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Development of integrated renewable energy system model for rural productivity zone in East Nusa Tenggara

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Abstract. East Nusa Tenggara (NTT) is a province with low electrification ratio (78.3%) and high number of underdeveloped villages (74.8%), despite its abundant renewable energy resources potential. The objective of this study is to obtain technically-economically feasible village model with integrated renewable energy system for developing productive zone, *Prukades*-postharvest cocoa processing, in Wewaria, NTT. The methodology used is techno-economic analysis, in which technical analysis include optimization for hybrid power generation system (HPGS), done by using HOMER Pro. Several financing schemes are proposed to evaluate the economic feasibility. Environmental comparative analysis of mitigated GHG emission is also evaluated. It is found that the HPGS consists of 95 kW photovoltaic, 78 kW wind turbine, and 200 kW diesel generator, equipped with battery storage, and the *Prukades* system has annual capacity of 250 tons of wet cocoa beans/year with 32.9% yield. *Prukades* system is economically feasible with all proposed schemes, and potential to increase annual income of cocoa farmers. On the other hand, HPGS is only economically feasible with FS-5 scheme with 100% grant as financial intervention. The economic attractiveness of both systems is relatively higher by using integrated scenario, both owned by the same business entity, resulting in 3 other schemes to be feasible.

1. Introduction

East Nusa Tenggara (NTT) is a province with the highest percentage of underdeveloped villages in Indonesia (74.8%) and low electrification ratio (78.29%) as per PLN data [1], despite its abundant renewable energy resources potential. This is disadvantageous since energy is the ‘fuel’ to economic growth and social development. Based on prior facts and challenges of increasing electrification rate and economic productivity in remote areas, the aim of this study is to obtain technically and economically feasible village model (named as RPZ Village), which consists of integrated renewable energy system and development of productive zone in Wewaria, Ende, NTT. The uniqueness of this research lies in the utilization of renewable energy for productive zone, as most international research regarding integrated renewable energy system, done by Barzola, et al. [2], Hassan [3], Chauhan and Saini [4], Sen and Bhattacharyya [5], Matin, et al. [6], and Balachander and Vijayakumar [7] still focus on meeting the energy demand of residential zone only, and have not yet emphasized on developing productive zone based on local potential, as discussed by Basu and Marett [8]. By developing productive zone, it is expected that access to energy will not be taken for granted for consumptive or non-productive use, since productive activities from income-generating are encouraged. Project of integrated renewable energy system for developing productive zone is found in other countries, e.g., done by United Nations Development Program in 2012 in Nepal, or by World

Bank and Global Environment Facility in 2003 in Sri Lanka, but has not been widely found in Indonesia. In this study, the selected productive zone to be developed is postharvest processing of cocoa. In addition, the study also proposes new integrated business scenarios between the hybrid power generation and the productive zone entity.

2. Methods

The proposed idea of developing an integrated renewable energy system and rural productivity zone as a sustainable development strategy for RPZ Village is illustrated in Figure 1.

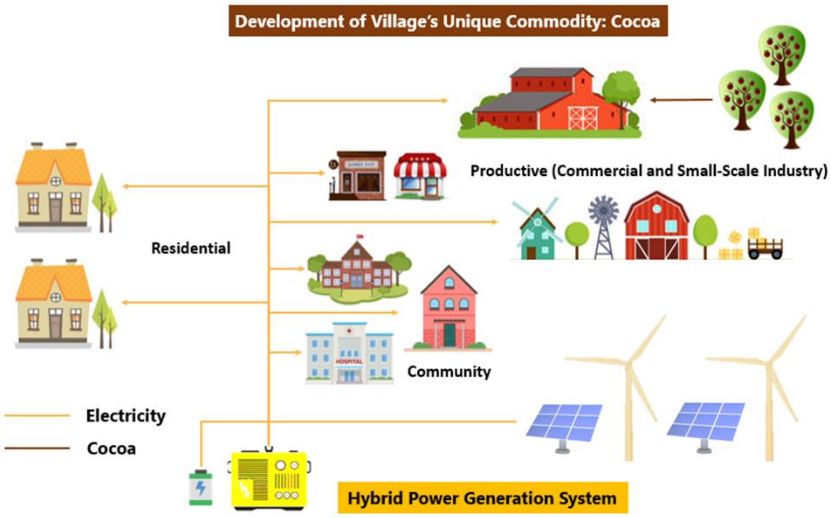

Figure 1. Proposed hybrid power generation system (HPGS) using renewable energy sources for rural productivity zone

