ECONOMY DIMENSION OF SUSTAINABLE DEVELOPMENT INDEX OF SOLAR POWERED ELECTRICITY PROJECT IN PILOLAHEYA AND PELITA HIJAU VILLAGES OF BONEBOLANGO REGENCY

SUMMARY

by. Raflin Hinelo
raflin@ung.ac.id

Several villages in Bone Bolango Regency are isolated because of geographical conditions and conservation reasons. There are no access road from paved road which can be used by PLN to installed grid. Several programs have been launched, including supply of electricity using renewable energy such as Micro hydro electric and solar cell, to help the villagers from blackout. Unfortunately most of installed power plants did not operate continuously since the human resources in the village is too weak to handle and maintain the sophisticated electrical instrument. Story of in Bone Bolango is not unique there are many similar stories in the entire Indonesia.

To address why the ideal program of government is failing, we proposed this research which has ultimate aim to solve the existing problem in the society through research using transdisciplinary approach. Our starting location is Bone Bolango regency where we have been in contact for years. The first year of research is focused on framing the problems in the society through eyes of researchers (academics), government and people. The second year of research will be focused on transferring knowledge from each side to the others with aim to create goal oriented solution. Ones we have it in the third year, we will delivered that together (co delivered) and see what happen.

The output research in every year is article published in peer reviewed and Scopus indexed journals and reputable international conference in Indonesia and Southeast Asia.

Keywords: Isolated, sustainable development, transdisciplinary approach.

I. INTRODUCTION

Sustainable development is a critical issue for everyone; developing countries need to use their natural resources to develop. Economic activities such as farming, logging, and fishing are preferable since it can be done using local knowledge. Increasing number of population demands more activities means opening more agricultural area (converting forest area into/cutting tree etc). Transforming forest (restricted are such as National forest) is illegal but in facts some people do it without fear, maybe driven by weak government institution and poverty (Wertz-kanounnikof and Kongphan-apirak 2008). The illegal logging also brings other problems: flood and shortage of fresh water resources. To solve this local government with help of central government run program to electrify the local population with renewable energy source. The plan is almost perfect, but it is failed (most of installed facility did not work anymore) (Laliyo 2016b; Laliyo 2016a).

What is lack in government plan on electrification of isolated villages?, by installing micro hydro electric power plant government expecting that agro industry can grow and increasing of income of population as illustrated in Figure 1. But points of views of population are may be totally different. There are several programs of government has been done for isolated people, but lack of sustainability were listed in Table 1.

Figure 1 Ideal plan of government for isolated village.

Table 1. Government, people and University (UNG) tasks and views on several problems in isolated Area.

Problem	Government	People	University
Electric energy	1. Installation of Micro hydro electric power plant. 2. Teach technician how to use and do small repairing.	1. Pay Rp. 10,000,- /house as Monthly maintenance fee regardless consumption, fail to adopt fair maintenance fee (eg. Based on consumption). 2. Can continue operating it and sometime do even more, replace broken water supply canal by themselves.	1. Do research mainly on mapping of potency of PLTMH (Amali, 2012) 2. Research on problem on using PLTMH (Laliyo 2016a)
Agriculture	1. Supporting farmer with corn seed and fertilizer. 2. Send the instructor to teach the farmer.	1. Do extensification (deforestration of national forest) 2. adopt new technologies (mainly come from Merchant/middleman/wholesaler)	1. It is arose from FGD on Mongiilo problem (Laliyo 2016a; Laliyo 2016b) 2.
Agro industry / palm sugar	1. Supporting with metal cylinder to replace bamboo. 2. Supporting to produce Gula gula semut Bulango Ulu Gabulu.	1. Use them to replace bamboo 2. Producing Gabulu	3. Training of Producing gula semut (Isa, 2012)

Table 1. Government, people and University (UNG) tasks and views on several problems in isolated Area. (cont.)

Problem	Government	People	University
Erosion	1. Building anti erosion wall on the slope	1. Passive, waiting government action/program (since it is too expensive to build, has no options yet)	1. Research on this problem mainly mapping the potency and risk of erosion only (Lihawa,) 2. No research on how to solve the problem yet, but we have started a pilot project (example) to use palm fiber based net for it (Jahja, 2015, 2016)
Transportation/isolation	1. Building road	1. Passive, waiting government program (since it is too expensive to build, has no options yet)	1. No research on this problem yet. (The steep and slippery road can be solved by solving erosion prob.)

