Available *online* at: http://ajeeet.ft.unand.ac.id/

Andalas Journal of Electrical and Electronic Engineering Technology

ISSN 2777-0079

Review Article

A Review of Renewable Energy Development and Planning for an Island Province in Eastern Indonesia: Case Study of North Maluku

Pinto Anugrah[1], Subhan Petrana[2], Heru Dibyo Laksono[1]

[1] *Electrical Engineering Department, Faculty of Engineering, Universitas Andalas, Padang 25163, Indonesia*
[2] *Department of Electrical Engineering, Faculty of Engineering, Universitas Khairun, Ternate 97719, Indonesia*

ARTICLE INFORMATION

Received: 27 June 2022
Revised: 18 July 2022
Accepted: 22 July 2022

KEYWORDS

Renewable Energy, Power Development and Planning, North Maluku

CORRESPONDENCE

Phone: +62 813 1704 1045
E-mail: pinto@eng.unand.ac.id

A B S T R A C T

Indonesia intends to use renewable energy both locally and on a national scale. Regional energy planning must be developed by provincial governments in accordance with national energy planning (RUEN). One of the few provinces that has already published its regional energy planning is North Maluku Province. The ambition to use more renewable energy technologies for power generation is already taken into account in their regional energy planning. However, North Maluku Province may rely on renewable energy as their primary source of power because of the abundance of these resources. The purpose of this paper is to examine renewable energy development and planning in relation to the RUPTL 2021-2030 power development plan. This review gives an insight that North Maluku Province still have untapped renewable energy potential which can be developed in the future to increase its renewable shares in electricity mix as well as to enhance energy security and accessibility in the region.

INTRODUCTION

Several types of energy are used directly by individuals or companies in their everyday lives. Electricity is one of the most extensively utilized energy sources. Electricity serves as a bridge between main energy sources such as coal and gas and our electrical gadgets. As a result, the government considers power availability and security to be critical parameters. On the other hand, one of the primary causes of global warming is attributed to energy usage [1]. Renewable energy has been shown to contradict that assertion because it does not emit greenhouse gases when in operation. One way to combat global warming is to switch to renewable energy. The Indonesian government accepted the Paris Agreement, promising to reduce emissions by 29 percent from the baseline by 2030 [2].

Indonesia intends to use renewable energy both locally and on a national scale. Regional energy planning must be developed by provincial governments in accordance with national energy planning (RUEN) [3]. One of the few provinces that has already published its regional energy planning is North Maluku Province. The ambition to use more renewable energy technologies for power generation is already taken into account in their regional energy planning. However, North Maluku Province may rely on renewable energy as their primary source of power because of the abundance of these resources.

In the rural electrification initiative, the use of renewable energy sources has emerged as a significant alternative to traditional power sources [4]. when oil prices are at their peak and conventional sources are exhausted. At this area, photovoltaic (PV) panels, wind turbines, and batteries use solar radiation to power renewable energy applications. The system is initially a single source system. To meet load demand, a single renewable energy source, however, often tends to be enlarged. Hybrid energy, which combines one or more renewable energy sources, will increase load factors and reduce maintenance and replacement costs since renewable energy sources may complement one another [5]. However, in order to optimize the system, the appropriate sort of renewable energy system must be evaluated [6].

Schmid and Hoffman conducted extensive research to assess the economics of renewable energy systems as alternatives to diesel generators [7]. Several publications in the literature have investigated the design and planning of hybrid renewable energy systems [8]–[10]. The purpose of this paper is to examine renewable energy development and planning in relation to the RUPTL 2021-2030 power development plan [11].

OVERVIEW OF NORTH MALUKU POWER SYSTEM

The electric power system in North Maluku Province consists of 7 systems with loads above 3 MW, namely the Ternate-Tidore, Tobelo-Malifut, Jailolo, Sofifi, Bacan, Sanana and Daruba systems. In addition, there are also 32 units of smaller-scale power plants in various locations.

The combined peak load (non coincident) of electric power systems in North Maluku Province is currently around 100.9 MW, supplied by gas power plant (PLTMG), distributed diesel power plant (PLTD) and solar PV (PLTS) which are directly connected to the 20 kV distribution system. Some of the smaller systems are connected directly to the 220 Volt (low voltage) grid. Some of the systems with the largest load in North Maluku can be seen in Figure 1.

