INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
D. Hadiyanto et al., Vol.9, No.3, September, 2019

An Indicator and Evaluation Criteria for Off-Grid Micro-Hydro Power Sustainability Assessment

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Received: xx.xx.xxxx Accepted:xx.xx.xxxx

Abstract- Very remote rural locations require the supply of electricity to be carried out with an off-grid system. The off-grid rural electrification can be developed by fossil fuels power plants or local renewable energy sources. The fossil fuel price, the long distance of fossil energy sources, and the environmental impacts make fossil fuel plants no longer be a priority to be developed in Indonesia. The Renewable energy generation provides the best alternative for the electricity supply. Micro-hydro power (MHP) is one of the many renewable energy power plants that has been built massively in the last 2 decades. Sustainability is a significant problem in micro-hydro power development in Indonesia. This paper aims to formulate a set of indicators and evaluation criteria for micro-hydro power sustainability assessment. The study begins with a literature review related to micro-hydro power sustainability both in terms of the power plant operations sustainability and sustainable development to identify the sustainability indicators and evaluation criteria. The expert judgment is needed to validate a set of sustainability indicators and evaluation criteria. The results of the paper review and expert opinion were obtained 54 indicators and evaluation criteria of micro-hydro power sustainability, in 5 dimensions: technical, economic, social, institutional, and environmental. Fifty-four indicators and evaluation criteria can be used to evaluate the micro-hydro power sustainability index.

Keywords micro-hydro power, sustainability, indicators, evaluation criteria.

1. Introduction

Indonesia is an archipelago located on the equator; this makes Indonesia have high rainfall. High rainfall is a hydro energy source especially in mountainous areas which can be used as an electrical energy source, through micro-hydro power plants, and hydroelectric power plants. The utilization of hydro energy for electricity generation in Indonesia is very low, for micro-hydro power is only 1% of the total potential of 19,385 GW [1].

Indonesia is an archipelago state that comprises 17,504 islands [2]. It is an enormous challenge in providing electricity. The Ratio between electrified households to all Indonesian households or electrification ratio is 98.0% in 2018 [3]. Although the electrification ratio value is quite high, which is close to 100%, there are still many Indonesians people who do not have access to cheap and sufficient electrical energy especially in rural areas. Various alternatives for rural electrification development in Indonesia can be seen in Fig. 1.

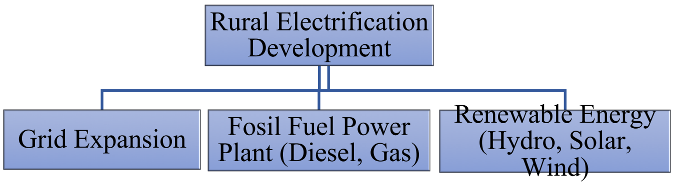

Fig. 1. Rural Electrification Development Alternatives.

Geographical conditions with a massive number of scattered islands in Indonesia is impossible to develop electricity infrastructure in the integrated system by national grid expansion. The best solution is to build a small-scale power plant that is separate from the national grid or the off-grid system. Indonesia has developed a lot of off-grid electricity for rural electrification at present.

In the off-grid system, several alternative power plants can be developed. The first, by using fossil-fuel power plants such as diesel and gas engine. The second, by developing power plants from local renewable energy sources such as wind power, micro-hydro power, solar photovoltaic, and so on. Fossil fuel prices are high and continue to increase, the far distance of fossil energy sources, and the environmental impact makes fossil fuel power plants less attractive to develop. The off-grid system with fossil fuel plants for rural electricity was no longer developed in Indonesia.

Renewable energy is one of the promising energy sources to be developed. Many advantages can be obtained with renewable energy. Major benefits of renewable energy sources may be summarized as follows: Ecological benefits; Sustainable resources; Energy, economy, employment; energy security [4].

Micro-hydro power plant and solar photovoltaic are the two types of renewable energy technology that were most widely built for rural electrification in Indonesia. This power plant was developed in an off-grid system separate from the national grid. In the remote areas, the off-grid system is the best way to electrify the villager [5].

Micro-hydro power has advantages in terms of investment costs per kW, which are relatively cheaper than solar photovoltaic. The investment cost per kW for solar photovoltaic ranges from 1,500 – 4,300 USD/kW, while micro-hydro power it is 1,000 – 3,500 USD/kW [6]. Micro-hydro power also has cheaper electricity generation costs per kWh average of 0.05 USD/kWh while the solar photovoltaic average of 0.1 USD/kWh [7].

Another advantage of micro-hydro power is that this power plant can produce more electricity per day with the same capacity. For example, 10 kW peak solar photo voltaic, only provides 45 kWh/day with an assumption the maximum peak radiation time in Indonesia is 4,5 hours/day [8]. While the micro-hydro power with a capacity of 10 kW, can produce 240 kWh/day electrical energy if it operated 24 hours/day at the maximum capacity.

Micro-hydro power plants (MHP) are a promising electrification technology that uses small river water resources for generating electricity [9]. Micro-hydro power is a small-scale off-grid power plant which is the priority to develop because of various advantages. Indonesia has developed a lot of micro-hydro power for off-grid rural electrification, especially for remote areas that located far away from the national grid. After construction, the micro-hydro power was handed over to the village community to be managed, operated, and maintained independently. The village community, together with the government, will form a management organization to control the power plant.

The importance and necessity of decentralized renewable energy systems in achieving this sustainability is highlighted [10]. Sustainability is a significant issue for micro-hydro development in Indonesia. Many micro-hydro powers stop operation shortly after hand over. On the other hand, micro-hydro power also less contribute to sustainable development in the rural community, which encourages economic growth, social development, and environmental protection for future generations.

The micro-hydro power sustainability can be viewed on two sides; the first is the sustainability of the power plant operation to supply electrical energy to the villagers. Research on sustainability power plant operations has been carried out by several researchers (references no 13-23). The second is micro-hydro power viewed from the sustainable development perspective by composing a set of indicators divided into several dimensions, such as economic, social, and environmental, that develop in a balanced manner. Research on sustainable development has been published by some researchers (references no 28-38). The aim of this study is composing micro-hydro power sustainability indicators and evaluation criteria in the two points of view, power plant operations sustainability and sustainable development so that a more comprehensive set of indicators and evaluation criteria can be obtained. The indicators and evaluation criteria can be used to evaluate the micro-hydro power sustainability.

2. Methodology

The research begins with a literature review related to the sustainability of micro-hydro power, both from the power plant operations sustainability, and the sustainable development side. The next step is to identify the sustainability indicators. Indicators that have been identified are classified into five dimensions of sustainable development: technical, economic, social, institutional/organizational, and environmental. After the sustainability indicator is completed, the next step is the expert opinion regarding the indicators. Experts are chosen based on the knowledge, experience, and position related to micro-hydro power sustainability and sustainable development.

