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Planning a Micro-Hydro System for Irrigation and Agricultural Electrification in Campaga Village, Tompobulu District

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ABSTRACT

Dependence on fossil fuels and limited access to electricity and clean water are challenges to agricultural productivity in many rural areas of Indonesia, including Campaga Village. This study aims to plan an appropriate water energy conversion (pico-hydro) system to meet the operational energy needs of agriculture, particularly irrigation pumps and lighting. The planning began with measuring the potential of resources (discharge, head) and analyzing energy needs based on agricultural applications. The measurement results showed an average discharge of 0.134 m³/s with an effective head of 10.5 m, with the potential to generate mechanical power for pumps of 3.9 kW and electrical power of 2.2 kW. The needs analysis confirmed that this potential is more than sufficient to power one irrigation pump unit (~3 kW) and light 21 road lighting points (0.63 kW). The technical planning recommends the use of a crossflow turbine and a standard AC generator in accordance with the principles of appropriate technology: simple, locally maintainable, and directly integrated with agricultural needs. The conclusion of this study shows that the designed pico-hydro system is not only technically feasible but also has the potential to become strategic supporting infrastructure to improve irrigation water resilience, extend farming hours, and ultimately empower the economy of agrarian rural communities.

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1. INTRODUCTION

Energy comes from nature, which will then be utilized as technology develops. These new technologies are based on the increasing number of human needs that must be met, one of which is water and electrical energy. The largest source of electrical energy in Indonesia currently comes from fossils, the existence of which continues to be depleted and can even run out within a certain period. In addition, the use of fossils impacts the environment, causing air pollution, global warming, and ecosystem damage.

At present, electricity plays a major role in increasing greenhouse gas emissions. Moreover, in rural and agricultural regions, such as Campaga Village, access to water and electricity is still restricted. These constraints have a direct impact on agricultural productivity because reliance on rainwater for irrigation and the absence of lighting for post-harvest tasks pose significant challenges. The situation is further worsened by challenging geographical factors, such as road accessibility and topography. In addition to topography, alterations in land cover also influence water availability, leading to greater fluctuations in river flow (Asrianto et al., 2023). Therefore, the development of renewable energy that is directly integrated with agricultural operational needs, such as running irrigation pumps and lighting work areas, is not only an energy solution, but also a strategy to improve food security and farmer welfare. These factors underscore the need for development that utilizes renewable energy while considering the needs, facilities, and infrastructure in the development area. One of the efforts made by the Indonesian government in addressing existing problems is through Presidential Regulation No. 112 of 2022 concerning the Acceleration of Renewable Energy Development for Electricity Supply in an Effort to Reduce

Greenhouse Gas Emissions (Alam & Fansuri, 2022).Renewable energy can be developed by utilizing water as an energy source. Water is an energy source that will never run out and, in the process of utilization, does not have an impact on the environment. Water utilization can be achieved by creating water pumping systems and power plants so that the energy produced can be allocated and benefit the wider community (Taufiqurrahman & Windarta, 2020).

The water pumping system and the power generation system are made based on the condition of an area where there is water flowing in a certain discharge and height difference, so that the flowing water has a speed that can rotate the turbine. In the process of making this system, it is necessary to plan a water energy conversion system into mechanical energy and electrical energy to obtain the efficiency of the turbine, water pump, and generator used and the power that can be generated by the system based on the data.

Based on the description above, this research was carried out by utilizing energy that does not damage the environment in producing electrical energy, so that research was carried out on The Planning of Water Energy Conversion Systems into Mechanical and Electrical Energy in Campaga Village, Tompobulu District.

Based on these issues, the objective of this study is to design an appropriate water energy conversion system (pico-hydro) to meet the energy needs of agricultural irrigation pumps and plantation access road lighting in Campaga Village. The design includes an analysis of the resource potential, calculation of requirements, and technical specifications of the system. The benefits of this research are as a reference for the application of renewable energy technology that is simple, can be maintained by the local community (appropriate technology), and is sustainable to support increased productivity in the agricultural sector in rural areas.