Based on problems and previous research have been done (listed in Table 1) we proposed the research with title **TRANSDISCIPLINARY APPROACH ON SUSTAINABLE DEVELOPMENT IN THE REMOTE, ISOLATED AND LACK BEHIND AREA: CASE STUDY IN BONE BOLANGO REGENCY, GORONTALO PROVINCE, INDONESIA.** The research proposed minimum three years with expected output listed in Table 2. This research is urgently needed since main aim is together with stakeholder we would like solve the problems in the society. Unlike ordinary research which aiming research for science only, here research outcomes (listed in Table 2) is a complimentary of main aim only. Through research publications we share our experiences with other researcher.

Table 2. Annual research outcomes planned

No	Type of Outcome		Indication		
			2017	2018	2019
1	Scientific Publication	International	submitted	published	Published
		National-Accredited	submitted	published	published
2	Invited Speaker	International	Registered	Has been conducted	Has been conducted
		National	-	Has been conducted	Has been conducted
3	Keynote	International	-	Has been conducted	Has been conducted
		National	Registered	Has been conducted	Has been conducted
4	Visiting Lecturer	International	Has been conducted	Has been conducted	Has been conducted
5	Intellectual Property Right		-	-	draft
6	Intermediate Technology		Laboratory tested	Small-scale tested	Public tested
7	Model		-	-	-
8	Book (ISBN)		Draft	Editing process	submitted
9	TKT		1	2	3

II. LITERATURE REVIEW

2.1 RENEWABLE ENERGY USE IN ISOLATED AREA

The use of non fossil energy is a global movement to stop CO_2 emission. Sources of non fossil energy are abundant: water, wind, and biomass and solar. In the isolated area like Mongiilo district in Bone Bolango Regency of Gorontalo Province, the water and biomass are abundant. The Regency government installed the Micro hydro electric power plant to electrify the several houses, and leave it to be managed by local people with minimum training. Laliyo (Laliyo 2016a; Laliyo 2016b) developed training (learning) model for local inhabitant to independently and sustainably use the Micro hydro electric power plant (PLTMH), increasing their income (eg. small scale industry to add value of agricultural products) and continues keeping nature (environment).

Conditions of two PLTMH installations in Bone bolango regency in 2013 are the following: (1) PLTMH of Tulabolo village (Suwawa district) was installed in 2007), of 15 operated dynamos now is only one is still running (not full condition). While (2) PLTMH of Mongiilo village (Bulango Ulu district) was installed 2009, but failed all in just months because of over capacity and the local people cannot buy the spare parts. Reinstalled again 2014 and now is still in operation (not full production capacity of 40 KWh) (Laliyo 2016a).

2.2 SUSTAINABLE DEVELPOMENT

Sustainable development is a concept that we often heard from government and academic institution but it has many different meaning (Hopwood, Mellor, and O'Brien 2005); does local inhabitant understand what all is about?. In the beginning it is about developing economy while keeping natural capital (Costanza and Daly 1992), but now it keeping social as well and all three are interconnected as depicted in Figure 2 (Giddings, Hopwood, and O'brien 2002). In developed county, the social dimension is getting much attention (Dempsey et al. 2011) since individualistic life is already dominant.

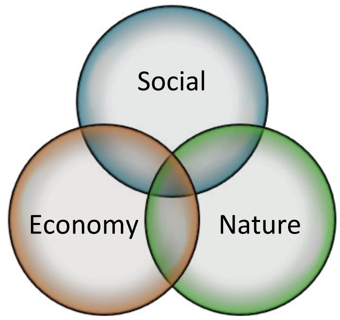


Figure 2. Components of sustainable development: Social, Economy and Environment.

2.3 TRANSDISICIPLINARY APPROACH

What is transdisciplinary research and why we need it?, There are many definition and reasons of doing it(Brandt et al. 2013; Sauvé, Bernard, and Sloan 2016; Mauser et al. 2013). Three keywords mentioned as alternative concepts of transdisciplinary research are Environmental science, sustainable development and circular economy (Sauvé, Bernard, and Sloan 2016). While others said it is co creation of knowledge for sustainability (Mauser et al. 2013). Steps of transdisciplinary research is given elsewhere (Brandt et al. 2013).

