Small-Scale Renewable Energy Technology to Support the Sustainability of a Food Security Village in Malang City

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Small-Scale Renewable Energy Technology to Support the Sustainability of a Food Security Village in Malang City

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Abstract. Nowadays, the energy transition from fossil fuels to renewable energies is taking place worldwide. Every year, the amount of renewable energy installed increases dramatically. Many small-scale renewable energy technologies have been developed, for example at the household level, or at the environmental level as community-owned renewable energy. This research focuses on the development of renewable energy technology using the resource potential and local community wisdom of *Glintung Water Street* (GWS), a flood-prone area in Malang City. The objectives of the study were to analyze the potential of water resources in the study area to be developed as renewable energy, particularly under low flow conditions, and to investigate community support for the program of energy independence as a basis for developing a green economy to strengthen GWS as a food security village. This study uses 2 types of data, namely qualitative and quantitative data. Qualitative data is used to deepen the urgency of using renewable energy as alternative energy to replace PLN electricity. Meanwhile, the quantitative data collection consisted of 2 types of data, namely data on the measurement of the hydraulic characteristics of the flow as a source of driving force for the water wheel, and data on the community response and support using a questionnaire instrument. The results showed that the minimum flow to drive the water wheel under low flow conditions was 3 l/s. The maximum RPM recorded during waterwheel operation is 9 RPM, i.e. after it rained the night before the measurement, and the resulting voltage was 20 Volt. However, at higher flow conditions, the voltage generated by the waterwheel can reach 40 Volts. The community strongly supports the energy independence program although there are still doubts due to limited knowledge and experience in applying renewable energy technologies.

1 Introduction

Nowadays, the energy transition from fossil fuels to renewable energies is taking place all over the world. Every year, the number of installed renewable energies increases considerably [1]. The way people perceive energy has also changed. More and more people are wondering where their electricity comes from, how they use it, and what impact energy

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use has on planet Earth and others. On the other hand, many creative ideas have emerged to reinforce climate change in positive and significant ways, including being developed as renewable energy through the mechanism of "harvesting" wind, "harvesting" sunshine, "harvesting" rain, etc. Many small-scale renewable energy technologies have been developed, for example at the household level, or at the environmental level [2] as community-owned renewable energy. Local community wisdom supported by strong leadership factors can develop community creativity and productivity that encourages people to innovate towards a sustainable society [3]. The use of local wisdom in the management of renewable energies toward energy independence can contribute to the economic growth of populations. Community involvement is not limited to normative recommendations but must be reinforced by government regulations so that the target of the Indonesian Government for the renewable energy hybrid program of 23% by 2025 can be achieved [4].

In Malang City, there is a slum village located in a floodplain that has successfully transformed into a well-organized village with the concept of sustainability [5]. The village is known as Glintung Water Street (GWS). The name GWS is taken from the condition of the village road or lane which turns into a canal when it rains heavily, especially on roads within ±100m of the river. In areas closest to rivers, water levels can reach 1.2 m. The situation worsens due to backwater when the water level in the main sewer rises and the water overflows into the village. The high creativity and productivity of the community, supported by strong leadership, encourages the community to innovate in the modification of the drainage channels constructed by the PUPR service at GWS [3]. The existence of a drainage channel managed to reduce flooding by up to 30% and the financial benefits of IDR 48 million in one year [6]. The modification of the canal which is made using the canal for the development of urban agriculture (agriculture, fishing, and poultry farming) has succeeded in bringing the village to be designated as a Food Security Village.

However, the Covid-19 pandemic which had a significant impact on the economic and social sectors [7] also led to a 50% drop in GWS revenues. The pandemic is also impacting the reduction of 37.5% of the infrastructure development budget of the Ministry of PUPR [8], so that funds are limited for the maintenance and repair of canals in GWS, as well as for the development of urban agriculture as a main activity for the GWS community. For this reason, efforts are being made to strengthen the current flood control program based on community participation in order to ensure the sustainability of the program by supporting the achievement of the three pillars of sustainable development, namely economic growth, social equality and environmental preservation in GWS. Strengthening efforts are being carried out through the development of waterproof building materials technology, as well as the independence of energy supply to support urban farms. The GWS Energy Independence Program is also needed to help GWS become a tourist destination village in line with the goal of Malang City Tourism Board. Renewable energy in GWS is needed to support lighting installations in urban agricultural areas and surrounding public roads. In the future, the urban agriculture area will also be developed as an educational park and culinary center for processed fish and poultry.

