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Original Research Article

SUSTAINABLE ENERGY PLANNING Case Study of Tomini Bay Region of Gorontalo Province

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ABSTRACT

The use of non-renewable energy in the Tomini Bay region of Gorontalo is high. At the same time, Indonesia's non-renewable energy reserves are dwindling. A breakthrough in energy planning is needed to meet regional energy needs in a sustainable manner. The purpose of this study is to determine energy demand and availability based on regional per capita growth in the present and future. The research method used was the observational method and energy modeling of the Long-Range Energy Alternatives Planning System (LEAP). The results showed that energy demand in Tomini Bay, Gorontalo has increased significantly. In 2050, the energy demand will be 1,425 MWh. The balance between energy demand and availability will be achieved by diversifying energy towards renewable energy and developing energy from natural resources (river energy). The energy value that can be obtained in 2050 is 1489.57 MWh. Good energy management planning can achieve energy balance.

KEYWORDS

Energy Sources, Renewable Energy, Non-renewable Energy, Energy Security, Sustainable.

INTRODUCTION

The availability of energy is one of the most important elements in the realization of national development [1]. Indonesia has various energy resources, both non-renewable and renewable [2]. Rapid development and a large population require adequate energy support [3].

The preparation of the Regional Energy Master Plan aims to support the achievement of the primary energy mix in accordance with national energy policy objectives and to increase the supply of new energy in accordance with regional potential [4]. Regional energy planning is a benchmark for future regional energy supply [5]. Energy plays an important role in accelerating the development and progress of a nation [6]. Without adequate energy availability, the region will face difficulties in its activities and regional development. The availability of energy sources plays a very important role in achieving sustainable development in a region. Several studies have shown that regional interaction with renewable energy transition in Asia and Europe positively supports sustainable development [7]. Research by N. Lomans (2024) shows that in the United States, renewable energy and energy innovation are having a positive impact on energy transition and sustainable energy management in both the short and long term [8]. Another study conducted by M.M. Al-Sawalha et al. (2024) shows that

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using renewable energy can improve human development in high- and middle-income countries [9]. On the basis of some of these research results, it can be stated that the availability of energy is very important for the support of the physical development and the human development of a region.

The availability of sufficient energy is one of the determining factors for sustainable regional economic growth [10]. Regions that have good energy reserves and management can achieve good economic growth [11]. Adequate energy availability can meet the needs of economic growth areas [12]. Energy security is a condition of guaranteed energy availability and community access on a continuous basis [13]. The management of energy use can be sustained over the long term while taking into account environmental sustainability. The environment plays an important role in maintaining the balance of human life [14]. While energy independence is the guaranteed availability of energy by using the potential of domestic resources as much as possible [15]. Energy management to determine regional energy demand and supply must be done as early as possible to anticipate energy crises due to imbalances between energy demand and availability [16]. With good energy management, supply and demand can be sustainable [17].

The purpose of the Regional Energy Master Plan (REP) is to identify the energy needs and the availability of energy in nature for the present and the future. With the REP, the balance between energy demand and availability can be linked, and efforts to meet energy needs can be maximized by strengthening existing energy potential. Of course, energy management in the present must be systemic and detailed so that in the future a region does not need to import energy materials from outside but can anticipate its own energy needs. This can have an impact on the realization of energy independence and energy security in an area so that it can continue to meet current and future energy needs.

Gorontalo The Tomini Bay area is an area of marine and maritime natural resource potential and is becoming an area of strategic value as a buffer zone for the development of natural resource potential into high-value and exportable products. The Tomini Bay area has been declared a rural-based special economic zone that will become the center for the development of the Gorontalo region and its surroundings into a new growth area in eastern Indonesia [18]. The establishment of special economic zones (SEZs) has been a driver of regional economic growth [19].

The energy supply in Gorontalo Province is currently not fully equitable, especially in several districts. This situation is influenced by the presence of poor people (reaching 18.32%). In addition, the uneven energy distribution infrastructure factor is the energy problem facing this province. Sustainable energy planning is expected to be a reference for an integrated regional energy management system to address energy problems and challenges in order to achieve energy security and independence in Gorontalo Province.