Literature reviews related to the power plant operations sustainability are carried out by reviewing each literature about the micro-hydro power operations sustainability in Indonesia. Many papers have been published by institutions, individuals, and group researchers. Some of the studies examined the viability of power plant operations. The factors that inhibit or promotes the durability of the micro-hydro power as off-grid rural electrification are identified.

Literature studies related to micro-hydro power sustainability in the context of sustainable development are carried out by the research related to sustainable development in the energy sector, specifically the energy supply for rural communities. Many studies have been published by researchers through various international journals and proceeding. The research has formulated a set of indicators to evaluate the sustainability of energy supply for rural communities — a set of indicators from the previous researcher as a reference for the micro-hydro power sustainability indicators.

The next step is to unite indicators that come from the sustainability of operations and indicators of sustainable development. Indicators that have similarities are put together, while different indicators stand alone. The formulated indicators are divided into five dimensions of sustainable development: technical, economic, social, institutional, and environmental. Each aspect consists of 10-12 indicators, which are quite moderate amounts for multi-dimensional analysis.

The micro-hydro power sustainability indicators and evaluation criteria are needed to be validated. The validation process can be done by expert judgment [11]. Experts must be related to micro-hydro power and sustainability. The experts will decide that: the indicators and evaluation criteria can be used without correction, the indicators can be used with an improvement, and the indicators may be rejected.

The experts must be meet the requirements; 1) expertise in the scientific field, 2) expertise as policymakers and 3) expertise due to specificity, such as local wisdom experts. The number of experts is 3 to 7 experts [12]. The number of expert respondents in this study is seven experts.

3. Micro-Hydro Power Operation Sustainability

Micro-hydro power usually handed over to the village community, after the government and donor agencies have completed it. Management, operation, and maintenance are carried out independently by the management agency. Control of micro-hydro power should be well done so that the electrical energy supply will available continuously. The sustainability of micro-hydro power operation is not only the management institution responsibilities. Consumers, governments, contractors, and manufacturers play an essential role in maintaining operation sustainability of power plant. Many cases of micro-hydro power have been built and handed over to management institutions, have sustainability problems [13].

The Ministry of Public Works [14] published research on the problem of micro-hydro power in the Lampung, West Java, Central Java, and East Java, Republic of Indonesia. There are several problems related to the sustainability of power plant operations in the three provinces. Fund collected from the rural community are often less than the operation maintenance cost of the power plant. Conflict of water use for other purposes such as community raw water needs makes power plant stop in operation. The entry of the State Electricity Company network has caused micro-hydro power customers to be State Electricity Company customers.

Energizing Development Indonesia (EnDev Indonesia) [15] published the performance of several micro-hydro power in Indonesia. Research is done by key performance indicator (KPI) survey on 20 units of the micro-hydro power in Sulawesi island and 27 units in Sumatra island. The capacity factor of micro-hydro power in Indonesia is relatively low at 6.1%, while availability factor is around 63%. Small capacity factors indicate that the electrical energy potential that can be produced is huge, but the utilization is low. Another result of other studies some power plant components are broken and not be repaired. Financial and administrative management is not done correctly. There are several powers plant have a water supply problem during the dry season due to land conversion in the upstream watershed. The availability of spare parts is the main problems that are quite disruptive to the electricity supply for the community because of the remote location of the plant.

Murni et al. [16] researched two units of micro-hydro power locations in Bawan Valley (Lian Butan and Tang Paye), East Kalimantan province, Republic of Indonesia. Some critical things can be learned in the development of micro-hydro power to be sustainable. The involvement of local communities starting from the planning stages, construction stages, operation, and maintenance stages is one of the keys to sustainability. An excellent engineering design, such as debit design is one of the critical factors so that the plant does not stop operation during the dry season. Safety induction can minimize workplace accidents during the construction, operation, and maintenance stages. Institutional capacity consisting of management, operational, and maintenance skills are a significant factor in the sustainability of power plant operations. Appropriate training for management institutions is the best ways to increase management institutions capability. Electricity tariffs are the principal capital to ensure the sustainability of the power plant operation.

EnDev Indonesia [17] published the research on the micro-hydro power operation sustainability of 32 units of micro-hydro power in Sulawesi island. Social conflicts between villagers as well as between villagers and management institutions cause fatal damage to the power plant, so the power plant stops operating. Conflict of water resources utilization for agriculture and plantations results in the power plant operation. The entry of the State Electricity Company electricity network has caused micro-hydro power consumers to move into State Electricity Company customers. Natural disasters such as floods and landslides caused damage to a civil component of the power plant. Another problem is the low quality of the civil, mechanical, and electrical components that cause damage to the power plants early. Figure 2 shows various issues that cause the micro-hydro power disruption. Disruption of power plant operation can be caused by multiple dimensions, not only technical problems.

Ranzanici [18] researched on the sustainability of micro-hydro power on Sulawesi island. They are needed a higher investment cost to build good quality power plants, which will significantly affect to power plant operation sustainability. Good technical design is not enough to guarantee sustainable micro-hydro power. Problems in the social and economic dimensions can be fatal to the sustainability of the power plant operations. The sustainability of micro-hydro power is a very complex interaction or various aspects: technical, economic, social, institutional, and environmental.