III. METHODOLOGY

3.1 Methods

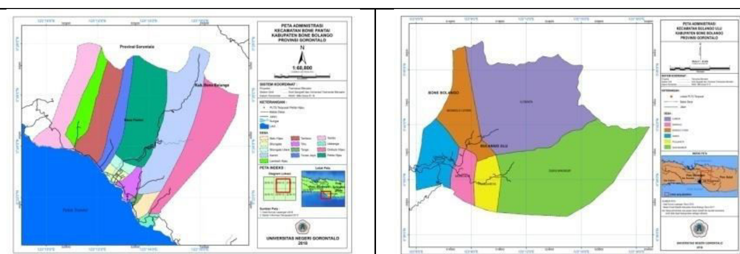
We used a descriptive survey method to get information from customers and management of PVPPs and combined with review of available written documentation. We visited the village and meet with respondents and interviewed them deeply in face to face rapport. Numbers of respondents of each village were 164, 181 and 124 for Tulabolo Timur, Pelita Hijau and Pilolaheya village respectively. The survey was conducted in Apr-May 2018 for two projects: Pelita Hijau village of Bone Pantai district and Pilolheya village of Bulango ulu district. Bone Bolango regency lies between 00° 18' 25" – 00° 48' 21" North latitude and 123° 03' 41" – 123° 33' 06" East Longitude. Total area of this regency is 1,984.31 km^2, containing 159 villages. Population of the regency mostly is Gorontalonese.

1.1 Pelita Hijau village

Pelita Hijau village has an area of 11.24 km^2 which is inhabitated by 181 housholds which are distributed into four hamlets namely Kayangan, Penghijauan, Landadu and Pooba. It is located in the Bone Pantai district as shown in Figure 1b. The inhabitants of Pelita Hijau mainly work as farmers.

1.2 Pilolaheya village

Pilolaheya village is one of six remoted area of Bulango Ulu district, the northern tip of the regency. There is no paved road into the village. The village is distributed into three hamlets namely, Tilihuwa, Tumba and Ombulo. It has an area of 12.63 km^2 and populated by 124 households, their main activities are farmer.



(a)	(b)

Fig 1. Map of the survey location, a) Pelita Hijau and b) Pilolheya. The access there is non-paved road shown by solid black lines. The red dots are the locations of the MHPP or PVPP installations.

3.2 Transdisciplinary approach

Three phase model (Brandt et al. 2013) of trans disciplinary approach will be adopted in this research. The phases are:

(i) Collaborative problem framing: at this stage researchers and stakeholders working together to identify and structure real-world problem. Reintegration of knowledge could be achieved through conceptualization of a methodological framework.

   a. To identify real-world problem in Mongiilo, we will use several techniques such as direct observation, interview and focus group discussion to encounter statistical data which are available (Statistics of Bone Bolango Regency 2016b). Outcomes of this step are characteristics of people who lived almost isolated from other region. Poverty, social and economic conditions of people, renewable energy issue, technology, job, income, public facilities (transportation).
   b. Mapping the problems, together with stakeholders we will identify (listed problems found) problems and put into diagram to find the real problems in the society. This is critical step, once the step is ignored the real problem never being found. Dialog and focus group discussion will be used in this step.

(ii) Co-creation of solution oriented and transferable knowledge: at this stage researchers adopts and applies integrative scientific methods. Through goal-oriented collaboration researchers and stakeholders integrating different knowledge bodies.

(iii) Integration and application of produced knowledge: researcher and stakeholder are ready to practice integrated knowledge socially and scientifically.

Fiscal Year 2017	Collaborative Problem Framing	
April - Mei	1. Getting preliminary data on Socioeconomic conditions, energy, technology, transportation, etc	- Literature Studies (Statistical Report data from Regency) - Direct Observation - Interview with
Mei - June	3. Find out the causes problem	- Among researchers - Together with stakeholders (via FGD)
June - July	2. Mapping the problems Socioeconomic conditions, energy, technology, transportation, etc for small/specific area	- Among researchers - Together with stakeholders (via FGD) - Write Abstract for ICMAR 2017
July - Aug	4. Getting more data for whole regency	
	5. Find out the causes	- Together with stakeholders (delivered the plan) - Presents at ICMAR 2017
Sep - Oct	6. Mapping the problems in the whole regency	- Together with stakeholders evaluating the trial solution - writing draft of publication
Nov - Dec	7. Reporting, publication, preparing the next year project 2018	- Submitting the publication - Writing the report