Based on availability and reliability of potential resources in designated area, it is decided to propose hybrid power generation system for the RPZ Village. Hybrid system is selected since all this time, power generation in remote areas relies solely on diesel, in which operating and fuel cost are expensive and they are not environmentally friendly. Hybrid option is considered as the most feasible and cost-effective for remote areas where national grid extension is considered impossible and not economical. The power generation system is used to meet the electricity demand of residential, community, and productive (commercial and small-scale industry) zone. In the productive zone, there is a small-scale industry (*Prukades* or *Pengembangan Produk Unggulan Kawasan Pedesaan* or Development of Village's Unique Commodity), one of Kemendesa's strategy [9]. It is a centralized postharvest processing unit of cocoa that utilizes pod breaking machine to break pod and obtain wet beans, fermentation box to ferment the wet beans, hybrid dryer powered by solar thermal and biomass to dry the wet beans, and beans sorting machine to sort the dry beans, which could increase the added-value of cocoa. To date, most farmers do not process the harvested cocoa, resulting in low quality cocoa beans, thus low selling price. The product (dry cocoa beans) is expected to meet cocoa beans specification.

2.1. Technical analysis: Prukades system

Prukades system is designed by adhering to heuristic approach (good practices) for each postharvest processing unit and machine, based on Mulato [10], Mulato [11], and Mulato, et al. [12]. Output of system design is capacity and sizing for each equipment, also electrical and thermal energy demand of *Prukades* system. Before-after comparative analysis from environmental perspective regarding mitigated greenhouse gas mitigation from proposed design, compared to conventional design, is also evaluated as kg CO_2-equivalent, based on Shen, et al. [13].

2.2. Technical analysis: hybrid power generation system

Electricity demand profile of each zone, both for primary and deferred load, are estimated based on typical load pattern and power consumption, ownership factor, number of users, and usage duration per day from Blum, et al. [14]. Then, optimization for mini-grid of hybrid power generation system is done by using HOMER Pro (Hybrid Optimization of Multiple Energy Resources) software as explained by Lambert, et al. [15]. There are 4 essential technical input variables for the optimization: electricity demand estimation; selection of system components based on rationale and their technical and economical parameters: Caterpillar 200 kW (250 kVA and 50 Hz) diesel generator, CanadianSolar MaxPower CS6U-330P polycrystalline photovoltaic solar panels, AWS HC 1.5 kW horizontal wind turbines, lead acid Rolls Surrette 6CS25P battery, and generic converter model; RPZ Village energy resources, i.e. horizontal daily solar radiation (5.76 kWh/m^2/day), clearness index (0.5835), and average wind speed (5.03 m/s), as well as property of diesel fuel and its price; also constraints and other parameters, i.e. maximum annual capacity shortage (MACS), operating reserves, discount rate, and project lifetime. From optimization, hybrid system configuration (combination of components and optimization variables), along with detailed output parameters for each component, and its supply profile, levelized cost of electricity (LCOE), Net Present Cost (NPC), excess energy production, renewable energy fraction, fuel consumption, and dispatch strategy, are obtained. Optimum solution that meets the objective function (which is least cost, solution with the lowest NPC), is selected. Before-after comparative analysis from environmental perspective regarding mitigated greenhouse gas mitigation from optimum solution, compared to base case, is also evaluated as kg CO_2-equivalent.

2.3. Economic analysis

Economic analysis is conducted by estimating capital cost and operating and maintenance cost of both systems. Several financing schemes are proposed to evaluate the economic feasibility of both systems using Microsoft Excel to calculate the cash flow for financial performances (Net Present Value, Payback Period, and Internal Rate of Return). There are two scenarios to be discussed, i.e. if the *Prukades* system and hybrid power generation system are owned by different business entity (scenario 1), and if both systems are owned by the same entity (scenario 2).

There are 4 financing schemes to be considered for *Prukades* system (scenario 1). Base case (business-as-usual) for this system is cooperative business model (cocoa pod from farmers is purchased first as pre-financing, and dry cocoa beans is directly sold to buyers with international selling price, i.e. Rp 45,000; once the beans are sold and generate profit, the profit is shared for farmers), with 100% loan as financing source, 13% loan interest with 5 years tenure, and no grant from government. The rest of financing schemes are varied in terms of loan interest and tenure (7% within 10 year besides 13% within 5 years), also availability of government grants (with and without grant).