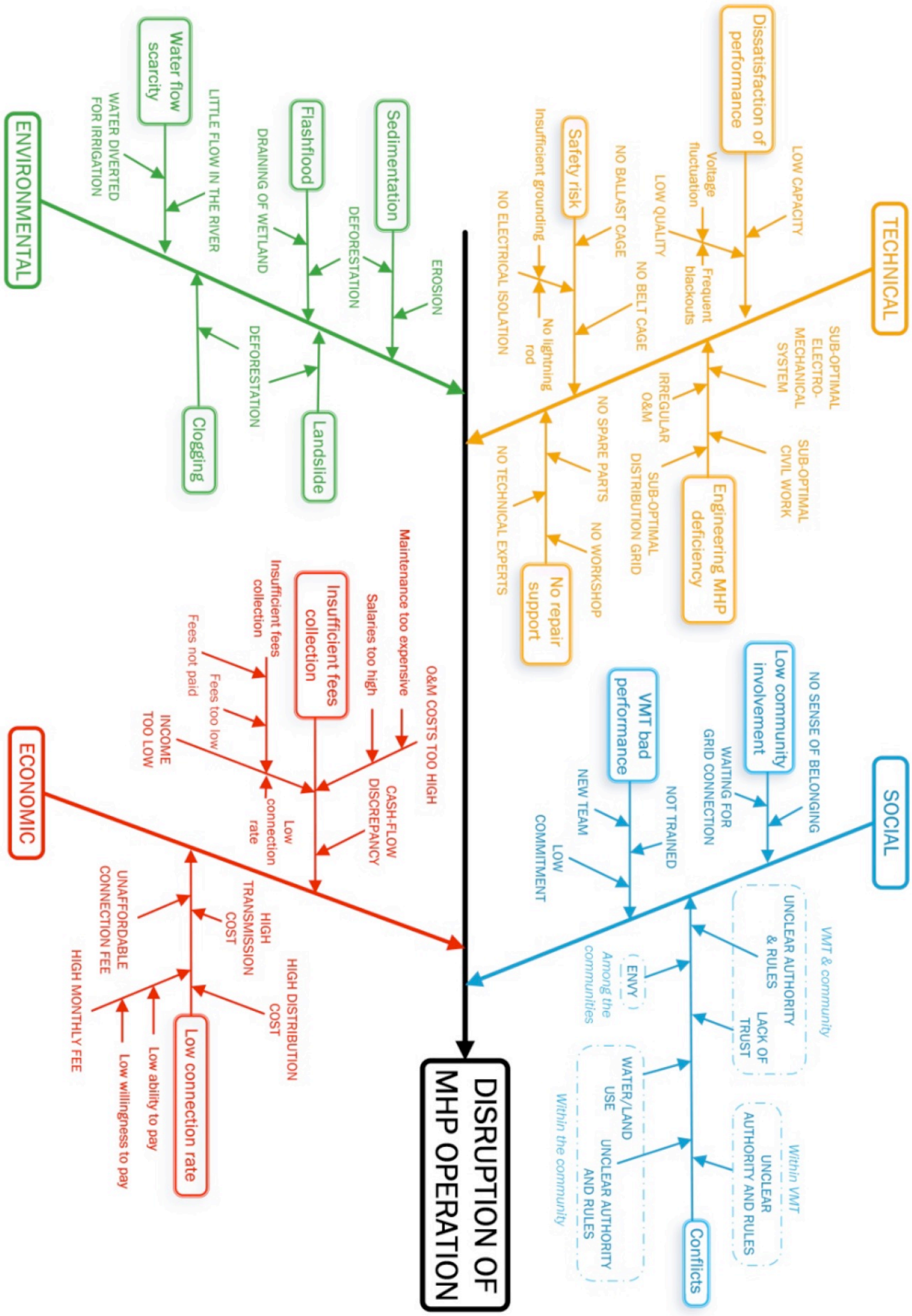

Fig. 2. Fishbone Diagram of Micro-Hydro Power Operation Disruption [17, 18].

Murni et al. [19] researched the sustainability of the micro-hydro power at six units of micro-hydro power in Ba'kelalan and four units in Krayan, East Kalimantan province. There are some similar research results with previous research in 2012; there is some factor that can guarantee the micro-hydro power operations sustainability such as good technical design, good institutional capacity, training for management institutions and proper electricity tariffs. Utilization of electric energy for productive activities can contribute to the micro-hydro power income to cover operating and maintenance costs. Institutional support, both technical and funding, is needed for the plant. Costumer load management and power reserves are essential factors in maintaining power plant operation sustainability [20].

Rosaira et al. [21] published the results of the micro-hydro power sustainability research in several locations in West Lombok Regency and Lumajang regency, Republic of Indonesia. Several vital things determine the power plant operations sustainability such as the management institution capability, micro-hydro power revenue, external institutional support, electrical energy utilization for productive activities, availability of spare parts and local experts, power reserves for future needs. The social condition of the community is one of the factors driving sustainability, such as the number of electrified population, community participation, and the role of community leaders.

Sallata et al. [22] conducted the Malimbu micro-hydro power research in North Luwu regency, Sulawesi island. This research confirms that the power plant operates well because of the active participation of the community. The presence of the micro-hydro power become a driver of conservation activities for the catchment area, which is the key to the availability of water discharge throughout the year.

Kumara et al. [23] researched the Karangasem micro-hydro power in Karangasem regency, Bali island. The unpreparedness of the community to manage the micro-hydro power is the main problem of power plant operation. Power plant management requires specific managerial skills and technical skills. The lack of institutional capacity development is the main reason for the Karangasem micro-hydro power to stop operating. The unclear status of power plant ownership causes the local government to have difficulties in supporting power plant operations and maintenance.

Sustainability is strongly influenced by supporting external institutions. Policy and funding support from the government from the village to the central government level is to determine the viability of the micro-hydro power operation. Funding support can be sourced from village funds, local government funds, or central government funds. Outside the government, there are other institutions such as manufacturers or workshops that play a significant role in maintaining the sustainability of the micro-hydro power operation. In general, support from workshops such as providing spare parts, local experts, and soft loans for power plant operation and maintenance.

4. Micro-Hydro Power Sustainability in Sustainable Development Context

The United Nations, through the World Commission on Environment and Development (WCED), introduces the concept of sustainable development. Sustainable development has an understanding of development to meet current needs without sacrificing the ability of future generations to meet their needs [24]. Sustainable development focuses on the balanced development between economic, social, and environmental dimensions that are realized simultaneously. These three dimensions must be understood in a balanced and synergistic manner as a form of development to meet current needs without endangering future generations. The sustainable development of micro-hydro power is expected to have a positive impact on the economic growth and social life of the rural community, and also providing a minimal impact on the environment. The link between micro-hydro power and sustainable development can be seen in Fig. 3.

Sustainable development places the foundations of sustainability in every dimension. Every development will have an impact on the environment, the economic, social condition of human life. The International Atomic Energy Agency (IAEA) in collaboration with the United Nations through the United Nations Department of Economic and Social Affairs (UNDESA), and the International Energy Agency (IEA), and the European Environment Agency (EEA) formulated energy indicators for sustainable development in 2007. Energy indicators for sustainable development encompass economic, social, and environmental dimensions. There are several main themes promoted by energy indicators for sustainable development, such as accessibility, affordability, disparities, safety, productivity, efficiency in transportation and transformation, energy security, energy availability, and environmental friendliness.

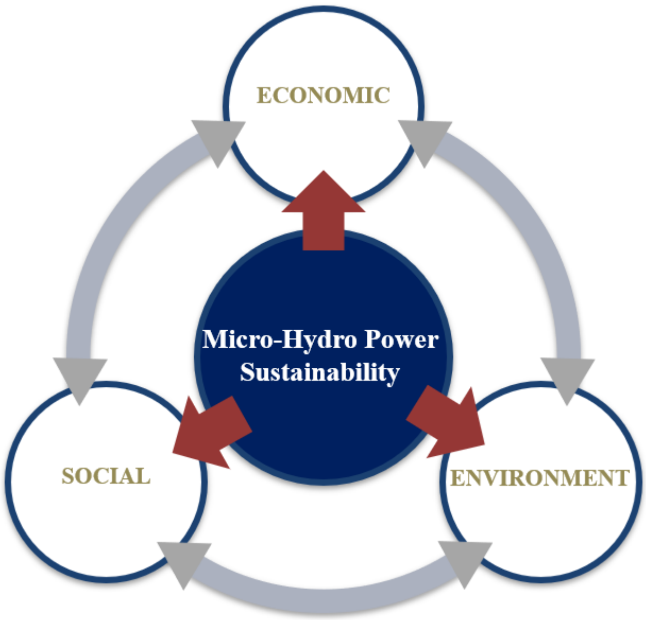

Fig. 3. Micro-Hydro Power and Sustainable Development.

