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SPIRAL CYCLE MICRO-HYDRO COMMUNITY SYSTEM MODEL FOR SUSTAINABLE DEVELOPMENT IN YOGYAKARTA, INDONESIA

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Abstract: Indonesia is committed to innovating and making breakthroughs in micro-hydro energy development. However, the problem is the lack of multi-stakeholder roles, especially local communities in its development, causing the poor operation of micro-hydropower plants. This research aims to apply the Spiral Cycle Micro-hydro Community System (SCMCS) Model through an eight-stage cycle process for the development of the Kedungrong micro-hydro power plant (MHPP) in Yogyakarta. The methods used are a qualitative approach, collecting data in the form of field observations, in-depth interviews and forum group discussion. The results and new findings indicate that SCMCS requires at least four cycles to be useful and sustainable. First is enhancing institutional, social and environmental aspects. Second is enhancing the technical aspects. Third involves improving the economic aspects. Fourth is optimizing the use of micro-hydro energy for micro-small enterprises. This model has successfully developed and preserved the MHPP project through integrated multi-stakeholder community participation in rural areas.

Keywords: Community system, micro-small enterprises, micro-hydro development, multistakeholder participation.

Abbreviations:

ABGCFIT	Academic, Business, Government, Company, Financial, Information and Technology
BBWS	Major River Basin Organization
BPDASHL-SOP	Watershed Management Agency and Protected Forest-Serayu Opak Progo
BPTTG	Appropriate Technology Development Office
BUMDes	Village-Owned Enterprises
BUMN	State-Owned Enterprises
CIT	Cihanjuang Inti Teknik
Disperindag	Industry and Trade Office
DLH	Environmental Office
DPMPT	Investment and Integrated Services Office
DPR-RI	House of Representative of Indonesia Republic
FKPDAS	Communication Forum Watershed Management
IIMC	Indonesia Integrated Micro-hydro Community
KLHT	Integrated Environmental Community
KSPPS	Saving and Loan Cooperatives and Islamic Financing
LAPPI	Indonesia Training and Education Institutions
MEMR	Ministry of Energy and Mineral Resources
PH	Power House

RUEN	National Energy General Plan
SCMCS	Spiral Cycle Micro-hydro Community System
Sekda	Regional Secretariat
UNS	Sebelas Maret University
UGM	Universitas Gadjah Mada

Introduction

Indonesia is committed to prevent climate change by reducing its greenhouse gas emission and increasing the use of renewable energy. Hydropower is a renewable energy (RE) and the country is believed to have the potential of generating 75,091 MW of hydroelectric energy nationwide. A smaller version of hydropower, known as mini- or micro-hydro energy is potentially able to generate 19,385 MW nationwide (Alatas *et al.*, 2020). Therefore, micro-hydro energy has the greatest potential to become a priority in the selection of new types of RE to be developed in Indonesia (Rimantho *et al.*, 2018) where electricity demand is expected to increase by an average of 6.0% annually until 2050 (Center of Assessment for Process and Energy Industry, 2018). The country's population has grown by 1.1% in 2017 compared with the previous year (Plecher, 2019). To anticipate the fulfilment of energy needs in Indonesia, it is necessary to optimize the use of RE instead of depending heavily on fossil fuel. RE potentials in Indonesia include hydroelectric, micro-hydro, wind, geothermal, solar, biomass and wave power. Indonesia has an abundance of water resources but 6.4% only of the national hydroelectric potential of 75,091 MW has been utilized. For micro-hydro power, 1.0% only of the 19,385 MW potential has been utilised (Presidential Regulation of the Republic of Indonesia No. 22, 2017). Micro-hydro power is a low-cost, environmentally friendly energy source (Anaza *et al*., 2017). The use of micro-hydro power is also more efficient than other renewable energy such as wind and solar power (Nasir, 2014; Erinofiardi *et al.*, 2017). Under the 2015 International Paris Agreement, Indonesia has committed to increase its use of RE from 23% in 2025 to 31% RE in 2050. The government predicts that the country's oil reserves may sustain for the next 12 years only, followed by natural gas at 33 years and coal for another 82 years. Therefore, Indonesia must optimize its new and RE resources to meet future demand. Erinofiardi *et al.* (2017) stated that micro-hydro power plants (MHPP) have a low payback period, and building such facilities requires government support and attention. The involvement of multi-stakeholders may make micro-hydro energy generation a sustainable venture. The biggest challenge faced in operating a MHPP is the inconsistent flow of water at waterways because of seasonal changes (Weking & Sudarmojo, 2019). This will affect the plant's potential to optimally generate power, especially during the dry season.

The Kedungrong MHPP in Purwoharjo Village, Yogyakarta, Java has relatively stable water discharge (Fajarsari *et al.,* 2015). The mainstay discharge range is determined based on the flow duration curve (FDC) which is 5 m^3/s with a probability of 85% at the power plant. The data used for the analysis of discharge from secondary irrigation is secondary data periodically for 11 years (Alatas *et al.,* 2021). Micro-hydro power is a solution and opportunity to power rural areas given the geographic conditions in Indonesia, which has many mountains, hills, rivers and islands (Hadiyanto *et al.,* 2019). Micro-hydro projects in rural areas have been carried out and the only obstacle is sustaining the projects (Hadiyanto *et al.*, 2018). Yogyakarta, a special administrative region in south central Java itself has ten micro-hydro power plants but currently only three are operating. Inconsistent management and poor maintenance, lack of awareness, low community participation and minimal multi-stakeholder involvement have caused the seven micro-hydro plants to cease operating.

The BluePrint for National Energy Management 2006-2025 aims to maximize the use of local energy sources to become an Energy Independent Village to support the government's efforts in national energy security and safeguarding the people's welfare. National programs to reduce poverty in Indonesia are the government's mandate in the Constitution of Indonesia (UUD'45) (Rangga *et al.*, 2021). There is a need for a spiral cycle micro-hydro community system (SCMCS) to generate electricity supply for rural residents. The findings of this research will support the United Nation's Sustainable Development Goal for sustainable energy use that meets the following aspects: (1) Institutional, (2) Technical, (3) Social, (4) Economy and (5) Environment. SCMCS has enhanced all the elements in sustainable micro-hydro power. It is expected to be a solution for the sustainable development of micro-hydro power and become the basis of government policy. This research is conducted to meet these implications when applying micro-hydro power development models in irrigation canals of farming communities as an integrated community-based sustainable energy source.

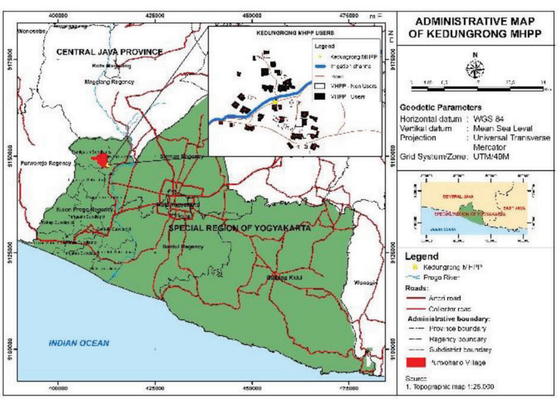
Materials and Methods

Study Area

The Kedungrong MHPP is located in Kedungrong hamlet, Purwoharjo village, Samigaluh sub-district, Kulonprogo Regency, Yogyakarta Special Region (DIY), Indonesia. The power plant was built on the primary channel of the Kalibawang irrigation canal. Geographically, the study location is approximately 7°42'35.1"S and 110°12'36.8"E (Figure 1 (a)).