As part of the development of an energy independence program to support the sustainability of the food security program in GWS, and considering that the investment costs that must be provided are relatively large, this research focuses on the development of renewable energy technology using the resource potential and local wisdom of the community. This study aims to analyze the availability of water resources in the study area developed as renewable energy, especially under low flow conditions, and to investigate community engagement and support, especially the role of women in the energy independence program as a basis for the development of a green economy to strengthen GWS as a food security village.

energy sources can be easily found even in the household environment. The renewable energy sources can be found in the form of water energy, wind energy, solar energy, etc. However, the use of This renewable energy source is still not optimal. The demand of the use of fossil energy sources is still high. At the end of 2021 it was reported that the world is experiencing an energy crisis caused by scarcity supply of fossil energy sources such as natural gas and coal [1].

2 Literature Review

2.1 Hydroelectric Power Technology

One of the hydroelectric power technologies is the water wheel. Waterwheel is a simple technology which is widely chosen as a turbine for hydroelectric systems. The design of the water wheel requires a geometry that will minimize losses, and retain water as long as possible in the machine [9]. Water wheels with very small height differences are an important and underutilized source of renewable energy. This design uses significant potential and kinetic energy to generate four times more energy than traditional designs, with the same amount of water [10]. A study of the effect of different immersion depths on waterwheel performance and flow characteristics using numerical simulations shows that the simulation method is consistent with experiment with a maximum error less than 5%. At the same rotational speed, the efficiency is much higher and the fluctuation of torque amplitude is much smaller with increasing dissipation radius ratio [11].

Several water wheel patents that already exist today include: Indonesian patent number IDP0000007984A with the title of invention: Water wheel with moving blades, published on November 2, 2000; U.S. Patent No. US4095422A for the Invention: Vertical Axis Composite Pendulum Vane Waterwheel, issued June 20, 1978; US patent number US5947678A under the title of invention: Hydraulic wheel with cylindrical blades, published on September 7, 1999; U.S. Patent No. US7222487B1 with the title of invention: Gravity Driven Wheel System for Portable Electricity Generating, issued May 29, 2007

2.2 Community Based Renewable Energy Development

Community-owned renewable energy is not only a good way to improve the environment, it's also a great opportunity for local people to come together and benefit economically. One of the strengths of community renewable energy is that each project will be slightly different, tailored to the needs and context of each community. Community-owned renewable energy projects create social, political, environmental, economic and technological benefits by strengthening local economies; educate the public about renewable energy and engage them in creating a sustainable low-carbon future; develop the renewable energy industry [1].

Community-owned projects are characterized by local stakeholders owning the majority of the project and voting rights and control being vested in the community organization. Therefore, most of the socio-economic benefits of the project are distributed at the local community level. The innovative aspect of the community-owned business model lies in the role of the community that goes beyond the production of renewable energy. Today, community ownership models span the entire energy value chain: they can provide local power generation, heat and energy-related services (e.g. storage, charging electric vehicles, energy exchange with local communities); enable efficient use of energy; and provide flexibility to the entire power system [12].

3 Material and Method

3.1 The Concept of Renewable Energy Development

The development of renewable energy in GWS aims to reduce the use of PLN electrical energy to support urban agricultural operations and nearby lighting. Urban agriculture in GWS includes vegetable growing, fishing and poultry farming. GWS is a floodplain which has abundant potential for water resources, especially during the rainy season. In the initial phase, a micro hydropower plant was developed using the water flow in the flood control channel in the GWS which is about 100 meters long with a height difference of 2 meters. The power plant is waterwheel breastshot type with 8 prismatic blades and with a diameter of 1.6 meters, the details are shown in Figure 1.

Fig. 1. Breastshot type waterwheel at Gilintung Water Street (GWS)

The waterwheel is designed to produce power between 20 to 50 watts. The thrust by the mass of water results from the passage of the flow through a modified trapezoidal sharp crested overflow. Modification was made by an additional construction for the overflow which protrudes 20 cm in order to produce greater water jump energy. This additional overflow causes a change of the hydraulic flow compared to a standard sharp-crested overflow. The waterwheel and spillway design is an implementation of utilizing local potential, both water resources and human resources, as the design is entirely an idea of the residents of GWS. The manufacture of windmills is also carried out jointly by the locals in mutual cooperation.