In 2015, the UN formulated seventeen sustainable development goals that are expected to be achieved in 2030 (The 2030 Agenda). The energy sector is one of the main parts of sustainable development. The 7th goal of sustainable development mandates the creation of clean and affordable energy [25]. Clean and affordable energy is expected to be realized through renewable energy development. Micro-hydro power is expected to be a renewable energy generator for rural electricity that is clean and affordable energy. Access to green energy and electricity, is crucial for reducing poverty and driving sustainable economic development [26].

IAEA has issued the indicators for sustainable development in the energy sector. The Energy Indicators for Sustainable Development (EISD) are discussed according to dimensions, themes, and sub-themes following the same conceptual framework used by the United Nations Commission on Sustainable Development (CSD). There are 30 indicators classified into three dimensions (social, economic, and environmental). These are further classified into, seven themes and 19 sub-themes [27, 28].

A set of indicators of EISD is still general, and national scale, a more appropriate set of indicators is needed to evaluate the sustainability of off-grid rural electricity development programs such as micro-hydro power. In 2008, Ilskog [28, 29] formulated 39 indicators to assess the sustainability index of various rural electricity programs based on renewable energy (solar photovoltaic) in Africa. Thirty-nine indicators cover five dimensions of sustainability. A set of indicators developed by Ilskoq can be seen in Table 1.

Table 1. Sustainability indicators for rural electrification assessment [29, 30]

Dimension	Key variable	Indicator
Technical development	Operation and maintenance	Efficiency
		Conformance with national standards
		Technical losses
		Compatibility with future grid service
		Availability of support infrastructure
	Technical client-relation issues	Daily operation services
		Availability of services
Economic development	Financial perspective	Profitability
		Costs for operation and maintenance
		Costs for capital and installation
		Share of profit for re-investment
		Tariff lag
	Development of productive uses	Share of electricity consumed by businesses
		Share of electrified households using electricity for income
	Employment	Business development
	Competition	Number of electricity service organizations in the area
Social/ethical development	Social electricity services	Share of a health center and schools with electricity
		Number of street lights in the area
		Share of public places and specialized businesses
	Credit facilities	Micro-credit possibilities available for electricity connection
	Equal distribution	Share of population with primary school education
		Share of population with access to electricity
		Distribution of electricity client households in income groups
		Subsidies offered for electricity services
		Share of economically active children
Environmental development	Global impact	Share of renewable energy in production
		Emissions of carbon dioxide from the production
	Local impact	Share of HH, electricity replaced other energy for lighting
		Share of HH, electricity replaced other energy for cooking
		Any serious local environment impact identified
Organizational/ institutional development	Capacity strengthening	Share of staff and management with appropriate education
		Degree of local ownership
		Number of shareholders
		Share of women in staff and management
		Staff turnover in an organization
		Number of years in business
		Share of staff and management with appropriate education
		Share of non-technical losses/Default rate
		Level of satisfaction with energy services
	Participation level	Auditing of financial reports every year

Brent and Rogers [31] published research on renewable energy sustainability evaluation for rural electricity in South Africa. The types of off-grid renewable energy power plants include solar photovoltaic and wind turbine. Twenty indicators are used, which comprise five dimensions of sustainability: economic, institutional, ecology, sociology, and technology.

Further research on sustainability evaluation of several energy access programs for rural communities was carried out by Bhattacharyya [32, 34]. Various kinds of rural energy access programs such as grid expansion, solar home system, petroleum cooking fuels, biogas, and improved cook stove. Sustainability evaluation of rural energy access programs using sustainability indicators developed by Ilskog by eliminating several indicators be adapted to the context of the study. The results of the study obtained 26 indicators which involve five dimensions of sustainability: technical, economic, social/ethical, environmental, and institutional.

Mainali et al. [34] published research on sustainability evaluation technique for rural energy programs in several developing countries such as China, India, South Africa, Sri Lanka, Bangladesh, and Ghana. Sustainability evaluation using a set of indicators, namely the Energy Sustainability Index (ESI). ESI consists of 13 indicators, which include five dimensions of sustainability: engineering, economic, socio-cultural, and environmental. Kabalan and Anabaraonye [36] conducted a holistic approach to evaluate the sustainability of two types rural electrification program (Solar Photovoltaic and Micro-Hydro Power) for the rural community in the Philippines. Evaluation is carried out using 16 indicators in six dimensions of sustainability: social, technical, environmental, economic, and political.

Lillo et al. [36] published research on sustainability evaluation of the energy and sanitation provision program for rural communities in Peru. There are 34 indicators which cover five dimensions of sustainability: technical, economic, social, environmental, and institutional. A set of indicators used to evaluate the level of sustainability of the energy and sanitation provision program for rural communities in Peru can be seen in table 2.

Table 2. Sustainability indicators for off-grid rural renewable energy projects evaluation [36]

Dimension	**Indicators**
Technical	Daily operation services
	Service is reliable; disruptions are minimal
	Service meets demand capacity requirements
	Support infrastructure (expertise, supply parts) is readily available
	The system is well maintained
	Service is safe to use and operate
	People are satisfied with the O&M service
	People are satisfied with the technology
Economic	The system breaks even (O&M costs are met)
	Tariff/other payments are convenient
	Tariff lag
	Energy is used for income-generating activities
	Reduction of energy costs (e.g., kerosene, candles, batteries)
Social/ethical	Share of population with access to energy services
	Energy is used in schools
	Micro-credit for energy service connection and tariff payment
	All households who want it can have access to energy service
	Women are trained for O&M
	Share of women in staff and management
	Women have more time for themselves
	Local innovations have been developed
	Local human labor has been used during installation
	Health improvement
	Increased number of hours for children's education at home
Environmental	Share of renewable energy in production
	Share of households where "dirty" energy has been replaced
	No adverse local environmental impacts have occurred
	Materials can be re-used or recycled locally after reaching a lifespan
Organizational/institutional	Appropriate training of staff
	The management model promotes organization skills
	Transparent financial accounts are kept
	There is an effective channel which complaints about the service
	Participation of users in General Assembly meetings

Purwanto and Afifah (2016) conducted a comparative study to assess the impact of techno socioeconomic factors on the sustainability of two micro-hydro power projects in Java Island, Indonesia. The sustainability assessment of the projects was based on sustainable development indicators for rural electrification, considering technical, economic, social, environmental, and institutional sustainability. There are 29 indicators used to evaluate the sustainability status of micro-hydro power [37] — this indicator base on sustainability indicators that have been developed by several previous researchers.

In 2018, Bhandari et al. published research about micro-hydro power sustainability in Nepal. The sustainability evaluation of the power plant is carried out to determine the sustainability index and the factor that need to be improved. The assessment of the power plant sustainability is carried out by using 74 indicators which are divided into 24 themes and four dimensions of sustainable development which include: technical, economic, environmental, and social [38].