Research Methods

The research method used a qualitative approach, where data were collected in field observations, in-depth interviews and forum group discussions (FGD). This research examined the institutional, technical, social, economic and environmental aspects of SCMCS with eight sub-processes as Table 1, which was a modification of Sullivan and Skelcher (2017). In comprised: (1) Identification of problem, (2) Initiation, (3) Deliberation, (4) Program, (5) Solution, (6) Action, (7) Monitoring and (8) Development. Community participation in meetings was held to convey ideas between the



(a)

(b)

Figure 1: (a) Map of study locations and Kedungrong micro-hydro power consumers: 36 houses, (b) A bird's eye-view of the power house at Kedungrong MHPP built on the Kalibawang primary irrigation canal

community and stakeholders to determine which policy was the main indicator in the decision-making stage (Nurvianti & Hastuti, 2021). The process and stages could be carried out with multi-stakeholder cooperation and integration including (1) academics, (2) businesses, (3) communities, (4) government, (5) financial institutions, (6) information and (7) technology elements (ABCGFIT elements). The research was limited to one micro-hydro group in a rural area for developing a model with the location of micro-hydropower plants in primary irrigation channels.

The interview process was carried out during FGD each stakeholder representative, in which the respondents were selected according to their capacity. The interview subject was a representative of the ABCGFIT elements, with a questionnaire used as a research instrument. In addition, MHPP users were also interviewed to determine electricity consumption and the impact of the plants on the institutional, social, economic and environmental aspects of their community. FGD activities and interviews were conducted in August 2019. The interviewees were competent and moved according to the field of integration in the system so that they could represent the entire population. The research flow is presented in Figure 2.

The stages were carried out coherently to determine the development and desire of the community in managing a sustainable micro-hydro power supply. Each SCMCS stage was carried out systematically, repeating again after one cycle, which would subsequently get bigger and bigger. If a new problem arose, then it would be solved in a second round and so on. The more advanced and developing a system was, the bigger and more complex it would become. The SCMCS cycle consisted of four stages sustainable for micro-hydro development (Figure 3), with an explanation of each stage in one cycle and the results of the activities of each stage presented in Table 2. Each stage of the SCMCS is carried out systematically and repeats with one round cycle which is getting bigger as it grows and if there is a new problem, it is solved with a second round and so on.

Results and Discussion

The results of this research are presented in Table 2. Each cycle of a round is described according to eight sub-stages. Based on the four rounds of SCMCS 1st, SCMCS 2nd, SCMCS 3rd and SCMCS 4th, the problems and solutions were as follows.

Table 1: The stages in SCMCS implemented in Kudongrong MHPP

No.	Stages	Explanation
1	Identification of problem	Identify existing problems that require urgent attention
2	Initiating problem solutions	Proposing suggestions, ideas or thoughts to solve problems
3	Deliberation	Conducting deliberations to reach a consensus or voting with the most votes or at least 50% + 1 (quorum)
4	Program	Drafting of a program to carry out solutions
5	Solution	The solution has been obtained based on mutual agreement
6	Action	Actual solution action and implementation
7	Monitoring	Monitoring to anticipate the possibility of new problems and opportunities for the developing systems and subsystems in sustainable micro-hydro power utilization
8	Development	Solution development to complete solutions with maximum results

