Microhydro Power in West Papua: A Comprehensive Assessment as a Potential Replacement for Diesel Generators

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Abstract- Fossil fuel-based sources of energy in both transition and developed countries are still the main primary contributors to the environmental carbon footprint. In Indonesia, West Papua province remains to depend largely on diesel generators as its primary source of electrical energy, rather than renewable energy sources. This situation occurs due to multiple socio-techno-economic factors, e.g. limited research for renewable energy potential, lack of public understanding of renewable energy benefits, and a shortage of national commitment. In this article, a thorough analysis of micro hydropower potential to electrify a typical development area in West Papua is provided in order to address the above-mentioned research challenges. The study introduces a method for determining the potential of micro hydropower in West Papua based on evapotranspiration, flow duration curve, and plant capacity factor. In this sense, Penman and F.J Mock approaches are proposed in order to calculate the evapotranspiration value and to calculate the discharge quantity respectively. In addition, a reliable discharge analysis will be conducted, which requires temperature, humidity, rainfall, solar radiation, and wind speed data. Thirty rivers in that area have the potential capacity to be used as micro-hydro generator facilities. Based on monthly data from 2012 to 2021, a micro-hydro power potential of 4,769.97 kW with an estimated annual energy production of 13,956.09 MWh to serve a demand of 25,087.02 kWh/year is calculated. Hydropower energy can save around 7,815.4 million CERs. Local governments can construct micro-hydro power plants in distant locations to replace diesel power plants, or build a hybrid system to improve service quality.

Keywords Diesel generator, microhydro, evapotranspiration, flow duration curve, emission.

1. Introduction

Electricity is a vital component in addressing fundamental human needs as well as supporting economic growth and social development. The demand for electricity has been steadily increasing and rising. In Indonesia, for instance, there has been a positive development on the demand side. The amount of energy consumed has been decreasing at a 1.7% annual rate, which is consistent with the national energy general plan goal of a 1% yearly reduction. With a 60% contribution to Gross Domestic Product, household-based small and medium enterprises (SMEs) are at the forefront of the trend. Despite the fact that domestic electrical demand is significant, it could be advantageous to the marketplace [1]. Furthermore, access to electrical energy remains a challenge for some people, especially those living in rural and underdeveloped areas. As stated by the International Energy

Agency (IEA), it is estimated that as many as 940 million population will be without electricity in 2030 [2]-[3].

There are several contributing variables, including low development costs for the electric power distribution network, varied population distribution, low economic conditions, and geographical conditions. Residents in rural areas utilize fossil energy sources, namely diesel and kerosene to meet their lighting needs. Utilization of this energy has many disadvantages such as high fuel costs, long transportation distances, high maintenance and operating expenses, and has a negative adverse effect on the environment [4]. Global climate change is mostly caused by carbon dioxide emissions. It is widely accepted that the world has to reduce emissions immediately in order to prevent the most severe consequences of global warming. Renewable technology advancements are critical for reducing emissions of greenhouse gases and carbon dioxide [5]. The costs for petroleum and coal are rising due to their rapid decline [6]. Developing new renewable energy technologies and innovations is essential to ensure the access to a clean, eco-friendly, and cost-effective electricity [7].

West Papua has created a model that includes baseline and mitigating scenarios. Total energy demand can be lowered by applying the mitigation scenario in comparison to the baseline scenario [8]. Renewable energy sources such as solar, wind, biomass, water, and other energy sources are abundant and easily accessible in rural areas. This energy source is one of the solutions to the rural areas' lack of access to electrical service, replacing diesel generators, and reducing carbon emissions. One of the difficulties of island’s electrical grids and microgrids is sustaining the balance between generation and demand. For this operation, diesel generators are still regularly used. Alternatives are being sought due to the unavoidable dependencies on fuel prices and delivery options, as well as the effects on the environment.

Because wind, solar, and micro-hydro energy are environmentally beneficial and do not rely on fossil fuels, these technologies are appropriate for islands and microgrids.Nevertheless, because these renewable energies depend on fluctuating resource availability, its maximum capacity for production varies. As a result, it is critical to devise strategies for optimally aligning generation and demand, as well as identifying the optimal combination of conventional and renewable energy.

Many researchers around the world have shifted their attention in the last decade to Hybrid Renewable Energy Systems (HRESs) to supply affordable, reliable, and CO_2 emission-free electricity to both grid-connected and off-grid connected areas [9][10]. As of today, various case studies have been conducted to optimize HRES [11],[12],[13]. With an area of 8.3 million km^2, Indonesia is one of the world's largest archipelagos, about 77% of which is surface water, and as many as 17,504 are islands. About 111 of them are on the outer islands which are directly adjacent to other countries [14]. Geographically, being in the middle of two continents, two oceans, and crossing the equator, Indonesia has abundant potential for wind, solar, and water energy. The total energy potential reached 441.7 GW and realized only 8.89 GW until 2018 [15]. Hydropower, or energy obtained from flowing water, is the world's major source of renewable energy supply, accounting for one-fifth of total electricity production.

Hydropower has accounted for 7% of Indonesia's electricity mix and 2.74% of overall energy supply since about 2019. An estimated 94 GW of hydropower potential is spread almost evenly across the archipelago. However, with approximately 5.88 GW installed as of 2019, Indonesia only uses less than 8% of its capacity. The government prioritizes hydropower development because it can provide long-term, consistent baseload power, allowing the country to meet its 23% renewable energy target. The government has set a target of 17.9 GW of new capacity from large projects by 2025, along with 3 GW from small hydro projects. Papua, Sulawesi, and North Kalimantan have been identified as priority areas for developing and increasing demand for hydropower to support electrification [16]. After China and Laos, Indonesia will be the third country to add 481 MW of hydropower generating capacity by 2021. The plan requires coal to be implemented by 2056, with hydropower accounting for 25.6% of the national electricity supply, followed by solar at 11.0% [17].