5. Results and Discussion

Micro-hydro power sustainability discusses not only the viability of power plant operations but also sustainable development. Sustainable development consisting of 3 dimensions sustainability include economic, social, and environmental. In the micro-hydro power sustainability, there are two additional dimensions (technical and institutional) according to the previous research. So that there are five dimensions of micro-hydro power sustainability: technical, economic, social, institutional and environmental. Each aspect consists of several indicators: technical dimension 10 indicator, economic dimension 12 indicators, social dimension 10 indicators, institutional 10 indicators, and environmental dimension 12 indicators.

5.1. Technical Dimension

In the technical dimension, there are ten indicators used to evaluate the sustainability of the micro-hydro power, as shown in table 4. The ten indicators consist of: daily operation, duration of outages, availability of service, availability of spare parts and local experts, power plant efficiency, reserves margin, customer power quantity, customer power quality, quality of design and maintenance, and safety.

One of the main indicators in the sustainable development energy sector is availability and reliability. In the technical dimension, electrical energy availability is the primary indicator to be evaluated. The primary purpose of micro-hydro power development is to provide electricity for the rural community. Availability of electricity in the community consists of two main parameters, i.e., duration and quantity of energy. Increasing duration and quantity of energy availability will increase energy production, in line with the main themes of sustainable development, i.e., productivity.

The duration of the electrical energy availability is influenced by the daily operating hours and the duration of the outages that occur. The duration of outages is influenced by the frequency of disturbances, the level of disruption, the availability of spare parts and local experts, and the availability of operation and maintenance funds in the economic dimension.

Table 3. Micro hydro power sustainability indicator and evaluation criteria in technical dimension

Code	Indicator	Good	Bad	Evaluation Criteria
TEC1	Daily Operation	3	0	(0) <12; (1) 12-16; (2) 16-20; (3) 20-24 (Hours/Day)
TEC2	Duration of Outages	0	6	(0) <5; (1) <5-15; (2) 15-30; (3) 30-60; (4) 60-90; (5) 90-180; (6) >180 (Hour/Month)
TEC3	Availability of Service	5	0	(0) <245; (1) 245-305; (2) 305-335; (3) 335-350; (4) 350-360; (5) >360 (Day/Year)
TEC4	Availability of Spare Parts And Local Experts	0	8	(0) <3; (1) 3-6; (2) 6-12; (3) 12-24; (4) 24-72; (5) 72-168; (6) 168-336; (7) 336-720; (8) >720 (Hour)
TEC5	Power Plant Efficiency	5	0	(0) <30%; (1) 30-40%; (2) 40-50%; (3) 50-60%; (4) 60-70%; (5) >70% (%)
TEC6	Reserves Margin	8	0	(0) <0%; (1) 0-10%; (2) 10-20%; (3) 20-30%; (4) 30-40%; (5) 40-50%; (6) 50-60%; (7) 60-70% (8) >70% (of Microhydro Power Capacity)
TEC7	Customer Power Quantity	4	0	(0) <1; (1) 1-2; (2) 2-4; (3) 4-6; (4) >= 6 (Ampere)
TEC8	Customer Power Quality	6	0	(0) <120; (1) 120-140; (2) 140-160; (3) 160-180; (4) 180-200; (5) 200-220; (6) 220-240 (Volt)
TEC9	Quality of Design and Maintenance	9	0	(0) 0-10%; (1) 10-20%; (2) 20-30%; (3) 30-40%; (4) 40-50%; (5) 50-60%; (6) 60-70%; (7) 70-80; (8) 80-90%; (9) 90-100% (of Maximum Score)
TEC10	Safety	9	0	(0) 0-10%; (1) 10-20%; (2) 20-30%; (3) 30-40%; (4) 40-50%; (5) 50-60%; (6) 60-70%; (7) 70-80; (8) 80-90%; (9) 90-100% (of Maximum Score)

Another technical aspect that determines the sustainability of the MHP is the power plant efficiency and reserves margin. Generator efficiency is a comparison between the produced electrical energy (output) to the used hydrological energy (input). The power reserve availability is needed to anticipate the increase of consumer load in the future.

Each indicator on the technical dimension has a different unit. A homogeneous one is needed to facilitate the assessment. In this study, the measurement scale for each indicator is changed in an ordinal scale (0,1,2,3,4, and so on) without any particular unit. The measurement scale of each indicator has two reference values: good and bad — the conversion process into an ordinal scale can be seen in the evaluation criteria. The evaluation criteria for each indicator are based on research, regulation, standards, and expert.

For example, the first indicator on the technical dimension, daily operation hours have measurement scales from 0 to 3 (0,1,2,3). Value 0 is the worst reference value (bad), while value 3 is the best reference value (good). While values 1 and 2 are condition between two reference values. If the micro-hydro power operates under 12 hours per day has a value of 0, or in the bad category. Conversely, if the power plant produces electrical energy for 20 to 24 hours per day has a value of 3, or in the good category. If the generator operates between 12 to 20 hours per day, then it has a value of 1 or 2 depending on the hours of daily operation.

Each indicator has a different measurement scale and reference value (good and bad). The indicator measurement scale in the technical dimension varies from (0-3) to (0-9) rating scales. High scores on each indicator do not always indicate a good condition Determination of rating scales and reference values based on the literature review and expert judgment. The complete measurement scale and reference values for each indicator in the technical dimension can be seen in table 3.

Eight of the ten indicators in the technical dimension have quantitative values, while two indicators have qualitative values. The two indicators with qualitative values are quality of design and maintenance, and safety. It is necessary to convert "a qualitative indicator" to make it easier to measure the value of an indicator. The conversion process is done by formulating a set of evaluation criteria to evaluate qualitative indicator to obtain quantitative values. Quantitative values are formulated in percent unit. A set of evaluation criteria is based on the literature review and expert judgment.

5.2. Economic Dimension

The economic dimension is a crucial aspect of micro-hydro power sustainability. In the economic dimension, there are 12 indicators used, as seen in table 4. The twelve indicators consist of: ability to pay, willingness to pay, electricity tariffs, total revenue, investment costs, periodic operation and maintenance expenses, incidental operation and maintenance costs, percentage of staff salary to total revenue, percentage of savings to total revenue, staff salary and workload comparison, percentage of productive business electricity income to total revenue, and percentage of costumer delinquent payment to total costumer.