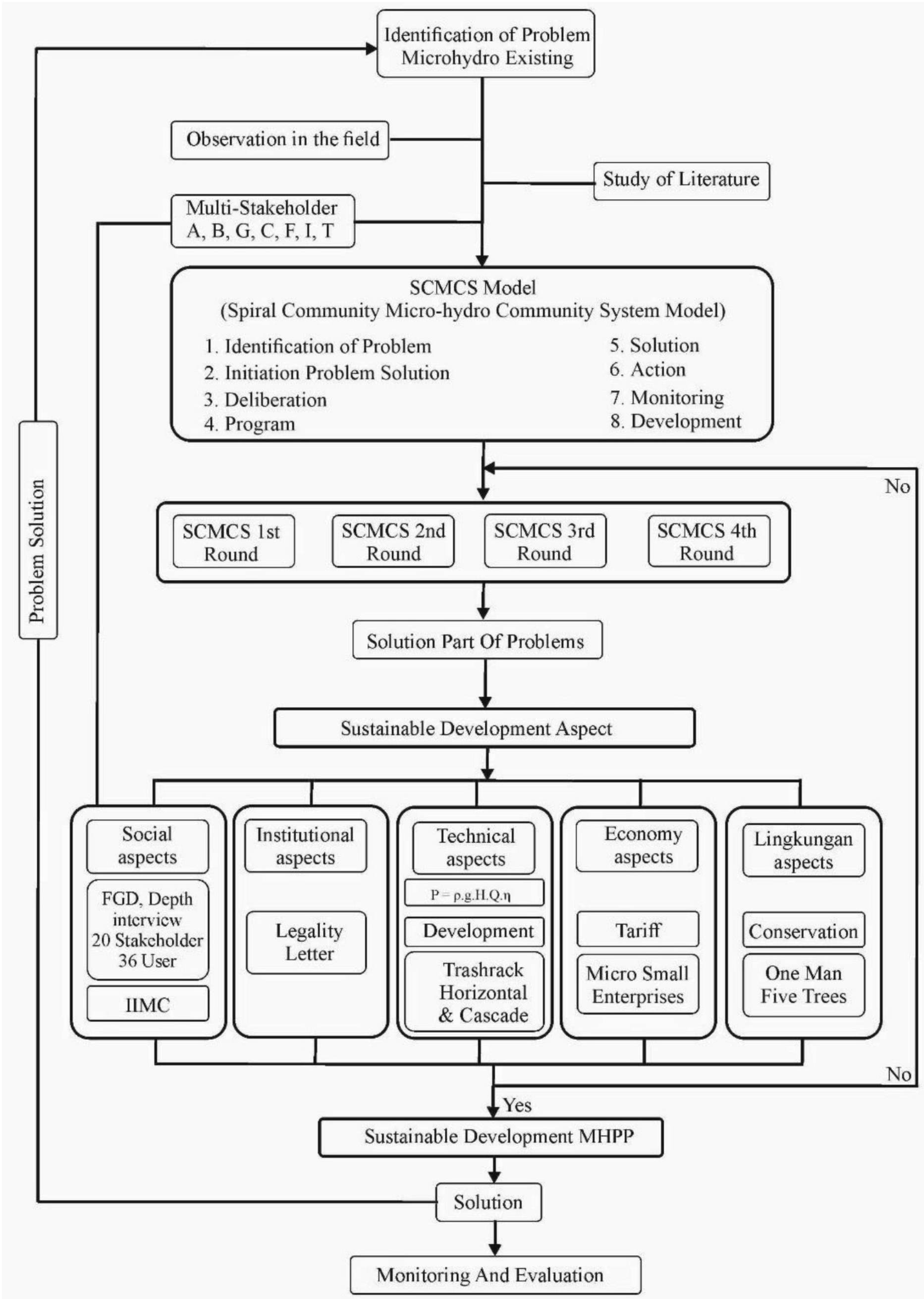


Figure 2: Diagram of research flow

SCMCS 1st Round

Data collection was carried out by identification or observation, in-depth interviews, deliberation to reach a consensus, FGD and documentation. Field observations were carried out and qualitative interviews were conducted by purposive sampling (Palinkas *et al.,* 2015), with informants representing the following members of the ABCGFIT elements: Academics (A), Government (G), Business or private (B) and Community (C). The sampling data consisted of 36 micro-hydro consumers (the informants were existing micro-hydro users). The ABCGFIT elements were selected based on the criteria of knowledge related to the topic, the role of the community and communication skills (Tongco, 2007; Etikan *et al.,* 2016). The formation of the Indonesian Integrated Micro-hydro Community (IIMC) Kedungrong Kulonprogo had failed to resolve problems arising from the implementation of the micro-hydro project. Jiao (2018) stated that the basis for energy system integration was an optimal production strategy that payed attention to the economy and environment (Elshaikh *et al*., 2018). The roles of IIMC elements were adjusted to their respective abilities and sectors based on the results of the interviews, which were presented in Table 3. Collaborative governance consisted of government and non-government actors, solving problems in society and/or creating public value through collective action (Morse & Stephens, 2012). The development of integrated micro-hydro management for institutional strengthening was carried out by a cultural approach and consensus deliberation, starting from coordination activities, discussion of leaders, FGDs, field activities and follow-up meetings. The analysis of the SCMCS model with eight stages is able to identify micro-hydro problems that exist in the location, with the result that the best solution is obtained by forming a community, hereinafter referred to as IIMC and becoming a development forum, and a forum for deliberation to reach consensus.

SCMCS 2nd Round

Garbage dumped into the Kalibawang irrigation channel had significantly affected the operations at Kedungrong MHPP (Figure 4). This problem was conveyed directly to the community users of the MHPP, at the same time stating that the community needed additional capabilities related to the use of electricity from MHPP as follows:

> "The electricity, the power is not maximal, Ms. So that flashing is not yet strong for business production. We also need training, making crafts and marketing. Often make things, don't know how to sell them", Tuminah (as an element of the community).

SCMCS 3rd Round

Round 3 resulted in a decision to impose a micro-hydro tariff of Rp7,000 per month on every household class of 450 VA to pay for maintenance cost and staff salaries. However, to improve services and ensure production stability, it was necessary to increase the contribution to Rp12,000 per month, by allocating the operator and maintenance officers to get a monthly fee or compensation. The average household electricity consumption under the micro-hydro project was 0.2 kWh x 24 hours x 30 days, which came up to 144 kWh per month. Compared with the PLN electricity tariff of Rp1,352 per kWh (Ministerial Regulation of MEMR No. 3/2020), the cost of electricity per household should come up to Rp194,688 per month but the consumers just pay Rp12,000 only per month, allowing them to save Rp182,688 per month.

Fourth Round of SCMCS 4th

The Kedungrong MHPP had an output capacity of 18 kW x two turbines or a total of 36 kW - field conditions allowed the operation of one turbine only due to technical defects. The power generated from one 18 kW turbine could be used for 27 street lights and 36 houses out of a total of 44 in Kedungrong hamlet. The use of electricity per house was at an average of 0.27 kWh, the highest usage was between 06.00 and