Figure 3. Planned research activities in fiscal year 2017

Fiscal Year 2018	Co creation of solutions oriented and transferable knowledge	
April - Mei	1. identify knowledge that is solutions oriented transferable	- Literature Studies - Direct Observation - Interview with Stakeholders (sampled) - Study on specific knowledge related to solutions (palm fiber based technology, agriculture technique based on local wisdom, new product creation to increase income, etc.)
Mei - June	2. Mapping the problems and solutions (readiness, etc.)	
June - July	3. Make a plan for solving the chosen problem (Co-planning)	
July - Aug	4. Delivered a plan for solving the chosen problem (Co-delivered) for trial	- Together with stakeholders (Co planning) - Presents at TREPSEA 2018
Sep - Oct	5. Evaluation of delivered a solutions	- Together with stakeholders evaluating the delivered solution - writing draft of publication
Nov - Dec	6. Reporting, publication, preparing the next year project 2019	- Submitting the publication - Writing the report

Figure 4. Planned research activities in fiscal year 2018

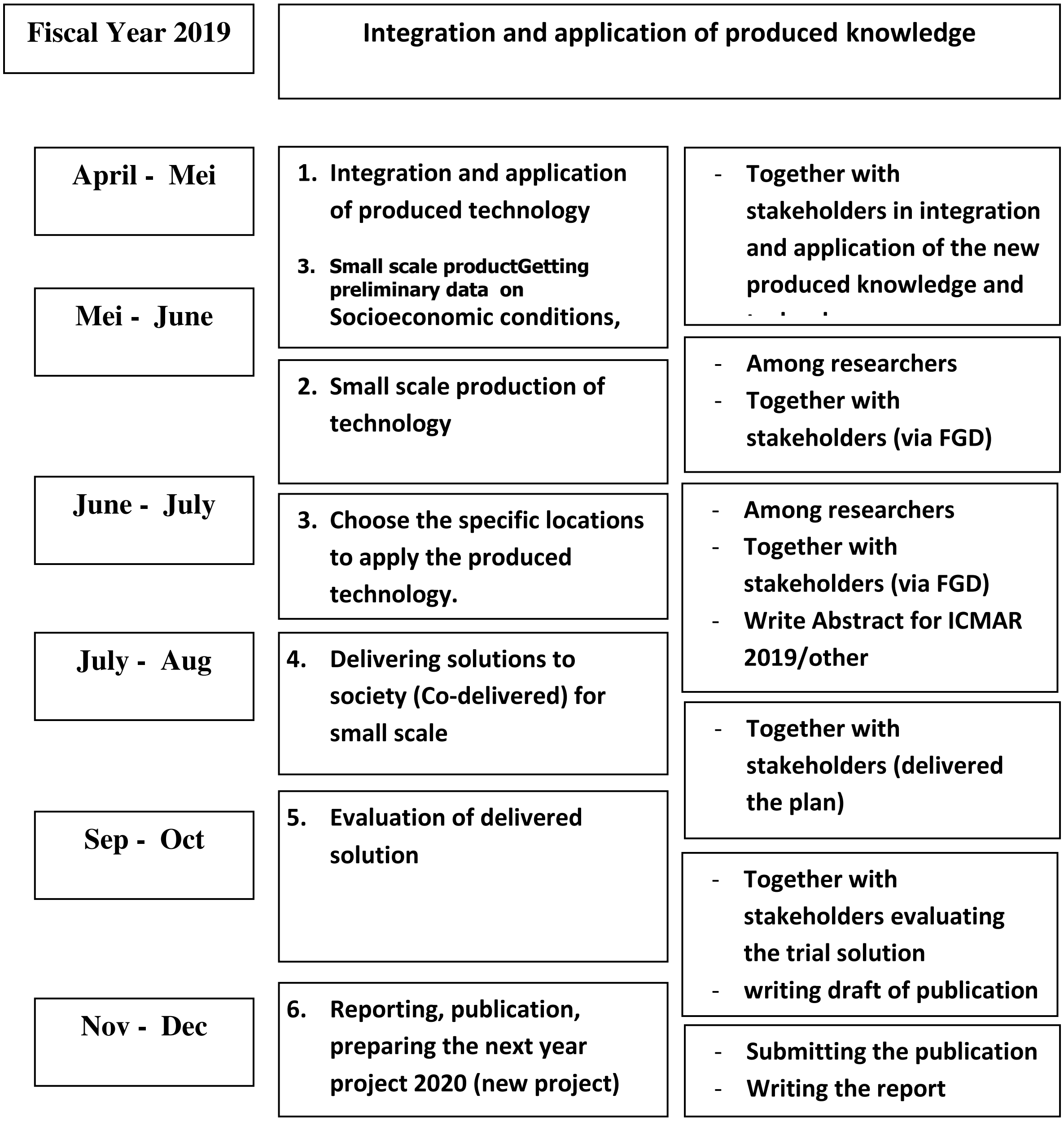


Figure 5. Planned research activities in fiscal year 2019

IV. RESULTS

4.1 Energy Use

Pilolaheya and Pelita Hijau are remote and isolated villages of Bone Bolango regency. Since there are no paved roads into the villages, PLN could not install electric grid and connected with nearby grids. To help the villagers the government installed grids of 15 using Photovoltaic as energy source in each village.