Table 4. Micro hydro power sustainability indicator and evaluation criteria in economic dimension

Code	Indicator	Good	Bad	Evaluation Criteria
EC1	Ability to Pay	5	0	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) 80-100%; (5) >100% (% of Minimum Wage)
EC2	Willingness to Pay	5	0	(0) <10; (1) 10-20; (2) 20-30; (3) 30-40; (4) 40-50; (5) >50 (Thousand (IDR)/Ampere)
EC3	Electric Tariff	5	0	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) 80-100%; (5) >100% (of National Tariff)
EC4	Total Revenue	5	0	(0) <1; (1) 1-2; (2) 2-3; (3) 3-5; (4) 5-10; (5) >10; (Million (IDR)/kW)
EC5	Investment Cost	5	0	(0) <10; (1) 10-20; (2) 20-30; (3) 30-40; (4) 40-50; (5) >50 (Million (IDR)/kW)
EC6	Periodic Operation Maintenance Cost	0	5	(0) <0,5%; (1) 0,5-1%; (2) 1-2%; (3) 2-3%; (4) 3-4%; (5)>4% (of Investment Cost) (annually)
EC7	Incidental Operation Maintenance Cost	0	5	(0) <2%; (1) 2-4%; (2) 4-6%; (3) 6-8%; (4) 8-10%; (5)>10% (% of Investment Cost) (annually)
EC8	Percentage of Staff Salary to Total Revenue	0	4	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) >80% (% of Total Revenue)
EC9	Savings	5	0	(0) <20; (1) 20-40; (2) 40-60; (3) 60-80; (4) 80-100; (5) >100 (Thousand (IDR)/kW)
EC10	Staff Salary and Workload	5	0	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) 80-100%; (5) >100% (% Minimum Wage To Standard Workload)
EC11	Percentage of Productive Income to Total Revenue	5	0	(0) <5%; (1) 5-10%; (2) 10-20%; (3) 20-30%; (4) 30-50%; (5) >50% (% of Total Reveneu)
EC12	Percentage of Costumer Delinquent Payment	0	4	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) >80% (% of Total Revenue)

The primary problem micro-hydro power sustainability in the economic dimension is the availability of funds for power plant operation and maintenance. Several factors influence the availability of operations and maintenance funds such as electricity tariffs, the number of consumers (social dimension), micro-hydro power income, employee salaries, periodic maintenance operating costs, incidental maintenance operating costs. Interaction between these factors has a significant effect on sustainability.

Electricity tariffs applied to consumers are the most important thing that determines the availability of funds collected for power plant operation and maintenance. Electricity tariffs that are applied should consider the operations and maintenance cost and the ability to pay of the rural community. In addition to the ability to pay, the willingness to pay also influence the amount of electricity tariff. It would be wrong if many costumers were able to pay more for the electricity, but did not want to pay more.

Investment costs are one of the determining factors for a micro-hydro power will operate properly. Many plants are built with minimal investment costs because of a limited budget. It results in a higher frequency of power plant interruptions. Further impacts certainly lead to high operation and maintenance expenses.

One of the goals of sustainable development is the creation of good economic growth. The micro-hydro power is expected to grow productive economic activities of the rural community. The productive business activities that are expected to provide additional revenue for the power plant and also for the community. Additional revenue will increase the availability of operation and maintenance fund so that the sustainability of the power plant is well maintained.

One obstacle to the availability of micro-hydro power operation and maintenance fund is the arrears in payment of electricity fees. Overdue payments result in cash flow constraints that are needed for operation and maintenance activities. The further impact will make a deficit cash flow so that funds for operation and maintenance are not available and even minus. The final impact is the power plant stop operation because there were no funds available.

Each indicator in the economic dimension has specific quantities and units (quantitative data). In general, there are IDR (Indonesian Rupiah) and percentages units. The conversion process of quantities and units for each indicator on the economic dimension into an ordinal scale can be seen in table 4 on the evaluation criteria section. Each indicator has a different range of ordinal measurement scales. The scale of the measurement scale varies from 4 (0-4) to 5 (0-5). The good and bad reference values for each indicator are the highest or the lowest values on the ordinal scale. The highest value is not always a good reference value; sometimes, the lowest value is a good reference value.

5.3. Social Dimension

The sustainability of the micro-hydro power is inseparable from the socio-cultural conditions of the community around the power plant. The sustainability indicators in the social dimension can be seen in table 5. In the social dimension there are 10 indicators of micro-hydro power sustainability, i.e.: number of consumers, percentage of electrified household, transfer of costumer, percentage of productive business consumers to total number of costumer, percentage of electrified public facilities to total number of public facilities, percentage of tariffs to average community income, subsidies, level of community participation, level of service satisfaction, and external institutional support.

One of the micro-hydro power social problems is related to the consumer's load, which continues to increase uncontrollably. Uncontrolled load growth causes the power plant to be overload; the further impact is more frequent power outages. Uncontrolled load growth can be caused by consumer growth and increasing consumer load.

Table 5. Micro hydro power sustainability indicator and evaluation criteria in social dimension

Code	Indicator	Good	Bad	Evaluation Criteria
SOC1	Number of Costumers	7	0	(0) <25; (1) 25-50; (2) 50-75; (3) 75-100; (4) 100-150; (5) 150-200; (6) 200-250; (7) >250 (Household)
SOC2	Percentage of Electrified Household	5	0	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) 80-100%; (5) 100% (of Total Household)
SOC3	Transfer of Costumers	0	6	(0) 0%; (1) 0-5%; (2) 5-10%; (3) 10-20%; (4) 20-30%; (5) 30-50%; (6) >50% (% of MHP Costumer)
SOC4	Percentage of Productive Business Costumers	5	0	(0) =0; (1) <10%; (2) 10-20%; (3) 20-40%; (4) 40-60%; (5) >60% (% of MHP Costumer)
SOC5	Percentage of Electrified Public and Social Facilities	5	0	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) 80-100%; (5) 100% (% of Total Public Facilities)
SOC6	Percentage of Tariff to Costumers Income	0	4	(0) <2,5%; (1) 2,5-5%; (2) 5-7,5%; (3) 7,5-10%; (4) >10% (% of Average Costumer Income)
SOC7	Subsidies	1	0	(0) No; (1) Yes
SOC8	Level of Community Participation and Ownership	5	0	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) 80-100%; (5) 100% (% of MHP Costumer)
SOC9	Service Satisfaction	4	0	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) >80% (% of Maximum Score)
SOC10	External Institutional Support	5	0	(0) <2; (1) < 2-5; (2) 5-10; (3) 10-20; (4) 20-40; (5) >40 (Million (IDR)/Year)

The next social problem is related to the existence of consumers. When the state electricity company network enters the village, the community sometimes change electricity subscription so that reduced micro-hydro power customers. Further impact, when many consumers move to another electricity provider, there are no funds available for power plant operations and maintenance. Change electricity subscription can be caused due to customer satisfaction level to electricity services.

The existence of development activity is expected to have a positive impact on the social community. The development of the micro-hydro power is expected to increase electricity access; in other words, an increase in electrified population; electrified social facilities; and electrified public facilities. Community access to energy is one of the main themes of sustainable development. Another impact of micro-hydro power existence is expected to improve community income through productive activities by utilizing existing electricity.

Disparities are one of the main themes of sustainable development in the energy sector, besides the accessibility and affordability. Reasonable electricity price is one of the crucial things to keep electricity prices affordable for all the community members. The subsidy is needed for the poor to support affordable electricity prices. Affordable electricity prices and the existence of subsidies for the community make a positive impact on social development in line with sustainable development goals.

Micro-hydro power will operate properly if it receives support from external parties. The most important is from community support, such as an idea, workforce, and funding. Another support from other external parties such as the government (village, sub-district, district, regency, province, and central) is needed for the power plant sustainability. Support from the government can be a policy tool and financial assistance for power plant sustainability. Manufacturers and workshops also become one of the external institutions that play an essential role.