West Papua's electricity system is divided into six isolated systems: Sorong, Fakfak, Manokwari, Kaimana, Teminabuan, and Bintuni, with the Raja Ampat system remaining connected to the Sorong system at 20 kV. In the Sorong system, there is only one transmission system of 150 kV that connects the Sorong gas power plant to the Aimas substation. According to the 2022-2030 Electricity Supply Business Plan, there are several planned locations for the 150 kV transmission line, along with the Gas power plant Sorong and Rufey for 10 km and the Manokwari system with three plans, each Andai-Manokwari for 12 km in 2023, Andai- Prafi for 20 km by 2025, and Andai-Ransiki for 75 km by 2029 [18].

The total capacity is 132.8 MW, with 4.6 MW (3.46%) of renewable energy flowing from hydropower. Diesel power plants supplied the most energy, followed by gas power plants, with 73.2 MW and 44.8 MW, respectively (55.6% and 44.8%). The West Papua power plant is sourced from three managers: The state electricity company (45.7 MW), excess power purchase (55 MW), and respective leases (32.1 MW).

The government intends to develop generation systems from gas, micro-hydro, and solar of 324.2 MW spread across few locations through the State Electricity Company until 2030 in an effort to increase the electrification ratio. West Papua's electrification ratio and village electrification ratio in 2021 are 99% and 95.19%, respectively. Among the activities undertaken are the development of a distribution network, the conversion of diesel generators to renewable energy generators, and the development of a diesel generator hybrid system with renewable energy.

West Papua's geographical conditions, unequal population distribution, and high investment costs make developing a network from the grid unfeasible. Stand-alone and hybrid electric energy generators are being developed to gradually replace diesel power plants. Mapping the potential for renewable energy is critical in all regions as part of the effort to replace diesel power plants. This is consistent with the government's pledge to transform existing power plants to generate renewable energy [18, pp. II–38] and *Sustainable Development Goals*. Goal 7 necessitates that all people must have access to inexpensive, dependable, sustainable, and modern energy by 2030 [19]. Furthermore, this is consistent with the state electricity company's strategy for the development of clean energy infrastructure. Three pillars must be considered when selecting a generator type, security of supply (availability and accessibility), affordability (least cost) dan environmental (acceptability) [18, pp. II–15].

The purpose of the paper is to investigate the potential of mini and micro hydropower deployment in West Papua, Indonesia, including non-electrified areas, utilizing a new approach based on evapotranspiration and flow duration.

2. Hydropower Systems

Water is a crucial variable in the feasibility analysis because it is used for operating the hydro power plant. Waterwheels or water turbines that leverage the presence of a waterfall or water flow in a river or ditch are commonly used to generate water energy. The plant turns water's kinetic energy (Eq. 1) into mechanical energy in the form of a hydro turbine spin, which is then utilized to operate a generator, which generates electrical energy (Eq. 2).

$$E = mgh \tag{1}$$

$$P = \frac{\rho A v^2}{2} \tag{2}$$

Where P is power (kW), h is head (m), and ρ is specific weight of water $\left(9{,}807\ {}^{KN}/_{m^3}\right)$, A is cross-sectional area of hydro flow (m^2), v is hydro flow velocity $({}^{m}/_{s})$, m is the hydro mass (kg).

The relationship between hydrological characteristics and hydropower can be designed using Flow Duration Curves (FDC) and Capacity Factor (CF) in run-off rivers [20]. According to Couto [21], the best location for a hydroelectric plant depends on the height of the waterfall and the location of the turbine. Numerous studies have been published that evaluate the potential of rivers' hydroelectric power using traditional, labor-intensive, time-consuming methods and geographic data. Giulia et.al [22] used a Geographic Information System (GIS) approach to determine the energy potential and feasibility study of a micro-hydro power plant from a river in an Alpine valley. Joan [23] used three analyses: Hydrologic Frequency Analysis (HFA), Rational Equation, and FDC to analyze the micro-hydro power. Himanshu [24] conducted a research on the potential of micro-hydropower in the Mahi Valley River Dam using HES-RAS software.

The two variables that are simulated are water discharge and height with an impulse turbine type. Kurse [25] conducted his research using GIS applications and hydrological modeling techniques, with some variables on topography, soil, land use, weather, and water discharge. Bousquet [23] organized research on the hydropower potential of wastewater treatment and utilization systems in Switzerland, covering an area of more than 41,000 km2 and a population of 8 million people. The researchers divided their work into two stages: the first was to calculate the annual production of electrical energy using GIS and the discharge from each wastewater treatment, and the second was to conduct economic feasibility studies and electricity tariffs.

Estimates of water supply for hydropower generators, run-of-river, or any other water resource development within the regions investigated can be obtained using multiple regression approaches [26]. Erinofiardi [27] said that in Indonesia, the potential for micro hydro from rivers was 143.85 MW in 142 locations among 20 provinces. Indonesia has three of the most promising renewable energy potentials: hydropower, geothermal, and bioenergy [18]. These resources do not fluctuate as much as other renewable energy such as solar and wind power. The Ministry of Energy and Natural Resources predicts the theoretically potential for water energy is 75 GW and 30% is in Papua and 29% in Kalimantan. The National Energy Plan is planned to add 32.5 GW of large hydropower and 19.4 GW of small hydropower in 2050 [28].