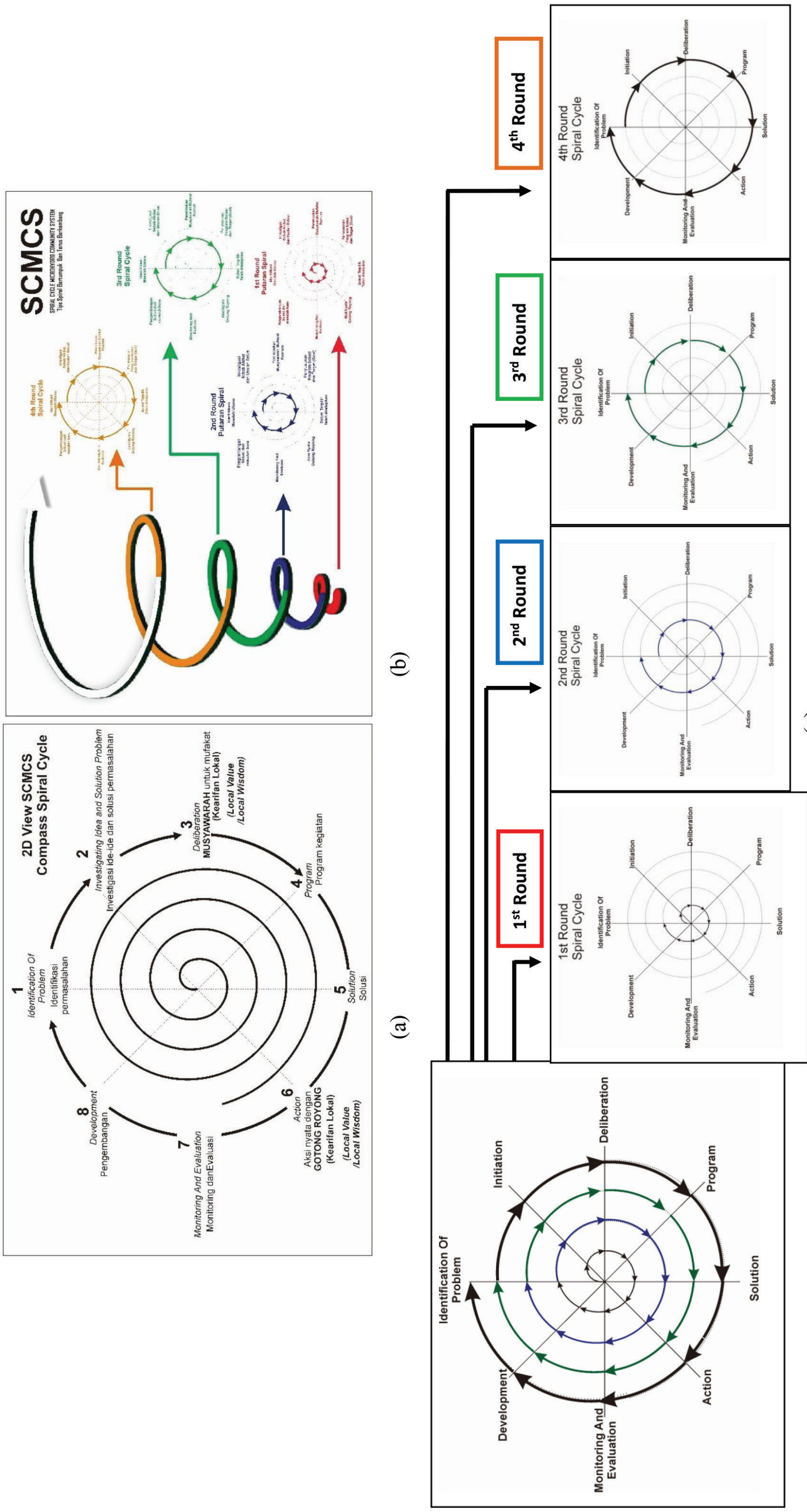


Figure 3: (a) Two dimensions of SCMCS - Spiral Cycle Compass, (b) Spiral Cycle Micro-hydro Community System (SCMCS) with stacking and growing type, (c) SCMCS 1st Round, 2nd Round, 3rd Round and 4th Round

Table 2: The results of the eight sub-stages in SCMCS

Sub	Results
	1st Round Spiral Cycle Micro-hydro Community System (SCMCS 1st)
1	Identification of problem: (1) The lack of social participation in micro-hydro plant management, (2) There is no legal standing for plant managers and (3) There is no structured maintenance program
2	Initiating problem solutions: (1) Initiation of society participation through FGD by developing a management structure from the group to community (bigger), (2) Initiating a legal submission of the local Village Head Decree and (3) Organise monthly and annual activity programs
3	Deliberation: (1) Holding FGD, accommodating aspirations. Declaring IIMC - Kedungrong, (2) Formation of IIMC
4	Program: Managers arrange daily, monthly and annual work programs
5	Solution: (1) Involve many communities, from 8 administrators to 29, (2) Obtain legal status for Village Head Decree No. 33 of 2020, (3) Programmed daily, weekly, monthly and yearly activities
6	Action: (1) Conduct community participation in accordance with duties and responsibilities
7	Monitoring: The community has created an online communication forum in social media to gather ideas
8	Development: Development of community participation in micro-hydro plant operations and optimizing the use of micro-hydroelectric energy
	2nd Round Spiral Cycle Micro-hydro Community System (SCMCS 2nd)
1	Identification of problem: (1) Garbage clogging the intake and turbine, causing it a shutdown three times a day and (2) Garbage cleaning of intake's trash rack carried out three times a day
2	Initiating problem solutions: Making waste diversion trash racks and discharge enhancing valves for production optimization
3	Deliberation: IIMC management meeting
4	Program: (1) Mutual cooperation plans to construct a waste diversion trash rack (welding done with micro-hydro electricity), (2) Mutual cooperation for installation of waste diversion trash rack and (3) Mutual cooperation to widen the intake section
5	Solution: (1) Making a horizontal trash rack for waste diversion, (2) Widening of intake and (3) Installation of horizontal trash rack
6	Action: Run and operate the waste diversion trash rack
7	Monitoring and evaluation: Reduce the cleaning of garbage from three times a day to once and control of the overflow in the spillway, in which previously the water level was below the overflow line
8	Development: Processing and sorting of garbage caught on the trash rack
	3rd Round Spiral Cycle Micro-hydro Community System (SCMCS 3rd)
1	Identification of problem: (1) The tariff per month is Rp7,000 and (2) The problem is that there is no compensation for operators (maintenance)
2	Initiation problem solutions: (1) Agreement among local communities to increase tariffs and (2) Proposed monthly fee for operators
3	Deliberation: (1) Organizing deliberations for management and accommodating aspirations for the proposed increase in electricity tariff
4	Program: Socialization plan for tariff increase from Rp7,000 to Rp12,000 according to the results of deliberations and the provision of incentives for operators and waste cleaners

5	Solution: (1) A new tariff of Rp12,000 per month and (2) Operators and garbage cleaners to be paid monthly salary
6	Action: (1) Implementing a tariff policy of Rp12,000 per month by increasing the stability of production and (2) Operators and officers are more diligent in maintaining the stability of micro-hydro energy production
7	Monitoring and evaluation: Communication officers to maintain production stability and cleaning garbage from intake
8	Development: The operations become more compact in terms of maintenance
	4th Round Spiral Cycle Micro-hydro Community System (SCMCS 4th)
1	Identification of problem: Production is design to produce 18 kW but average usage is less than 8 kW
2	Initiation problem solutions: (1) Optimizing the energy production and (2) Generating micro-business in energy supply
3	Deliberation: (1) Organizing deliberations between management and related stakeholders in developing small businesses
4	Program: Usage of energy for micro-enterprises
5	Solution: Micro-enterprises (ME): Electric welding, carpentry, electric sewing, motorbike repair shop, tire patching, portable pico hydro turbine plant, egg incubator, bottled drinking water production, Village Clean Water Distribution development, aquaculture development and others
6	Action: (1) Coordination in the formation of micro-enterprises
7	Monitoring and evaluation: The development of 6 micro-enterprise start-ups going well. 5 of the enterprises are in the process of seeking support and cooperation capital
8	Development: Development of small-micro-enterprises

Table 3: The role of ABCGFIT elements in IIMC

No.	Elements	Institutions Involved
1	Academic (A): Mentoring, education, research and community service	Universitas Gadjah Mada (1), Sebelas Maret University (3), Proclamation University 45 (1), Yogyakarta Institute of Technology (4), Yogyakarta National Institute of Technology (1). Number of people participation: 10 people
2	Business (B): Private or business ventures	Indonesian Research & Training Institute (2), Madani Cooperative (3). Number of people participation: 5 people
3	Government agencies related to energy, water resources, watershed, social and economic development (G)	DPR RI expert staff (1), Ministry of Energy and Mineral Resources DIY (1), Jasa Tirta Energi (3), BPDASHL SOP (3), DLH Kulonprogo (2), KSPPS Madani (3), Disperindag (3), DPMPT-PT (3), Village Head (1). Participation: 20 stakeholders
4	Community forum or society (C)	KLHT Al Dzikro (1), FKPDAS DIY (1), Micro-hydro users (36). Number of participants: 38 (community and user)
5	Financial (F)	CSR Madani Cooperative, CSR LAPPI, CSR PT. JTE.
6	Information (I)	Media Merapi (1), Minggu pagi (1), Jogja TV (2)
7	Technology (T)	Cihanjuang Core Technique (1)

17.00 kWh by micro-businesses, namely sewing and carpentry factories. The carpentry factory used a welding base, hand saws, dowels and electric saws which were tools that required a considerable amount of power. The average hourly electricity usage and total average

(a) (b) (c) (d) (e) (f)

Figure 4: (a) Garbage in the Kalibawang irrigation canal caught on the trash rack of Kedungrong MHPP, (b) and (c) Diverting trash rack installed at the Kudungrong MHPP intake, (d) Widening of the intake mouth, (e) Construction of new trash racks and (f) Installing the trash rack at the trash rocker

electricity consumption of MHPP Kedungrong was 4.91 kWh. Based on the 18 kW supply, the production was used only up to 27.3%. Therefore, the micro-hydroelectric energy had not been used optimally in the area. The results showed that the energy consumption of MHPP Kedungrong by all consumers (36 consumers) was below 8 kW from the total production of 18 kW. The difference or remaining untapped micro-hydro energy (ΔP) was 10 kW (Figure 5). To optimize the use of energy generated by the MHPP, there were plans to add six new micro-enterprises in the area (Figure 6).