Table 3 Presentation of target level an indicator's values

Indicator	Target level (%)	Value (V)	
		PVPP Pelita Hijau	PVPP Pilolaheya
Technical			
Capacity, TND1	Min 95%	100	100
Compatibility with grid of PLN, TND2	Yes	Yes	Yes
Daily Operation, TND3	24h	12	12
Availability, TND4	100%	90	90
Economic			
Profitability, ECD1	Min 35%	0	62.5 %
Share, ECD2	100 %	0	0
Tariff lag, ECD3	50 %	0	0
Share for business, ECD4	Min 5%	0	0
Share for income, ECD5	Min 5%	0	0
Share for Bussiness development, ECD6	Min 1	0	0
Social			
Share of school and health service, SOD1	Min 95%	100	100
Street light, SOD2	1/40	4/59	4/90
Microcredit, SOD3	Min 1	0	0
Primary school, SOD4	Min 80%	100	100
Access to electricity, SOD5	Min 90%	100	100
Subsidies, SOD6	Max 1	0	0
Economically active children, SOD7	Max 5%	0	0
Environmental			
Share of renewable energy, END1	100 %	100	100
Share of CO2 emission, END2	0 %	0	0
Share of lighting, END3	100 %	100	100
Share of cooking, END4	Min 50 %	0	0
Environtal damage, END5	No	No	No
Weather END6			
Institutional			
Share of staff with primary education, IND1	Min 50 %	100	100
Staff turnover in organization, IND2	0	0	0
Number of year in business, IND3	Min 5 yr	7	2
Share of non tech losses. IND4	0 %	0	0
Level of satisfaction, IND5	100 %	90	90
Auditing, IND6	1 time	No	No

4.2. Sustainable development indicator assessment

The target and number/value of indicators for each dimension are given in Table 3, and the scoring of sustainable development