On the other hand, there are 10 financing schemes for hybrid power generation system (scenario 1) and integrated system (scenario 2). Base case for this system is 30% of financing source comes from equity with 12% cost of equity, and 70% of financing source comes from debt with 5.8% cost of debt, with no grant and no tax exemption (normal tax rate is applied). The hybrid power plant is owned by Independent Power Producer (IPP)/Special Purpose Vehicle (SPV) who sells electricity to PLN at maximum Power Purchase Agreement (PPA) selling price, i.e. 85% of the local electricity generation cost. For Ende, the local electricity generation cost is 17.72 cents USD/kWh, thus the maximum selling price of electricity is approximately 15.1 cents USD/kWh (Rp2,039/kWh). The rest of financing schemes are varied in terms of cost of debt (financing source intervention), availability of grant and its percentage (financial intervention), and availability of tax exemption (fiscal intervention). FS-2 represents financing scheme with fiscal intervention only (with tax exemption, not subjected to 25% income tax); FS-3 (50% grant), FS-4 (75% grant), and FS-5 (100% grant) represents financing scheme with financial intervention only (with no tax exemption); FS-6 (50% grant) and FS-7 (75% grant) represents financing scheme with combination of financial and fiscal intervention (with tax exemption); FS-8 represents financing scheme with financing source and fiscal intervention (3.77% cost of debt with no grant); FS-9 (50% grant) and FS-10 (75% grant) represents financing scheme with combination of financing source, financial, and fiscal intervention (with 3.77% cost of debt and tax exemption).

In scenario 2, purchase of cocoa pods as raw material is not needed and selling of dry cocoa beans is not taken into account as revenue because the revenue comes from imposing cocoa processing tariff to farmers as services. In addition, there is no electricity cost because the electricity generated by hybrid power plant can be used directly for own use, and the joint cost concept is used. There are 2 types of cocoa processing tariff to be considered: scenario 2a and 2b. In scenario 2a, tariff that is applied generates farmers' income similar to scenario 1, which is equivalent to the processing cost, i.e. Rp 1,300 (9.6 cents USD) per kg of wet cocoa beans. While in scenario 2b, maximum tariff that could be charged to farmers by assuming the maximum willingness-to-pay is when Return on Investment by processing cocoa is no lower than 50% is applied. Based on the selling price of wet and dry cocoa beans, the cocoa processing tariff is set at Rp1,790 (13.3 cents USD) per kg of wet cocoa beans.

3. Results and Discussions

3.1. Technical analysis: hybrid power generation system

For Prukades system, it is obtained that the capacity of processing unit is 5 tons of wet cocoa beans per batch, equivalent to 250 tons of wet cocoa beans per year (each batch is 7 days). Dryer is selected to fully utilize the processing capacity, therefore in dry season and during daytime, thermal energy demand is met by solar, while in rainy season and during nighttime, thermal energy demand is met by biomass (firewood). From the mass balance calculation, the yield of sorted cocoa beans from wet cocoa beans reaches 32.9%. From design process, it is obtained that cocoa pod breaking machine will have capacity of 10,000 pods/hour with electricity requirement of 0.746 kW. Fermentation boxes will have capacity of 625 kg/box with arrangement of 8 rows box for 2-stage fermentation and dimension of 1.5 x 1.2 x 0.4 m. The dryer will be operated for 48 hours drying time at 55^{o}C temperature with dimension of 5 x 3 x 0.3 m. Solar air heater will be made from galvanized iron sheet and corrugated polycarbonate sheet with 40% thermal and optical efficiency and is modelled as flat type with 269.65 m^2 area and 25^{o} inclination to receive 194.15 kW energy incident. Backup heater is a biomass furnace equipped with heat exchanger, with capacity of burning 25 kg biomass/hour and 55% thermal efficiency. The fans installed will be axial type with 30% efficiency and 0.74 kW electricity requirement. The blower chosen is centrifugal type with 20%-30% efficiency and 0.3 kW electricity requirement. The cocoa beans sorting machine will be able to sort 1 ton/hour cocoa beans with 0.746 kW electricity requirement. The processed cocoa beans will be stored in a sack with capacity of 60 kg of beans per pieces on wooden pallet with dimension of 1.3 x 1 x 0.14 m. The proposed Prukades system (hybrid dryer powered by solar thermal and biomass) could reduce dependence on firewood by 96,800 kg per year compared to the conventional system (biomass-fired dryer) and mitigate greenhouse gas emissions by 38,096 kg CO_2-eq/year (from 165,296 kg CO_2-eq/year to 127,199 kg CO_2-eq/year), generating emissions that is 23% lower than conventional system emissions. In addition, the proposed system is relatively economical and profitable compared to the conventional system.