Growing concerns about environmental degradation, increasing carbon dioxide emissions, and depleting non-renewable energy reserves require intelligent efforts to find potential alternative energy sources (renewable energy) [20] and to develop strategic management to manage and realize future energy security. Increasing public awareness of sustainable energy use requires balanced energy planning and management. Fossil energy use needs to be reduced and replaced by renewable energy sources. This research aims to plan for sustainable energy development to realize future energy security in the Tomini Bay region of Gorontalo.

The advantage of this study compared to previous ones is that the analysis is more comprehensive, as it analyzes not only the energy demand for electricity but also for all fuel oil energy used for transport and industry. In general, this research will play a very scientific role in knowing the future energy needs and the availability of energy sources that can be pursued to meet the energy needs in an area that is planned as an area that has strategic value in supporting regional economic development and growth.

The hypothesis of this study is that the energy demand in the Tomini Bay region of Gorontalo will increase significantly in the period 2015-2050. Energy modeling planning will be carried out to balance the energy demand and availability on an ongoing basis. This research contributes greatly to ensuring the sustainability of life in a region (case study in Tomini Bay, Gorontalo), especially in the provision of future energy. This regional energy research is a relatively new and very important research in the field of sustainable energy.

METHODS

The research method uses exploratory research methods, particularly in exploring the potential of natural energy resources in Tomini Bay, Gorontalo. An exploratory research method is used to obtain information about the existence of energy sources in Tomini Bay, Gorontalo. The energy potential of natural resources is focused on energy sources with large capacities. The analyses used include:

- For the potential of water/river energy, it is analyzed using the *Discharge Ratting Curve* (DRC) method by analyzing the relationship and influence of water level on river discharge. Determination of the river's mainstay discharge using the *Flow Duration Curve* (FDC) method [21].
- The potential of solar energy in the area of Tomini Bay has been analysed by means of a Global Horizontal Irradiance (GHI). The total solar irradiation received by horizontal surfaces on Earth is the sum of direct and diffuse horizontal irradiation [22].

$$\text{GHI} = \text{DHI} + \text{DNI x cos}\,(\theta Z\ sun) \tag{1}$$

where:
GHI = Global Horizontal Irradiance
DHI = Diffuse Horizontal Irradiance
θZ,sun = is the solar zenith angle and θT, $array$ is the tilt angle of the PV array

- Elasticity and customer factor

$$\text{Elasticity} = \frac{\text{ratio of growth in electricity sales}}{\text{economic growth (GRDP)}} \tag{2}$$

$$\text{The customer factor} = \frac{ratio\ of\ the\ number\ of\ customers}{\text{economic growth (GRDP).}} \tag{3}$$

Regional energy planning uses the Long-Range Energy Alternatives Planning System (LEAP) model with an econometric approach and an end-use approach to analyze energy supply and demand. Electricity demand forecasting is carried out using econometric, trend, and end-use approaches with business-as-usual and policy scenarios [23].

The approach to energy planning is done through 2 approaches, namely:

1. Econometric approach
   The main component of the analysis with econometric models is the input data or variables of an economic nature associated with the level of electricity power demand. The model of the econometric approach is formulated as follows: [24]
$$E = aY^{\alpha}\ P^{\beta}\ \ (\text{kW}) \tag{4}$$
   where :
   E = electricity power demand   α = elasticity of energy demand
   Y = Income   β = price elasticity of energy demand
   P = energy price   a = coefficient

2. End-use approach
   The end-use approach model, also known as the engineering model approach, is used to consider the technology used in the energy flow process. Energy efficiency projections explicitly account for changes in technology and service levels. The energy demand of each activity is analyzed based on the level of activity (energy service) and energy intensity (energy used per unit of energy service) [25]. Mathematically, the end-use approach model is formulated as:

$$NC_{R(t)} = \left(\left(\frac{RE_{(t)}}{100}\right)\left(\frac{JP_{(t)}}{P/Hh_{(t)}}\right) x\ 1000\right) \quad (5)$$

where:
$NC_{R(t)}$ = number of household customers in year t (population). (t) = year
$RE_{(t)}$ = Electrification rate in year t
$JP_{(t)}$ = Total population in year t
$(P/Hh)_{(t)}$ = Number of persons per household in year t

$$NC_{B(t)} = \left(1 + \left(\frac{CF_{B(t)} x FG_{B(t)}}{100}\right) NC_{B\,(t-1)}\right) \quad (6)$$

where :
$NC_{B(t)}$ = Number of business customers t (persons)
$CF_{B(t)}$ = capacity factor of household customers in year t
$GD_{B(t)}$ = growth of business customers in year t (%)

$$NC_{P(t)} = \left(1 + \left(\frac{CF_{P(t)} x FG_{P(t)}}{100}\right) NC_{P\,(t-1)}\right) \quad (7)$$