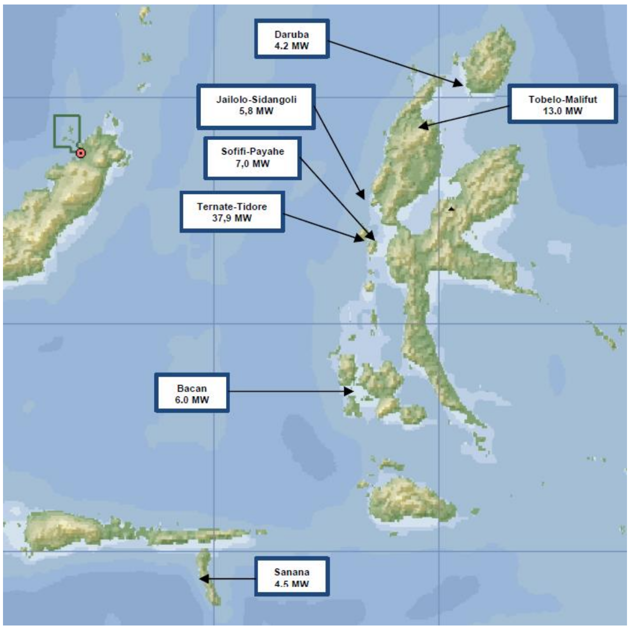

Figure 1. Power Plant Location Map in North Maluku Province [11]

Electricity consumption from 2011-2020 grew by an average of 10.9%. The composition of energy sales and the number of customers in 2011-2020 for each customer group are shown in Figure 2 and 3.

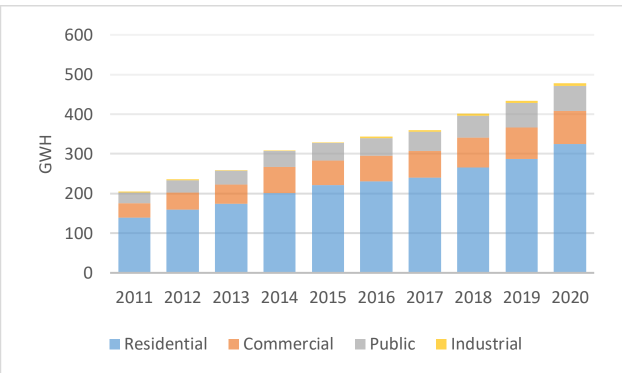

Figure 2. Electricity Sales 2011-2020

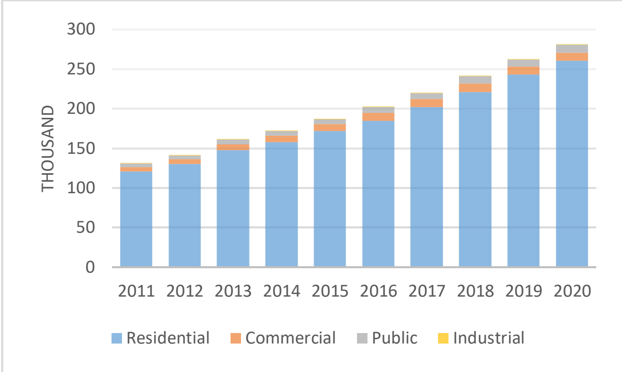

Figure 3. Electricity Customers 2011-2020

The largest power system in North Maluku is the Ternate-Tidore System where it has around 70.0 MW power supply with a net capacity of 52.8 MW and a peak load of 36.2 MW. The installed capacity of the electric power system in North Maluku Province can be seen in Table 1 and Table 2. In addition to the development of the 150 kV network for the Ternate-Tidore system, a 150 kV system is also planned for Halmahera system. Both system maps are given in Figure 4 and 5.