Meanwhile, optimization result of different configuration of system components generates 11 solutions for hybrid power generation system, in which the most optimum solution is hybrid configuration of 95 kW of photovoltaic (contributing to 44.1% of total electricity production), 78 kW of wind turbine (contributing to 29.9% of total electricity production), and 200 kW of diesel generator (contributing to 26% of total electricity production), equipped with battery (64 in quantity) and converter (38.1 kW), while base case (diesel-fired power plant) ranks as the 2nd least optimum solution. The dispatch strategy used is combined dispatch, which combines the advantages of load following and cycle charging strategy. The optimum design has its own unique yearly and daily supply profile that describes when exactly each component is operating to meet the load (presented as time series). For instance, in July 22, at 12.00 PM, the load is met by electricity generated by photovoltaic and wind turbine, and the excess energy production is stored in battery. At 06.00 PM, most of the load is met by electricity generated by diesel generator, and the rest of it is met by electricity generated by wind turbine. Information of details of levelized cost of electricity of each component can also be inferred from optimization results. The selected optimum solution of hybrid power generation system could reduce dependence on diesel by 130,163 L per year compared to base case and mitigate greenhouse gas emissions by 1,246,816 kg CO_2-eq/year (from 1,560,862 kg CO_2-eq/year to 314,047 kg CO_2-eq/year), generating emissions that is 80% lower than base case emissions, providing opportunity for the project to get access to carbon financing, which could increase the economic attractiveness of the project and lower the electricity generation cost.

3.2. Economic analysis

Cost estimation. In scenario 1, Prukades system has capital cost of Rp 234,392,800 and operating and maintenance cost of Rp 2,860,155,841. Whereas, hybrid power generation system has capital cost of USD 329,727.79, replacement cost of USD 54,636.24, and operating and maintenance cost of USD 34,510. Projected annual revenue comes from selling of 250 tons of dry cocoa beans and selling of 287,597 kWh of electricity. In scenario 2, Prukades system has capital cost of Rp 359,248,500 and operating and maintenance cost of Rp 269,446,500. Whereas, hybrid power generation system has capital cost of USD 320,479.01, replacement cost of USD 54,636.24, and operating and maintenance cost of USD 34,510. Projected annual revenue comes from selling of 250 tons of dry cocoa beans and selling of 279,530 kWh of electricity.

Impact of financing scheme. For Prukades system, all financing schemes are economically feasible comparing to diesel-fired power plant tariff. This indicates that financial intervention, neither government grants nor low-interest loan, significantly affect the economic feasibility, since the base case financing scheme is already profitable. All financing schemes are potential to generate relatively high annual income per farmer. The economic attractiveness of the Prukades system is high, regardless of the financing scheme used, since the gross profit margin of cocoa is fixed and high, i.e. Rp 4,475 per kg of processed cocoa beans. For hybrid power generation system (scenario 1), it can be concluded that hybrid system with high renewable energy fraction, has high initial capital costs (USD 329,728), making it difficult to obtain access to financing, but its operating and maintenance costs (USD 41,205) and fuel costs (USD 285,506) are low. In contrast, conventional energy system has low initial capital costs (USD 50,000), but has high operating and maintenance costs (USD 134,329) and fuel costs (USD 1,419,315), causing NPC and LCOE of base case to be much higher than that of optimum solution.