4.2.1. Target level of indicators

In choosing the target levels, the standards were purposely set high to show positive results of the dimension [19]. It was proposed for the technical, social, environmental, and institutional dimension. Both projects were characterized by investments in MHPP that were seen as part of the 'social infrastructure.' Due to their social objectives, these experiences have often generated little information on the capital and operating costs or cash flow returns of the investment [29]. Therefore, the target levels for economic indicators were determined by considering the socio-economic status of the villagers and proposed based on their average value. Capacity factors of hydropower projects around the world yield between 23% and 95% [30], and the minimum target is set at 95%; daily operation services are 24 h, and the availability of services is roughly 100% [15]. Compatibility with future grid service is YES [18]. The minimum target for ECD1 is determined by the average of profitable MHPPs in Indonesia, i.e., roughly 35% [31]. Tariff lag is set at 50%, determined by considering the 2013 inflation rate of approximately 6% and the economic feasibility analysis of MHPP Wangan Aji in Wonosobo Indonesia, which sets the tariff increase 3% per year [32]. For ECD4, a minimum target of 5% was established to make a significant change in business and income generating activity [19]. The minimum targets of ECD5 and ECD6 are set, respectively, as 10% and 1 unit [33].The share of health centers and schools with electricity is approximately 70%e100% [19] with an average of 88% [33], and the share of the population with primary school educations is approximately 50%e100% [19] with an average of 77% [33]. The target number of street lights in the community is 1 lamp every 40 m [34]. The minimum available micro credit is set as 1 unit, and the maximum share of economically active children is set as 5% [19]. A minimum range of 100% and 50% was generally considered as the lowest acceptable level for local key variables END3 and END4 [34]. Microhydro energy has been clearly defined as clean and environmentally friendly. The target level of END1 (the share of renewable energy in production) and END5 (any serious local environment impact identified) is established as 100% and ‘NO’, respectively. Any extreme weather condition will disturb the project in an unexpected manner. Staffs that need appropriate education are the operators, so the minimum target for the indicator IND1 is established as roughly 50%. Turn-over of staff will have a negative impact on the organization, and we set this target level to 0%. The average number of years of MHPP operation is approximately 66 months [16]. We set as 0% the target level of indicator IND4 (the share of non-technical losses) and 100% for indicator IND5 (level of satisfaction). Auditing of financial reports (IND6) is performed a minimum of 1 time every year. 3.2.2. Technical dimension sustainability In general, the values of technical indicators are almost the same, and the differences are seen in the capacity factor. The capacity factor of MHP shows the proportion of effective capacity compared to installed capacity that is expected to be delivered by the PVHP to the community. The calculation is performed by comparing the gross energy (kWh) production annually with the total installed capacity (kW) when plant operated for 8760 h/year. The gross production is the energy (kWh) generated by the generator before deducting the energy used for own purpose or the production of electric energy measured at the generator terminal. Installed capacity is the capacity of one generating unit as written on the generator name plate [35]. The lack of a measurement of the capacity factor is due to the unavailability of control and monitoring equipment (kWh meter) and the logbook, which records electricity generation. Without it, the estimation is only based on instantaneous Amperemeter and Voltmeter readings, which are likely to not reflect the actual output generated by the MHPP and used by customer. It is in line with [31] that meters are often not employed in small off-grid electricity networks. The capacity factor of the PVPP is not optimal because the customer has not fully utilized the energy produced. Energy consumption per household (Watt-hour/household/day) is very low due the demand for electricity being generally limited to lighting, rice cooking, and television (see Table 2). These pieces of equipment generate a low capacity factor. The both of PVPPs are not interconnection to national grid at the present. The presence of grid service, which offers a cheaper alternative and better comfort in the availability of electricity 24 h a day, can make households leave PVPP services [26,29]. However, the other approach views that sales to the grid represent a special case of cash-generating end-uses. Sales, when power is in excess, could provide a better load and the potential for reliable cash flow [29]. Advantages for the consumers would be induced by overcoming capacity restrictions and also for the stability of the national grid it might be advantageous to connect decentralized generation capacity in order to counteract voltage losses due to huge distribution distances [33]. To promote sustainability of MHPP, in 2012, the national FiT scheme in Indonesia was announced and established in the MEMR Regulation No. 4. This regulation put an obligation on PLN, Indonesia's utility, to purchase electricity from small- and medium-scale renewable energy (up to 10 MW in capacity) or excess power by giving different incentive factors for different regions. A case study of MHPP in Sulawesi was analyzed and showed increasing financial feasibility of MHPP and in order to make the FIT scheme really able to overcome the fixed costs related to these plants as well to create a real economic benefit for the beneficiary communities, a capacity of at least 30 kW is hereby suggested [16]. Currently, many MHPPs are located in immediate vicinity of the PLN grid include both of MHPPs. It means that MHPPs have the opportunity to connect to national grid.

However, these options depend, of course, essentially on the government support and the readiness of the PLN policy toward strategic cooperation like this. PVPP-Pelita Hijau provides electricity service every day: approximately 16 h for five days and 24 h for 2 days. On the contrary, the electricity service of MHPP-Tulabolo Timur is supplied approximately 24 h for five days and 16 h for 2 day. The availability of the service during scheduled operating hours is 99% for both of the cases. The frequency of outages is approximately 2e4 times per month with an average downtime of 1 to 2 h due to blockages of garbage. More regular forebay and channel maintenance could significantly reduce this problem. KPI method define the availability factor as the ratio of actual operation time with the expected time of operation (24 h) and showed that the average of some MHPPs in Sulawesi and Sumatera are available for 63% of the expected time and the highest is 96% [15]. Low availability factor indicates two aspects, comprise low operating hours and the operation experienced significant technical problems which could be caused by natural forces or inadequate maintenance. The most common breakages of electrical-mechanical equipment occur on the turbine, generator and controller. In addition, some components must be replaced periodically, such as belts and bearings. For civil structures, the most common problems are reported on channels, forebays and blockages [29].