2. MATERIALS AND METHODS

2.1. Materials

This research was carried out on a surface water stream in Campaga Village, Tompobulu District, Bantaeng Regency, South Sulawesi. The tools used in this research were laptop, Microsoft Excel, ArcGIS software, stopwatch, meter, ruler, 600 ml bottle, and GPS. The materials used are rope, wood, DEM data, and rainfall data for the last six years from 2018 to 2023.

2.2. Research procedure

The research procedure was designed to achieve system planning in accordance with the principles of appropriate technology. This included collecting field data to accurately understand the potential of natural resources, as well as needs analysis focused on agricultural applications. The research stages are outlined as follows.

2.2.1 Data Retrieval

Research preparation was carried out with a site survey and literature study on energy conversion system planning so that research data collection could be carried out. The data collection process was as follows:

A. Flow Discharge Measurement.

The discharge measurements in this study were carried out 10 times by measuring the cross-sectional area and flow velocity using the float method with a bottle. The discharge data collection was performed five times.

B. Water Fall Height Measurement.

Measurement of the height difference from the starting point to the end point of the water flow was performed using GPS. The height obtained was 11 m.

2.2.2 Data Processing

Data processing was carried out in the following stages:

A. Creation of Research Location Map

Map making of the research location was carried out using ArcGIS software, and map making was carried out using DEM, contour, and elevation data based on the research coordinate points in Campaga Village, Tompobulu District, and Bantaeng Regency.

B. Flow Discharge

The discharge (Q) was obtained by multiplying the flow velocity (v) by the cross-sectional area (A). According to Widiarta et al. (2021), the cross-sectional area and flow velocity can be calculated using Equations (A) and (v).

$$A_n = i_n \times \left(\frac{d_{n-1}+d_n}{2}\right) \quad (1)$$

Where A_n cross-sectional area (m^2), i is the segment distance (m), d is the depth (m), and n is the number of segments.

$$v_a = v_f \times c \quad (2)$$

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

where v_a is the average velocity (m/s), v_f is the flow velocity (m/s), c is the correction factor, s is the distance traveled in units (m), and t is the travel time (s).

C. Water Fall Height (Head)

Head calculation can be performed by calculating head losses and head effectiveness based on the following equation (Abdulsalam et al., 2014):

- Head Losses

$$H_1 = \frac{10.67\ x\ Q^{1.85}}{C^{1.85}\ x\ d^{4.85}} \text{ x L} \quad (4)$$

Where H_l is the head loss (m), Q is the discharge (m^3/s), C is the Hazen-Williams pipe roughness coefficient, d is the pipe diameter (m), and L is the pipe length (m).

- Head Effective

$$H_{eff} = H - H_l \text{ x eff} \quad (5)$$

Where H_{eff} is the effective head (m), H is the head (m) and eff is the pipe efficiency (%).

D. Energy Potential Analysis

According to Rauf & Nur (2019) the calculation of generated power can be calculated using several equations, as follows:

- Power Available

Available power is the amount of potential energy available from a water flow, which depends on the magnitude of the falling point (head) and the flowing water discharge per second.

$$P_{water} = \rho \times Q \times g \times H \quad (6)$$

- Turbine Power

The water turbine power was determined by multiplying the amount of available power by the turbine efficiency. The value of turbine efficiency according to Ointu et al. (2020), the lowest value of turbine efficiency can be used, which is 70%.

- Pump Power

The pump power was obtained from the calculation of the available power multiplied by the pump efficiency. According to Nurdiana et al. (2021), the pump efficiency can be calculated using

$$\text{Efisiensi} = \frac{P_{out}}{P_{in}} \times 100\% \quad (7)$$

- Generated Power

The power generated by the generator can be calculated using the efficiency values of the turbine, pump, and generator. The generator efficiency value that can be used as a reference is 80%; therefore, the generated power can be calculated based on the following equation:

$$P = \rho \times Q \times g \times H \times \eta_t \times \eta_p \times \eta_g \quad (8)$$

Where P_{air} is the available water power (kW), P is the output power (Watt), is the density of water (kg/m^3) with a value of 1000 kg/m^3, Q is the discharge (m^3/s), g is gravity (m/s^2) with a value of 9.81 m/s^2, H is Head (m), t is turbine efficiency (%),p is pump efficiency (%) and g is generator efficiency (%).

E. Energy Needs

The energy requirements in this study are divided into two, namely, the energy needs of pumps to drain water and the need for electrical energy for street lighting.

