

Potential Analysis of Micro Hydro Power Utilizing Irrigation Canal Flow for Local Energy Autarky: A Case Study in Sumbergempol, East Java, Indonesia

Rizqa Ulya Fakhrun Nisa¹, Suyono Thamrin², Guntur Eko Saputro³

¹ Master's Program in Energy Resilience, Republic of Indonesia Defense University, Indonesia

^{2,3} Lecturer in Energy Resilience, Republic of Indonesia Defense University, Indonesia

Corresponding Author: rizqa.nisa@mp.idu.ac.id

Abstract

Energy self-sufficiency (energy autarky) is an important issue in the development of sustainable energy systems, especially in rural areas that still depend on external energy networks. One renewable energy source that has not been optimally utilized is irrigation flow, which has a stable discharge throughout the year and can be converted into electrical energy through micro-hydro power plant (MHP) technology. This study was conducted to analyze the micro-hydro energy potential of irrigation channels in Sumbergempol District, Tulungagung Regency, as an effort to support local energy autarky. The research methods included direct flow rate measurements using the float method and area-velocity calculations, as well as manual head measurements. The measurement results showed a representative flow rate of 0.90-0.91 m³/s and an effective head of 0.80 m, resulting in a hydraulic power potential of 7.14 kW and an effective output power of approximately 4.28 kW. Based on the low-head characteristics, the most suitable turbine is the Archimedes Screw, with a recommended generator capacity of 6-7 kVA. Load requirement analysis shows that the micro-hydro power plant is capable of supplying approximately 3.16 kW for public street lighting, residents' homes, and mosque facilities. This study aims to provide a technical basis for the utilization of irrigation channels as an alternative energy source that supports increased energy access and local energy autarky in rural areas.

Keywords: Micro hydropower; Irrigation canal; Energy autarky; Low-head turbine



INTRODUCTION

Energy autarky or energy autarky is a strategic concept in the development of sustainable energy systems, whereby a region is able to meet its energy needs independently through the management of local resources without being fully dependent on external energy networks (Müller et al., 2011). In the global context, the push towards a low-carbon society has encouraged many countries to strengthen their energy autarky through the use of community-based renewable energy, especially in rural areas (Streimikiene et al., 2021). This concept not only focuses on energy production capacity, but also covers aspects of reliability, sustainability, and local energy security in the face of supply disruption risks.

In Indonesia, efforts to increase energy autarky are in line with the national energy transition policy outlined in the National Energy General Plan (RUEN), which targets an increase in the renewable energy mix to 23% by 2025 (Montakhabi et al., 2021). The government is also encouraging the implementation of distributed renewable energy systems to strengthen village energy security, especially in areas that are not optimally covered by the PLN interconnection system. In this context, the utilization of local energy resources such as irrigation water, biomass, and solar energy is an important instrument for improving energy access while strengthening regional energy autonomy.

One potential local resource that has not been optimally utilized is the irrigation network. Indonesia has more than 11 million hectares of technical irrigation networks that flow throughout the year Tirtalistyani et al. (2022), generating kinetic and potential energy that can be converted into electrical energy. Irrigation flows generally have stable and sustainable discharge, making them a suitable renewable energy source for micro-hydro power plants (MHP). MHP is a technology capable of converting low-head water flow energy into electrical energy, and has the advantages of low installation costs, minimal environmental impact, and suitability for village scale (Sudibyo et al., 2021).

The Tulungagung region, particularly the Sumbergempol District, is an area with an extensive irrigation network and relatively stable discharge throughout the growing season, thus having great potential to be developed as a community-based micro-hydro energy source. However, the utilization of micro-hydro energy in this area is still limited to only a few locations, while most irrigation flows have not been used as alternative energy sources. This condition indicates the need for research to assess the technical potential and feasibility of utilizing irrigation channels as a source of local electricity.

A number of previous studies have examined the potential of micro-hydro in various regions in Indonesia, both in irrigation channels and small rivers (Alatas et al., 2021; Gokhale et





al., 2017). However, most studies still focus on medium head flows, or do not include load analysis and its relevance to local energy autarky. In addition, there are still few studies that evaluate the potential of micro-hydro in areas with low-head characteristics such as Sumbergempol, even though modern turbine technologies such as the Archimedes Screw allow for the utilization of low heads with fairly good efficiency.