Small hydropower is thought to be critical for rural power generation and community strengthening, despite some challenges such as limited infrastructure, lack of access to finance, foreign investment, government responsibilities, the cheapest price, and no training for local operators [29]-[30]. A study of small hydropower potential in Nusa Tenggara Timur, Maluku, Maluku Utara, and Sulawesi has been conducted in order to offer hydropower in those regions for both grid expansion and isolated systems, as well as to provide a list of small hydropower sites for development [31].

There have been a few studies on energy sources in West Papua, including the Hink River in the Arfak Mountains, which has a potential of 25.2 kW [32]. A river with a potential of 10 kW runs through Kampung Sasnek [33]. The F.J. Mock method was used to conduct research on micro-hydro potential in the Arfak Mountains district, taking into account geological and hydrological conditions [34]. There are several potential micro-hydro locations in South Manokwari Regency [35].

This paper is organized as follows. The potential of considering micro-hydropower plants as renewable energy sources is being investigated as a future replacement for diesel generation systems (Section 1). Meanwhile, Section 2 examines the state of the art. The proposed methodology will be the focus of Section 3. The simulation results and discussion are presented in Section 4. Finally, in Section 5, the conclusions are provided.

3. Methodology

3.1 Selected Site

West Papua Province is one of the six provinces on the island of Papua after experiencing division in 2022. This province lies between 00 – 40 South Latitude and 1240 – 1320 East Latitude. The area of West Papua province is 102.955,15 km^2. It is divided into twelve regencies and one city [36]. From 2019 to 2021, the research was carried out in 59 villages, 30 districts, and 8 regencies in West Papua province. It was carried out in four regencies in 2019, such as Manokwari Selatan with four districts and seven villages, Teluk Wondama with four districts and seven villages, Pegunungan Arfak with three districts and six villages, and Kaimana with three districts and three villages (Fig. 1).

In 2020, detailed design was conducted in two locations: Susmorof village and Nyambouw village. In 2021, research was conducted in four regencies such as Fak Fak with six districts and nine villages, Tambrauw with five districts and eight villages, Sorong Selatan with two districts and twelve villages, and Sorong with four districts and seven villages.

Fig. 1. Research location in West Papua [18]

The proposed case study was determined through collaboration between the State Electricity Company (PLN) and the local government. The general description of the electrical system in the research location is that they do not have electricity facilities yet and have to rely on various sources of energy like solar home systems, communal solar systems, genset (15 kW generator that the community has independently acquired, run, and maintained), micro hydropower plants, and diesel generators, which are managed by the state electricity company.

There are ten research sites that do not have access to electricity yet; the largest of them is in the South Manokwari district, followed by the Fakfak district. Figure 2 depicts the electrical infrastructure and power generation technology implemented at the research site. The solar home system (SHS) provides the most electrical energy, followed by diesel generators, managed by the state electricity company in collaboration with the local government.

Considering electrical energy is one of the most fundamental needs of rural communities, they are encouraged to purchase 15kW diesel generators on their own. The village chief assembles a team to manage and collect the payment for the diesel generator's procurement, operation, and maintenance. A case study of the operating costs of a generator set is in Inyuara village, Isim district, Manokwari Selatan regency, where a 15 kVA generator is installed. This generator was purchased with the village self-help funds, which also covered operational costs. The generator is turned on between 6 p.m. to 12 p.m., with a one-day on, one-day-off system. One barrel of fuel oil costs USD 312.65, with gasoline costing USD 117.25 and transportation costing USD 195.40.

The same thing happened in Naikere village, Teluk Wondama district, where the village head purchased a generator from the village fund allocation despite the fact that they already had the SHS facility (Fig. 3). Residents contribute

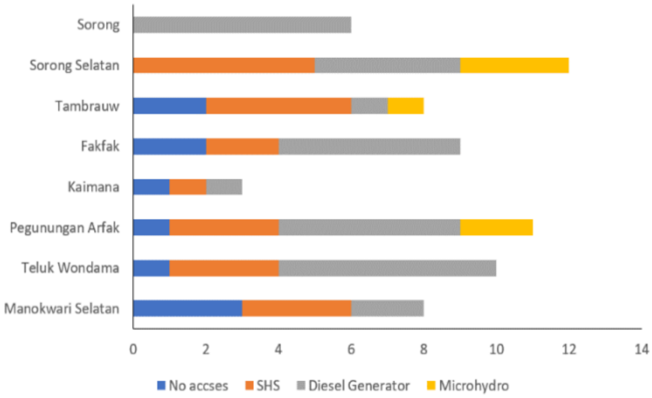

Fig 2. The electrical system in the research area

Fig. 3. Generator set in Inyuara village, Manokwari Selatan and SHS in Mitimber village, Fak Fak

to operational costs willingly, with each head of the family contributing 5 liters for one month's consumption to turn on the lights between 6 p.m. to 12 p.m.

3.2 Data Collection and Measurement

For data collection, multiple natural conditions and other technical aspects, i.e., dependable discharge, potential height of waterfalls, distance of the planned powerhouse from the load center, and social data, were taken into consideration. The process of measuring water discharge, river width, river depth, waterfall height data, and area is depicted in Fig. 4. Secondary data was gathered from laws and regulations, scientific articles, and institutional data. Secondary data is used to determine research locations and analytical methods. Other secondary data, such as temperature, wind speed, humidity, radiation, number of rainy days, and rainfall, are obtained from NASA data over a ten-year period (https://power.larc.nasa.gov/data-access-viewer/).

The effective height and area of the watershed were determined using the DJI Phantom 4 Pro Drone, while the water discharge was measured using the Global Water Fp-111 Current Meter Stick.