- Pump Energy Requirement

The pump energy requirement is determined based on the existing potential, so that the planning can determine the type of pump that is in accordance with the pump power capacity generated by the water flow.

- Electricity Energy Requirement

The need for electrical energy is determined based on the number of lamp points needed based on Equation (T), so that the total power needed for lighting is obtained based on Equation (P) (Putra et al., 2020).

$$T = \frac{L}{S} + 1 \quad (9)$$

$$P= P_l \times w \quad (10)$$

Where T is the number of light points, L is the length of the road (m), S is the pole distance (m), P is the electrical power (kW), P_l is the lamp power (Watts), and w is the number of lights.

3. RESULTS AND DISCUSSION

3.1 Research Location

Campaga Village is one of the villages located in the Tompobulu Sub-district, Bantaeng Regency, South Sulawesi. Geographically, the area of Campaga Village is 5.01 km^2 and the distance from Tompobulu District is ±2 km. Campaga Village is located in a highland area with an altitude of 500-700 m above sea level. The coordinates of the research location are 5°27'16.2 "S and 120°01'04.9 "E.

3.2 Energy Potential

The energy potential in this study is the ability of the water flow to produce energy so that it can be utilized for pumping systems and generating electricity. The energy potential is obtained based on the following parameters:

3.2.1 Flow Discharge

Water flow discharge was obtained from data on the cross-sectional area and water flow velocity. The discharge value obtained was the instantaneous discharge value. The results of the discharge calculations are presented in Table 1.

Table 1. Discharge calculation results.

No	Measurement Date	Flow Velocity (m/s)	Cross-Sectional Area (m^2)	Flow Discharge (m^3/s)	Rainfall (mm)
1	11/10/2022	0.341	0.413	0.141	5.49
2	11/22/2022	0.302	0.401	0.121	3.08
3	11/24/2022	0.454	0.447	0.203	10.53
4	02/06/2023	0.292	0.385	0.112	1.57
5	02/07/2023	0.285	0.360	0.103	0.9

The measurement of river flow velocity was carried out by utilizing a buoy as a measurement tool. The water flow velocity was calculated based on the distance and travel time of the measuring instrument. The travel distance used is 2.20 m. River roughness must be calculated based on the correction factor value. In accordance with shallow river conditions with a height of less than 0.5 m, the correction factor used was 0.45. This is in accordance with the statement that the shallow channel type (<0.5 mm) in the calculation uses a correction factor of 0.45. The measurement results of the water flow velocity in Table 1 show that the highest velocity occurred in the third measurement of 0.454 m/s, while the lowest flow velocity occurred in the fifth measurement of 0.285 m/s.

The cross-sectional area of the river was measured based on its width and depth. The river width was measured and divided into four segments. The depth of the river is measured in each segment with a width of 0.3 m in each segment. The results of the calculation of the cross-sectional area of the flow are obtained by multiplying the segment distance by the average depth. The largest cross-sectional area occurred at the third measurement (0.447 m2), whereas the smallest cross-sectional area occurred at the fifth measurement (0.360 m2).

The measured flow width is 1.5 m so it can be classified as a small river flow. This is in accordance with the statement that a flow width of 1-3 m is classified as a small river flow (Hayati et al., 2014).

The flow discharge results obtained have different values every day, where the greater the value of water flow and the cross-sectional area of the flow, the greater the resulting discharge. Water flow discharge is also influenced by regional rainfall, so a graph of the relationship between rainfall and flow discharge can be seen in Figure 2.

3.2.2 Rainfall Data

The results of the last 6 years of rainfall data processing from 2018 to February 2023 are presented in Figure 1, which shows that rainfall in November and February is high compared to other months where the average rainfall in November is 150.48 mm and February is 245.88 mm.