Table 1. PLN-owned Power Generation in North Maluku

Type	System	Unit	Installed Capacity (MW)	Net Capacity (MW)	Peak Load in 2020
Coal (PLTU)	Ternate-Tidore	2	14,0	12,0	12,0
Gas (PLTMG)	Ternate-Tidore	4	40,0	35,5	35,5
Diesel (PLTD)	Ternate-Tidore	7	16,0	5,3	2,2
	Tobelo	10	9,1	6,6	4,1
	Malifut	5	2,1	1,5	1,3
	Jailolo	4	3,4	3,4	2,9
	Sofifi	1	1,6	1,2	1,0
	Bacan	5	4,2	2,4	2,2
	Sanana	1	4,3	1,7	0,3
	Daruba	7	3,7	2,8	2,2
Total		***46***	***98,4***	***72,3***	***63,6***

Table 2. IPP-owned Power Generation in North Maluku

Type	System	Unit	Installed Capacity (MW)	Net Capacity (MW)	Peak Load in 2020
Diesel (PLTD)	Tobelo	15	9,0	9,0	6,3
	Jailolo	5	2,0	2,0	1,4
	Sofifi	8	4,0	4,0	1,4
	Bacan	9	7,7	5,4	3,2
	Sanana	5	4,3	4,3	3,0
	Daruba	4	2,0	2,0	1,4
Total		***46***	***28,9***	***26,6***	***16,6***

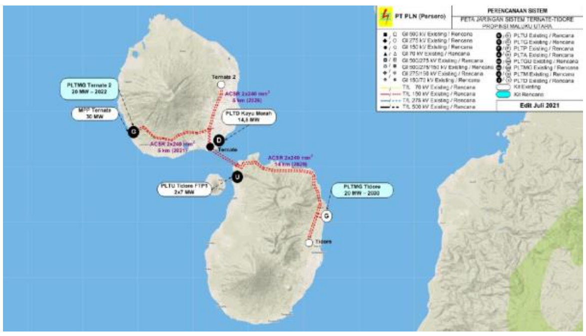

Figure 4. System Development Plan for 150 kV Ternate-Tidore [11]

 https://doi.org/10.25077/ajeeet.v1i1.21

Figure 5. System Development Plan for 150 kV Halmahera [11]

METHODOLOGY

Photovoltaic

The PV power output is calculated based on equation (1) While the energy output from PV is calculated using equation (2) [12].

$$P_{PV} = f_{PV} \times Y_{PV} \times \frac{G_T}{G_{T,STC}} \tag{1}$$

$$E_{PVG} = G(t) \times A \times P \times \eta_{PVG} \tag{2}$$

Wind Turbine

Power output from wind turbine is calculated using equation (3) while the energy output per hour from wind turbine is defined by equation (4) [13].

$$P_{WT} = \frac{1}{2}\rho A v^3 C_p = \frac{1}{2}\rho \pi r^2 v^3 C_p \tag{3}$$

$$E_{WT}(t) = P_{WT} \times t \tag{4}$$

Diesel Generator

Power output of diesel generator is calculated using equation (5) and the energy output is defined using equation (6) [14].

$$P_{gen} = F \cdot F_0 \cdot \frac{Y_{gen}}{F_1} \tag{5}$$

$$E_{gen}(t) = P_{gen}(t) \times \eta_{gen} \tag{6}$$

Inverter

The inverter model for the PV generator and battery is given in Equation (7) and (8) [15].

$$E_{PVG-INV}(t) = E_{PVG}(t) \times \eta_{INV} \tag{7}$$

$$E_{BAT-INV}(t) = \left[\frac{E_{BAT}(t-1) E_{Load}(t)}{\eta_{INV} \times \eta_{DCHG}} \right] \tag{8}$$

The rectifier is used to convert surplus AC/DC electricity from the PV generator units and diesel generator units, when the energy generated by the Hybrid System exceeds the load requirement. The rectifier model is given by the equation (9) and (10).

$$E_{REC-out}(t) = E_{REC-in}(t) \times \eta_{REC} \tag{9}$$

$$E_{REC-in}(t) = E_{SUR-AC}(t) \tag{10}$$

for each t hour

$$E_{SUR-AC}(t) = E_{SHP}(t) + E_{WEG}(t) + E_{DEG}(t) - E_{Load}(t) \tag{11}$$

Battery

To prevent overcharging the Battery, a charge control is used to detect when the Battery is fully charged and to stop or reduce the amount of energy flowing from the energy source to the battery. The model of the Charge Controller is expressed by the equations below [15].