Each indicator in the social dimension has different units, such as percentage, rupiah, and household. The conversion process of each indicator value into an ordinal scale can be seen in table 5. The range of ordinal scales for each indicator varies from 1 to 7, depending on the characteristics of each indicator. The highest and lowest value reference is a good and bad reference value for each indicator. The lowest value can be a bad reference value or good reference value for each indicator. The details of good and bad reference value for each indicator can be seen in table 5.

Each indicator on the social dimension has a quantitative measurement value, except for service satisfaction indicators. This indicator has a qualitative value, so it needs to be converted into a quantitative value — the conversion process by making a set of assessment criteria so that quantitative quantities are obtained. The quantitative quantities in percentage units then converted into an ordinal scale with good and bad reference values.

5.4. Institutional Dimension

After complete the construction of micro-hydro power, the power plant usually handed over to the community. The next stage, the community will form institution management to manage, operate, and maintain the plant. Micro-hydro power institution management is an essential factor in the sustainability of the power plant. The sustainability indicators of the micro-hydro power on institutional dimensions consist of: formal education of the staff, training frequency, year of power plant operation, management capability, operational capability, maintenance capability, regulation and enforcement of the rules, guidelines and equipment, financial and administrative report, and gender equality. Sustainability indicators for micro-hydro power on institutional dimensions can be seen in table 6.

Table 6. Micro hydro power sustainability indicator and evaluation criteria in institutional dimension

Code	Indicator	Good	Bad	Evaluation Criteria
IN1	Staff Formal Education	4	0	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) >80% (of Maximum Score)
IN2	Frequency of Staff Training	4	0	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) >80% (of Maximum Score)
IN3	Year of Operation	6	0	(0) <1; (1) 1-3; (2) 3-5; (3) 5-10; (4) 10-15; (5) 15-20; (6) >20 (Year)
IN4	Management Capability	9	0	(0) 0-10%; (1) 10-20%; (2) 20-30%; (3) 30-40%; (4) 40-50%; (5) 50-60%; (6) 60-70%; (7) 70-80; (8) 80-90%; (9) 90-100% (of Maximum Score)
IN5	Operation Capability	9	0	(0) 0-10%; (1) 10-20%; (2) 20-30%; (3) 30-40%; (4) 40-50%; (5) 50-60%; (6) 60-70%; (7) 70-80; (8) 80-90%; (9) 90-100% (of Maximum Score)
IN6	Maintenance Capability	9	0	(0) 0-10%; (1) 10-20%; (2) 20-30%; (3) 30-40%; (4) 40-50%; (5) 50-60%; (6) 60-70%; (7) 70-80; (8) 80-90%; (9) 90-100% (of Maximum Score)
IN7	Regulation and Enforcement	9	0	(0) 0-10%; (1) 10-20%; (2) 20-30%; (3) 30-40%; (4) 40-50%; (5) 50-60%; (6) 60-70%; (7) 70-80; (8) 80-90%; (9) 90-100% (of Maximum Score)
IN8	Guidelines and Equipment	9	0	(0) 0-10%; (1) 10-20%; (2) 20-30%; (3) 30-40%; (4) 40-50%; (5) 50-60%; (6) 60-70%; (7) 70-80; (8) 80-90%; (9) 90-100% (of Maximum Score)
IN9	Administrations and Financial Report	9	0	(0) 0-10%; (1) 10-20%; (2) 20-30%; (3) 30-40%; (4) 40-50%; (5) 50-60%; (6) 60-70%; (7) 70-80; (8) 80-90%; (9) 90-100% (of Maximum Score)
IN10	Gender Equality	2	0	(0) 0 ; (1) 1; (2) > 1 Number of Women Staff

Proper management institutional is a guarantee of the operation and maintenance of the micro-hydro power to run well. Institutional capacity is supported by the quality of existing human resources. There are several indicators of the quality of human resources that can be used, such as formal education level, frequency of training, experience, management ability, operational and maintenance capability.

The quality of human resources is the main factor that determines institutional capacity. Other factors determine institutional capacity, such as the availability of guidelines and equipment for operations and maintenance of the power plant. The guidelines can be a standard operation procedure (SOP) for plant operation and maintenance. In addition to the guidelines, work equipment, and measuring equipment for operation and maintenance are one of the crucial tools that determine the micro-hydro power operations.

Another indicator of institutional capacity is the existence of regulation and enforcement of rules. Regulation to organize between management as electric producers and the community as electric consumers. Proper regulation and enforcement ensure the continuity of power plant operations..

Transparency is an essential part of increasing consumer trust in micro-hydro power management. Financial management of micro-hydro power that is not transparent often results in conflicts between institution management and consumers. The transparency in micro-hydro power management can be financial administration reporting that is delivered regularly.

One of the sustainable development goals is gender equality. The involvement of female staff in managing micro-hydro power is needed to promote gender equality. Women staff generally have better abilities in administrative and financial activities.

Most indicators in the institutional dimensions have qualitative value, except for years of operation and gender equality indicators. Each indicator that has a qualitative magnitude is converted into a quantitative quantity using a set of assessment criteria so that the qualitative quantity is obtained — qualitative quantity in units of the percentage to the maximum score. Then the percent value of each indicator is changed to an ordinal scale with two good and bad reference values, as shown in table 6.

5.5. Environmental Dimension

Micro-hydro power is a power plant that utilizes water/hydro energy. Environmental conditions play a significant role in the sustainability of a micro-hydro power. In the ecological dimension of micro-hydro power sustainability there are 12 indicators, i.e.: natural disaster impact: flood and landslide, water discharge availability, land cover (forest), river regime coefficient, sedimentation and trash, pollutants substances: crust, corrosion, abrasion, watershed conservation, water use conflict, requirements discharge/minimum river discharge, percentage of non-renewable energy power plant installed. The sustainability indicators of micro-hydro power in environmental dimensions, as shown in table 7.