Where:
$NC_{P(t)}$ = number of public customers t (persons)
$CF_{P(t)}$ = capacity factor of public sector clients in year t
$GD_{P(t)}$ = growth of public sector customers in year t (%)

$$IF\ GD_{I(t)} < 0, NC_{I(t)} = \left(1 + \left(\frac{CF_{I(t)} x\ 0}{100}\right) NC_{I\,(t-1)}\right) \quad (8)$$

$$GD_{I(t)} < 0, NC_{I(t)} = \left(1 + \left(\frac{CF_{I(t)} x\ GD_{I(t)}}{100}\right) NC_{I\,(t-1)}\right) \quad (9)$$

Where:
$NC_{I(t)}$ = Number of industrial consumers t (persons)
$CF_{I(t)}$ = capacity factor of industrial consumers in year t
$GD_{I(t)}$ = growth of industrial customers in year t (%)

$$IF\ GD_{I(t)} < 0, EC_{I(t)} = \left(\left(1 + \left(E_{I(t)} \frac{0}{100}\right)\right) EC_{I\,(t-1)}\right) \quad (10)$$

$$GD_{I(t)} > 0, EC_{I(t)} = \left(\left(1 + \left(E_{I(t)} \frac{GD_{I(t)}}{100}\right)\right) EC_{I\,(t-1)}\right) \quad (11)$$

where
$EC_{I(t)}$ = energy consumption of the industrial sector in GWh
$E_{I(t)}$ = energy consumption elasticity of the industrial sector in year t
$ETO_{I(t)}$ = total energy consumption of large customers on the waiting list in year t

The potential of hydropower or river flow for electricity generation is analysed on the basis of the energy conversion principle using the equation [26] :

$$P = g\ x\ Q\ x\ H\ x\ \eta E \ \ (kW) \quad (12)$$

where:
P = electric power produced (kW)
ηE = plant efficiency
g = gravitation rate
Q = water discharge (m^3/sec)
H = height relative to the earth's surface (m)

The field discharge value is analyzed using the equation Q = flow velocity x cross-sectional area of the river.

RESULT

Electricity supply in Gorontalo Province, where the peak load reaches 17.63 MW, is supplied by power plants located in Gorontalo Province and the North Sulawesi-Gorontalo Interconnection System. The condition of electricity in Gorontalo Province in 2023 is Installed Capacity 21.18 MW, Capable Power 20.85 MW, and Peak Load 17.63 MW (Gorontalo state electricity company, 2023). Gorontalo's electricity system includes one unit with Minahasa and Kotamobagu systems, which is named the North Sulawesi (North of Sulawesi) interconnection system. Gorontalo Electricity System has 7 substations, namely Buroko Substation, Isimu Substation, Anggrek Substation, Botupingge Substation, Tilamuta Substation, Gorontalo Baru Substation, and Marisa Substation, which are interconnected with a 150 kV high-voltage transmission network system. The power plants that supply the electrical energy to Gorontalo are listed in Table 1.

Table 2. The Power Plant in Gorontalo

Plant Type	Fuel	Installed Capacity (MW)	Capable Power (MW)
Diesel power plants	Fuel Oil	27.10	25.00
Natural gas power plants	Natural gas	100.00	100.00
Hydropower plants	Water	6.20	4.00
Geothermal power plants	Geothermal	76.00	55.00
Solar power plan	Sunlight	2.00	1.80
Total		**152.50**	**141.00**

Source: General Directorate of Electricity, 2022

Gorontalo Province electrification ratio in 2022, according to the electricity statistics of the Directorate General of Electricity of the Ministry of Energy and Mineral Resources, is shown in Table 3.

Table 4. Gorontalo Province electrification ratio, 2022

Description	Quantity	Unit
State electricity households	2.446,609	Households
Households with power from non-state sources	1,522	Households
Total Households	2,448,131	Households
Electrification Ratio	99.90	%
Number of electrified villages	736	Villages

Source: General Directorate of Electricity, 2022

The number of vehicles consuming fuel oil energy in Gorontalo is shown in Table 5.