$$E_{CC-out}(t) = E_{CC-in}(t) \times \eta_{CC} \tag{12}$$

$$E_{CC-in}(t) = E_{REC-out}(t) \times E_{SUR-DC}(t) \tag{13}$$

The battery state of charge (SOC) is related to its condition before to charging as well as the system's energy production and consumption conditions from (t-1) to (t). The SOC is the cumulative amount of transfer discharge in every hour t. The available battery bank capacity at t hours may be expressed by the equation (14) below when the total output of all generators throughout the charging process exceeds the demand load.

$$E_{BAT}(t) = E_{BAT}(t-1) - E_{CC-out}(t) \times \eta_{CHG} \tag{14}$$

The available battery bank capacity at t hours can be expressed by the equation (15).

$$E_{BAT}(t) = E_{BAT}(t-1) - E_{Needed}(t) \tag{15}$$

POWER DEVELOPMENT PLAN IN NORTH MALUKU

Demand Projection

Ternate is the largest city in North Maluku Province and has the largest population in this province. The natural resources of North Maluku Province are mostly nickel mines, concentrates and anode mud, and gold which can be found on Halmahera Island. Those resources are expected to give a positive impact on economic development in the neighboring area. The province's economic growth is quite high and in the last five years from 2015 to 2019 it reached an average of 6.5% per year.

Based on the realization of PLN's electricity sales in the last five years and considering economic growth after the Covid-19 pandemic occurred, population growth and an increase in the ratio of PLN's electricity household customers in the future, the projected electricity demand for 2021-2030 is shown in Table 3.

Table 3. Electricity Demand Projection in North Maluku

Year	Economic Growth (%)	Electricity Sales (GWh)	Peak Load (MW)	Customers (Thousand)
2021	5.6	542	116	300,217
2022	5.8	942	201	319,461
2023	5.7	1,075	227	339,158
2024	5.6	1,296	271	359,305
2025	5.5	1,431	297	379,899
2026	5.4	1,665	343	400,870
2027	5.3	1,708	349	422,180
2028	5.1	1,751	355	443,721
2029	5.0	1,796	361	465,509
2030	5.0	1,842	367	488,163

The projected electricity demand above includes the demand for Morotai Special Economic Zone (SEZ), Buli Industrial Area, potential smelter customers and other potential large customers in North Maluku Province. To fulfill the needs of SEZs, industrial areas and potential large customers, PLN has prepared the infrastructure for the electric power system (generation, transmission and substations).

Power Plant Development

The current condition of the Ternate–Tidore 150 kV power system is without adequate backup, while the peak load of the system is estimated to still grow quite high. To overcome these short-term conditions, the Ternate–Tidore system has operated a mobile power plant (MPP) with a capacity of 30 MW dual fuel and a dual fuel generator with a capacity of 20 MW will be added so that the system does not experience a power deficit. In addition, to overcome the power shortage in the provincial capital and its surroundings, a dual fuel power plant with a capacity of 10 MW will be built at Sofifi. In Tobelo, it is planned to add a dual fuel generator with a capacity of up to 30 MW considering the potential for growth in electricity demand and a fairly high peak load in Tobelo, in addition there is potential for renewable energy such as geothermal or solar PV which can be studied and developed further to meet electricity needs, achieving energy mix targets, and lowering BPP in the Tobelo System or the Halmahera System. Along with interconnection through the 150 kV SUTT on Halmahera Island, a 60 MW Halmahera PLTMG is also planned.

To provide certainty of electricity supply in the future, several dual fuel generators will be built in a number of scattered location systems, as well as optimizing the utilization of Songa Wayaua geothermal power (PLTP) and several other geothermal potentials. For the future development of power plants, a dual fuel generator type is planned as an effort to place the power plant close to primary energy sources. The development of small-scale coal power plant (PLTU) is not an option for long-term planning, given the unavailability of coal energy sources in North Maluku Province. The construction of power plants in North Maluku has considered the possibility of a smelter industry that will enter. In addition to the power plant plan, a study is also underway for the combined cycle power plant (PLTGU) relocation plan from the Java-Bali Electricity System or the construction of a new PLTGU plant specifically for smelter customers in East Halmahera. This study was conducted by a subsidiary of PLN according to the assignment from PLN. This plan is highly dependent on the certainty of prospective smelter customers to be served by PLN.

