Feasibility Study Analysis of Hybrid Power Plant: Case Studies of Biomass and Solar PV at Bangka Island

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Abstract **-** In 2021, the Indonesia New Renewable Energy (NRE) mix achievement was 11,5% while the target for NRE mix targeted by Ministry of Energy and Mineral Resources (ESDM) in 2025, 2030, and 2050 was 23%, 25%, and 31%.
On Bangka Island, current NRE power plant installed capacity was 11,2 MW or 4,6% from total energy mix in Bangka – Belitung Islands Province, whereas Government of Bangka – Belitung Islands Province through Rencana Umum Energi Daerah (RUED) 2019 – 2050 planned to increase NRE mix at least 31,42% until 2025 with NRE power plant installed capacity at least 246,44 MW, and at least 39,31% until 2050 with NRE power plant installed capacity at least 560 MW.
This paper presents analysis to seen potential of generated electricity and Life Cycle Cost (LCC) & Levelized Cost of Energy (LCOE) of NRE power plant with types of Biomass Power Plant fueled by Empty Fruit Bunches (EFB) and Ground Mounted Solar PV on Bangka Island.
The result of this analysis indicates that potential of generated electricity from Biomass power plant fueled by EFB was 443,401 GWh/year according to availability of EFB on Bangka Island and potential energy production from Solar PV was 0,721 kW/m^2/day according to solar radiation on Bangka Island and efficiency of solar panel, inverter, and other equipment efficiency. LCC for 10 MW Biomass power plant was IDR 557.386.383.703 with LCOE IDR 544,37/kWh, also LCC for 2 MW Solar PV Power Plant was IDR 48.949.012.349 with LCOE IDR 1.336,54/kWh. LCOE for hybrid biomass and solar PV power plant system is Rp. 940,459/kWh. The LCOE of hybrid system is less than PLN electricity tariff limit on Bangka Island which is Rp. 2.006,52/kWh or cent USD 13,77/kWh.

Index Terms- Biomass, Solar PV, Potential Generated Electricity Energy, LCC, LCOE

I. Introduction

The dominant climate crisis caused by the use of fossil fuels has prompted countries in the world to agree to reduce global Greenhouse Gas (GHG) emissions, as outlined in the Paris Agreement. Indonesia ratified the Paris Agreement through Undang – Undang No. 16 Year 2016 and commited to reducing national GHG emmisions by 29% in 2030 with their own efforts and 41% with international assistance. One of the efforts made to reduce GHG emissions is by increasing the New Renewable Energy (NRE) mix in the national energy mix. In 2021 the NRE mix that was successfully achieved was 11,5%, while the targets for achieving the NRE mix targeted by the Indonesia Ministry of Energy and Minerals Resources (ESDM) in 2025, 2030, and 2050 were 23%, 25%, and 31%.
Another attempt to increase the NRE mix is carried out by Perusahaan Listrik Negara (PLN) through the Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) years 2021 – 2030, were the NRE mix in the RUPTL planned to reaches 51,6% of the total energy mix of 40,6 Gigawatts (GW), while in the previous RUPTL years 2019 – 2028, the NRE mix is only planned to reach 29,6% of the total energy mix of 56,4 GW.
At this time, the use of electrical energy derived from fossil fuels (coal, gas, and oil) to fullfilled the electricity demand is still very high. The availability and reserves of fossil energy sources are decreasing over time, therefore the dependence on fossil energy as a power plant fuel must be reduced. In addition, during the process of fossil fuel converting into electrical energy may releases harmfull pollutant gases into the air, the impact of these pollutants causes global warming and high GHG emissions. Many parties that often to fund the power plant projects, especially banks, has begun to stop funding fossil fuel power plants, especially coal and prioritize funding for NRE power plants.