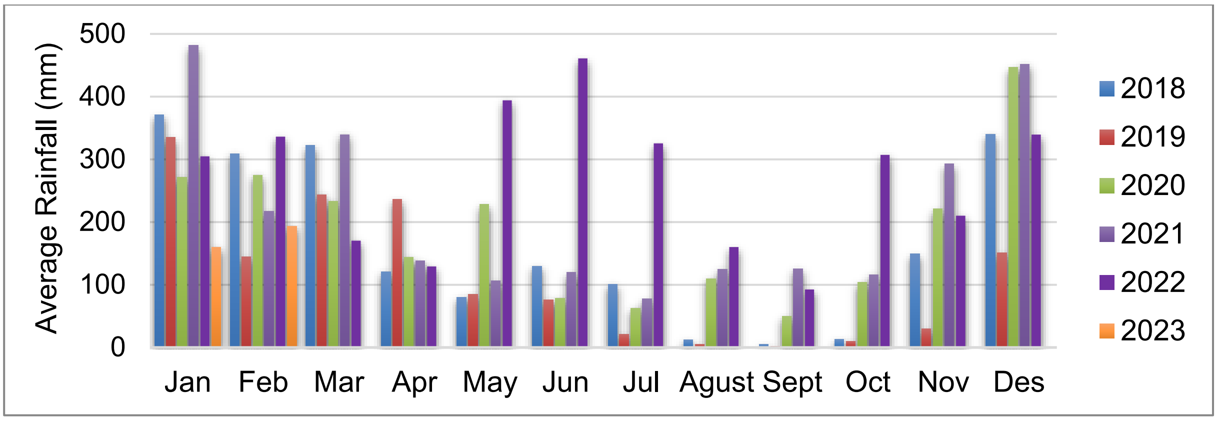

Figure 1. Graph of rainfall from 2018 to 2023.

Rainfall data from 2018 to 2023 were obtained from the NASA POWER website, and the monthly rainfall was averaged using Excel. Discharge data were collected in November 2022 with rainfall of 210.07 mm and February 2023 with rainfall of 193.59 mm. The existence of greater rainfall in other months causes measurements that are not at the peak discharge to be taken. This can be observed in the data shown in Figure 1.

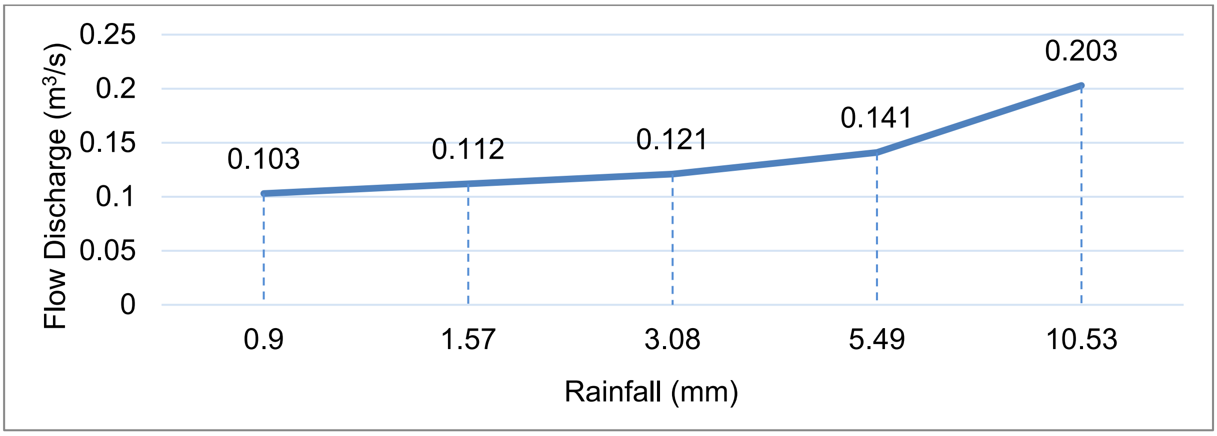

Figure 2. Graph of the relationship between rainfall and flow discharge.

The graph in Figure 2 shows that the relationship between rainfall and discharge is directly proportional, where if rainfall is high, the value of the water flow discharge will be greater. The highest discharge occurred in the third measurement of 0.203 m^3/s, with a rainfall of 10.53 mm, while the lowest discharge occurred in the fifth measurement of 0.103 m^3/s with a rainfall of 0.9 mm. The average discharge obtained was 0.134 m^3/s.