Table 7. Micro hydro power sustainability indicator and evaluation criteria in environmental dimension

Code	Indicator	Good	Bad	Evaluation Criteria
EN1	Natural Disaster Impact: Flood and Landslide	6	0	(0) < 1%; (1) <1-3%; (2) 3-5%; (3) 5-10%; (4) 10-15%; (5) 15-25%; (6) >25% (of Number of Hour per Year)
EN2	Water Discharge Availability	6	0	(0)<50%; (1)50-60%; (2) 60-70%; (3) 70-80%; (4) 80-90%; (5) 90-100%; (6) 100% (of Number of Hour per Year)
EN3	Land Cover (Forest)	4	0	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) 80-100% (of Watershed Area)
EN4	River Regime Coefficient	0	4	(0) <20; (1) 20-50; (2) 50-80; (3) 80-110; (4) >110 (Times)
EN5	Sedimentation and Trash	4	0	(0) <10; (1) 10-20; (2) 20-30; (3) 30-50; (4) >50 (Day Cleaning Period)
EN6	Pollutants Substances: Crust, Corrosion, Abrasion	4	0	(0) 0-20%; (1) 20-40% (2) 40-60% (3) 60-80% (4) 80-100% (of Maximum Score)
EN7	Watershed Conservation	4	0	: (0) There are rules, but counter conservation; (1) There are no regulations; (2) Exist, not practice; (3) There are limited practices; (4) There are, widely practiced
EN8	Water Use Conflict	0	6	(0) 0; (1) <4; (2) 4-8; (3) 8-12; (4) 12-16; (5) 20-24; (6) 24; (Outage Hours per Day)
EN9	Requirements Discharge/ Minimum River Discharge	0	5	(0) < 20; (1) 20-40; (2) 40-60; (3) 60-80; (4) 80-100; (5) >100 (%)
EN10	Percentage of Non-Renewable Energy Power	0	5	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) 80-100%; (5) >100% (%) (of MHP Capacity)
EN11	Environment Impact	0	4	(0) < 20%; (2) 20-40%; (3) 40-60%; (4) 60-80%; (5) >80% (%) (of Maximum Score)
EN12	CO_2 Emission Abatement	4	0	(0) <20%; (1) 20-40%; (2) 40-60%; (3) 60-80%; (4) 80-100% (%) (of Maximum CO_2 Emission Abatement)

The availability of water discharge is the main factor that will guarantee the sustainability of power plant operations. The availability of water discharge must be sufficient for micro-hydro power operations throughout the year. Water discharge availability is influenced by several factors, such as land cover, rainfall, and so on. The condition of the watershed strongly affects water discharge availability. The maximum discharge to the minimum discharge ratio of the river indicates the good or bad of a basin. Conservation of the catchment area is needed to maintain the condition of the watershed.

The sustainability of micro-hydro power operations is not only influenced by the availability of water discharge. The other environmental factors such as natural disasters; trash and sediment content; and pollutant content influences sustainability. Natural disasters sometimes disrupt plant operations, such as landslides and floods. The high content of debris and sediment can disturb the water discharge that is needed by the power plant. The other environmental factors that sometimes disrupt micro-hydro power operations is the pollutants in water, such as lime, acid, and sand. These three substances can easily damage the mechanical components, such as penstock and turbines.

The environmental dimension is an important dimension that is sometimes be ignored to pursue economic growth. Sustainable development aims to reduce the environmental impact caused by development activities. Every activity of electricity generation has an impact on the environment. The environmentally friendly power plants are the mandate of sustainable development. The environmental impact is one of the indicators of power plant sustainability.

Greenhouse gas emissions are a big issue today because it is suspected to be the leading cause of climate change. Greenhouse gases can be CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6. In general, power plants in Indonesia are fossil fuels power plant, which produces CO2 gas emissions. Micro-hydro power is a power plant that does not produce exhaust gas emissions. This power plant contributes to a decrease in CO_2 emission.

Each indicator in the environmental dimension has different unit quantities, such as hours, days, m^2, times, tons, kW, percent, and so on. Because the units are different, it needs to be equated in an ordinal scale, with two reference values: good and bad — the scale range of each indicator between 4 (0-4) to 6 (0-6). In detail, the conversion process of quantities and units for each indicator in the environmental dimension into an ordinal scale can be seen in table 7.

Most of the indicators on the environmental dimension are quantitative indicators that have specific quantities and units, except for three indicators, i.e., pollutants substances, watershed conservation, and environmental impact. The conversion process on qualitative indicators to quantitative indicators is done using a set of evaluation criteria. Evaluation criteria are based on the literature review and expert judgment. The detail conversion process can be seen in table 7.

6. Conclusion

The research on indicators and evaluation criteria is the framework for sustainability micro-hydro power assessment. The sustainability indicators of the micro-hydro power are prepared by considering the indicators of the sustainable development for the energy sector. The indicator is formulated by the United Nations (UNDESA), IAEA, and IEA. The sustainability of micro-hydro power is not only related to sustainable development but also the sustainability of power plant operations. Many cases of micro-hydro power, have stopped operating because of technical, economic, social, institutional, and environmental problems.

This study develops a more comprehensive set of indicators and evaluation criteria than previous studies, which discussed the sustainability of MHP in two perspectives, that is sustainable development and sustainability of power plant operations. Fifty-four indicators were successfully formulated based on the literature review and expert judgment in this study. Fifty-four indicators are divided into five dimensions of sustainability, include: technical, economic, social, institutional, and environment. Fifty-four indicators in 5 aspects of sustainability interact with each other that determine the sustainability of the micro-hydro power. The technical aspect evaluates the availability, quality, and quantity of electrical energy service. The economic dimension evaluates the financial, economic conditions that influence the sustainability of the power plant operation and the impact of micro-hydro power on the economic conditions of the community. The social dimension evaluates the socio-cultural conditions of the community that influence the sustainability of the power plant operations and the impact given by the micro-hydro power on the socio-cultural conditions of the community. The institutional dimension evaluates the micro-hydro power institution capacity to manage, operate, and maintain the power plant. The environmental dimension evaluates environmental factors that influence the sustainability of power plant operations and the environmental impact of micro-hydro power.

Another difference, the formula for evaluating criteria in the same measurement scale, so that it can be integrated for each indicator to establish the sustainability index. The ordinal scale with two reference values (good and bad). The same measurement scale makes it easy to aggregate the value of each indicator. Each indicator has a different unit and quantities, such as hours, days, rupiahs, percent, and so on. Conversion needs to be done on the same unit or scale to facilitate multidimensional analysis. In a multidimensional analysis, there will be the aggregation of the values of each indicator, so that the final value of the micro-hydro power sustainability index is obtained. In this study used ordinal scales (0, 1, 2, 3, and so on), with two reference values: good and bad, to describe the condition of each indicator. The conversion process into an ordinal scale uses a set of evaluation criteria that can be seen in table 3 until table 7.

This paper is the framework for empirical research to determine the sustainability status of off-grid micro-hydro power for rural electrification. Multidimensional scaling

(MDS) analysis can be used to determine the sustainability status of the power plant. In multidimensional scaling analysis, the same unit or scale is needed for each indicator (in this study is an ordinal scale). The follow-up of this paper is field research to evaluate the off-grid micro-hydro power sustainability by using the indicators and evaluation criteria that have been developed.

The indicators and evaluation criteria in this study can be used to evaluate the sustainability of various types of renewable energy generation with some revisions. Sustainable development is the paradigm for any development today. Sustainable development puts economic, social, and environmental aspects growth in balance. It becomes crucial to evaluate the sustainability of development, including the development of the renewable energy sector.

Acknowledgements

This paper was written in the scope of the research program at Natural Resources and Environmental Management Department, Bogor Agricultural University. This research fully funded by the Ministry of Energy and Minerals Resources. The authors would like to thank the anonymous reviewers for their valuable comments, which have helped to enhance this paper and acknowledge all the people who participated in this research.

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