Based on these conditions, there is a research gap in the form of a lack of comprehensive studies on the utilization of irrigation channels as a source of low-head micro-hydro energy directly linked to the potential for energy autarky in rural communities. The research gap also includes a lack of realistic local load evaluation and its integration with the output capacity of small-scale micro-hydro power plants. Therefore, this study aims to analyze the micro-hydro energy potential in irrigation channels in Sumbergempol District, Tulungagung Regency, with a direct measurement approach to discharge, head, and power estimation, followed by the selection of the appropriate turbine type for low-head conditions and an evaluation of the potential use of electricity to support local energy autarky.

LITERATURE REVIEW

Energy Autarky

Energy autarky refers to a situation where a region is able to meet its own energy needs through the use of local resources with minimal dependence on external supplies, an idea that emphasizes decentralized energy systems and infrastructure resilience (Müller et al., 2011). In the Indonesian context, this concept is important for addressing regional energy access gaps and supporting national targets for increasing the share of renewable energy. Various small-scale renewable energy technologies, such as micro-hydro, solar, and biomass, are considered suitable for regions with limited infrastructure because they can utilize local potential while increasing supply reliability. Energy autarky is typically evaluated using the 4A + 1S framework (availability, accessibility, affordability, acceptability, and sustainability), in which micro-hydro technology generally meets most of these criteria, mainly due to stable water flow, relatively low investment costs, and minimal environmental impact (Lixia, 2021).

Microhydro Power Plant

Micro-hydropower (MHP) is a small-scale power generation system that utilizes the potential energy of water to produce power, generally applied in rural areas that have adequate water flow but limited access to electricity (Jamakhandikar et al., 2022). The working principle is to convert the potential energy of water into mechanical energy through a turbine, then into



electrical energy through a generator, with the amount of power determined by the height of the water fall (head) and the flow rate. Technically, MHP consists of an intake, penstock, turbine, generator, and control system that ensures voltage and frequency stability. As a form of efficient and environmentally friendly renewable energy, microhydro is categorized as having a capacity below 100 kW, and its performance is greatly influenced by hydraulic design and the compatibility between the turbine and generator (Jawahar & Michael, 2017).

The amount of energy produced is influenced by two main parameters, namely the head and the flow rate. The relationship between the two is expressed by the following hydraulic power equation (Nasir, 2014).

$$P = \rho g h Q \quad (1)$$

where ρ = density of water, g = acceleration due to gravity, h = height of water fall, and Q = flow rate.

Water Discharge

Water discharge is the volume of water flow passing through a channel cross-section per unit of time and is expressed in m^3/s . It is an important parameter in determining the power potential of a micro-hydro power plant (Lee & Cheong, 2009). Discharge measurements are generally carried out using two approaches, namely the manual method and the weir method. In the manual (area-velocity) method, discharge is calculated by multiplying the cross-sectional area of the flow (A) by the average velocity of the water flow (v), as stated in the following equation:

$$Q = A \times v \quad (2)$$

where $A = w \times d$, where w is the channel width (m) and d is the average depth (m). Water velocity is measured using the float method. The formula for calculating velocity is:

$$v = \frac{s}{t} \quad (3)$$

where t is the travel time (s) and s is the path length (m).

Meanwhile, the weir method utilizes the relationship between the height of the overflowing water and the amount of water flowing, where the difference in water height upstream of the weir is directly proportional to the resulting discharge. The results of the weir discharge measurements are then presented in tabular form.