Table 6. The Number of vehicles using fuel oil energy in Gorontalo, 2023

District/City	Car (units)	Bus (units)	Truck (units)	Motorcycle (units)	Total (units)
Boalemo	2,120	17	2,619	43,812	48,568
Gorontalo	10,462	68	10,093	149,930	170,553
Pohuwato	3,252	25	3,485	53,713	60,475
Bone Bolango	3,886	28	2,687	58,741	65,342
Gorontalo Utara	2,234	20	2,538	27,197	31,989
Gorontalo Province	21,854	158	21,422	333,393	376,927

Source: Finance Agency of Gorontalo Province, 2023

The population of Gorontalo Province in 2023 reached 1,227.80 people, which experienced an average growth of 1.46% from the previous year. Based on this figure, only 0.44% of the total population of Indonesia in 2024 will live in the administrative area of Gorontalo Province. The percentage of people living in urban areas in this province reaches 39%, which means that the population living in urban areas is relatively less than that living in rural areas. Total Population of Gorontalo Province.

The GRDP (gross regional domestic product) per-capita of Gorontalo Province in 2023 is as follows:

Per capita income in 2023 = (GRDP in 2023)/(total population in 2023)
= (31,647,600,000 Rupiah)/(1,213,180 people)
= 26,086.48 Rupiah.

The total energy consumption in Gorontalo in the year 2023 will be 251.2 toe per-thousand. The consumption of energy in Gorontalo is shown in Figure 1.

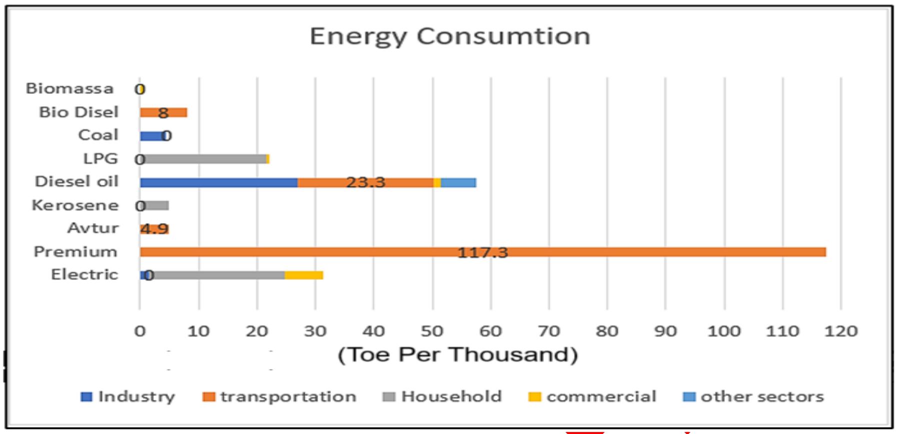

Figure 2. The consumption of energy in Gorontalo

The number of vehicles in Gorontalo Province in 2015-2050 will continue to increase, so the energy demand for transport, especially fuel, will also increase. Based on the calculation of the projected number of vehicles in 2025, there will be 32,929 cars, 1,162 bus, 24,418 trucks, and 444,102 motorcycles. By 2050, the number of vehicles will have increased to 65,550 cars, 3,455 bus, 53,622 trucks, and 605,154 motorcycles. The load factor for each vehicle in Gorontalo Province is 98% cars, 18% bus, 18% trucks, and 98% motorcycles. The mileage of each vehicle is: car 19,000 (km/year), bus 50,000 (km/year), truck 50,000 (km/year), and motorcycle 11,500 (km/year).

Based on the LEAP model analysis of energy demand in the Tomini Bay region of Gorontalo, the industrial sector in 2015 amounted to 260.9 toe/thousand, increasing to 1090.2 toe/thousand in 2050. In the transportation sector in 2015, it amounted to 227.5 toe/thousand, increasing to 794.2 toe/thousand in 2050. Energy demand in the housing & office sector was 80.6 toe/thousand in 2015. It increases to 430.4 toe/thousand in 2050. Energy demand in the commercial sector was 8.6 toe/thousand in 2015. In 2050, it increased to 190.4 toe/thousand. In addition, other sectors also increased from 6.1 toe/thousand in 2015 to 58.1 toe/thousand in 2050. The detailed projection of final energy demand per user sector is shown in Figure 3.