The demand for electricity from 2021 to 2030 will be met by developing PLTMG, PLTP and PLTM as well as PLTS as shown in Figure 6.

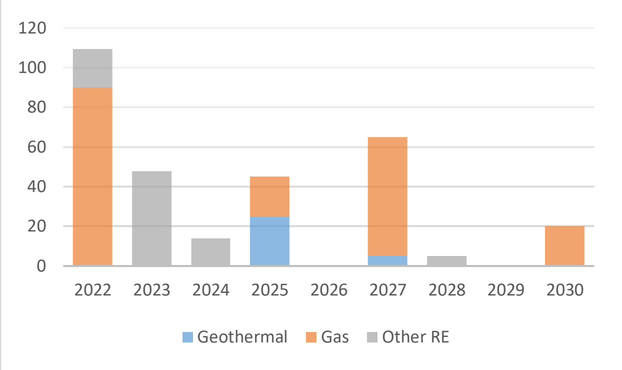

Figure 6. Additional Installed Capacity in North Maluku System

In the development of EBT, it is planned that a quota of generating capacity can enter the system. This quota can later be fulfilled by the development of PLN's power plants and the planned IPP power plant which has not yet entered the PPA stage. This power plan is expressed as a capacity quota spread over a system. The distributed capacity quota can be filled by potentials, both those already listed in the potential list and those that have not, if they have completed a feasibility study and a connection study verified by PLN and have the ability to finance development, and the price of electricity is in accordance with applicable regulations.

Several PLTGU plants that are not yet under construction will use the relocation PLTGU engine from the Java System. This is done to optimize the utilization of the existing PLTGU generators in Java. This relocation plan is included in the list of power plant development above but is not calculated as an additional power plant capacity because it is only a power plant relocation.

Especially for the power system in underdeveloped and outermost areas with small loads that have fuel transportation routes, which are not possible to be connected to the grid and the development of gas plants is not economical and the development of EBT will not be built in the near future PLTD and PLTD relocation from large systems will be built according to the needs of the development of the electric power system in these areas, then when it is ready to be developed, further development will be carried out to convert it into a hybrid power plant. In the future, updates will be made to the monitoring, control, and automation system for the generation system which is ready to be developed. To improve the electrification ratio, service reliability, and service hours, PLN plans that the entire electric power system in North Maluku Province can operate 24 hours starting in 2021.

CONCLUSIONS

Renewable Energy Technology is a solution for energy security that is available, inexpensive, and robust. Renewable energy sources are relatively evenly distributed across all regions and provinces in Indonesia. It is not impossible to rely only on renewable energy for our electricity. Many countries and regions have already pledged their support and developed strategies to attain that aim. For a long time in certain nations, renewable energy technology has been the primary source of power. This review gives an insight that North Maluku Province still have untapped renewable energy potential which can be developed in the future to increase its renewable shares in electricity mix as well as to enhance energy security and accessibility in the region.

ACKNOWLEDGEMENT

The author acknowledged the support received from Electrical Engineering Department, Faculty of Engineering, Universitas Andalas through publication grant.

REFERENCES

[1] R. Arisyadi, "A progressive alternative of energy planning for West Sumatera province," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 753, no. 1, p. 012032, May 2021, doi: 10.1088/1755-1315/753/1/012032.

[2] *Law No. 16 Year 2016 about Endorsement of Paris Agreement to the United Nations Framework Convention on Climate Change*. 2016.

[3] Government of The Republic of Indonesia, *Presidential Decree No. 79 Year 2014 on National Energy Policy*. 2014.

[4] S. Bahramara, M. P. Moghaddam, and M. R. Haghifam, "Optimal planning of hybrid renewable energy systems using HOMER: A review," *Renew. Sustain. Energy Rev.*, vol. 62, pp. 609–620, Sep. 2016, doi: 10.1016/j.rser.2016.05.039.