Table 1. Discharge Measurements using the Weir Method (liters/second)

Water Height (mm)	Waterfall Width (mm)								
	100	200	300	400	500	600	700	800	900
50	1.9	3.9	5.9	7.9	9.9	11.9	13.8	15.8	17.8
75	3.6	7.2	10.9	14.5	18.2	21.8	25.4	29.0	32.7
100	5.5	11.0	16.8	22.0	27.9	33.6	39.1	44.0	50.3
125	7.8	15.6	23.4	31.2	39.1	46.8	54.7	62.4	70.5
150	10.2	20.5	30.8	41.0	51.4	61.1	71.6	82.0	92.5
175	12.9	25.8	38.6	51.6	64.7	77.6	90.6	103.0	116.0
200	15.8	31.6	47.4	63.2	79.1	95.0	110.0	126.0	140.0
225	18.8	37.6	56.6	75.2	94.4	113.0	132.0	150.0	170.0
250	22.1	44.2	66.3	88.4	110.0	132.0	154.0	177.0	199.0
275	25.5	51.0	76.5	102.0	127.0	153.0	178.0	204.0	229.0
300	29.0	58.1	87.2	116.0	145.0	174.0	203.0	232.0	261.0
325	32.7	65.4	98.3	130.0	161.0	199.0	229.0	260.0	295.0
350	36.6	73.2	110.0	146.0	183.0	220.0	256.0	292.0	330.0
375	40.6	81.2	122.0	162.0	203.0	244.0	284.0	324.0	366.0
400	45.0	90.0	135.0	180.0	225.0	270.0	315.0	360.0	405.0
425	49.0	98.0	147.0	196.0	245.0	294.0	343.0	392.0	441.0
450	53.4	106.0	160.0	212.0	267.0	320.0	374.0	424.0	480.0
475	57.9	115.0	173.0	230.0	289.0	346.0	405.0	460.0	510.0
500	62.5	125.0	187.0	250.0	313.0	375.0	438.0	500.0	563.0

Source: Wibawa (2017)

Head

Head in a micro-hydro power plant system is the difference in height between the water surface at the intake and the turbine outlet, which determines the amount of potential energy. The greater the head, the greater the power that can be generated (Prayogo & Hadi, 2019). Head is classified into high head (>50 m), medium head (15–50 m), and low head (<15 m) (Wibawa, 2017).

Turbine Types

A water turbine is a mechanical device that converts the potential and kinetic energy of water flow into rotational energy, which is then converted into electricity. In a micro-hydro

power plant system, the selection of a turbine is largely determined by local hydrological conditions. In general, turbines are divided into two main types: impulse and reaction, where impulse turbines work from the impact of high-speed water jets, while reaction turbines utilize pressure changes and operate in submerged conditions. Each type of turbine has specific requirements related to head, discharge, rotational speed, and efficiency level. According to Wibawa (2017), the selection of water turbine or micro-hydro turbine types can be classified as follows.

Table 2. Turbine Types

Specifications	Pelton	Francis	Kaplan	Crossflow	Archimedes Screw
Water Fall Height/Head (m)	20-500	8 – 150	2 - 50	2 – 120	0,2 – 5
Water Discharge (m ³ /s)	0,002 – 2	≤10	≤20	0,02 – 1	0,03 – 1
Turbine Wheel Rotation Speed (rpm)	12 – 30	80 – 400	340 – 1000	20 – 480	10 – 80
Generation Power (kW)	10 – 5000	± 3000	± 3000	5 – 200	1 – 500
Maximum Efficiency	90	90	90	60 – 80	60 – 85

Source: Wibawa (2017)

Generator Capacity

Generators in micro-hydro power plant systems convert mechanical energy from turbines into electrical energy, and their capacity must be adjusted to the turbine output power, power factor, and system efficiency. According to Canturk et al. (2015), generator capacity is determined based on the ratio between real power and apparent power, which is generally formulated as

$$S = \frac{P}{\cos \phi} \quad (4)$$

The power factor ($\cos \phi$) in small generation systems ranges from 0.8 to 0.9, so generators are usually selected with a capacity greater than the output power to avoid overload during flow fluctuations or peak loads (Alberts & De Kock, 2017).