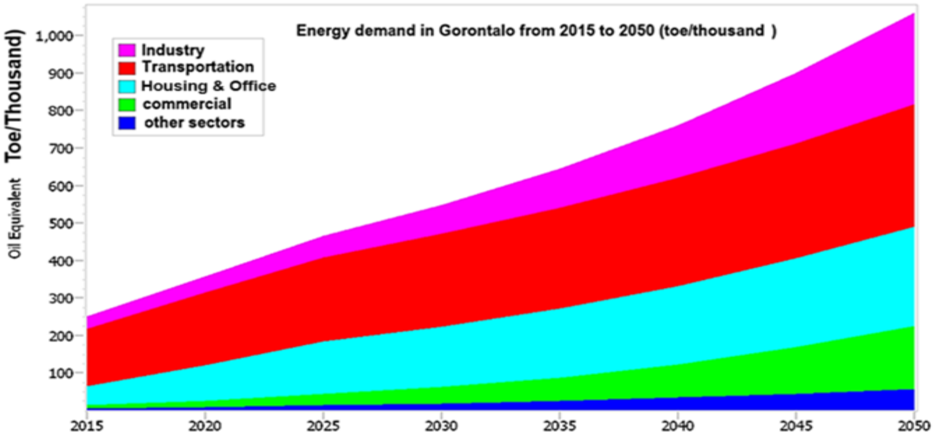

Figure 4. Energy demand in Gorontalo, from 2015-2050 (Toe/Thousand)

The projected demand for energy from new renewable sources such as biodiesel and biofuels will increase and is expected to replace fossil fuels such as coal and petroleum. Kerosene, diesel, and avtur are expected to disappear by 2050. The projected energy demand from renewable energy sources has the largest annual growth, at around 13%. Demand from fossil energy sources (oil) has the lowest growth at around 4%. Projected energy demand by energy source in Gorontalo Province up to 2050 is shown in Figure 5.

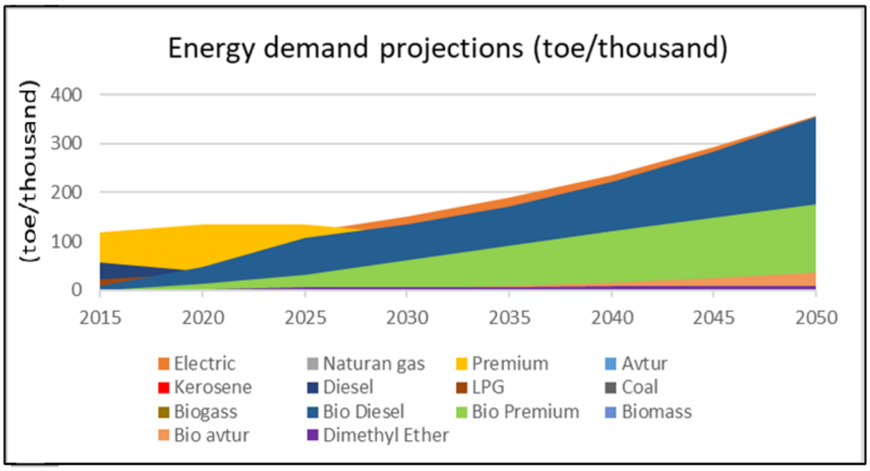

Figure 6. The projected demand for energy, 2015-2050

Generation capacity is needed to meet the growing per capita demand for electrical energy. Based on the analysis of LEAP model, the demand for electrical energy in Gorontalo Province will increase. In 2015, the energy demand was 152.4 MWh, increasing to 717.5 MWh in 2025 and 1,425 MWh in 2050. The natural gas power plant will continue to meet the energy demand of Gorontalo Province until 2050, reaching 700 MWh.

Hydropower and biomass are expected to support the electricity supply in Gorontalo Province, replacing fossil fuel power plants. Figure 7 shows the projections for the types of electricity generation for the period 2015-2050.