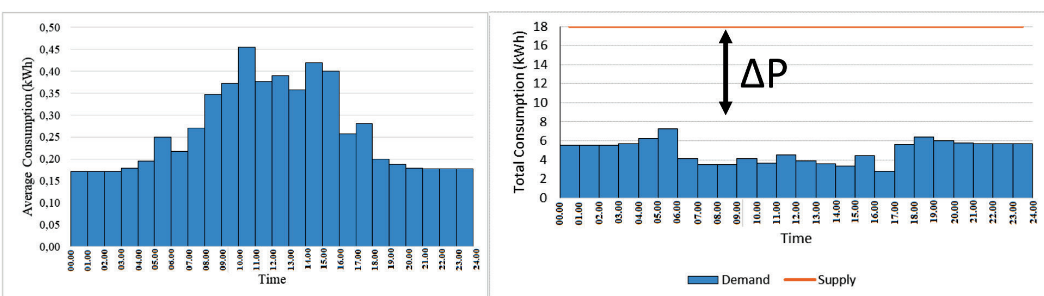
The structure of micro-hydro energy demand in Kedungrong MHPP was modified from Huang *et al*. (2015). The electricity generated by the plant was used for street lighting, household appliances, economic activities, environmental management and new energy projects (micro-hydrogen generation). The energy demand and supply for the housing sector at the research location were modified from Karunathilake *et al.* (2018) as Figure 7.

The concept of small micro-enterprises using renewable energy like micro-hydroelectricity had been developed to establish energy-independent industrial areas and create renewable energy education tourism villages, which were all in line with the Yogyakarta Tourism Development Vision (2012-2025). It aims to create a world-class tourist destination with a competitive advantage to encourage village and regional development based on community empowerment as the main pillar of the economy (Aziz *et al.*, 2020).

Sustainable Development Goal's Aspect: The Institutional, Economic, Social and Environmental Aspects of Kedungrong MHPP Based on the Results of the Application of the SCMCS Model

Institutional Aspects

Efforts are needed to increase the capacity of local communities so that the community



(a) (b)

Figure 5: (a) Average daily electricity usage per house, (b) Comparison of demand and supply of Kedungrong MHPP, which the remainder has not been used (ΔP)

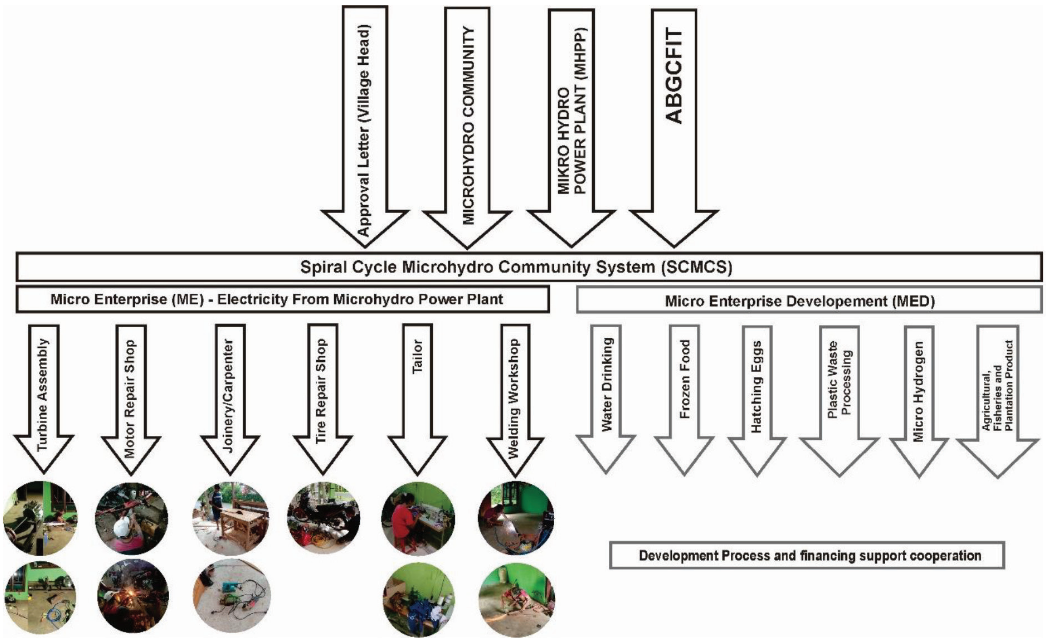


Figure 6: Establishing micro-enterprises to optimize the use of micro-hydroelectric energy and its development

Table 4: Description of the development of micro-enterprise activities by using micro-hydro electricity

No.	Types of Micro-enterprise	Description of Micro-enterprise	Usage of Micro-hydro Electricity
1	Turbine assembly	Assembly, repair and manufacture of pico hydro portable turbines	Micro-hydro electricity for welding, pico hydro turbine assembly
2	Motor repair shop	Motorcycle and car mechanics	Micro-hydro electricity for welding, compressors and servicing
3	Joinery/carpentry	Manufacturing of furniture like frames, tables and chairs from wood	Micro-hydro electricity for wood cutting machines, hand drills, sandpapering and others
4	Tyre repair shop	Motorcycle and car tyre repair shop	Micro-hydro electricity for air compressors
5	Tailoring	Sewing clothes, face masks and others	Micro-hydroelectricity to run sewing machines
6	Welding workshop	Welding metal to make fences, canopies, repairing heavy machines and others	Micro-hydroelectricity for welding
	Micro-enterprise Development		
7	Drinking water supply	Production of bottled water for drinking	Micro-hydro electricity to power the submersible pump and run the water bottling machines
8	Frozen food and ice	Cooler for fish, chicken and nuggets, crystal ice	Micro-hydro electricity for chillers and refrigerators, and crystal ice machines

9	Egg hatching (poultry)	Production of chicken and duck hatchlings	Micro-hydro electricity for heating egg incubators
10	Plastic waste processing	Plastic waste is broken, heated and molded into other products	Micro-hydro electricity to run plastic-chopping and molding machines
11	Micro-hydrogen generation (new energy)	Converting water into hydrogen and oxygen	Micro-hydro electricity to conduct electrolysis
12	Agricultural, fisheries and plantation products	Agriculture, aquaculture and plantation	Micro-hydro electricity for aeration, food processing and packaging