METHOD

This study applies a quantitative approach with a descriptive-analytical design to evaluate

the micro-hydro energy potential in irrigation channels in Sumbergempol District, Tulungagung Regency, East Java. This approach was chosen based on the need to obtain a numerical representation of key hydrological parameters such as discharge and head, which are the main determinants in micro-hydro power estimation. The research was conducted from August to November 2025 and included preliminary surveys, field measurements, data validation, and technical analysis. Field measurements were conducted on September 21, 2025, coinciding with the late dry season when discharge variability tends to be low, resulting in more stable and representative data for analyzing local energy potential.

Discharge data collection was carried out using two field measurement methods commonly used in small-scale water resource studies, namely the manual calculation method and the simple weir method. In the first method, channel dimensions were measured using a measuring tape and wooden sticks as depth gauges to obtain the wet cross-sectional area. Flow velocity was determined using the float method, namely dry leaves as floating objects, whose travel time was measured with a stopwatch on a measured track. The float technique was chosen because it is suitable for low to medium surface flows and is recommended for hydrological surveys in remote or irrigation areas (Shaw et al., 2010). The flow velocity and dimension values were then processed using the discharge formula as described in the literature review. Meanwhile, the simple weir method was carried out by utilizing a modified bucket as a flow threshold. The water level before overflowing was measured with a meter, and the value was converted into discharge based on the overflow discharge classification at the weir. The use of two methods allowed for triangulation of the results, thereby increasing the validity and reliability of the data (Seo et al., 2016).

The measurement of water head is carried out by measuring the difference in elevation between the upstream and downstream points at locations with potential for micro-hydro installation. Measurements are taken directly on the flow path using a meter to ensure accurate representation of the local topography. All field data is then quantitatively analyzed using a water potential energy calculation model to determine the potential electrical power that can be extracted. The analysis is supplemented by a technical review of the suitability of relevant micro-hydro turbine types based on discharge-head characteristics, as described in the literature review.

RESULTS AND DISCUSSION

Physical Characteristics of the Research Location



Figure 1. Research Object

The research location is on an irrigation channel in Sumbergempol Subdistrict, Tulungagung Regency, which consists of two branches as shown in the field observation document. The first branch has a flow width of approximately 2 m, while the second branch has a width of approximately 0.8 m, with both showing stable and continuous surface flow in accordance with the function of the channel as an active irrigation network. The physical condition of the channel is dominated by concrete structures with varying depths, allowing direct measurement of hydraulic dimensions. The measurement of the water head was carried out at the point of change in the channel elevation and produced a value of 0.80 m.

Flow Velocity and Discharge Measurements

Flow velocity measurements were carried out using the float method on a 5 m track, with the travel time recorded five times to obtain a representative average value. The measurement time data is shown in Table 2.

Table 2. Flow Velocity Measurement Experiment Results

Experiment	Time (s)
1	8.76
2	8.49
3	7.90
4	8.07
5	7.95
Average	8.23

Source: Researcher (2025)

Flow velocity is calculated using Equation (3):

$$v = \frac{5}{8,23} = 0,607 \text{ m/s}$$

With a flow cross-sectional area of $A = 1.50 \text{ m}^2$, the discharge from the manual method is calculated using Equation (2):

$$Q = 1,50 \times 0,607 = 0,91 \text{ m}^3/\text{s}$$

These results are consistent with the discharge obtained using the weir method. Based on Table 1 with flow width parameters of 2000 mm and water height of 400 mm, the discharge reading is 900 L/s ($0.90 \text{ m}^3/\text{s}$), while at the second branch (width 800 mm, $h = 400 \text{ mm}$) the recorded discharge is 360 L/s ($0.36 \text{ m}^3/\text{s}$). The consistency between these two methods shows that a discharge of $0.90 - 0.91 \text{ m}^3/\text{s}$ is a representative value for the study site. The discharge of $0.90 \text{ m}^3/\text{s}$ from the first branch is used as the main discharge in the power calculation because it is the largest and most relevant flow for micro-hydro energy utilization.