The alternative power produced by the waterwheel is meant to reduce the burden of electricity costs that has to be borne by the community every month, which is IDR 250,000. In the long-term plan, the need for electric power can be met through renewable energy technology, not only using water resources, but also other resources such as solar and wind power. For this reason, it is necessary to carry out an analysis taking into account all the costs and benefits obtained as a basis for planning future development programs to maintain GWS as a food security village based on green economy and sustainable development.

3.2 Research Method

According to the research objectives, this study uses two types of data, namely qualitative and quantitative data. Qualitative data is used to deepen the urgency of using renewable energy as an alternative energy to replace electricity from State Electricity Company. Qualitative data collection through focus group discussions with six informants consisting of one officer from ESDM department who directly handles energy issues, one renewable energy practitioner, Lurah as community leader at sub-district level, the head of RW as a leader who deals directly with the community, the head of PKK as a leader of a women's organization directly involved in the daily use of energy in the household, the head of the youth organization as the next generation which will greatly determine the future of the nation. Based on the literature review, an interview instrument was developed as one set of questions consisting of five categories, namely commitment to developing renewable energy technology from a sustainability perspective, community-based social innovation [13], financial availability and support, collaboration with multiple parties [14], experience using technology [15]. The questions in the interview instrument can be modified or further developed based on the responses of the informants. Meanwhile, the quantitative data collection consisted of two types of data, namely flow measurement data as a source of waterwheel propulsion, and community response and support data using a questionnaire instrument. Flow data includes channel and overflow technical data, flow data, water level at overflow and tail water. While the questionnaire instrument consists of 15 questions which are divided into the same 5 categories as the interview instrument, the only difference is in the delivery mechanism, namely in the form of a completed questionnaire form by the respondent. The respondents were determined using purposive sampling overall 221 people representative of the family.

3.3 Flow Calculation and Analysis

The calculation of the availability of flow rate as a driving force for the waterwheel uses a flow approach through a modified trapezoidal sharp crested overflow. The shape of the spillway is as shown in Figure 2.

(a) (b)

Fig. 2. Modified trapezoidal sharp crested overflow front view (a), and side view (b)

The measurement of velocity on the overflow manually cannot give accurate results due to turbulence of flow along the additional construction of the overflow. For this reason, the flow velocity is calculated using a theoretical velocity approach which is calculated using Equation (1) below [16].

$$u = \sqrt{2gh} \quad \text{i)}$$

Where u = flow velocity (cm.s-1), g = acceleration due to gravity (cm.s-2), h = water level above the overflow. Furthermore, the theoretical discharge is calculated by multiplying the average wet cross-sectional area and the theoretical velocity. The average wet cross-sectional area is calculated based on the wet cross-sectional area at the inlet point of the overflow and the wet cross-sectional area at the downstream end of the overflow, which is 30 cm apart. The observed discharge and theoretical discharge are then calibrated to obtain the discharge coefficient (Cd) for the modified trapezoidal sharp threshold overflow model.

The analysis was carried out to determine the model of the relationship between the flow rate and the rotation of the wheel, the model of the relationship between the water level at the downstream end of the overflow and the flow rate, the relationship model for the water level at the downstream end of the overflow and the falling velocity of the flow.