4.2.3. Economic dimension of sustainability

The economic dimension is recognized as the most fundamental for sustainability of projects. From a financial perspective, MHPP Tulabolo Timur is better than PVPP-Pelita Hijau. To run an MHPP sustainably, the management team needs sufficient financial means to cover maintenance costs and management salaries. Income for the MHPP management teamis generated from the electricity tariff collected. The tariff system is also an indicator for community participation and their sense of appreciation and ownership [15]. Similar with other studies [15,28,29], the price for electricity services charged by the MHPP is a flat tariff system with a fixed monthly base, and it is presented in Table 3. During the operation, neither projects raised the tariff. The highest tariff paid by clients is 0.035 USD/kWh, while the cost of electricity production closes to 0.07 USD/kWh. This fare falls below the cost of production, meaning that reinvestment cannot be achieved. From the economic feasibility, reinvestment can be overcome if the tariff is set to follow FiT. In this case, government intervention is needed, for example by subsidizing electricity tariff. The main differences between the cases can be found in the profitability. Both of microhydro power projects are operated by community and can be considered as informal sector. They are not paying tax, neither considers depreciation. Profitability is defined as the ratio between the total profit (total revenue minus the cost of O&M) and total revenue. Profitability of MHPP-Tulabolo Timur looks better because the cost of O&M is much smaller. In addition to the salaries, PVPP-Pelita Hijau must pay for land and village retribution as an administrative cost. It must be noted that the O&M cost factored in the calculation is only based on the actual O&M regular maintenance cost and did not include any major repairs. The cost of capital is a grant from the provincial government. Microhydro plants below 1 MW can have significantly higher capital costs, and the range can be from USD 3400 to USD 10,000/kW [30]. The capital cost and installation indicator are not considered in this study because MHPP is a very specific location, so the level target is not easy to fix. In fact, the tariffs were too low to allow accumulation of capital costs for re-investment. From the perspective of the development of productive uses, PVPP-Pelita Hijau is better than MHPP-Tulabolo Timur. Productive end-uses can be described as: 'small scale income generating or cost-avoiding activities (by households or small companies) that are powered by MHPP electricity that is not required for other community purposes [20]. PVPP-Pelita Hijau had a business unit processed coffee beans since 2011, which consumes electricity at a rate of approximately 1164 kWh/year. Productive uses development is also carried out by five households. Their activities are groceries, snack-making, carpentry, bamboo crafts and sewing. Electrical equipment is used, including lights, refrigerators, wood machines, and sewing machines. Productive end use of homemade products may experience various problems due to low capital, awareness, knowledge and skill, electrical capacity, and the existence of many competitors.

4.2.4. Social dimension sustainability

Some of the social indicators show measures of the impact of electrification. All of the public facilities (the elementary school, mosque, and village hall) in both of the locations are serviced by electricity from the MHPPs, but neither project supplies lamps.Streetlights have been found to reduce the feeling of insecurity when walking the streets after dark and are appreciated, in particular, by women [36]. This could easily be improved if the lights were fixed, but no client claims responsibility for the maintenance of the lights due to it being a public good. The availability of an electrical service that can provide better illumination is expected to help the quality of residents' education. Lighting permits home study, increases security, and enables the use of educational media and communications in schools, including information and communication technologies. More than 80% of respondents who had family members who attended school felt there were benefits for children's learning activities. There are no credit facilities currently available. The availability of micro-credit will help villagers be able to access electricity to pay a connection fee or to generate their business. However, it is unlikely to be available in the near future because any lending institutions would consider these people high-risk clients. The last key variable, equal distribution, it shows that more than 90% of the population has primary education and access to electricity. PVPP-Pelita Hijau offers subsidies of the tariff for elderly people whom no longer work. The indicator share of economically active children is less than 5% for PVPP-Pelita Hijau but more for MHPP-Tulabolo Timur. As an economic reason, some children in remote or rural areas must be involved in economic activities, mainly in the farming sector. Access to electricity reduces the time spent by children on basic survival activities, such as gathering fuel wood, fetching water, and cooking [37].