Hydraulic Power Estimation

The water head was measured directly at the point of elevation change in the irrigation channel using a meter, and an effective head value of 0.80 m was obtained. This value was used as the main parameter in calculating the hydraulic power potential. The power calculation was performed using Equation (1)

$$P = 1000 \times 9.81 \times 0.8 \times 0.91 = 7144.3 \text{ Watt}$$

From these results, the theoretical hydraulic power of the location is approximately 7.14 kW. To obtain an estimate of the electrical output power, the total efficiency of the micro-hydro system, which includes the turbine, generator, and mechanical losses, is assumed to be 0.60, in line with typical values for small-scale micro-hydro power plants.

$$P_{out} = 0.6 \times 7.14 = 4.28 \text{ kW}$$

This value indicates that the potential electrical power that can be utilized from irrigation channels is in the range of 4–5 kW, depending on seasonal discharge fluctuations and operational conditions. This power estimate is the basis for determining the turbine type and generator capacity.

Turbine Selection

Turbine selection was carried out by matching the hydraulic parameters of the research location with the operating ranges of various types of micro-hydro turbines as listed in Table 2. The research location has low head (0.80 m) and high discharge ($\approx 0.90 \text{ m}^3/\text{s}$) characteristics, thus falling into the low-head, high-discharge category. Based on Table 2, Pelton and Francis turbines cannot be applied because they require a much higher head than the field conditions. Crossflow

turbines, although flexible in terms of discharge, have a minimum head limit of around 2 meters, making them unsuitable for a head of 0.8 m. Kaplan and Archimedes Screw turbines are the main candidates for low-head conditions; however, Kaplan turbines are generally used at a minimum head of 2 meters, making their application less than optimal at head values <1 m. Conversely, Archimedes Screw turbines are specifically designed for operation at very low heads starting from 0.2 m and are capable of handling large flow capacities of up to $1 \text{ m}^3/\text{s}$, making them the most suitable for field conditions.

In addition to its suitability for the operating range, the Archimedes Screw has the advantages of high tolerance to sediment, stable low rotation, simple construction, and 60-85% operational efficiency, making it ideal for irrigation channels with characteristics such as those at the research site. Therefore, the Archimedes Screw turbine was selected as the most appropriate type of turbine for utilizing micro-hydro energy potential in Sumbergempol.

Determination of Generator Capacity

Generator capacity is determined based on the output power generated by the micro-hydro system and the power factor used. In this study, the output power obtained from hydraulic power conversion is 4.28 kW. Generator capacity is calculated using the relationship between real power and apparent power as stated in Equation (4). With a system power factor value of $\cos \phi = 0.85$, the minimum generator capacity required to distribute the output power is:

$$v = \frac{4.28}{0.85} = 5.03 \text{ kVA}$$

This value is the minimum theoretical capacity. In small-scale generation systems, especially under fluctuating discharge conditions, standard practice recommends a safety margin of 20–30% to avoid overloading and maintain generator operating stability. Applying a safety margin of 25%, the recommended generator capacity is calculated as follows:

$$S = 1.25 \times 5.03 = 6.29 \text{ kVA}$$

Thus, the most suitable generator capacity for the hydraulic conditions and load characteristics at the research site is in the range of 6–7 kVA. This capacity range is considered optimal to ensure stable operation, good efficiency, and long-term reliability of the micro-hydro system.

Analysis of Load Usage Potential

Power usage from the micro-hydro power plant needs to be adjusted to the system's output capacity and the actual needs of the community around the research site. Considering

that the micro-hydro power plant has an output power of around 4.28 kW, the load that can be supplied must be selected selectively so that operations remain stable and efficient. Load selection takes into account the conditions of the rice fields, the existence of mosque facilities, and residents' houses located around the irrigation channels. The planned loads are oriented towards basic services that provide direct benefits, such as public street lighting, mosque water needs, and household electricity consumption. The proposed load usage plan is shown in Table 4.

Load Name	Quantity	Watt/Unit (W)	Total Consumption (W)
Public Street Lighting	10	60	600
Musholla Water Pump	1	400	400
Residents' Houses	3	720	2160
TOTAL			3160 W

Source: Researcher (2025)

The load plan analysis in Table 4 shows that the total power consumption is 3.16 kW, or about 74% of the micro-hydro power plant's output of 4.28 kW. This value is within the safe range of 70-80% of operating capacity, so the system still has tolerance for flow fluctuations and load variations. The load composition used in the table is representative, describing typical needs in a rice field environment, including public street lighting, water needs for mosques, and electricity consumption for residents' homes with relatively complete household loads. These loads were selected to provide a realistic picture of the utilization of micro-hydro power plant energy in the field context, but can still be replaced or adjusted to the actual needs of the surrounding community.