1.1 Electricity Condition in Bangka Island

The electric power system on Bangka Island is supplied from PLN's Coal Power Plant (PLTU), Gas Engine Power Plant (PLTG), and Diesel Engine Power Plant (PLTD), besides that it is also supplied from Biogas Power Plant (PLTBg) and Biomass Power Plant (PLTBm) owned by Independent Power Producer (IPP) and excess power through the 150 kV and 20 kV networks. The capacity of the operating power plant serving the electricity needs on Bangka Island can be seen in the following table:

Table 1
Operating Power Plant on Bangka Island

POWER PLANT TYPE	UNITS	TOTAL CAPACITY (MW)	NETT AVAILABLE POWER (MW)	HIGHEST DMP IN PREVIOUS 1 YEAR (MW)
PLTU (Coal)	2	60	44	44
PLTS (Solar)	2	0,2	0,2	0,2
PLTD (Diesel)	46	90	58	58
PLN TOTAL	**50**	**150,2**	**102,2**	**102,2**
IPP				
PLTG (Gas)	2	50	50	50
PLTBm (Biomass)	2	8	8	5
PLTBG (Biogas)	2	3,2	3,2	3,2
IPP TOTAL	**6**	**61,2**	**61,2**	**58,2**
RENTED				
PLTD (Diesel)	6	38	38	38
RENTED TOTAL	**6**	**38**	**38**	**38**
GRAND TOTAL	**62**	**249,4**	**201,4**	**198,4**

According RUPTL PLN 2021 – 2030 simulation result for electricity supply and demand in Bangka Belitung Islands Province, there will be an electricity deficit in 2024 because the current generating capacity is 278,8 MW while in 2024, the peak load of electricity is 289 MW.

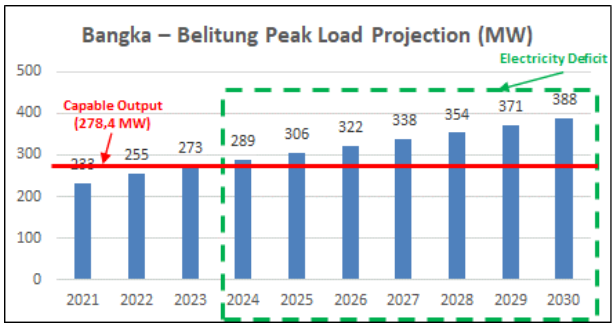

Fig. 1 Bangka – Belitung Peak Load Projection (MW)

1.2 NRE Development Plan in Bangka Belitung Island Province

Bangka Belitung Island Provincial Government through Rencana Umum Energi Daerah (RUED) year 2019 – 2050 has planned to increase NRE mix at least 31,42% until 2025 by providing NRE power generation capacity to 246,44 MW, details of NRE power plant up to 2025 according to RUED 2019 – 2050 can be seen below:

- Biomass Power Plant (PLTBm) 113,34 MW (Palm Shell fuel based)
- Wind Turbine Power Plant (PLTB) 4,15 M
- Biogass Power Plant (PLTBg) 17,4 MW (POME fuel based)
- Biodiesel Power Plant (PLTD) 10 MW

As for the target up to 2050 targeting NRE mix at least 39,31% by providing NRE power generation capacity to 560 MW, details of NRE power plant up to 2050 according to RUED 2019 – 2050 can be seen below:

- Biomass Power Plant (PLTBm) 280 MW (Palm Shell fuel based)
- Solar PV (PLTS) 220 MW
- Wind Turbine Power Plant (PLTB) 20 MW
- Biogass Power Plant (PLTBg) 20 MW (POME fuel based)
- Biodiesel Power Plant (PLTD) 20 MW

1.3 Biomass Potential in Bangka Island

Bangka Island is one of the largest CPO producing regions in Indonesia, in 2021 production (CPO) on Bangka Island reach 800,400 Tons and is the 12th (twelve) CPO producing region in Indonesia (Indonesian Central Bureau of Statistics, 2022). With this relatively large amount of CPO production, of course, the availability of solid waste from CPO processing is abundant, so there is potential to utilize this solid waste as fuel for power plants.

1.4 Solar PV Potential in Bangka Island

Indonesia as a country located on the equator has considerable potential in the provision of solar-based renewable energy power plant. The potential for solar energy in Indonesia is around 3,294 GWp (Anditya, 2021).

According to the Photovoltaic Power Potential Map published by the World Bank Group, Bangka Island has potential for solar energy of around 3,4 Kwh/kWp per day or 1.241 Kwh/Kwp per year.