3.3 Data Analysis

3.3.1 Evapotranspiration

In the natural environment, evaporation is a fundamental component of the hydrologic cycle. Evapotranspiration (ET) is the total vaporization resulting from the combination of processes of evaporation and transpiration [37]. Evaporation is influenced by four things: solar radiation, wind, relative humidity, and temperature. While transpiration is the release of water from the plant tissue [38]. Evapotranspiration can be estimated directly in a controlled agricultural area using lysimeters or a water balance, but this method is complex, expensive, and time-consuming.

Fig. 4. Measurement of water discharge and data collection using drone

However, some mathematical models based on climatic factors such as temperature, humidity, wind speed, and radiation can be used to calculate evapotranspiration. Some of them are the Penman-Monteith method (1998), Hargreaves and Sammani method (1985), Blaney Criddle method (1950), Thornwaite method (1948), Turn method (1961), Priestley Taylor method (1972), Hamon method (1963), Romanenko method (1961), Penman method (1948), Makkink method (1957), Jensen Haise method (1963) [39].

In 1997, evapotranspiration was calculated using the development of the Penman equation by Doorborens and Pruitts. Several parameters are required for this equation, including air temperature (°C), air humidity (%), irradiance (%), monthly rainfall or rain (R), number of rainy days (n), and wind speed (m/s) [40]. The evapotranspiration value can be calculated by Eq. (3-11) and when compared to other methods such as Thorthwaite, Hargreaves, Hamon, Rs-based radiation, and Rn-based radiation, the choice of this method is based on the types of considered variables.

$$Eto = C(WxRn + (1 - W)xf(u)x(es - ea)) \quad (3)$$

$$Rn = Rns - Rnl \quad (4)$$

$$Rns = (1 - \alpha)x\ Rs \quad (5)$$

$$Rs = (0{,}25 +)0{,}5x(\frac{n}{N})xRa \quad (6)$$

$$Rnl = f(T)x\ f(es)x\ f(\frac{n}{N}) \quad (7)$$

$$f(es) = 0{,}34 - (0{,}044xe^{\frac{n}{N}}) \quad (8)$$

$$f\left(\frac{n}{N}\right) = 0{,}1 + 0{,}9(\frac{n}{N}) \quad (9)$$

$$f(u) = 0{,}27\left(1 + \frac{U}{100}\right) \quad (10)$$

$$e_a = e_s(\frac{RH}{100}) \quad (11)$$

where Eto is evapotranspiration $(mm/month)$, C is correction factor due to day and night climate, W is temperature and radiation dependent coefficient factor, Rn is net radiation (mm/day), ea is air pressure $(mbar)$, es is saturated vapor pressure $(mbar)$, Rnl is net longwave radiation (mm/day), Rns is net shortwave radiation (mm/day), $\alpha = 0.25$, Ra is solar radiation value (mm/day), N is the maximum average length of sunshine, $n = N\ x$ exposure time $(hours/day)$, $f(T)$is the effect of temperature, $f(n/N)$ is the ratio actual irradiance to maximum irradiance, wind speed function $f(u)$), U is the wind speed $(km\ /\ hour)$, determines the vapor pressure deficit $(e_s - e_a)$, saturated vapor pressure (e_s), obtained based on the temperature function occurring air, actual vapor pressure, RH *is* relative humidity.

3.3.2 Dependable Discharge, and Flow Duration Curve

With a calculated failure risk, the amount of discharge available throughout the year. The mainstay debit is determined using the prior year's planned base-year technique. Using the recorded debit data, the mainstay debit can be computed. With a minimum data requirement of 10 years, the amount of reliable discharge for power plants is 85-90%.

Long-term discharge data can be obtained using the ranking method (Weibull) or statistical methods. If discharge data is insufficient or unavailable, a rain-flow simulation, like F.J. Mock, Rain-Run, or NRECA, can be used to calculate the monthly average or semi-monthly discharge value. The FJ Mock model is utilized to conduct reliable discharge analysis, which requires temperature, humidity, rainfall, solar radiation, and wind speed data (Fig. 5). Data from ten rivers were employed to analyze the mainstay of river discharge.

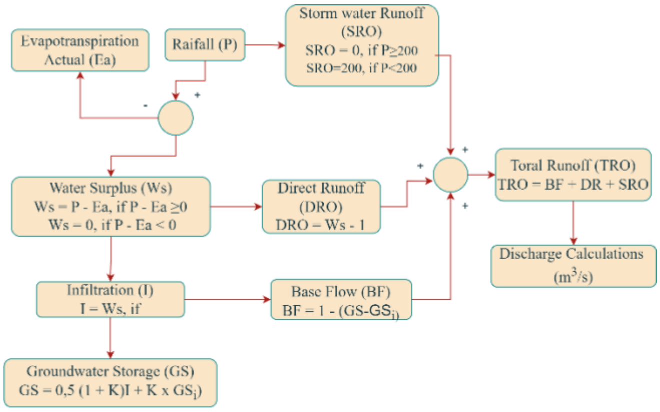

Fig. 5. Flowchart of FJ. Mock [41]

FDC represents the percentage of time specified flows were met or exceeded. This curve is commonly used to analyze and understand the flow characteristics of a river or stream over a recorded period [39], where the time horizon is the mean daily, weekly, monthly, or seasonal discharge. Using the Weibull formula in Eq. (12) to calculate the probability of events. Then, a curve called FDC is applied/used to determine the level of reliability [42].

$$P = \frac{i}{n+1} \times 100\% \quad (12)$$

where *i* is the serial number of discharges in descending order of occurrence, *n* is the data amount, and *P* is the probability of the expected set of values occurring during the observation period (%). The mainstay debit was chosen with a percentage of 80% - 96% for a data length of 10 years in this study [43] and Komariah [41] by 85% - 90%.