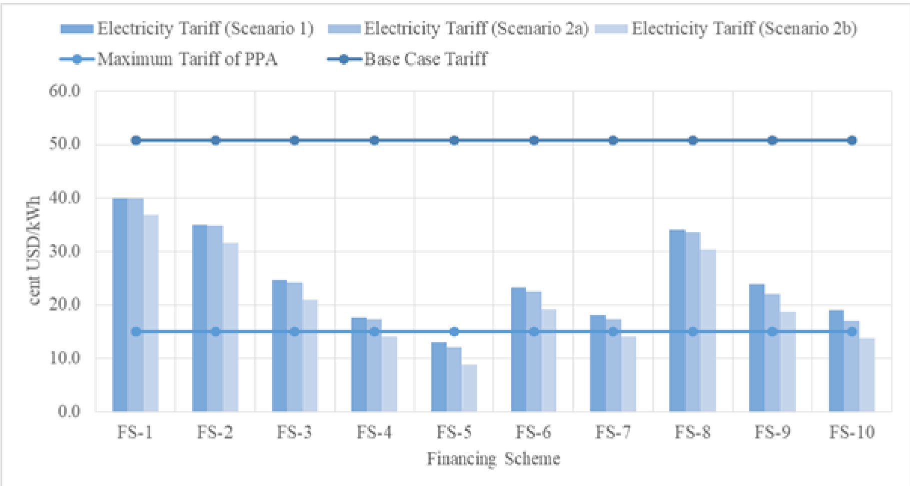

Figure 2. Comparison of electricity tariff of each financing scheme (scenario 1, 2a, and 2b)

Figure 2 compares tariff of each financing schemes in scenarios 1, 2a, and 2b maximum tariff of PPA as baseline, as well as base case tariff as benchmark tariff. It can be concluded that for all scenario and all financing schemes are economically feasibel if base case tariff as reference and for scenario 1, almost all financing scheme are not economically feasible except FS-5. Financial intervention in form of grants and low-interest loan makes schemes to be economically feasible if the value is significant

(100% grant or very-low-interest loan with long-term payment tenure that is close to project lifetime). Meanwhile, fiscal intervention in form of tax exemption does not significantly affect the economic feasibility of the project. However, compared to base case, the cost of hybrid power generation is more economical and profitable. Each year, the government can save around USD 108,654 on electricity subsidies if it prefers the optimum solution (the subsidy needed is around USD 29,047) to base case (the subsidy needed is around USD 137,701). Providing base case subsidy annually to cover the difference between electricity fees paid by user and the cost of generation generates much higher NPC (USD 1,499,351) than giving 100% grant to cover the initial capital cost of hybrid power generation project (USD 382,446). Overall, it can be concluded that for RPZ Village, hybrid solution is the optimum solution in the long term (over the project lifetime) rather than base case option. When compared to the savings gained, the decision to set maximum tariff of PPA for renewable energy generation is actually a bit unfair if the local electricity generation cost is used as reference, since electricity generation cost of conventional power plant is certainly much lower than that of hybrid power generation system. To attract more investors, the government may reconsider the PPA capping price policy (85% of local electricity generation cost). The government may also consider implementing the Feed-in-Premium, where tariff above conventional market price with cap and floor system is applied (which is slightly different from fixed Feed-in-Tariff). The government may also charge carbon tax for fossil fuel power plants or divert fossil fuel subsidies, therefore revenues gained can be used as financial incentives to finance project in renewable energy. In addition, the government may review Build-Own-Operate-Transfer (BOOT) scheme because it is considered disadvantageous to the developers, where in nonrecourse project financing, bank do not accept the power plant as collateral since at the end of project lifetime, the power plant will be transferred to the government. This scheme limits the role of small developers who do not have assets, and only accommodates large developers who can provide guarantee. It also negates the salvage value. Consequently, the government may undertake advanced legal and techno-economic assessments, as well as take many factors into account before setting tariff, scheme, or regulation by accommodating interest of various stakeholders to make effective long-term win-win solution that can increase investment certainty, with minimum amendments and revocation.

If scenario 2a is used, the result is pretty similar to scenario 1. Integration of both systems has little impact on project economics, since additional revenue stream (from Prukades system) is not high enough to compensate for the costs incurred and to contribute significantly to lower the electricity generation cost. Meanwhile, if scenario 2b is used, there are 3 additional financing schemes which were economically feasible, i.e. FS-4, FS-7, and FS-10. This indicates that imposing slightly higher processing tariff could have considerable impact on the project economics, since additional revenue stream is high enough. However, it should be noted that the willingness-to-pay of cocoa farmers is sensitive to tariff. On the other hand, the average additional income per farmer decreased from Rp 2,666,370 in scenario 1 and scenario 2a to Rp 2,255,610 in scenario 2b, illustrated in Figure 8, as processing cost per farmer increased from Rp 1,092,840 in scenario 1 and scenario 2a to Rp 1,503,600 in scenario 2b.