Public street lighting is the dominant load because it plays an important role in improving visibility and safety at night, especially in rice field areas with minimal lighting infrastructure. The 400 W mosque water pump can also still be supported by the system, given that its operation is not continuous. Meanwhile, three residential units with consumption of 720 W per house are a significant load but are still within the supply capacity of the micro-hydro power plant.

Analysis of the Potential Application of Micro-Hydropower Plants Based on the 4A + 1S Framework

The feasibility analysis of utilizing micro-hydro power plants to support local energy autarky in this study was evaluated using the 4A + 1S framework, which includes Availability,



Accessibility, Affordability, Acceptability, and Sustainability. This framework is widely used to assess the implementation of renewable energy systems based on local potential.

1. Availability (Energy Source Availability)

Energy source availability was reviewed based on the stable irrigation flow rate and low head that was continuously available at the research site. Based on field measurements, the representative flow rate was 0.90–0.91 m³/s with a head of 0.80 m, producing 7.14 kW of hydraulic power and an effective output of 4.28 kW. This value indicates that the irrigation channel has high availability because it is part of an active irrigation network that operates throughout the year. This condition allows for a relatively consistent energy supply, especially during the planting season, making it reliable for priority loads such as lighting and public loads.

2. Accessibility (Ease of Use and Technology)

The accessibility of the technology is assessed based on the suitability of the hydraulic parameters of the location to the characteristics of the available turbines. With low head and high discharge, Archimedes Screw turbines are the most suitable choice because they can operate at heads between 0.2-5 m and discharges of up to 1 m³/s. This technology is known to be easy to install, sediment-friendly, and does not require complex building infrastructure. Thus, the accessibility of micro-hydro systems at the research site can be categorized as high, because the required technology is suitable for local hydraulic conditions and can be operated without complex technical expertise.

3. Affordability

In terms of affordability, micro-hydro power plants on a scale of 4–5 kW are classified as economical systems because they do not require high-pressure turbines or large civil construction. The total load planned in this study is 3.16 kW, which provides a safe operating margin compared to the output power. By utilizing existing irrigation infrastructure, installation costs can be minimized. In addition, the use of low-head turbines such as Archimedes Screws also reduces maintenance requirements and increases operational life, thereby adding to long-term affordability.

4. Acceptability (Social Acceptance and Minimal Environmental Impact)

MHP has a high level of social acceptance because it does not produce air pollution, has low noise levels, and does not interfere with the main irrigation flow. The selected loads, such as street lighting, residents' homes, and mosque facilities, are loads that provide direct benefits to the surrounding community, thereby increasing the level of acceptance of the technology. This system also does not change the character of the rice fields, does not





interfere with irrigation, and can operate with minimal environmental impact. This makes micro-hydro power plants in line with the social values of rural communities.

5. Sustainability

The aspect of sustainability includes the ability of the system to operate in the long term and continue to meet the energy needs of the community. Stable irrigation discharge, the selection of reliable low-head turbines, and the use of a load of 3.16 kW (approximately 74% of the micro-hydro power plant's capacity) indicate that the system can operate sustainably without overburdening component performance. In addition, this micro-hydro power plant supports the use of renewable energy, increases village energy security, and contributes to a sustainable clean energy transition.