3.3.3 Power Availability and Capacity Factor

The actual electrical power accessible from mini- and micro-hydropower plants is calculated by the available discharge after changing for flow-dependent hydraulic losses and tailrace decreases (Eq. (13-14)). The hydroelectric power plant is dependent on two major variables: discharge and falling water height [42], [44]. As a result, hydroelectric power plants are highly reliant on topographical conditions. The elevation of the waterfall can be boosted by building a dam or diverting the water parallel to the river; another essential factor is the availability of water supply.

$$P = Q\ x\ H_g\ x\ \rho_{water} \quad (13)$$

$$P_m = Q_d\ x\ H\ x\ \eta_{hyd}\ x\ \rho_{air} \quad (14)$$

Where Q is discharge $(m^3/_s)$ and H_g is head (m). Total power is affected by efficiency system (turbine and generator), η_{hyd} is system efficiency (87%) [20], [45], H is effective height (m), Q_d design discharge $(m^3/_s)$.

One important factor for power plant design is *the Capacity Factor* [46]. CF is defined as the ratio of the energy generated within a time interval divided by the power capacity installed at the plant. A power plant cannot, in fact, perform at 100% annual CF. It will need some scheduled maintenance, which will involve some downtime. A hydroelectric power plant's output is influenced by a variety of factors, including the amount of water in the dam, unforeseen maintenance, the fluctuation of energy intake, and market factors. The amount of water itself is influenced by the hydrological conditions of the local area. The maximum power and energy produced by a hydroelectric power plant are calculated using Eq. 15-16).

$$P_{max} = \frac{P_m}{CF} x\ 100 \quad (15)$$

$$E_a = \frac{CF\ x\ P_{max}\ x\ 8760}{100} \quad (16)$$

Where P_m is the average power (kW) generated in the time period (for example one year), P_{max} is the rated power (kW) and E_a is annual energy $(kWh/year)$. There are differences in the capacity factor of hydropower in different parts of the world. Indonesia has 60% [47], Ocean: 32%, Latin America: 54% and globally: 44% [20].

3.4 Load Profile

To show the typical rural community's hourly energy consumption profile of a typical rural community, the load profile of houses, healthcare facilities, public buildings, schools, and houses of worship was estimated. For each facility, the loads usually consist of refrigerators, compact fluorescent lamps, fans, televisions, and other small appliances (Table 1).

Table 1. Appliances and capacity

Appliances	Power
TV	70 W
Lighting	10 W
Fans	25 W
Refrigerator	85 W
Radio	2.4 W
Computer	100 W
Printer	16 W
Charging Telephone	2.25 hour/day

In general, the majority of the loads operated for a few hours each day. On the contrary, lighting and other amenities like clinic loads, village offices, houses of worship, and schools made up a larger portion of the electrical consumption in remote regions. There is a low demand for energy from resident dwellings due to sunlight and people working in the fields in the morning from 7 a.m. until noon. Meanwhile, lightning is required from 6 to 9 p.m. because most people are at home. Peak loads in the public building vary from 8 a.m. to 1 p.m.

Other parameters derived from key stakeholder interviews and secondary data were used to estimate energy demand in each case study village [48]-[49]. In-depth discussions with community leaders such as village heads and

Fig. 6. Deep interview with community leader (Sururey village) and focus group discussion (Susmorof village)

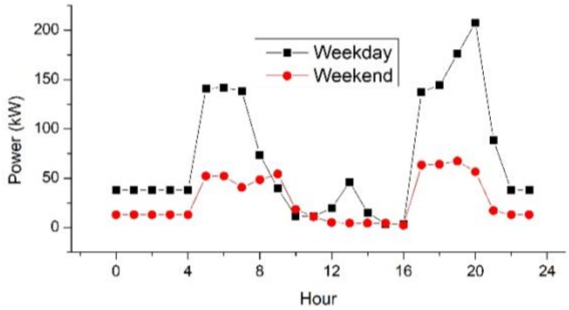

Fig. 7. Load profile Susmorof village

local community leaders yielded information on the pattern of burden use and the type of burden used by the community. The discussion took place in Sururey village, Pegunungan Arfak regency, with Mr. M. Saiba as the village head. He emphasized the importance of electricity to the community, which have 86 households and other facilities such as elementary schools, health centers, offices, and houses of worship.

Figure 6 also depicts a discussion held at the Susmorof village office, attended by the village head, Mr. Yustus Aiba, a religious figure, Mr. Martinus Mandacan, village officials, Mr. Elieser Aiba, and some members of the community. Making a statement of willingness to hand over the land for the construction of a micro-hydro power plant facility. Also, "one aspect of seriousness is the establishment of an institution for handling and maintaining the operations of the power plant", they declared.

Figure 7 illustrates the load profile of Susmorof village, which has 156 heads of households, two houses of worship, and one school, office, and health center. Calculation of energy requirements using Eq. (17-18) [48].

$$ED\ = \text{Load demand x duration} \quad (17)$$

$$\text{TED} = \sum_{t=1}^{n} \text{n x ED} \quad (18)$$

Where ED is energy demand (kWh), load demand (kW), duration (hour), TED is total energy demand (kWh), and n is 24 hours.

4. Result and Discussion

This part provides a thorough examination of three sites that represent several regencies (Sorong, Sorong Selatan, and Pegunungan Arfak), the characteristics of the region (mountain, mainland, and coast), and the potential for electricity (low, middle, and high). The Inggemun River in

Pegunungan Arfak, the Sailala River in Sorong, and the Kolam Biru River in Sorong Selatan are three rivers that serve as symbols. Power, annual energy production, load, an estimated Clean Development Mechanism (CDM) for 30 locations (rivers), and a flow duration curve all have been supplied in the appendix.