3.2.3 Water Fall Height (Head)

The measurement result of the water fall height was 11 m. Calculation of the water fall height or head is first performed by calculating the head losses. Head losses were calculated to determine the amount of pressure drop in the fluid in the pipe. Head calculations are made based on the pipe specifications that will be used, which are presented in Table 2 below:

Table 2. Head calculation results.

Specifications	Unit	Value
Pipe Lenght	m	40
Pipe Diameter	m	0.274
Correction Factor	-	0.002
Head Losses	m	0.591
Head Effectif	m	10.5

The head loss value obtained is 0.591 m. After obtaining the value of head losses, head effectif calculation is carried out based on several measurement parameters so that the head effective value of 10.5 m is obtained. The resulting head is included in the low head, which is based on the head classification that the height of the falling flow at a distance of 2-30 m is classified as low head (Ibrahim et al., 2020).

3.2.4 Potential Energy

Energy potential analysis is carried out by calculating the available power, turbine power, pump power, and generator power. The following are the results of the calculation of the energy potential.

Table 3. Energy potential calculation results.

Energy Potential	Available Power (kW)	Turbine Power (kW)	Pump Power (kW)	Generator Power (kW)
Value	14.456	10.119	3.903	2.185

The available power is the potential energy of a water source. Available power is obtained based on data on water density, discharge, gravity, and head. The available power obtained is 14.456 kW; therefore, pikohydro power plants and microhydro power plants can be constructed at this flow. Available power does not include output power in the system, so it is necessary to calculate turbine and generator power.

Turbine power is the energy converted from kinetic energy in a pipe to mechanical energy in a turbine. The turbine power was obtained by multiplying the discharge data, water mass, head, and turbine efficiency. The turbine power obtained was 10.119 kW with a head of 11 m and a discharge of 0.134 m^3/s. The pump power is the amount of energy produced by the pump in the system. The result of the pump power calculation was 3.903 kW.

The generator power is the result of the process of converting mechanical energy into electrical energy. Generator power is calculated based on water density, discharge, gravity, head, turbine efficiency, pump efficiency, and generator efficiency. The potential electrical energy generated was 2.185 kW. Based on the amount of potential electrical power to be generated, the manufacturing of this power generation system is included in the picohydro category because it is less than 5 kW. This is in accordance with the statement that picohydro electricity is a hydroelectric power plant with an output power of hundreds of watts to 5 kW (Nakhoda et al., 2018).

3.2.5 Energy Needs

The energy needs of the Campaga Village community were analyzed based on two main agricultural support functions: lighting for farming activities, and irrigation water supply. The results of the analysis (Table 4) show that 21 lights with a total power of 0.63 kW are needed. Meanwhile, the largest power requirement, amounting to ~3.9 kW, is for the operation of water pumps. These pumps are designed to distribute water to community farmland to support more reliable irrigation while also meeting the clean water needs of farmers' households. By fulfilling these two requirements, it is hoped that land productivity will increase through crop intensification and extended safe working hours for post-harvest activities.

Table 4. Energy requirements.

No	Energy Needs	Usage	total	Unit Power	Total Power Required
1	Lighting	Lamp	21 pcs	30 Watt	0.63 kW
2	Irrigation Water Supply	Pump	1 pcs	3,903 Watt	3.903 kW

A pump is needed to channel water to residents' homes and gardens based on the potential power capacity of the pump, which is 3.903 kW, while for the needs of street lighting to residents' plantations, 21 lamps are needed with the electric power used by each lamp of 30 Watt so that the total electric power needed is 0.630 kW.

Based on the calculations, the available pico-hydro power is sufficient to drive the pumps and lighting. However, the utilization of this power would be optimal if accompanied by efficient water management. In this context, Rosalinda et al. (2025) showed that the application of an automatic control system in irrigation can regulate the duration of watering according to plant needs, so that the available water can be used more effectively. With this principle, the use of pico-hydro energy not only guarantees the availability of power for pumps but also allows for expanded irrigation coverage through more efficient water management.

3.2.6 Planning

The planning in this study was carried out by considering the energy potential and energy needs of Campaga Village. The energy potential is obtained through direct measurement and calculation so that the following planning is carried out:

A. Turbine Planning

In the calculation of energy potential, a discharge of 134 l/s is obtained with a head of 11 m and the potential power of the turbine is 10.119 kW. Based on the discharge, head, and potential power, a crossflow-type turbine can be used. This is in accordance with the statement that the crossflow turbine can be operated at a water discharge of 20-10,000 l/s and a head between 1-200 m with a power of 5-100 kW (Saleh et al., 2019).