CONCLUSION

The irrigation channels in Sumbergempol Subdistrict have sufficient potential to be utilized as a low-flow micro-hydro energy source, with a discharge of 0.90-0.91 m³/s and an effective head of 0.80 m, producing approximately 7.14 kW of hydraulic power and an effective output of 4.28 kW. The Archimedes Screw turbine was identified as the most suitable option for low-head conditions, while the optimal generator capacity was in the range of 6-7 kVA to maintain operational stability. Load potential analysis showed that the micro-hydro power plant was capable of supplying a load of 3.16 kW, covering public street lighting, mosque water needs, and residential loads with full household electricity consumption. These results confirm that the micro-hydro power plant is not only technically feasible but also has the potential to become a sustainable and reliable local energy source. To strengthen the community's energy autarky, it is recommended that the micro-hydro power plant system be integrated with a village-based community management scheme, the implementation of adaptive load management, and the use of low-power electrical equipment so that energy capacity can be maximized without overloading the system. Additionally, developing village-scale microgrids and exploring combinations with other renewable energy sources such as solar power can enhance the reliability and continuity of energy supply. These efforts are expected to strengthen local energy security, reduce dependence on external electricity grids, and encourage the implementation of sustainable energy autarky strategies in rural areas.

REFERENCE

Alatas, M., Sri Budiastuti, M. T., Gunawan, T., & Setyono, P. (2021). Stage of potential identification irrigation channel topography analysis for micro-hydro power in the





- Kalibawang irrigation primary channel, Yogyakarta, Indonesia. *International Journal of Sustainable Development and Planning*, 16(5), 953–964.
- Alberts, J. A., & De Kock, J. A. (2017). Impact on power factor by small scale renewable energy generation. 2017 International Conference on the Domestic Use of Energy (DUE), 146–151.
- Canturk, S., Balci, M. E., & Hocaoglu, M. H. (2015). On the definition of apparent power. *Electrical Power Quality and Utilisation. Journal*, 18.
- Gokhale, P., Date, A., Akbarzadeh, A., Bismantolo, P., Suryono, A. F., Mainil, A. K., & Nuramal, A. (2017). A review on micro hydropower in Indonesia. *Energy Procedia*, 110, 316–321.
- Jamakhandikar, A., Painter, R., Doshi, A., & Bade, M. (2022). Micro-hydropower generation for sustainable development: a review. *Conference on Fluid Mechanics and Fluid Power*, 791–799.
- Jawahar, C. P., & Michael, P. A. (2017). A review on turbines for micro hydro power plant. *Renewable and Sustainable Energy Reviews*, 72, 882–887.
- Lee, S., & Cheong, T. S. (2009). Development of regression equations for the water discharge estimation in tidally affected rivers. *KSCE Journal of Civil Engineering*, 13(3), 195–203.
- Lixia, Y. (2021). Energy Security: Concepts, Frameworks and Indicators. *Energy Security in Times of Economic Transition: Lessons from China*, 17–38.
- Montakhabi, M., Zobiri, F., van der Graaf, S., Deconinck, G., Orlando, D., Ballon, P., & Mustafa, M. A. (2021). An ecosystem view of peer-to-peer electricity trading: Scenario building by business model matrix to identify new roles. *Energies*, 14(15), 4438.
- Müller, M. O., Stämpfli, A., Dold, U., & Hammer, T. (2011). Energy autarky: A conceptual framework for sustainable regional development. *Energy Policy*, 39(10), 5800–5810.
- Nasir, B. A. (2014). Design considerations of micro-hydro-electric power plant. *Energy Procedia*, 50, 19–29.
- Seo, I. W., Do Kim, Y., Park, Y. S., & Song, C. G. (2016). Spillway discharges by modification of weir shapes and overflow surroundings. *Environmental Earth Sciences*, 75(6), 496.
- Streimikiene, D., Baležentis, T., Volkov, A., Morkūnas, M., Žičkienė, A., & Streimikis, J. (2021). Barriers and drivers of renewable energy penetration in rural areas. *Energies*, 14(20), 6452.
- Sudibyo, H., Pikra, G., & Fudholi, A. (2021). The potential of hydro renewable energy technology to electricity remote villages in papua and Maluku Islands, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 927(1), 012002.
- Tirtalistyani, R., Murtiningrum, M., & Kanwar, R. S. (2022). Indonesia rice irrigation system: Time





for innovation. Sustainability, 14(19), 12477.

Wibawa, U. (2017). Pendekatan praktis pembangkit energi baru & Terbarukan. Universitas Brawijaya Press.