4.1 Evapotranspiration

Several data are required for Eq. (3-9), such as temperature, relative humidity, solar radiation, wind speed, number of days within one month, and other constant variables, as shown in Fig. 8. This study estimated the average monthly evapotranspiration value over a ten-years period. Evaporation from free water surfaces is solely determined by meteorological factors like radiation, temperature, relative humidity, and wind speed [50].

The evapotranspiration value began to fall in March and was at its lowest from May to June. It increased again in July, and the highest value was from September to January. This pattern repeats itself year after year. Temperature, wind speed, and humidity levels have an impact on the reference evapotranspiration value as depicted in Fig. ***9***.

Evapotranspiration occurs at a higher rate when the temperature rises. Evaporation increases because there is a bigger quantity of energy available to convert the liquid water to water vapor [51].

The relationship between temperature and evapotranspiration is directly proportional, which means that when the temperature of the Kolam Biru River rises, so does its evapotranspiration value.

The relationship between temperature and evapotranspiration is directly proportional, which means that The Sailala River and the Inggemun River came next. The Ingemun River's temperature peaked in the 46th month at 28.41°C, while its evapotranspiration rate peaked at 185.25 mm/month. The Ingemun River, on the other hand, has a low evapotranspiration value of 68.03 mm/month and a lowest temperature of 20.04 ºC.

High wind speeds create air turbulence, which causes more water to evaporate from the surface, affecting the evaporation process significantly. The speed, in addition, is at which wind transitions from a high-pressure area to a low-pressure one. Winds up to 5.15 m/s cause evapotranspiration of 160.15 mm/month on the Kolam Biru River, while winds down to 2.4 m/s cause 149.71 mm/month.

The cold condition of the Inggemun River in the Arfak Mountains absorbs solar radiation and heat emitted by the earth, resulting in a low air temperature. Things are different in the Kolam Biru River and Sailala River, which are located on the coast and the mainland, respectively. The difference is because air humidity is inversely related to evapotranspiration. The Ingemun River has higher air humidity than the other two rivers and this is inversely proportional to the evapotranspiration value.

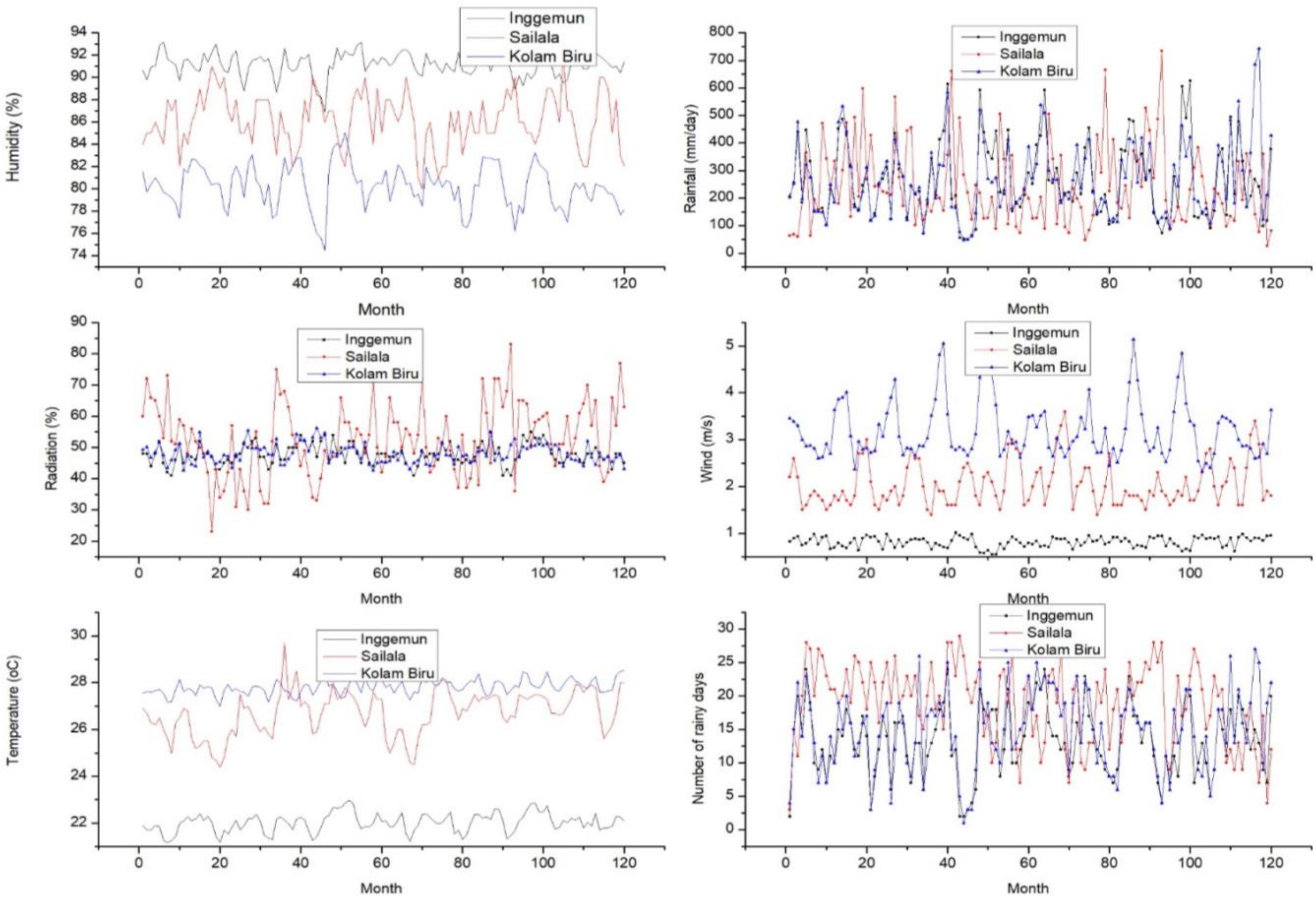

Fig. 8. Input parameters used in the calculation of Eto by Penman: relative humidity (%), rainfall (mm/day), solar radiation (%), wind speed (m/s), average temperature (ºC), and number of rain.