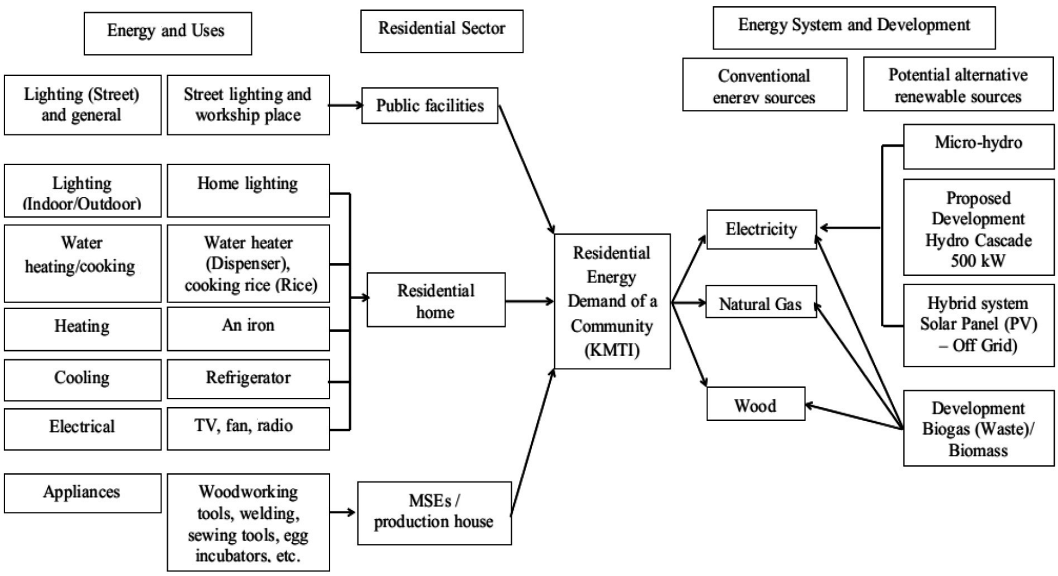


Figure 7: Energy demand and availability in the housing and development sector (modified from Karunathilake *et al.,* 2018)

was more independent (Utami *et al.*, 2018). Involvement of the academia, businesses, and local and national governments to provide assistance to local communities as consumers and MHPP administrators would strengthen the development of the micro-hydro power system. The RE project could not be implemented without support from the local government (Marquardt, 2014). Efforts to strengthen micro-hydro institutions had been declared with a letter of commitment from multi-stakeholders by producing the Indonesia Integrated Micro-hydro Community (IIMC) that had been granted a certificate and legal status from the local village head.

Engineering and Development Aspects

Increasing the water flow by widening the plant's intake point would result in a discharge that was more stable and caused little overflow in the spillway. The installation of a diverting trash rack would prevent blockage of turbines and reduce their cleaning process from three times a day to once. Besides the installation of pico hydro turbines, the MHPP had also incorporated portable micro-hydroelectric-powered pumps to supply clean water to 40 houses. New potential findings were being considered to upgrade the MHPP cascade with a production capacity of 600 kW, H 12 m, Q 5 m^3/s and Turbine Kaplan Horizontal S Type.

Benefits and Social Development Aspects

Generally, the social benefits obtained were namely community empowerment through training, gaining new knowledge about micro-hydro operations and increasing capacity in management and organization (Institute for Essential Services Reform, 2011). Figure 8 (a) shows the percentage impact of the Kudongrong MHPP on social capital. Social relations and solidarity between local communities had increased and all the communities agreed that the MHPP had not disturbed the local wisdom (59%). The community also agreed that the MHPP project had increased harmony between residents (76%) and was carried out mutually (62%). The number of participants and the role of groups had also increased (59%), with local communities getting involved in the MHPP management (66%) and the MHPP project increasing local norms and regulations (45%). Figure 8 (b) shows that access to human needs was also getting easier and faster, improving community skills through training by sub-sectors.

Development of Economic Aspects through Micro-enterprises

Sustainable micro-hydro power development and the formation of integrated communities could provide benefits to the local economy. Among them were opening up new jobs, both for technical development of the MHPP and other innovations through the formation of small micro-enterprises. The cost of electrification capital for businesses and household activities would also be reduced (Sapkota *et al.*, 2014). The benefits that micro-hydro electricity could provide for the village economy included 12

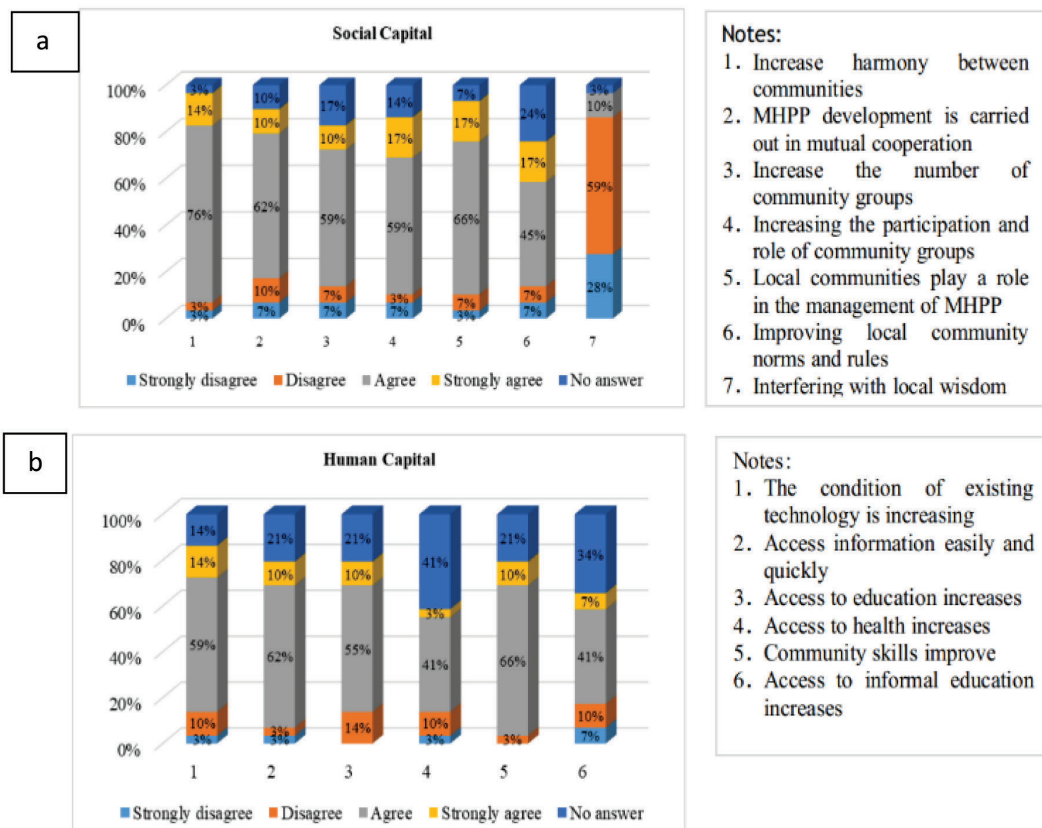
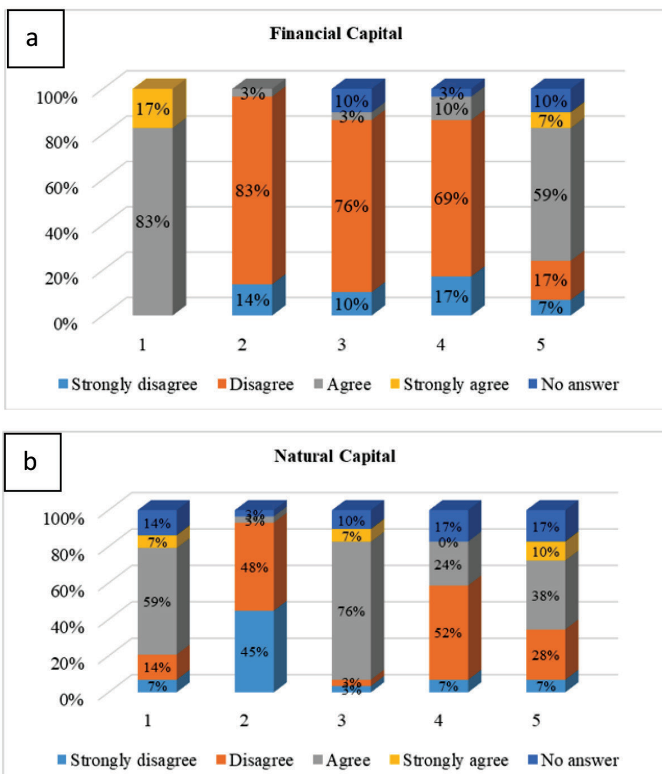