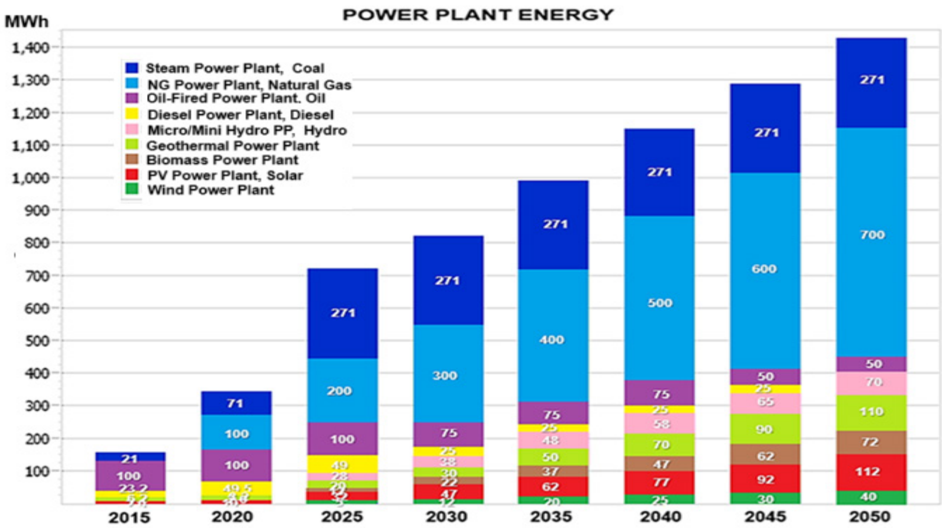

Figure 8. The projections for the types of electricity generation (Model LEAP)

River flow energy is energy that is large enough to be used for power generation. The rivers in Gorontalo that have large water flows are the Randangan River, Paguyaman River, Bulango River, and Bone River. Based on the results of direct discharge measurements in each river, several river discharge values were obtained, measured at different times. The measured river discharge data were compared with secondary data (2024 discharge data). Using the flow curve method (water level - discharge) with the equation Y = a X^z, a hydrograph of each river discharge value (data year 2024) can be obtained, as shown in Figure 5(a), 5(b), 5(c), and 5(d).

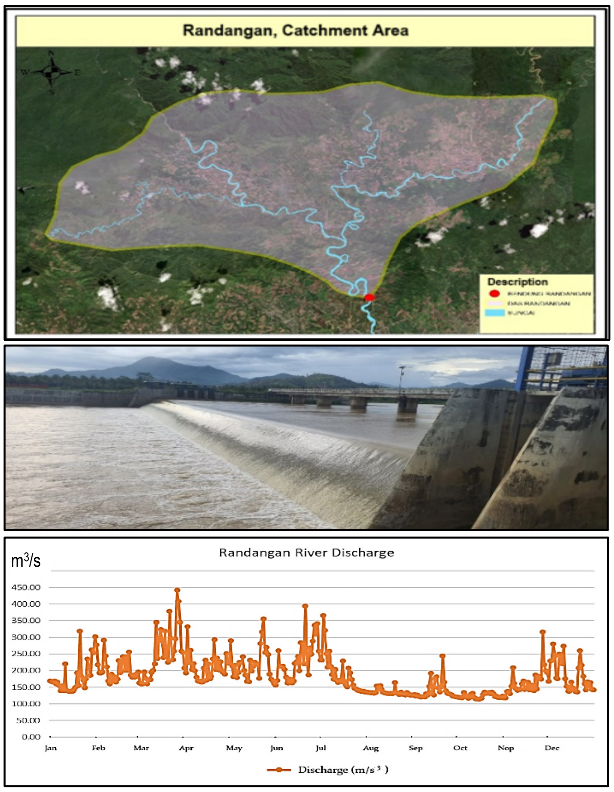

Figure 5(a). Watershed, river, and hydrograph of the discharge of the Randangan River (processed year 2024)