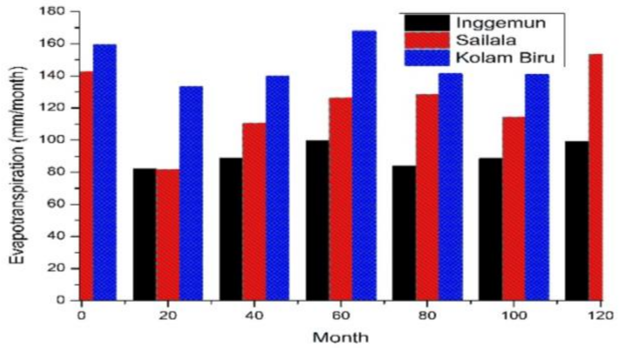

Fig. 9. Evapotranspiration 2012 to 2021

4.2 Flow Duration Curve and Power

The flow duration curve indicates the percentage of time during a historical period when a river's daily, monthly, or other time interval flows are equaled or exceeded. The FDC is frequently interpreted as a counterbalance to the flow's cumulative distribution function that provides a graphical representation of the relationships between flow frequency and magnitude, making it a suitable signature of a catchment's operation.

A streamflow duration curve demonstrates how streamflow frequency and magnitude are related. Flow duration curves have been used to solve problems in water quality management, hydroelectric power generation, river flow methods, water use planning, flood control, and river and reservoir sedimentation, as well as for scientific references of watershed river flow characteristics. A river's daily runoff is used to determine its water resources. The daily flow is not well monitored in many catchments.

FDC is a vital aspect of daily runoff and is used to develop water conservation projects. Understanding flow characteristics can be gained by evaluating the distribution functions and flow duration curve parameters in unmeasured catchments [52]. Fig. ***10*** depicts FDC and power for 2012-2021 based on F.J. Mock. Discharge is directly proportional to power, as in Eq.(14). The discharge values for the Inggemun, the Sailala, and the Kolam Biru are 9.268 m^3/s, 5.087 m^3/s, and 5.799 m^3/s, respectively, at an 80% probability. This discharge generates 129.009 kW, 26.555 kW, and 110.991 kW of power.

The output power of the Inggemun and the Sailala rivers is directly proportional to the water discharge, which corresponds to the height of the waterfall, which is 16 meters and 6 meters for the Inggemun and the Sailala rivers, respectively. The output power of the Inggemun River is slightly higher than that of the Kolam Biru River, despite the difference in waterfall height, namely the Kolam Biru River at 22 meters and the Inggemun River at 16 meters.

The difference is between the Sailala River and the Kolam Biru River, with almost the same discharge but a different waterfall height, causing a power of about four times. The higher the probability used, the smaller the power generated. At 90% probability, the output power is respectively 72.791 kW, 17.789 kW, and 67.035 kW for the Inggemun, the Sailala, and the Kolam Biru rivers, or each experiences a decrease of 43.58%, 33.01%, and 39.60%.

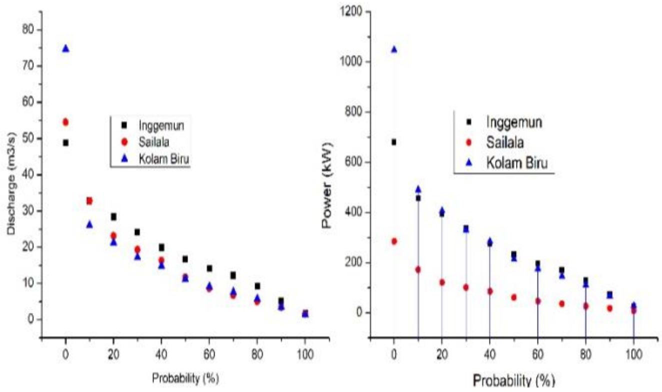

Fig. 10. Discharge and power

From the data, it is seen that the relationship between FDC and power generation varies according to the type of hydropower system that is being used. In general, high flow rate hydropower systems generate more power than low-flow-rate hydropower systems. The FDC is a crucial component in determining the run-of-river hydropower plant's output, which generates electricity by using the natural flow of a river. A high flow rate during the wet season produces more power, whereas a low flow rate during the dry season produces less power. The FDC is still important in a reservoir-based hydropower system, which uses a dam to store water and control the flow rate. The FDC of the river feeding the reservoir will affect the reservoir's water level, thereby affecting the system's power generation capacity.

4.3 Discussion

The cost per watt for a diesel generator power plant can vary greatly depending on factors such as generator capacity, generator brand and model, location, and installation costs, whereas a microhydro power plant's price per watt is also changable according to variables like turbine size, water head and flow rate, location, and installation costs. Based on the levelized cost of electricity (LCOE), diesel power plants are more expensive than micro hydropower plants. As compared to other generation sources, the diesel mini-grid has the highest LCOE and is most susceptible to changes in fuel prices. Emilia [53] compared the LCOEs of diesel (USD 0.92/kWh to USD 1.30/kWh), solar PV (USD 0.40/kWh to USD 0.61/kWh), and hybrid diesel and solar PV (USD 0.54/kWh to USD 0.61/kWh). Based on IRENA [54], LCOE micro hydro (0.047 USD/kWh) and Solar PV (0.068 USD/kWh). As a result, using diesel represents the most expensive solution. The LCOE value of a hybrid system combining renewable energy and diesel generators is lower, albeit this is dependent on the hybrid system's location and design. Microhydro-diesel is the most economical hybrid system [55], followed by solar PV-diesel, wind-diesel, and PV-wind-diesel.