[5] J. K. Kaldellis, E. Kondili, and A. Filios, "Sizing a hybrid wind-diesel stand-alone system on the basis of minimum long-term electricity production cost," *Appl. Energy*, vol. 83, no. 12, pp. 1384–1403, Dec. 2006, doi: 10.1016/j.apenergy.2006.01.006.

[6] A. Ahadi, S.-K. Kang, and J.-H. Lee, "A novel approach for optimal combinations of wind, PV, and energy storage system in diesel-free isolated communities," *Appl. Energy*, vol. 170, pp. 101–115, May 2016, doi: 10.1016/j.apenergy.2016.02.110.

[7] A. L. Schmid and C. A. A. Hoffmann, "Replacing diesel by solar in the Amazon: short-term economic feasibility of PV-diesel hybrid systems," *Energy Policy*, vol. 32, no. 7, pp. 881–898, May 2004, doi: 10.1016/S0301-4215(03)00014-4.

[8] S. Ashok, "Optimised model for community-based hybrid energy system," *Renew. Energy*, vol. 32, no. 7, pp. 1155–1164, Jun. 2007, doi: 10.1016/j.renene.2006.04.008.

[9] O. Ekren and B. Y. Ekren, "Size optimization of a PV/wind hybrid energy conversion system with battery storage using response surface methodology," *Appl. Energy*, vol. 85, no. 11, pp. 1086–1101, Nov. 2008, doi: 10.1016/j.apenergy.2008.02.016.

[10] J. Paska, P. Biczel, and M. Kłos, "Hybrid power systems – An effective way of utilising primary energy sources," *Renew. Energy*, vol. 34, no. 11, pp. 2414–2421, Nov. 2009, doi: 10.1016/j.renene.2009.02.018.

[11] PLN, "RUPTL 2021-2030." 2021.

[12] Y. Tanoto, "Analisa Optimasi Modular Distributed Generation Untuk Beban Listrik Terisolasi," 2010.

[13] R. Thaib and H. Umar, "Studi Pemanfaatan Pembangkit Listrik Hibrid (Energi Angin-Surya-Diesel) di Kepulauan Simeulue Aceh," 2014.

[14] G. H. Susilo, Hermawan, and B. Winardi, "Pemodelan Sistem Pembangkit Listrik Hibrida Diesel dan Energi Terbarukan di Pulau Enggano, Bengkulu Utara Menggunakan Perangkat Lunak HOMER," *Transient*, vol. 3, no. 2, pp. 237–244, 2014.

[15] D. Kumar Lal, B. Bhusan Dash, and A. K. Akella, "Optimization of PV/Wind/Micro-Hydro/Diesel Hybrid Power System in HOMER for the Study Area," *Int. J. Electr. Eng. Informatics*, vol. 3, no. 3, pp. 307–325, Sep. 2011, doi: 10.15676/ijeei.2011.3.3.4.

NOMENCLATURE

P_{PV}	PV power output (kW)
E_{PVG}	Energy generated by PV (kWh)
f_{PV}	PV derating factor (%)
Y_{PV}	Power output on standard testing condition (kW)
G_T	Radiation on PV array surface (kW/m^2)
$G_{T,STC}$	Radiation on standard testing condition (kW/m^2)
A	PV array surface area (m^2)
η_{PVG}	PV efficiency
P_{WT}	Wind turbine power output (kW)
E_{WT}	Energy generated by wind turbine (kWh)
ρ	Air density (1,2929 kg/m^3)
A	Blade swept area (m^2)
v	Wind speed on blade (m/s)
C_P	Power coefficient
r	Blade radius (m)
t	time (hour)
P_{gen}	Power output of diesel generator (kW)
E_{gen}	Energy generated by diesel generator (kWh)
F	Fuel consumption rate (L/hour)
F_0	Fuel intercept coefficient curve (L/hour/kW)
F_1	Fuel curve slope (L/hour/kW)
Y_{gen}	Diesel generator capacity (kW)
η_{gen}	Generator efficiency