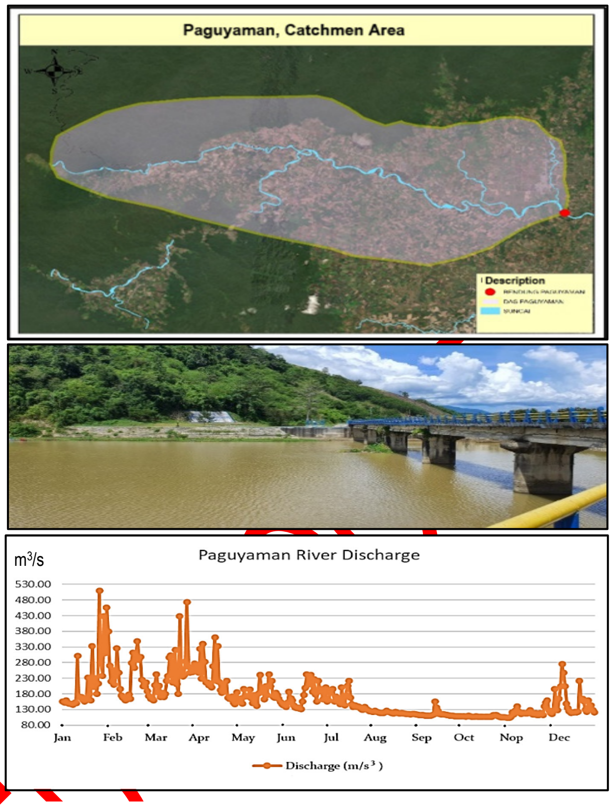

Figure 9(b). Watershed, river, and hydrograph of the discharge of the Paguyaman River (processed year 2024)

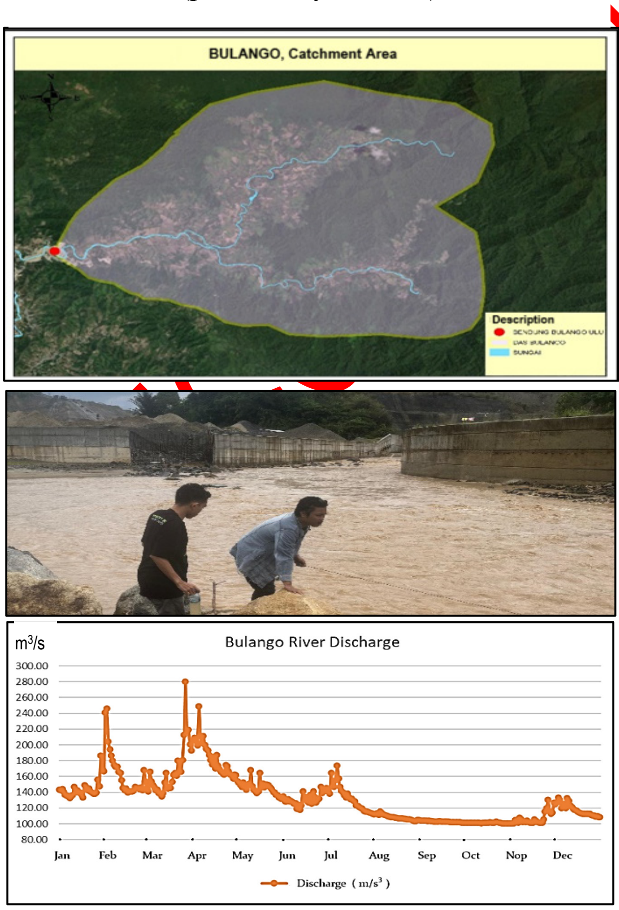

Figure 5(c). Watershed, river, and hydrograph of the discharge of the Bulango River (processed year 2024)