3.4 Questionnaire Analysis

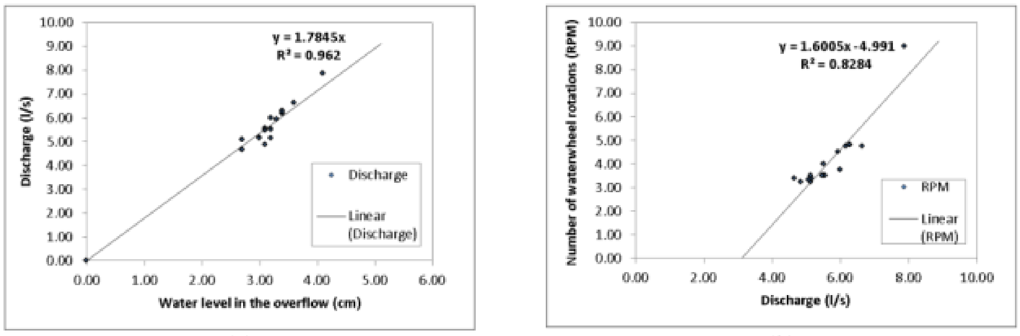
In this study, the population was 884 people, 426 men and 458 women [17]. Determination of the number of samples is determined by purposive sampling where the respondent is the head of the family. As a comparison, the proportion of the number of samples was also calculated by the Slovin formula. The Slovin formula is a formula or formula to calculate the number of samples that are not known with certainty. Slovin is used in survey research which usually uses a large number of samples, so a formula is needed to get a small sample but can represent the entire population.

The distribution of the questionnaires used a questionnaire form to all heads of families (KK) in GWS. Assuming the average population per household is five people, then there are 176 households. A total of 176 questionnaires were distributed according to the number of households. Respondents' answers to questions on the questionnaire were directed to five alternative answers according to the Likert Scale. The five alternative answers are: very good, score 5; good, score 4; enough, score 3; less score 2; very poor, score 1. Analysis of the questionnaire was grouped by gender to determine the difference in response and support between men and women. This grouping is based on Javanese culture, where there are still significant differences in roles and responsibilities between men and women, so it is assumed that they will provide different responses and support for the Energy Independence Program. Furthermore, the validity and reliability of the data were tested using the statistical analysis facility in Microsoft Excel.

4 Result and Discussion

4.1 Discharge Availability fot the Waterwheel

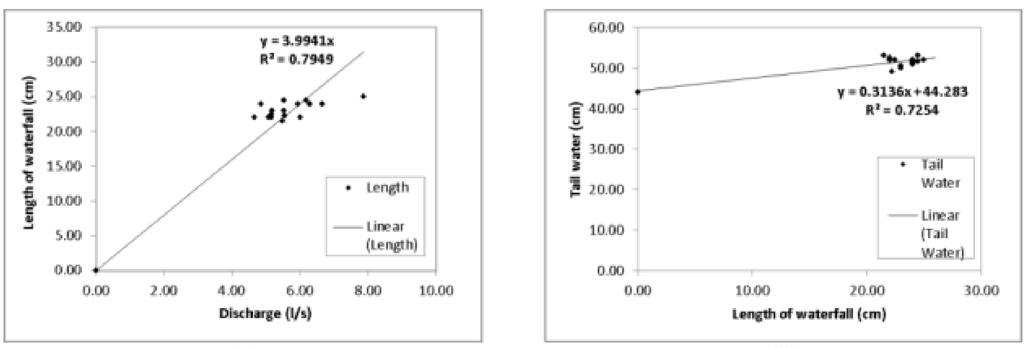
One of the research objectives is to analyze the potential of water resources available in the study area under low flow conditions. Measurements are made at the upstream of the waterwheel, at the location of the wheel and at the overflow that produces water shot for the waterwheel. The measured data includes channel technical data, flow rate, water level at the upstream end and downstream end of the additional construction of the overflow, the tail water, and the speed of rotation of the waterwheel (RPM). The complete data processing results are presented in Figure 3 and Figure 4 below.



(a) (b)

Fig. 3. Linear relationship model between water level in the overflow and discharge (a), linear relationship model between discharge and number of waterwheel rotations per minute (b).

Figure 3 (a) shows that if the water level in the overflow is equal to 0, then there is no flow through the overflow. The flow rate through the channel can be determined by measuring the water level above the overflow using the equation written in the figure. While Figure 3 (b) shows that the waterwheel begins to rotate at a minimum discharge of approximately 3 l/s. The number of wheel rotations is positively correlated with discharge. This result support previous research stating that the potential power of a breastshot waterwheel depends on discharge [18]. At the trial stage, the maximum rotation generated is 9 RPM at an observed flow of 7.9 l/s or a model discharge of 8.7 l/s, the resulting electrical voltage is 20 Volts. The electrical power generated can be used to charge a battery.



(a) (b)

Fig. 4. Linear relationship model between discharge and horizontal water shot length in the waterwheel channel (a), linear relationship model between water shot length and tail water (b).

