An Analysis of Renewable Energy Potential and Deployment towards Bali Net-Zero Emission

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Abstract – The Bali Provincial Government has declared a commitment to achieve Net Zero Emissions (NZE) by 2045. This involves transitioning from non-renewable energy sources to renewable energy to reduce emissions from the energy sector. The policy aligns with the growing demand for electricity and the abundant renewable energy potential in Bali Island. Three scenarios were simulated using the Open Source energy Modelling System (OSeMOSYS) software to evaluate Bali power system with renewable energy potential from 2024 to 2045. The results indicated that to achieve NZE in year 2045, for the optimistic scenario, the renewable energy share may reach 85.62% and result in a reduced emission to 5.78 million tons of CO_2eq. For the moderate scenario, Bali Island is required to have a renewable energy share of about 84.13% and 4.15 million tons of CO_2eq at the end of year 2045. Meanwhile, for the pessimistic scenario, the renewable energy share must be about 82.65% and with an emission of 3.19 million tons of CO_2eq in 2045.

***Index Terms*— Renewable Energy, Emissions, Electricity Generation, OSeMOSYS.**

I. INTRODUCTION

As the population density within a region increases, so does the electricity demand. This fact certainly requires an increase in electricity production to adequately meet the growing demand [1]. Most of power plants currently in operation however, rely on non-renewable sources, making them the primary contributors to emissions compared to renewable energy sources. Furthermore, the limited availability of the fossil fuels as the primary energy source for non-renewable power plants, thus requires a reduction in their operation and a transition towards more environmentally friendly renewable energy sources.

Over the past two years, from 2021 to 2022, total emissions in Bali Island have increased by 3.74%, from 11,653.69 GgCO_2eq to 12,471.61 GgCO_2eq. The energy sector consistently accounts for the highest proportion of emissions, averaging 7,908.30 GgCO_2eq per year [2].

According to the 2023-2060 National Electricity System General Plan (RUKN), Bali province possesses abundant renewable energy resources, including hydropower (208 MW), mini-hydro and micro-hydro (15 MW), biomass (146.9 MW), biogas (44.7 MW), solar power (1,254 MW), wind power (1,019 MW), ocean energy (320 MW), and geothermal energy (262 MW) [3].

In the transition to renewable energy, Bali province is striving to achieve Net Zero Emissions by 2045 to minimize the use of non-renewable power plants and reduce emissions from power generation. Bali aims to be a pioneer in the renewable energy transition by setting a target 15 years ahead of the national target in 2060. This target is expected to encourage other regions to adopt similar initiatives in achieving renewable energy and reducing emissions from the energy sector [4].

Based on these challenges, this research focuses on planning to meet Bali province's electricity generation needs by optimizing the available renewable energy potential, aiming to achieve energy self-sufficiency with clean and environmentally friendly energy. To accomplish this, three scenarios, namely optimistic, moderate, and pessimistic were simulated using the Open Source energy Modeling System (OSeMOSYS) software.

II. LITERATURE REVIEW

A. *Related Studies*

In a study conducted by Handayani et al. [5], a roadmap projection towards net zero for ASEAN countries was carried out for the period 2021-2050, using three scenarios: Reference (REF), Renewable Energy Target (RET), and Net Zero Emission (NZE). The results showed that in 2050, the REF scenario produced emissions of 2,044 million tons of CO_2eq, the RET scenario resulted in emissions of 1,416 million tons of CO_2eq, while the NZE scenario successfully achieved zero emissions in 2050.

Another study by Purnomo et al. [6] analysed the emission reduction of Bali Province from 2021-2030 against the target achievement of the Nationally Determined Contribution (NDC) of 19% and 27%. Using two scenarios and the LEAP software, the results showed that the RUPTL scenario with an installed capacity of 1881.1 MW generated emissions of 8,070 million tons of CO_2eq, while the BAU scenario with an installed capacity of 2,1493.3 MW resulted in emissions of 10,190 million tons of CO_2eq.

Rahmatullah et al. [7] analysed the potential of renewable energy, namely wind energy and solar cells, applied to simple houses in Medan. The results showed that this could generate the required electricity for the house, ranging from 100-250 Watts.

Sonjaya et al. [8] analysed the potential of renewable energy on the island of Sumatera from 2020-2050 in accordance with the RUED plan using the LEAP software. The results showed that renewable energy potential could meet energy needs but could produce 59.1 million tons of CO_2 emissions in 2028, and most of the power generation was still dominated by hydropower from 2020-2050.