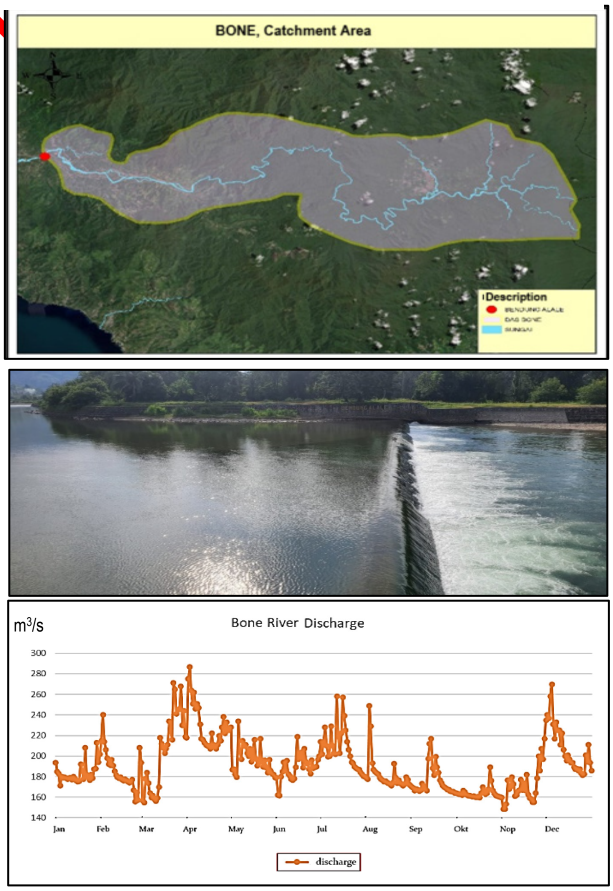

Figure 5(d). Watershed, river, and hydrograph of the discharge of the Bone River (processed year 2024)

Based on the results of the analysis using the Flow Duration Curve (FDC) method and the electrical power equation, the value of the reliable discharge and electrical power of each river is obtained, as shown in Table 7.

Table 8. Values of 90% Dependable Discharge and Electrical Power of Rivers, Year 2024

Name of River	Dependable discharge 90%, (m^3/s)	Electrical Power (kW)
Randangan	220.00	18,326.00
Paguyaman	201.00	16,743.30
Bulango	147.10	12,253.43
Bone	207.00	17,243.10
Total	**775.10**	**64,565.83**

Other energy potential in Gorontalo Province is shown in Table 9.

Table 10. Energy Potential in Gorontalo Province

No	Types	Location	Energy Potential (kW)
1.	Mini and Micro hydro	• Atinggola Sub-district, North Gorontalo District • Bone Sub-district Bone Bolango District	6.200
2	Biomassa Energy	Kecamatan Pulubala Kabupaten Gorontalo	500
3	Solar Energy	• Sumalata Sub-district, North Gorontalo District • Isimu Sub-district Gorontalo District	12.000
		Total	**18.700**

Source: Analysis results, 2024

Based on the analysis carried out, it can be concluded that energy planning in the Tomini Bay Gorontalo region is based on the knowledge that energy demand will gradually increase until 2050. In 2025, the energy demand is 1,425 MWh, and in 2050, it increases to 700 MWh. The energy supply can be obtained by developing steam power plants, natural gas power plants, mini/micro hydro, geothermal, biomass, and solar cells with a total power of 714 MWh in 2025 and 1,424 MWh in 2050. The energy supply that can be obtained from hydropower plants using river flow is 64.57 MWh. The total energy available in 2050 is 1489.57 MWh. Thus, energy planning in the Gorontalo Tomini Bay area can meet the needs in a sustainable manner until 2050.

CONCLUSION

1. The condition of power availability in Gorontalo Province, particularly in the Tomini Bay region, for diesel, natural gas, micro-hydro, geothermal, and solar power plants is that the installed capacity is 152.5 MW and the available capacity is 141 MW, with an electrification rate of 99.9%.
2. Energy planning in the Tomini Bay area of Gorontalo Province based on the LEAP model shows a significant increase. In 2015, the demand for electrical energy was 152.4 MWh.

It increases to 717.5 MWh in 2025 and to 1425 MWh in 2050.

3. The energy supply can be obtained by developing steam power plants, natural gas power plants, mini/micro hydro, geothermal, biomass, and solar cells with a total power of 714 MWh in 2025 and 1,424 MWh in 2050. The energy supply that can be obtained from hydropower plants using river flow is 64.57 MWh. The total energy available in 2050 is 1489.57 MW.
4. Sustainable energy management in Tomini Bay Gorontalo region is done by maximizing the conversion process of non-renewable energy into renewable energy. Large capacity energy sources can be obtained by utilizing the energy of river water flow for hydroelectric power plants. The use of sustainable energy is highly dependent on the preservation of forest areas and the environment in the cathmen area.

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NOMENCLATURE

Simbols	Meaning
Y^{α}	Income, elasticity of energy demand
P^{β}	energy price, elasticity of energy demand
$(P/Hh)_{(t)}$	Number of persons per household in year t
$NC_{P(t)}$	number of public customers t (persons)
ηE	plant efficiency

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