In general, the integrated system could increase the economic attractiveness of the project. Prukades has much lower capital and operating and maintenance costs than hybrid power generation system, yet the share of revenue contribution from Prukades is significant. To make this integration strategy more profitable, it is recommended to design processing units for commodities with higher gross profit margins or to be more flexible for multiple product (not specific to one type only), to upscale the processing unit capacity, i.e. by expanding the processing center from village to sub-district level, and to choose the right productive zone that correlates with the occupation of majority.

4. Conclusions

From the results and discussion section, it can be concluded that:

- The design of Prukades system is proposed to be a centralized hybrid (solar thermal-biomass) postharvest processing unit. The optimum solution of hybrid power generation is solar PV (95 kW)-wind (78 kW)-diesel (200 kW) equipped with battery, with potential savings of electricity subsidy up to USD 108,654 compared to base case of diesel-fired power plant.

- For diesel-fired electricity tariff as reference, all scenario and financing schemes are economically feasible and the proposed hybrid system design is an economical and environmentally-friendly option, which increases annual income per farmer.

- Based on maximum tariff of PPA, using scenario 1 and 2a, almost all financing schemes are not economically feasible except FS-5. Meanwhile, using scenario 2b, there are 3 additional financing schemes which were economically, i.e. FS-4, FS-7, and FS-10. The integration of Prukades system with hybrid power generation system could enhance the economic attractiveness and lower the electricity generation cost.

- The selected optimum solution of hybrid power generation system could reduce dependence on diesel by 130,163 L per year and generate emissions that is 80% lower than the base case (diesel-fired power plant). Meanwhile, the proposed Prukades system could reduce dependence on firewood by 96,800 kg per year and generate emissions that is 23% lower than the conventional system (biomass-fired dryer).

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5. References

[1] Perusahaan Listrik Negara 2018 *Rencana Usaha Penyediaan Tenaga Listrik PLN 2018-2027* (Jakarta)
[2] Barzola J 2016 Analysis of hybrid solar/wind/diesel renewable energy system for off-grid rural electrification *Int. J. Renew. Energ. Res.* **6** 1146–52
[3] Hassan Q 2016 Optimization of PV/wind/diesel hybrid system in HOMER for rural electrification *J. Phys. Conf. Ser.* **745** 1–8
[4] Chauhan A and Saini R P 2016 Techno-economic feasibility study on integrated renewable energy system for an isolated community of India *Renew. Sust. Energ. Rev.* **59** 388–405
[5] Sen R and Bhattacharyya S C 2014 Off-grid electricity generation with renewable energy technologies in India: an application of HOMER *Renew. Energ.* **62** 388–98
[6] Matin M A 2013 Optimum planning of hybrid energy system using HOMER for rural electrification *Int. J. Comput. Appl.* **66** 45-52
[7] Balachander K and Vijayakumar P 2012 Optimization, simulation and modeling of renewable electric energy system with HOMER *Int. J. Appl. Eng. Res.* **7** 245–54
[8] Basu A and Marett D 2014 *Integrated sustainable rural development: renewable energy electrification & productivity zones* (Denmark: United Nations Development Programme)
[9] Kementerian Desa, Pembangunan Daerah Tertinggal, dan Transmigrasi 2017 *Percepatan Pembangunan Desa* (Jakarta: Forum Merdeka)
[10] Mulato S 2001 *Development and Evaluation of a Solar Cocoa Processing for Cooperative Use in Indonesia* (Universität Hohenheim: Dissertation)
[11] Mulato S 2010 *Cocoa Processing and Machinery Development in Indonesia* (Jember: Indonesian Coffee and Cocoa Research Institute)
[12] Mulato S 2010 *Pengolahan Produk Primer dan Sekunder Kakao* (Jember: Pusat Penelitian Kopi dan Kakao Indonesia)
[13] Shen X 2015 The comparative life cycle assessment of power generation from lignocellulosic biomass *Sustainbility* **7** 12974–87

[14] Blum N U 2013 Rural electrification through village grids–assessing the cost competitiveness of isolated renewable energy technologies *Renew. Sust. Energ. Rev.* **22** 482–96
[15] Lambert T 2006 Chapter 15: Micropower system modeling with HOMER *Integration of Alternative Sources of Energy* (New Jersey: John Wiley & Sons, Inc)