1.5 Hybrid Power Plant System

In its development, NRE power plant that have an intermittency factor always developed using hybrid technology, which combines two or several types of power plant to meet the electricity demands at the same electricity load, it was developed to ensure the energy production, reliability, and availability can be maintained. In addition, a hybrid power plant was developed to be able to utilize NRE potential sources.

With availability and abundant of NRE potential sources in Bangka Island, especially EFB from CPO solid waste which can be used as biomass power plant fuel and solar radiation which can be converted into electricity energy, its very possible to develop biomass and solar PV power plant with hybrid technology to produce sustainable and reliable electricity. Beside that, the development of NRE with hybrid system can increase the power generation capacity, increase NRE mix in electricity system, reduce dependence on fossil power plant, reduce air pollution and GHG effect on Bangka Island.

1.6 Problem Identification

1. There is a deficit potential in capable power generation in Bangka Island on 2024, the current capable power generation is 278,4 MW, while PLN RUPTL 2021 – 2030 simulation result projected electricity demand in 2024 is estimated at 289 MW.
2. The NRE mix in Bangka Island on 2022 is only 4,6% with an installed capacity of NRE power plant is 11,2 MW, while the target to achieving the NRE mix in 2025 planned by the government of Bangka Belitung Island Province is 31,42% with installed capacity of NRE power plant is 246,44 MW.
3. Utilization of NRE sources in Bangka Island still not maximized yet, especially EFB from CPO solid waste and solar radiation.

1.7 Research Objectives

1. To know the potential electricity energy that can be generated by Biomass (EFB fuel based) and Solar PV on Bangka Island

2. To know Life Cycle Cost (LCC) and Levelized Cost of Energy (LCOE) of Biomass and Solar PV on Bangka Island.

II. LITERATURE REVIEW

2.1 Review of Empirical Studies

There have been many previous studies and research about NRE potential electricity energy, LCC, and LCOE from various power plant type namely Biomass, Solar PV, Wind, and Thermal power plant.

In the study done by Perkins (2018) which analyzed and calculating Levelized Cost of Energy (LCOE) from 2 different system, Solar PV + Battery and Solar PV + Combustion Bio Crude & Biomass. The findings revealed that hybrid solar PV + Bio-Crude & Biogas power plant has competitive LCOE than Solar PV + Battery Storage.

According to Singh and Baredar (2016), which researching about techno – economy anaysis of hybrid Solar PV + Battery + Biomass Gasifier. The result of research is the LCOE of hybrid power plant LCOE is Rs 15,064/kWh.

Solar PV + Biogass power plant has Net Present Cost (NPC) USD 67.616 and Cost of Electricity (COE) USD 0,164/kWh. Solar PV + Diesel power plant has NPC USD 115.355 and COE USD 0,280/kWh (Sanni et al., 2021).

Ara, Paul, and Rather (2021) research about techno – econimic of hybrid wind + solar PV power plant with 2 different scenarios. The result of the research found that from 2 scenarios (power plant output 320 MW and 343 MW) known that 343 MW output scenario has better efficiencies and economic feasibility. LCOE from 320 MW output is 7.975 INR/MWh and from 343 MW output is 7.316,8 INR/MWh.

According to Khaur, Gupta, and Dhingra (2021), which conducting research about analysis of hybrid solar biomass power plant for generation of electric power in Punjab, India. The result is potential electricity energy generating from biomass is 62,73 MW and from solar PV average is 5,23 kWh/m^2/day. The LCOE from hybrid power plant system is 10,39 INR/kWh.

According to previous research on Biomass, solar PV, and other hybrid NRE power plant type, this research focused on hybrid power plant of biomass power plant fueled with Empty Fruit Bunches (EFB) and solar PV which located in Bangka Island, Indonesia, focused to find out potential generated electricity energy from biomass also to know the LCC and LCOE.

2.2 Research Framework

Research concept framework is a description and visualization of the relationship and links between concepts or variables that will be observed or measured through the research (Notoatmodjo, 2012).

