Connection	6,615,000,000	472,500	6,982,500,000	498,750
VI	TESTING COMMISSIONING PHASE	1,050,000,000	75,000	1,050,000,000	75,000
Total Investment		77,520,800,000	5,537,200	91,325,150,000	6,523,225
Investment index		2.21	USD/MW	2.61	USD/MW

Appendix F

Biomass Impurities

Table 18. Biomass Impurities

Oxide composition	% (Dry ash basis)										
	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₃	SO ₃	Cl	K ₂ O	CaO	Fe ₂ O ₃	Others
Eucalyptus wood	-	3.8	0.1	1.6	3.4	3.9	3.4	57.0	24.7		2.0
Rubber wood	0.3	6.0	0.9	5.5	3.1	3.1	0.1	21.7	55.5	3.5	0.2
Palm EFB	0.4	5.3	0.6	25.0	5.4	2.8	2.8	43.6	12.3	1.5	0.3
Rice Husk	-	0.2	0.2	93.5	1.0	0.4	0.1	3.1	1.1	0.1	0.1
Rice Straw	0.7	1.2	0.1	61.5	3.1	0.9	4.2	19.6	3.2	0.4	5.1
Sugarcane bagasse	0.3	3.8	1.3	65.7	3.7	5.2	0.2	8.2	5.6	1.4	4.6

Note:

■ Erosion

■ Fouling

■ Clinker Formation