The consistency of Indonesia's energy policy in achieving energy transition with the National Energy Policy (KEN) in 2050 was studied by Siagian [9]. The results showed that Indonesia's energy policy was not yet consistent in achieving the energy transition and still relied on coal.

This research is based on the projection of electricity consumption needs in Bali Province, the highest peak load that has ever occurred from 2024-2045, technical parameters in each power generation and energy loss were modelled in the simulation.

B. Bali Electrical Power System

PT. PLN distributes electricity through two methods: firstly, by relying on electricity supply from Java Island through a 400 MW submarine cable, and secondly, by utilizing power plants located in Bali Island with a capacity of 949.2 MW. The combination of both provides a total capacity of 1,349.3 MW [10].

Table 1. Existing Capacity of Bali Electricity System

Power Plant	Capacity (MW)
PLJawa (Interconnection)	400
PLTU Celukan Bawang	380
PLTG Jawa Bali	322
PLTD Jawa Bali	59.5
PLTD Tiga Nusa Bali	1.9
PLTMG Jawa Bali	182.40
PLTA Muara Panji	1.4
PLTS Kubu	1
PLTS Banglet	1
Total	**1,349.2**

C. Bali Renewable Energy Potential

Based on the earlier studies, there are numerous types of renewable energy power plants that can be utilized for decarbonization purposes [10]. Considering the relatively small potential of renewable energy in fulfilling the electricity demand for Bali Island, this model requires energy storage to serve as a backup for electricity supply. This energy storage can act as a reserve for electrical energy from renewable power plants. In this model, two types of energy storage will be used, namely Pumped Hydro Energy Storage (PHES) and Battery Energy Storage System (BESS).

Table 2. The Potential of Renewable Energy in Bali

Power Plant	Potential
PLTS (Solar PV)	26,45 GW
PLTA (Hydro power)	25,5 MW
PLTB (Wind power)	1 GW
PLTBm (Biomass)	615 MW
PLTSa (Waste)	57,6 MW
PLTP (Geothermal)	225 MW
PLTAL (Sea current)	320 MW

D. Technical Parameters of the Power Plant

Technical parameter data for simulation was collected from the document of "Technology Data for The Indonesian Power Sector", released by the Ministry of Energy and Mineral Resources and Danish Energy Agency in 2021 [11]. For technical parameters not listed in this document, the model was created using the available data from similar studies focused on energy modeling in Indonesia.

Table 3. Technical Parameters of Power Plant and Storage

Technology	Fuel/ Resource	Operating Life (Year)	Efficiency (%)	Max Availability (%)
PLTU *Subcritical*	Lignite coal	30	34	80
PLTG	Natural gass	25	34	80
PLTD	Diesel	25	46	80
PLTGU	Natural gas	25	56	80
PLTS	Solar irradiation	35	21	17
PLTA	Mechanical Energy of Water	50	95	41
PLTM		25	80	46
PLTB	Kinetic energy of the wind	27	100	28
PLTSa	Solid waste	25	29	80
PLTBm	Biomass	25	32	80
PLTP	Geothermal energy	30	16	80

PLTAL	Mechanical Energy of Water	25	90	33
PHESS		50		20
BESS	Storage	50		50

E. RUPTL 2021-2030

RUPTL is a document compiled by PT PLN (Persero) that focuses on the provision of electricity based on specific planning policies and criteria. The RUPTL 2021-2030 is an improvement of the previous edition and is categorized as a "Green RUPTL" due to a large portion of planning for renewable energy development. In the latest RUPTL, the development plan for the renewable energy exceeds 51% or about 20.93 GW, compared to fossil fuel-based power plants of about 19.7 GW [10].

F. Assumption for Power System Model

Transmission and distribution losses is assumed to decrease up to 4% in 2045. A 30% reserve margin was specified in the model for generating units contributing to peak load coverage, excluding intermittent solar and wind power plants that are incapable of providing reserve capacity. Table 4 shows the assumptions for the power system model.

Table 4. Assumptions for power system model

Parameter	Assumptions (2024-2045)
Transmission and Distribution Losses	5,30% – 4,00%
Reserve Margin	30%

G. Peak Load

Prastika et al. [12] analyzed the projected energy demand in Bali Island and the results showed that with a projected load factor of 85.86%, the peak loads for each scenario in 2024 was 950.16 MW (optimistic), 907.03 MW (moderate), and 855.92 MW (pessimistic). For year 2045, the projected peak load would be 5,723.92 MW for optimistic scenario, 3,695.79 MW for moderate scenario, and 2,571.96 MW for pessimistic approach [12].