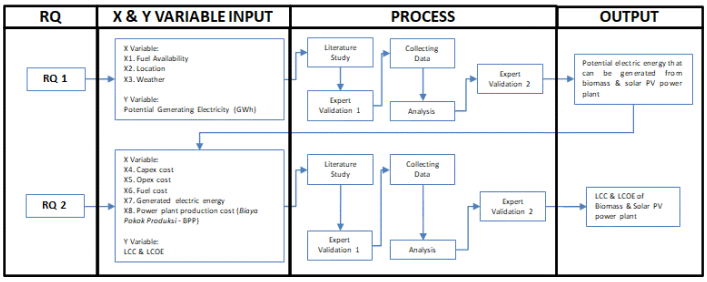

Fig. 2 Research Concept Framework

III. METHODOLOGY

This section aims to present the methodology of research to know potential electricity energy that can be generated from biomass and solar PV in Bangka Island and to know LCC and LCOE.

3.1 CPO Waste Production

CPO waste production is the residue from CPO processing which can be utilized to produce products that have an added value. The CPO waste consist of Empty Fruit Bunches (EFB), shell, fiber, and liquid waste. In general, the composition of CPO waste production can be determined by converting CPO production using the approach from research conducted by Lappeenranta University of Technology (2009) which can be seen below:

Table 2
Composition of Waste Production from CPO Processing

Per Tonne Fresh Fruit Bunch (FFB)			
Inputs	**Lowest**	**Average**	**Highest**
FFB (kg)	1000	1000	1000
Electricity (MJ)	58	65	75
Steam (MJ)	1100	1400	1700
Outputs	**Lowest**	**Average**	**Highest**
Main Products			
CPO (kg)	190	200	210
Palm Kernels (kg)	50	70	80
Palm Waste			
EFB (kg)	220	240	300
Fibre (kg)	120	140	160
Shell (kg)	50	70	80
POME (kg)	500	590	700

Source: Lappeenranta University of Technology (2009)

3.2 Biomass Fuel Needed

According to NEDO (2011), fuel needed for biomass power plant which using 100% EFB can be calculated using the following equation:

- Ratio according to calories:
  a. kWh production:
     Capable Capacity (kW) x Hours/Year (hour) x Capacity Factor (CF)
  b. Joule needed:
     kWh production x 3,59 MJ
  c. Thermal efficiency according to assumption (17%):
     (Energy produced x 100) / 17; per year

• Ratio according to volume needed:

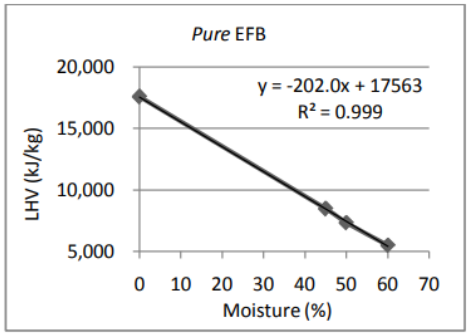

Fig. 3 EFB Calorific Value Function

Y = -202x + 17563

where:
Y = LHV (kj/kg)
X = Moisture (EFB moisture assumption is 40%)

3.3 Solar Radiation

Solar radiation data will be obtained from Meteonorm by entering coordinates of Bangka Island location. Meteonorm records solar radiation data from 1991 – 2010 and air temperature data between 2000 and 2009. Meteonorm is a software that provides weather data from trusted sources. In addition, Meteonorm can process weather data very accurately and represent more than 30 weather parameters. The processed data is obtained from more than 8000 weather stations, 5 geostationer satellites, and aerosol climatology which calibrated globally.

3.4 Potential Generated Electric Energy

Potential generated energy from biomass power plant is dependent on EFB availability on Bangka Island which is used as a power plant fuel, EFB production data for calculation of potential generated electricity energy will taken from the last 5 years. Potential generated electricity energy can be calculated using the following equation:

$$Potential\ Generated\ Energy = \frac{Avg.Annual\ EFB\ Production\ (ton)}{EFB\ Consumption\ per\ MW\ per\ years\ (ton)}$$

3.5 Life Cycle Cost (LCC)

Life Cycle Cost (LCC) is all the cost incurred during the lifetime of the power plant includes initial investment cost, maintenance cost, and equipment replacement cost. In general, LCC for biomass and solar PV power plant can be calculate using the following equation:

$$LCC = C + M_{PW} + R_{PW}$$

where:
C = Initial Investment Cost
Mpw = O&M (fixed and variable) cost
Rpw = Equipment replacement cost.