Figure 4 (a) shows that in conditions without flow or discharge = 0, then the shot length is also equal to 0. If the shot length = 0, the measured tail water is 44 cm (Figure 4 b). In conditions without any flow, there is still water in the waterwheel channel because at the downstream there is a 44 cm high weir. In conditions where there is a flow with fluctuating discharge, the tail water ranges from 48 – 52 cm. The water level in the tail water channel is maintained so that it does not exceed 52.5 cm so that it does not hit the blades of the waterwheel, causing a tractive force that can inhibit the speed of rotation of the waterwheel. At a maximum tail water condition of 52 cm, the maximum length of the waterfall is 60 cm at a discharge of 15 l/s. At a discharge of 15 l/s, the waterwheel rotation is 19 RPM and a voltage of approximately 40 Volts. In low flow conditions, the waterwheel can function properly close to what was planned.

4.2 Design Parameters of Community Commitment

Analysis of community commitment to renewable energy development programs uses data from questionnaires which are grouped into one design parameter and four observation parameters. In this research, the design parameter is a commitment to develop renewable energy technology. Factors that influence commitment are identified based on the results of interviews, focus group discussions and literature studies. Some of the results of interviews and discussions are presented in Table 1 below.

Table 1. Snippets of interview and group discussion results from 6 informants

Date	Respondent Code	Statement
May 20, 2022	A	"The GWS community is very curious and dares to try something new. In EBT technology, residents, especially Mr. RW, have asked several times for socialization about EBT, because there is one resident who has a lot of experience but is still reluctant to develop technology that is directly applied to GWS. Maybe he doesn't know what the procedure is, especially when it comes to financial support".
May 20, 2022	B	"We are ready to implement an energy independence program, there is even one resident who can build a waterwheel because he has had several jobs to build a waterwheel. Later the design and implementation can fully involve the residents and of course there will be assistance from related parties. The only problem is the funds".
May 20, 2022	C	"For residents, especially women, what is important is that we can continue to work on planting and processing vegetables, flowers, and family medicinal plants without water problems and not adding to the burden of RW costs. The important thing is to remain a food security village".
May 20, 2022	D	"Residents here have a variety of skills that can be used to run any program as long as the planning is clear, what resources are needed, and how the implementation mechanism is".
May 24, 2022	E	"Renewable energy technology planning should pay attention to its significance in terms of how much conventional energy loads will be transferred to renewable energy, the needs and facilities to be made also need to be calculated properly to suit".
May 24, 2022	F	"The idea of developing renewable energy in a community is very good, we will support it, because it will accelerate the achievement of Indonesia's renewable energy use target".

Based on the statements of informants as shown in Table 1 above, There are four observed parameters identified, namely the availability and support of funds, community-based social innovation, experience using technology, collaboration from several institutions. Furthermore, research variables were developed based on design parameters and observed parameters as presented in Table 2 below.

Table 2. Research Variable.

Number	Variable Code	Variable Name
1	Y	Commitment to develop renewable energy (dependent variable)
2	X1	Fund availability and support (independent variable)
3	X2	Community-based social innovation (independent variable)
4	X3	Having experience (independent variable)
5	X4	Collaboration between institutions (independent variable)

The relationship model between the dependent variable and the four independent variables was developed based on the results of the questionnaire data processing which was quantified using a Likert Scale. Model development using multiple regression analysis was processed using Microsoft Excel. The results of the analysis are presented in the following community commitment section.

4.3 The Community Commitment

An overview of community commitment was obtained using a questionnaire analysis. A total of 176 questionnaires were distributed, while 147 returned by respondents which were filled out by 80 male respondents and 67 female respondents. Furthermore, the questionnaire was analyzed to obtain quantitative data from five variables consisting of one dependent variable and four independent variables such as described above. Based on the reliability test of the questionnaire simultaneously, all variables obtained Cronbach's Alpha values of 0.68 and 0.61 for the male and female categories respectively. All of Cronbach's Alpha values are above 0.6, which means that the questionnaire instrument used is reliable [19]. Furthermore, the relationship between the independent variable and the dependent variable can be analyzed using regression analysis. The validity of the question categories in the questionnaire were analyzed simultaneously and resulted in a validity coefficient of 0.75. The results of the calculation of the P-value at a significance level of 0.00 are lower than 0.05 [20]. The strength of the relationship between variables in this study is indicated by the correlation coefficient, while the effect of each independent variable on the dependent variable is indicated by the coefficient of determination. The correlation coefficient and the validity test results are as shown in Table 3 below.