Figure 8: The impact of MHPP on (a) social and (b) human capital

types of micro-enterprises, in which six were running businesses (turbine assembly, motor repair shop, joinery/carpentry, tyre repair shop, tailoring, welding workshop) and six were economic efforts (drinking water supply, frozen food and ice, egg hatching, plastic waste processing, micro-hydrogen generation, and agricultural, fisheries and plantation products) as Table 4. The government could take concrete actions to support and advance the micro-enterprises (Ruchkina *et al.*, 2017). Figure 9 (a) shows the percentage of impact that the Kudongrong MHPP had on the financial capital of the local community. A total of 83% of residents surveyed agreed that the MHPP project had increased their income, namely through the generation of micro-household businesses. The MHPP actually reduced expenses because the cost of electricity was cheaper compared to the national tariff. The community disagreed (69%) that the MHPP project had disrupted the productivity of rice fields because the water used to generate electricity was not diverted elsewhere and returned to the irrigation channel. The increase in community income through micro-enterprises could be used as an additional contribution (fees) to maintain the micro-hydro plant. However, the fees generated from user communities were not sufficient. In reality, the low fees were hampering the development and expansion of the micro-hydro project. According to Sato *et al.* (2017), to improve the finances in managing MHPPs, collaborations between local potentials and private companies could be mooted.

Environmental Quality Improvement through IIMC

After the development of MHPP and formation of the IIMC, the local community perceived that the watershed had become cleaner (59% agreed) and the water quality was maintained (76% agreed), as presented in Figure 9 (b).



Notes:
1. Increased revenue
2. Increased expenditure
3. Generating externality costs
4. Disrupting the productivity of rice fields
5. MHPP as a source of regional funding

Notes:
1. The areas around the river have become cleaner
2. Damaging the environment
3. Water quality in the irrigation canal is maintained
4. Water discharge has increased
5. Increased soil fertility

Figure 9: The impact of MHPP on (a) financial and (b) natural capital

The turbines could be kept running without being disrupted by rubbish frequently due to the installation of the trash rack. Another impact on the environment was the reduction in greenhouse gas emission and tree planting activities in the upstream of the watershed and its catchment area (IESR (Institute for Essential Services Reform), 2011). The IIMC had planted fruit trees to rehabilitate the environment and generate economic value. The one-man-five-trees program would soon be implemented every year at the beginning of the rainy season in October.

Effects of SCMCS Model on MHPP Kedungrong (Before and After)

MHPP development programs would run optimally if the stakeholders could benefit directly from social, economic and environmental outcomes (Utami *et al.*, 2018). The sustainability of micro-hydro projects and its managing communities was very much influenced by the vital role of technical, social and economic elements and the environment (Dahal, 2014). The role of multi-stakeholders was greater and aspects of sustainable development could increase the value of its benefits. The benefits of implementing the SCMCS are presented in Table 5.

Table 5: Changes in institutional, technical, social, economic and environmental aspects in implementing the SCMCS project

Description of SCMCS Results	Before	After
Institutional aspects		
1. Type of management	Small group	Indonesia Integrated Micro-hydro Community
2. The number of managers	Eight people	29 people
3. Village head licensing decree	-	IIMC Legal Letter from the Village Head of Purwoharjo No. 33 of 2020
4. The number of stakeholders	Two stakeholders	10 multi-stakeholders
Technical aspects		
1. Widening of micro-hydro intake	-	Mutual cooperation to widen the plant intake to increase water discharge
2. Trash rack system	Single trash rack	Double diverting trash rack installed
3. Portable pico hydro turbine	-	Five pico hydro portable development units installed
4. Rural drinking water	-	1 unit distribution submersible pump for 40 houses
5. Energy of production	15,000 Watt	18,000 Watt
6. Smart hybrid	-	Installation of solar panels, biogas utilization
7. Feasibility study (Plan)	-	MHPP cascade P 600 kW, Kaplan S-Type
Social aspects		
1. Micro-hydro users	36 users	44 users/consumers
2. Cascade 500 kW (Plan)	-	1,000 users/consumers
Economic aspects		
1. Micro-enterprises	Four running	Six to 12 developments
2. Consumer tariff	Rp7,000 per month	Rp12,000 per month
3. The value of income	-	± Rp3-5 million per month

Environmental aspects		
1. One-man-five-trees program	-	100 fruit trees/year
2. Organic and plastic waste	-	Organic waste fertilizer and plastic waste recycling
3. Reduction of greenhouse gas emission emissions	-	The campaign prioritizes the use of micro-hydro power with zero-emission
4. Energy-independent village and pro-climate status	-	Energy and pro-climate village gate

Conclusion

Out of ten MHPPs in Yogyakarta, three of them could not operate optimally due to lack of management and participation of stakeholders. The results of this research on the SCMCS model could provide solutions to these problems. The heptahelix Integrated Community concept, which comprised the ABCGIT elements, were recruited as members of the Indonesia Integrated Micro-hydro Community (IIMC).

The SCMCS could provide a solution for the sustainable development of micro-hydro aspects, i.e., institutional, social, economic and environment. Increasing the social aspect had resulted in an increase in the number of consumers, which in turn, had increased the prospect of the communities' willingness to pay a higher tariff from Rp7,000 to Rp12,000 per month for better management of the MHPP. Improving the economic aspect had led to the setting up of more micro-enterprises. Finally, the environmental aspects of the One-man-five-trees program and the efficient processing of organic and inorganic waste will add value to the declaration of Purwoharjo village as an energy-independent and pro-climate village.