O&M (fixed and variable) cost can be calculate using the following equation:

$$M_{PW} = A\left[\frac{(1-i^n)-1}{i(1-i)^n}\right]$$

where:
A = O&M cost value
i = interest value
n = asset lifespan.

Equipment replacement cost can be calculate using the following equation:

$$R_{PW} = F(1+i)^{-n}$$

where:
F = Equipment price
i = interest value
n = time period to replace the equipment

3.6 Levelized Cost of Energy (LCOE)

Levelized Cost of Energy (LCOE) can be calculated by divided LCC into annual cost (annual LCC) then divided with annual energy production from power plant. Annual LCC can be calculated using the following equation:

$$Annual\ LCC = LCC\frac{i(1+i)^n}{(1+i)^n-1}$$

where:
LCC = Life Cycle Cost value
i = interest value
n = asset lifespan.

After knowing annual LCC and annual energy production from power plant, then LCOE can be calculated using the following equation:

$$LCOE = \frac{Annual\ LCC}{Annual\ Energy\ Production}$$

3.7 Technical Details

This research will assume Biomass power plant capacity is 10 MW and Solar PV capacity is 2 MW. Technical details for this research will be shown below:

Table 3
Technical Detail of 2 MW Solar PV Power Plant

Project Location	Bangka Island, Indonesia
Power Plant Capacity (kWp)	2.000
Technology	Solar Photovoltaic
Module Efficiency (%)	20.9

Module Temp. Efficiency (%)	1.19
Inverter Efficiency (%)	98.8
Cable & Other Equipment Efficiency (%)	85
Type of Module	Mono-Crystalline
Solar Panel (wP)	545
No. of Solar Panel	2500
Capital Cost of The Plant (Rp.)	35,700,000,000

Table 4
Technical Detail of 10 MW Biomass Power Plant

Project Location	Bangka Island, Indonesia
Power Plant Capacity (kW)	10.000
Lossess & Personal Usage (kW)	1.000
Supplied Energy (kW)	9.000
Technology	CFB Boiler
Capacity Factor (%)	80
Capital Cost of The Plant (Rp.)	255,750,000,000

IV. RESULT & DISCUSSION

4.1 Biomass Potential Energy Generated

A. Fuel Needed

Biomass power plant fuel needed calculated using equation from sub-chapter 3.2 and the result can be seen below:

Table 5
Biomass Power Plant Fuel Needed

Annual kWh Production (kWh)	63.072.000
Joule Needed (MJ)	226.428480
Energy Needed (Thermal Eff.: 17%) (MJ)	1.331.932.235
Assumed EFB Moisture (%)	40
LHV (kJ/kg)	9,48
EFB Needed for Annual Op. 10 MW Biomass (Ton)	140.499

B. Potential Energy Generated

Potential energy generated from biomass power plant is depend on production of EFB on Bangka Island which will be used for main fuel, EFB production data for past 5 years shown a stable trend.

Table 6
EFB Production on Bangka Island

Year	EFB (Ton)		
	Low.	**Avg.**	**Hi.**
2017	875.484	907.320	1.080.143
2018	1.042.453	1.080.360	1.286.143
2019	944.495	978.840	1.165.286
2020	976.105	1.011.600	1.204.286
2021	926.779	960.480	1.143.429
Average	**953.063**	**987.720**	**1.175.857**

Calculation for potential energy generated is according to fuel needed for operated 10 MW Biomass power plant and average EFB production on Bangka Island, the result is potential energy generated from Biomass power plant is 443,401 GWh/year.

4.2 Solar PV Potential Energy Generated

Solar PV energy output is depended on solar radiation and weather condition during the day. Solar radiaton and weather condition on Bangka Island presented on table below:

Table 7
Solar Radiation & Temperature on Bangka Island

Month	POA (kWh/m^2)	POA (kWh/m^2/day)
January	107,8	3,59
February	108,7	3,62
March	129,8	4,33
April	120,9	4,03
May	137,1	4,57
June	140,2	4,67
July	141,6	4,72
August	142,4	4,75
September	141,3	4,71
October	128,6	4,29
November	103,3	3,44
December	97,6	3,25
Average	**124,94**	**4,16**

Ambient temperature (°c)	28,5

According to Meteonorm, average solar radiation on Bangka Island is 4,16 kWh/m^2/day.