H. Emission Factor

An emission factor describes the relationship between the amount of greenhouse gas (GHG) emissions released into the atmosphere and the activity data associated with those GHG emissions.

$$E = DA \times FE \qquad (2.1)$$

Where:
E = GRG emission (tons)
DA = Activity (Tj)
FE = Emission Factor (tons/Tj)

The emission factors generated from each generating unit are as follows [13].

Tabel 4. Emissions Factors of a Power Plant

Power Plants	Emission Factors (tons/MWh)
PLTU (Coal Fired)	1.14
PLTG (Gas)	1.002
PLTGU (Combined Cycle)	0.505
PLTD (Diesel)	0.786
PLTP (Geothermal)	0.2

I. Net Zero Emission (NZE)

The NZE program has gained popularity in various countries following the Paris Climate Agreement of 2015. This program aims to reduce environmental pollution caused by greenhouse gas emissions. The energy sector, which produces significant emissions, is one of the key areas of implementation for the NZE program. Currently, the Indonesian government is taking serious steps to address greenhouse gas emissions, with a commitment to achieving net zero emissions by 2060, or even earlier. Bali Province has set a more ambitious target of achieving Net Zero Emission by 2045, fifteen years ahead of the national target. To achieve this 2045 target, several strategies are needed, one of which is to minimize the operation of coal-fired power plants. The goal of this strategy is to reduce the emissions generated by these power plants. The utilization of renewable energy power plants will replace the operation of coal-fired power plants with a more environmentally friendly alternative.

J. OSeMOSYS

OSeMOSYS is a user-friendly software because it is designed as open-source, enabling anyone to access, examine, modify, and share the models developed within the system. OSeMOSYS can be employed to develop energy system models ranging from the global, continental, national, regional, to the village scale. The models represented in OSeMOSYS provide a framework for long-term energy system modeling and optimization, used for conducting long-term analyses and planning of energy systems. Additionally, it can be utilized for optimizing renewable energy sources to minimize emissions generated from fossil fuel power plants. Beyond representing long-term energy system modeling and optimization, OSeMOSYS can also represent economic analyses of the developed plans, such as the required investment costs, operational costs, and maintenance costs [14].

III. RESEARCH METHOD

A. Energy System Chain

An energy chain model for simulations is shown in Figure 1. This chain shows the energy resources and the energy flow from generation to its utilization.

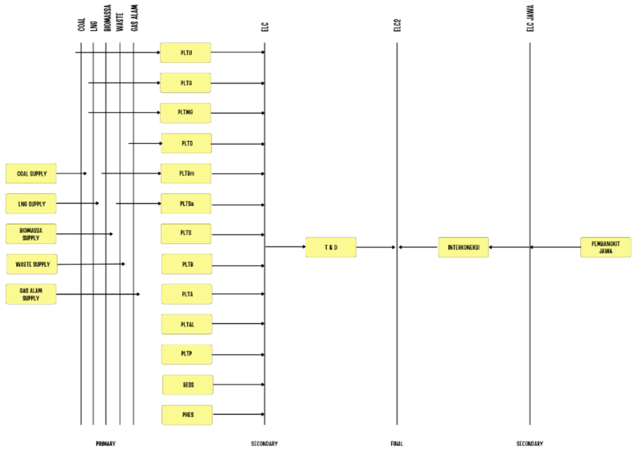

Figure 1 Model of the Energy Chain

B. *Reserve Capacity*

The reserve capacity of the power plant is considered about 30% of the peak load. It is also determined that the transmission and distribution losses decrease to 4% at the end of the modeling year.

C. *Solar and Wind Power Model*

Solar Radiation Curve

The modeled solar radiation curve represents the average of hourly solar irradiance in September for 24 hours in each regency of Bali Province, based on data obtained from NASA. The results show that the maximum solar radiation is reached at noon with a value of 984.10 W/m² as shown in Figure 2 [15].