Diesel generators and microhydro systems can be both practical choices for generating electricity in off-grid locations where access is insufficient or nonexistent [56]-[57]. However, the specific reliability of each system will be affected by variables such as the local climate, available resources, and maintenance personnel knowledge and experience. In remote areas with consistent water flow, such as mountainous regions with consistent rainfall or snowmelt, microhydro systems may be more reliable. These systems are typically low-maintenance and can run for extended periods of time without requiring extensive repairs or fuel delivery. Microhydro systems are also renewable, which means they can provide a sustained and long-term source of electricity.

The Indonesian government has made a number of initiatives to encourage the use of renewable energy sources and lessen greenhouse gas emissions in order to achieve zero emissions by 2060. According to the National Energy Strategy 2014–2025, 23% of the nation's energy should come from renewable sources by 2025. The Feed-in Tariff (FIT) program for Renewable Energy offers financial incentives to encourage the development of renewable energy plants. The Low Carbon Development Initiative (LCDI), seeks to encourage sustainable development in Indonesia while decreasing the emission of greenhouse gases. The LCDI includes programs that promote renewable energy, low-carbon city development, and sustainable mobility. Emissions can be minimized by using hydropower, although these sources are typically more expensive [58]. The Kyoto Protocol's Clean Development Mechanism (CDM) encourages sustainable growth and carbon reductions. Under the CDM, projects in development nations may produce Certified Emission Reduction (CER) credits, each of which is equal to one tonne of CO_2. Industrialized nations apply CERs to partially achieve their Kyoto Protocol emission reduction goals.

The gross annual energy production (AEP) potential of 13,956.09 MWh and an estimated CDM of 7,815.41 million CER per year with a load factor of 37.7% for small-scale hydropower and 31.8% for large-scale hydropower in 2021, a CO_2 emission factor of 0.56 in 2019 and power output (kW). This will help to achieve Indonesia's greenhouse gas reduction targets by 2030.

Renewable energy is an important component of the government's efforts in West Papua to promote sustainable development and reduce greenhouse gas emissions. West Papua is a prospective area for the development of renewable energy system since it has a tremendous amount of natural assets, including the potential for geothermal, solar, wind, and hydropower. The West Papua micro-hydro power project proposes to build micro-hydroelectric generation facilities to generate energy for the province's remote populations. The initiative is focused on providing sustainable, clean electricity to off-grid, off-the-grid rural places.

5. Conclusion, Limitation, and Future Research

Given that energy sources based on fossil fuels are the primary source of greenhouse gas emissions, renewable energy is emerging as the best option for fulfilling the rising demand for energy in many countries, both developing and advanced. West Papua is an Indonesian developing province where diesel generators provide the majority of the electricity. The need for non-conventional energy exploration, such as micro-hydro, has been described. Micro-hydro power plants need a large area and access to high river flow rates, so they have a lot of potential. Due to the presence of numerous rivers, West Papua's geographical conditions favor the use of micro-hydro energy sources. West Papua has a high micro-hydro potential river flow that has not been explored yet.

The study introduces a method for determining the potential of micro hydropower in West Papua based on evapotranspiration, flow duration curve, and plant capacity factor. The evapotranspiration value is determined using the Penman method, and the discharge quantity is calculated using the F.J. Mock method. The FJ Mock model is utilized to conduct reliable discharge analysis, which requires temperature, humidity, rainfall, solar radiation, and wind speed data from 2012 to 2021. Temperature, wind speed, and humidity levels have an impact on the reference evapotranspiration value. According to these three criteria, temperature has a greater impact on baseline evapotranspiration than the other two. The relationship between streamflow frequency and magnitude is depicted by a streamflow duration curve. FDC has been used to resolve water quality management issues, hydroelectric power generation, river flow methods, water use planning, flood control, and river and reservoir sedimentation, as well as for scientific references of watershed river flow characteristics.

The proposed method to assess the potential of micro-hydropower in West Papua was based on evapotranspiration, flow duration curve, and capacity factors. The potential for micro-hydro things is possible for the replacement of the 91,213 MW of present diesel generator use within six regions: Kaimana, Fak Fak, Teminabuan, Bintuni, Sorong, and Manokwari. Water energy potential exists in thirty locations. Based on monthly data from 2012 to 2021, the micro hydro potential is estimated to be 4,769.97 kW, with a demand of 25,087.02 kWh/year. The estimated annual energy production is 13,956.09 MWh, resulting in a total of 7,815.4 million CER.

The proposed investigation in this paper can be used to assess the water supply demand capacity for the development strategy that must be implemented using an assumption value approach that is matched to the current situation and anticipated future developments. The use of renewable sources strengthens national resilience to the effects of variable fossil fuel prices and is a key component of the global effort to reduce and eventually phase out the use of fossil fuels, offer an ongoing and reliable source of electricity, and reach zero emissions.

In this research work, data was precision of the findings should be further improved by future studies employing more precise data and hypotheses. For instance, the debit data for river measurements and the time series data required for calculations are both larger than or equal to five years. Further research will map additional renewable energies such as solar power, biomass, and wind. A hybrid renewable energy system is still being the main solution to increase the electrification ratio, system reliability, and gradual replacement of fossil generators.

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Appendix: Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.5281/zenodo.8019217

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