Potential energy generated is based on average solar radiation on Bangka Island and solar PV power plant technical specification, the calculation result can be seen at table below:

Table 8
Solar PV Potential & Energy Production

Solar Radiation (kWh/m^2/day)	4,16
Module Efficiency (%)	20.9
Module Temp. Efficiency (%)	1.19
Inverter Efficiency (%)	98.8
Cable & Other Equipment Efficiency (%)	85
Potential Energy Production (kW/m^2/day)	0,721
2 MW Power Plant Annual Production (kWh)	2.527.118

According to the calculation, 2 MW Solar PV Power plant can produce electricity 2.527.118 kWh per year and has potential energy generated 0,721 kWh/m^2/day.

4.3 Life Cycle Cost (LCC) & Levelized Cost of Electricity (LCOE)

A. Power Plant Cost

Power plant cost consist of Component A (Invesment Cost), Component B (Fixed O&M Cost), Component C (Fuel Cost), and Component D (Variable O&M Cost). Biomass and Solar PV power plant cost, cost breakdown will be presented on table below:

Table 9
10 MW Biomass Power Plant Cost

Component A (Investment Cost; Rp.)	255.750.000.000
Component B (Annual Fixed O&M Cost; Rp.)	12.858.681.605
Component C (Annual Fuel Cost; Rp.)	2.653.873.417
Component D (Annual Variable O&M Cost; Rp.)	3.068.100.000
Annual Depreciation (Rp.)	10.230.000.000

Table 10
2 MW Solar PV Power Plant Cost

Component A (Investment Cost; Rp.)	35.700.000.000
Component B (Annual Fixed O&M Cost; Rp.)	357.000.000
Component D (per-5 yrs Variable O&M Cost; Rp.)	2.856.000.000
Annual Depreciation (Rp.)	1.428.000.000

B. Life Cycle Cost (LCC)

LCC will be defined as the total cost of the power plant during its lifetime and will be calculated using data of power plant cost. Life time of power plant is set to 25 years and assumed inflation rate is 3,64%. Calculation result show that 10 MW Biomass power plant LCC is Rp. 557.386.383.703 and 2 MW Solar PV power plant LCC is Rp. 48.949.012.349.

C. Levelized Cost of Electricity (LCOE)

LCOE will be calculated based on power plant annual LCC and power plant annual energy production, LCOE will defined as the price at which the generated electricity should be sold for system break event at the end of its lifeteme. From the calculation known that 10 MW Biomass power plant LCOE is Rp. 544,37/kWh and 2 MW Solar PV power plant LCOE is Rp. 1.336,54/kWh. According to LCOE of each power plant, the LCOE of hybrid system of Biomass and Solar PV is Rp. 940,459/kWh.

V. CONLUSION

Total of potential generated electricity energy from Biomass power plant fueled by empty fruit brunch (EFB) on Bangka Island is 443,401 GWh/year and from solar PV according to solar radiation and efficiency solar panel, inverter, and other equipment is 0,721 kWh/m^2/day.

In developing country, such as Indonesia, this research offers a new perspective on renewable technology and their potential. This research has covers energy from Biomass and solar PV. Life Cycle Cost (LCC) of 10 MW Biomass power plant is Rp. 557.386.383.703 and 2 MW Solar PV power plant is Rp. 48.949.012.349.

Levelized Cost of Electricity (LCOE) of 10 MW Biomass power plant is Rp. 544,37/kWh and 2 MW Solar PV power plant LCOE is Rp. 1.336,54/kWh, the LCOE of biomass and solar pv hybrid system is Rp. 940,459/kWh, the LCOE of hybrid system is less than PLN electricity tariff limit on Bangka Island which is Rp. 2.006,52/kWh or cent USD 13,77/kWh.

Hybrid system of biomass and solar PV development has benefits:

a. Suitable for produce and distributed electricity in remote area, especially area around or near palm oil plantation
b. Reduced palm oil wastes
c. Employment local people
d. Utilization of available renewable energy resources
e. Increase NRE mix on Bangka Island and Indonesia.

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