Table 3. Results of validity and correlation test

Code	Variables	Male Category			Female Category		
		r	P-value	Significance	r	P-value	Significance
X_1	Fund availability and support	0.368	0.016	valid	0.263	0.049	valid
X_2	Community-based social innovation	0.216	0.013	valid	0.537	0.000	valid
X_3	Having experience	0.395	0.008	valid	0.327	0.964	not valid
X_4	Collaboration between institutions	0.398	0.003	valid	-0.100	0.044	valid

By considering the results of reliability tests, validity tests, correlation coefficients and coefficients of determination, it is known that for the male category, all independent variables can be used to construct the dependent variable, while for the female category not all independent variables construct the dependent variable. There is one variable that should be discarded because it is not valid, namely having experience (X_3). The validity of variables indicated by Cronbach's Alpha is greater than 0.6 and P-value is less than 0.05. Multiple regression analysis was performed for male and female categories. The resulting model, respectively, is as Equation (2) for male category, and Equation (3) for female category.

$$Y = 0.21\,X_1 + 0.20\,X_2 + 0.22\,X_3 + 0.35\,X_4 \qquad \text{(ii)}$$

Equation (2) shows that for the male category, building community commitment in developing renewable energy is formed by all the factors that have been previously identified. Availability and financial support are positively correlated with commitment with a coefficient of 0.21, community-based innovation is positively correlated with a coefficient of 0.20, having experience in implementing technology is positively correlated with a coefficient of 0.22, and collaboration between institutions is positively correlated with a coefficient of 0.35. The collaboration parameter has the highest weight in building community commitment. These results support research conducted in Tridi Kampong, a densely populated kampong along riverbanks that has also been successfully changed into a tourist destination kampong. This success is supported by the local community's creative and innovative ideas and collaboration with external parties [21].

$$Y = 0.22\,X_1 + 0.98\,X_2 - 0.32\,X_4 \qquad \text{(iii)}$$

Equation (3) shows that according to women, commitment to renewable energy development is only formed by three parameters, namely the fund availability and support has positive correlation with a coefficient of 0.22, community-based innovation has positive correlation with a coefficient of 0.98, and collaboration between institutions has negative correlation with a coefficient of 0.32. Community-based innovation has the greatest correlation in building community commitment. This result is in accordance with the statement of one informant, that women are more focused on sustainability in keeping the family healthy, with or without other parties helping.

The difference in influencing factors between male and female categories indicates that there are different perspectives and mechanisms in building commitment, which are caused by differences in roles in carrying out daily life. Actually, women are more implementative in responding to a change. Women rely more on the ability, creativity and internal innovation of the community. This supports the opinion of Ambar Pertiwiningrum which states that although women are rarely fully involved in energy and food independence programs, women actually have an important role in the sustainability of these programs, and should be involved since planning. program and not just as a user [22].

5 Conclusion

Measurements on the channel where the waterwheel is placed with a modified trapezoidal sharp-crested overflow were carried out to study the flow conditions as a source of propulsion for the chest-type waterwheel in Glintung Water Street Village (GWS), in the city of Malang. Based on the data collection and analysis results, it was found that under low flow conditions, with a minimum flow of 3 l/s, the waterwheel was able to rotate. However, the state of the channel around the waterwheel is placed to limit the maximum flow to 15 l/s with a rotation of the waterwheel of 19 RPM and a voltage of approximately 40 Volts.

The results of the focus group discussion and analysis of the questionnaire data concluded that the community has high commitment and support for the energy independence program, particularly from women, with key considerations being that there is a real community innovation and funding availability. As for men, there are two other factors to consider, namely experience in using technology and the collaboration of several institutions. This shows that women's support will be more optimal if all their ideas and innovations are adequately taken into account, and even women are involved in planning, implementation, monitoring, and evaluation.

Further studies are needed on the placement site of the waterwheel so that greater electrical power can be generated to accommodate the innovations of the GWS community towards sustainability as a food security village. If necessary, it can also be investigated to develop renewable energy using other resources such as solar and wind.

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