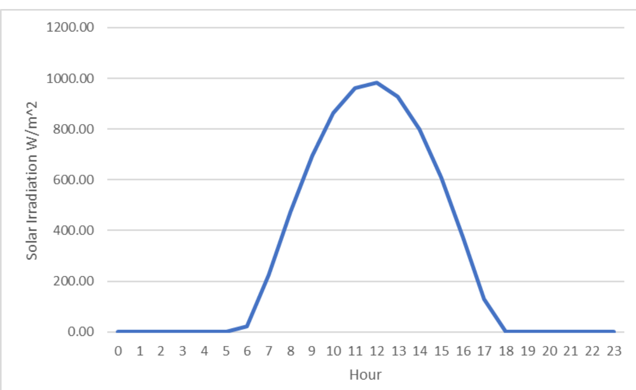

Figure 2 Solar Irradiation Curve

Wind Velocity Curve

The modeled wind velocity curve represents the average hourly wind speed in Bali Province during September for all regencies in Bali Province, based on data obtained from the NASA as shown in Figure 3. The maximum wind speed is about 4.40 m/s [16].

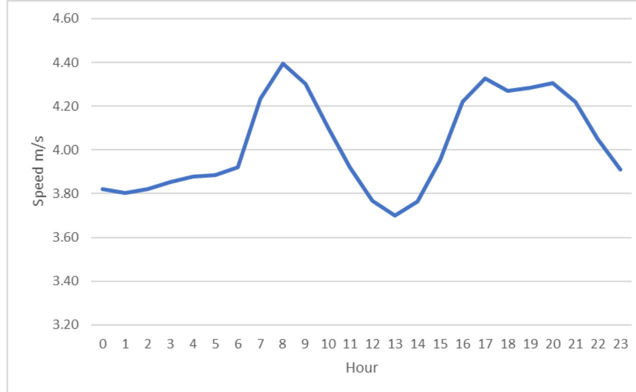

Figure 3 Wind Velocity Curve

D. *Power Balance*

The power balance is calculated based on the three different scenarios to meet the electricity system's power needs by considering renewable energy potential without adding new fossil-fuel power plant. Note that the coal-fired power plants should be shut down by 2045.

E. *Simulation Scenario*

Three scenarios were analysed, starting from optimistic, pessimistic, and moderate scenarios based on the least running cost with the assistance of OSeMOSYS software. Subsequently, a running cost analysis will be conducted, and a decision will be made to prioritize the fulfillment of the cheapest power generation needs up to their maximum availability.

IV. RESULTS AND DISCUSSION

A. *Power Plant Capacity*

Figure 4 shows the required additional capacities of power plant to fulfill the projected demand. In 2024, each scenario has the same power generation output of 1,420.50 MW, with a contribution of 1,345.80 MW from non-renewable power plants and 74.70 MW from renewable power plants. At the end of year 2045, the optimistic scenario indicates an increase in about 19,410 MW, with a 965.80 MW for non-renewable power generation capacity and a 18,444 MW from renewable power generation. For the moderate scenario, there is an increase in about 13,420 MW, with details of 965.80 MW for non-renewable power generation capacity and 12,455.10 MW for the renewable power generation. In the pessimistic scenario, there is an increase in approximately 9,752 MW, with details of 965 MW for non-renewable power generation capacity and 8,786 MW for renewable power generation.

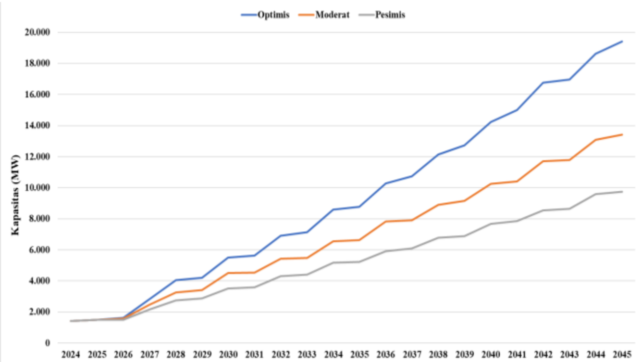

Figure 4 Comparison of Power Plant Capacity for Three Scenarios

B. *Electrical Energy Production*

Figure 5 depicts the electrical energy production for year 2024-2045. It shows that in 2024, the optimistic scenario yields 7,502 GWh, increasing to 44,741 GWh in 2045, with an average annual growth rate of 8.88%. In the moderate scenario, it yields 7,177 GWh, increasing to 29,022 GWh in 2045 with an average annual growth rate of 6.88%. In the pessimistic scenario, it yields 6,793 GWh, increasing to 20,552 GWh in 2045, with an average annual growth rate of 5.36% per year.