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References

Alatas, M., Budiastuti, M. T. S., Gunawan, T., Setyono, P., Burlakovs, J., & Yandri, E. (2020). The identification of micro-hydro power plants potential in irrigation areas based on Unmanned Air Vehicle (UAV) Image Processing. *E3S Web of Conferences*, *190*, 1-7. https://doi.org/10.1051/e3sconf/202019000024

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. https://doi.org/10.18280/ijsdp.160516

Anaza, S. O., Abdulazeez, M. S., Yisah, Y. A., Yusuf, Y. O., Salawu, B. U., & Momoh, S. U. (2017). Micro hydro-electric energy generation-An overview. *American Journal of Engineering Research (AJER)*, *6*(2), 5-12.

Aziz, N. A., Muslichah, I., & Ngah, A. H. (2020). Understanding factors influencing community life satisfaction towards sustainable heritage tourism destination: The case of Yogyakarta, Indonesia. *Journal of Sustainability Science and Management*, *15*(1), 37-51.

Center of Assessment for Process and Energy Industry. (2018). *Indonesia Energy Outlook*

2018. Sustainable Energy for Land Transportation. Center of Assessment for Process and Energy Industry, Agency for the Assessment and Application of Technology.

Dahal, S. (2014). Sustainability of Micro-Hydropower in Nepal: A case study of Rukum District. *Proceedings of IOE Graduate Conference*.

Elshaikh, A. E., Jiao, X., & Yang, S. (2018). Performance evaluation of irrigation projects: Theories, methods, and techniques. *Agricultural Water Management*, *203* (August 2017), 87-96. https://doi.org/10.1016/j.agwat.2018.02.034

Erinofiardi, 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*(December 2016), 316-321. https://doi.org/10.1016/j.egypro.2017.03.146

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics*, *5*(1). https://doi.org/10.11648/j.ajtas.20160501.11

Fajarsari, A. D., Sulaiman, M., & Setiawan, B. (2015). Developing a model of a sustainable micro hydropower plant management system: A case study Kedungrong MHP Purwoharjo Village Samigaluh District Kulon Progo Regency Yogyakarta Province. *ASEAN Journal of System Engineering*, *3*(1), 18-27.

Hadiyanto, D., Noorachmat, B. P., Sapei, A., & Purwanto, Y. A. (2018). Sustainability challenge of Micro Hydro Power Development in Indonesia. *IOP Conference Series: Earth and Environmental Science*, *147*. https://doi.org/10.1088/1755-1315/147/1/012031

Hadiyanto, D., Purwanto, Y. A., Noorachmat, B. P., & Sapei, A. (2019). An indicator and evaluation criteria for Off-Grid Micro-Hydro Power Sustainability Assessment. *International Journal of Renewable Energy Research*, *9*(3).

Huang, Z., Yu, H., Peng, Z., & Zhao, M. (2015). Methods and tools for community energy planning: A review. *Renewable and Sustainable Energy Reviews*, *42*.

IESR (Institute for Essential Services Reform). (2011). *Cinta Mekar Micro-Hydro Power Plant Giving Power to the People. IESR, Indonesia*. http://iesr.or.id/old/wp-content/uploads/The-Cinta-Mekar-Micro-Hydro-Power-Plant.pdf

Karunathilake, H., Perera, P., Ruparathna, R., Hewage, K., & Sadiq, R. (2018). Renewable energy integration into community energy systems: A case study of new urban residential development. *Journal of Cleaner Production*, *173*, 292-307.

Marquardt, J. (2014). A struggle of multi-level governance: Promoting renewable energy in Indonesia. *Energy Procedia*, *58*, 87-94.

Morse, R. S., & Stephens, J. B. (2012). Teaching collaborative governance: Phases, competencies, and case-based learning. *Journal of Public Affairs Education*, *18*(3).

Nasir, B. A. (2014). Design considerations of Micro-Hydro-Electric Power Plant. *Energy Procedia*, *50*, 19-29. https://doi.org/10.1016/j.egypro.2014.06.003

Nurvianti & Hastuti. (2021). Community participation in the development of Taman Sari Tourism Village, Yogyakarta, Indonesia. *Journal of Sustainability Science and Management*, *16*(5), 263-287. https://doi.org/10.46754/JSSM.2021.07.017

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Adm Policy Ment Health*, *42*, 533-544. https://doi.org/10.1007/s10488-013-0528-y

Plecher, H. (2019). *Indonesia: Population growth from 2007 to 2017*. https://www.statista.com/statistics/319176/population-growth-in-indonesia/

Presidential Regulation of the Republic of Indonesia Number 22 of 2017 concerning the General Plan of National Energy. (2017). https://jdih.esdm.go.id/peraturan/Perpres 22 Tahun 2017.pdf

Rangga, K. K., Gultom, D. T., Hasanuddin, T., & Viantimala, B. (2021). Effectiveness of self-help groups in the implementation of livelihood improvement programs and food security in Lampung, Indonesia. *Journal of Sustainability Science and Management*, *16*(4), 149-161. https://doi.org/10.46754/JSSM.2021.06.013

Rimantho, D., Putra, W. A., & Hidayah, N. Y. (2018). Determining the key criteria development of renewable energy in Indonesia using a combination ISM and AHP methods. *Journal of Sustainability Science and Management*, *13*(2), 117-128.

Ruchkina, G., Melnichuk, M., Frumina, S., & Mentel, G. (2017). Small and medium enterprises in the context of regional development and innovations. *Journal of International Studies*, *10*(4).

Sapkota, A., Lu, Z., Yang, H., & Wang, J. (2014). Role of renewable energy technologies in rural communities' adaptation to climate change in Nepal. *Renewable Energy*, *68*, 793-800.

Sato, T., Ide, J. 'ichiro, Isa, M. A., Rahadian, F., Fujimoto, T., & Shimatani, Y. (2017). A challenge for sustainable electrification, respecting the local tradition in Ciptagelar Village, West Java, Indonesia: Complementary approach with a private company. *Energy Procedia*, *141*, 368-372.

Sullivan, H., & Skelcher, C. (2017). *Working across boundaries: Collaboration in public services.* Macmillan International Higher Education.

Tongco, M. D. C. (2007). Purposive sampling as a tool for informan selection. *Ethnobotany Research & Aplications*, *5*, 147-158.

Utami, T., Setyono, P., Nurhaeni, Ida & Suntoro, S. (2018). Institutional representation of forest and land conservation in upper Bengawan Solo watershed Indonesia. *Ecology, Environment, and Conservation*, *24*(3), 1115-1122.

Weking, A. I., & Sudarmojo, Y. P. (2019). Prototype Design of micro hydro using turbine archimedes screw for simulation of hidropower practical of electro engineering students. *Journal of Electrical, Electronics and Informatics*, *3*(1), 6-14. https://doi.org/10.24843/JEEI.2019.v03.i01.p02