B. Pump Planning

The potential pump power generated for the pumping system was 3.903 kW. A pump that can work with this power capacity is needed, so planning can be made using a sprayer-type pump that can work at a power of 3-3.9 kW. The use of pump types based on the existing power potential makes the pump work so that it can be used to distribute water to the community.

C. Power Plant Planning

The potential power obtained to generate electricity with an average discharge of 0.134 m^3/s is 2.185 kW; therefore, in this planning, an AC generator can be used with the specifications listed in Table 5.

Table 5. AC Generator Specifications.

Specifications	Unit	Value
Voltage	V	120
Engine Speed	Rpm	3600
Engine Power	Watt	2000

Electrical energy to illuminate the streets will be used for ±12 h at night and in dark situations, so a switch or switch is needed to drain and cut off or close the load current generated by a generator that works for 24 h. Planning the installation of street lights to the plantation with a deserted situation, the use of a switch with a light sensor can be used so that it will automatically drain the current if the lighting area is in a dark situation.

The lamp power needed to go to the residents' plantation area is 0.630 kW with 21 lamps, and the distance of each lamp is 15 m. The potential electrical power generated is 2.185 kW so that lamps with a power of 25-30 Watt can be used, so that electrical energy needs can be met with existing potential.

Based on the existing potential and needs, planning for the utilization of water energy conversion results was carried out. The planning results based on potential and needs can be seen in Table 6.

Table 6. Energy utilization results.

No	Energy	Energy Potential	Energy Needs	Utilization Energy
1	Electric Energy (kW)	2.185	0.630	0.63
2	Pump Energy (kW)	3.903	3.903	3

Table 6 shows that the potential energy is greater than or equal to the energy demand, so planning can be done. The total energy utilized for power generation is 0.630 kW, while the total energy utilized to run the pump is 3 kW.

D. Planning System

The planning of the pumping and power generation system is assembled such that the process of energy conversion and delivery can be observed in detail. The system is organized as follows:

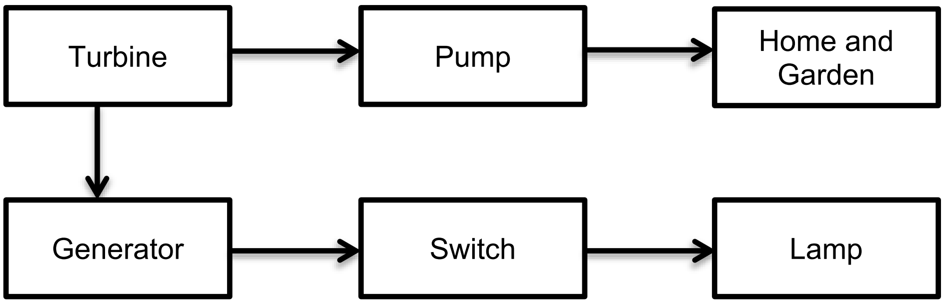

Figure 3. Planning of conversion energy system.

The block diagram shows the flow used to rotate the turbine, and then the rotation is forwarded to rotate the pump used in channelling water to the houses and gardens of residents. The turbine torque is used to rotate the generator, and then the voltage from the generator distributes electrical energy to power the lights.

4. CONCLUSION

Based on research on the Planning of Hydro-Energy Conversion Systems into Mechanical and Electrical Energy in Campaga Village, Tompobulu District, it can be concluded that

1. The planning of an efficient conversion system for the utilized surface water flow is done by using turbines to convert potential energy into mechanical energy and using generators to convert mechanical energy into electrical energy.
2. The design of a micro-hydro system with crossflow turbines represents an appropriate technological solution, as it is based on the suitability of the scale of resources, ease of maintenance, and availability of components at the local level.
3. The potential of local surface flow energy with an average discharge of 0.134 m^3/s and a head of 11 m can meet the basic needs of agricultural support, namely, the power supply for irrigation pumps (~3.9 kW) and lighting (0.63 kW). This technical feasibility forms the foundation for implementation of the system.

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