This plan is in line with the RUKN which states that the renewable energy share should reach 83% of the national electricity supply by 2060. The simulation results for the optimistic scenario shows that the renewable energy contributes about 85.62% of Bali electricity generation, which is 2.62% higher than the national target. In the moderate scenario, renewable energy contributes 84.13% to Bali electricity generation, which is 1.13% higher than the national target. Whilst for the pessimistic scenario, the renewable energy contributes about 82.65% to Bali electricity generation, which is 0.35% lower than the national target. Figure 6 exhibits the comparison of the renewable energy share for the 3 Scenarios.

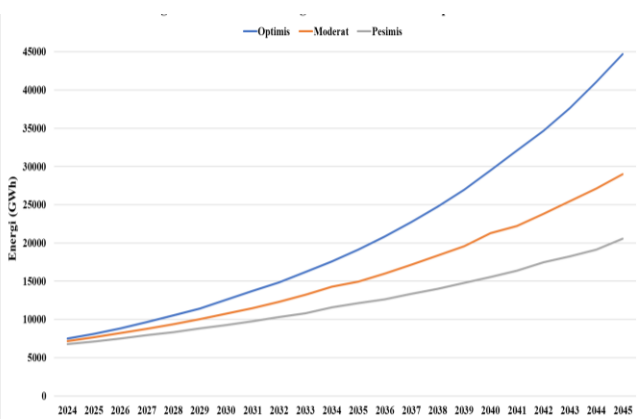

Figure 5. Comparison of Electrical Energy Production for the 3 Scenarios

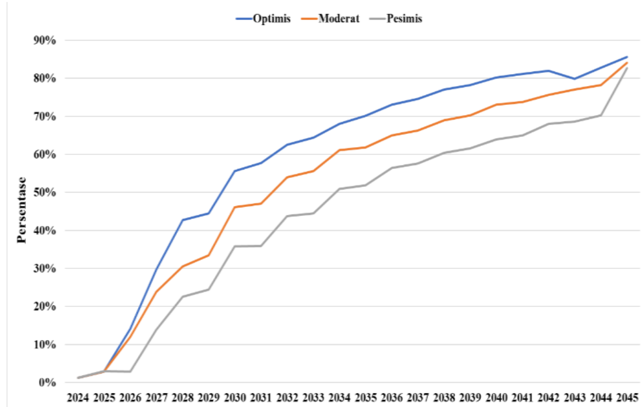

Figure 6. Comparison of Renewable Energy Share for the 3 Scenarios

C. *Emissions*

The comparison of emission from the three scenarios is shown in Figure 7. It is clear that for the optimistic scenario, the initial emission contribution is 6.99 million tons of CO_2eq decreases to 5.78 million tons of CO_2eq in year 2045. For the moderate scenario, the initial contribution of emissions is about 6.70 million tons of CO_2eq decreases to 4.15 million tons of CO_2eq at the end of year 2045. For the pessimistic scenario, the initial emission is 6.36 million tons of CO_2eq decreases to 3.19 million tons of CO_2eq in 2045.

V. CONCLUSIONS

Based on the simulation results, it can be concluded that to achieve NZE in year 2045, for the optimistic scenario, the renewable energy share may reach 85.62% and result in a reduced emission to 5.78 million tons of CO_2eq. For the moderate scenario, Bali Island is required to have a renewable energy share of about 84.13% and 4.15 million tons of CO_2eq at the end of year 2045. Meanwhile, for the pessimistic scenario, the renewable energy share must be about 82.65% and with an emission of 3.19 million tons of CO_2eq in 2045.

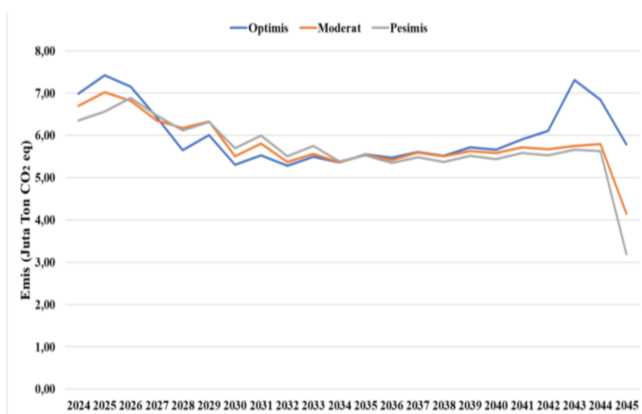

Figure 7 Comparison of Emissions for the 3 Scenarios

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