3.2.5. Environmental dimension sustainability

The environmental dimension can be interpreted from the local to the global level. In the context of global impact, there is no difference between the two projects; electricity is generated 100% from renewable sources, so there is zero emission of carbon dioxide. Off-grid microhydro energy systems that will be installed will directly displace diesel fuel oil (DFO) used in diesel power generation. In this regard, the CO2 emission factor is 0.975 tons CO_2/MWh [38]. The reductions of CO2 emissions generated by PVPP-Pelita Hijau and Tulabolo Timur are 97 tons of CO2/year and 105 tons of CO2/year, respectively. The local impact, meanwhile, showed that all households use electricity for lighting. The preferences of residents also showed that 100% of respondents would prefer electrical energy for lighting due to it being brighter, more practical, less expensive, and not damaging to the aesthetics of the house. The share of electrified households where electricity has replaced other energy sources for cooking rice is approximately 50%. Electrification has not resulted in a significant shift from wood fuel to electricity for cooking in electrified households of Pelita Hijau, regardless of the power and their habits. More than 90% of the customers of the PVPPs used to have firewood as fuel for cooking. LPG was used by 56% of the customers of PVPP-Pelita Hijau and 12% of the customers of PVPP-Tulabolo Timur. Firewood became the main fuel due to its abundant availability and it not requiring a fee. Using firewood for cooking is still common for households in Indonesia, as indicated from the 2010 national socioeconomic survey, which showed that some 40% (24.5 million households) continue to depend primarily on firewood. Rural households continue to prefer firewood because firewood is readily available in the local environment at little or no cost, except for the time spent collecting it. However, the use of wood needs to be examined from the perspective of forest preservation as a catchment area. The use of electricity to replace kerosene for lighting and firewood for cooking can reduce CO_2 emissions by 13-35tons of CO2/year [40]. In this dimension, we add one indicator, 'extreme weather condition'. In 2012, a landslide heap piled the head channel of PVPP-Pelita Hijau so that the MHPP was not in operation for a month because of the large costs of the repair. The lesson learned was that MHPPs are often not operating due to natural disasters, such as landslides and floods. Sustainability of an MHPP is determined by the support of the potential of existing natural resources, especially the availability of river water as the primary energy source for the MHPP. The availability of water is highly dependent on the conservation of the catchment area of the river upstream. Environmental sustainability is among the most difficult aspects to control, as it is affected by external causes that are, in many cases, difficult to prevent. The over exploitation of fuel wood may also lead to deforestation in rural areas, which can impact micro- or pico-hydro energy resources. Deforestation appears to be the root-cause for poor MHPP performance. Incidences of flooding, landslides and consequential damage to infrastructure are more prevalent at sites with a high rate of observed deforestation.

4.2.6. Institutional dimension sustainability

The dimension of institutional sustainability is closely linked to the other dimensions in the context of sustainable development. The differentiating indicators are the share of staff and management with appropriate education and the number of years in business. Upon project completion, the ownership of the project is submitted to the local residents. To maintain the MHPP and keep the system running, a strong and reliable management team is required. Both of the PVPPs are managed by 6-7 members, consisting of a manager, secretary, accountant, and 3 to 4 operators. PVPP-Pelita Hijau shows better results for institutional sustainability. During operation of the MHPP, there has not been turnover of the staff. The share of non-technical losses includes unpaid electricity bills. Customers of MHPP-Tulabolo Timur are more obedient in paying electricity bills than those of PVPP-Pelita Hijau. Both of the PVPPs show an inability to raise the tariff, as this decision has to be supported by the majority of the electricity clients. Customer satisfaction with the electric service of the MHPPs is quite high, above 90%. The majority of residents are satisfied with the electrical service of MHPP. They are satisfied because they get better lighting and do not need to take care of it themselves because they can use a variety of electrical equipment at a reasonable cost, and because of the alertness of the operator. Dissatisfaction of customers is mainly due to the lack of electrical service hours. In the off-grid MHPP, the government often acts as the funder to provide technology and is responsible for increasing capacity building of the village community. In addition, non-government agencies (NGO) often support the role of government by providing some training for the community. Communication between the government and the management of PVPP-Pelita Hijau is still actively performed each year. Despite their formal education, elementary school to junior high, the government and NGO agencies continue to increase their capacity through institutional means and operation of micro hydro training almost every year. Mostly, the government does not schedule monitoring or auditing of the operational and financial reports of PVPPs, whereas it is necessary to monitor the sustainability of PVPPs.

4.2.7. Scoring of the overall sustainability

The SDI total score of Pelita Hijau is 72%, while that of Tulabolo Timur is 60%. Generally, the SDI of PVPP-Pelita Hijau is greater than that of MHPP-Tulabolo Timur except for the economic dimension (SDI scores of 30% and 36%), and their scores for the technical dimension are almost the same (SDI scores of 73-75%). The values of the technical indicator are approaching the target level, especially for key variable technical client relations. Weaknesses seem to focus on the low capacity factor regarding the utilization of electricity for productive end uses. Compatibility with future grid services becomes an opportunity to improve the financial perspective as long as customer satisfaction is met. Another threat in MHPP operations is the availability of water and the chance of natural disasters. The economic dimension becomes the most vulnerable dimension because the tariff policy applied is still below the production cost of electricity generation and there is no fare adjustment each year. The lack of funding microcredit, the spirit of entrepreneurship and business skills are also factors that weaken the economic dimension. The increase of income generation will depend on two basic things: human innovation and skill training from external institutions [19]. PVPP-Pelita Hijau offers more social benefits for its customers with an SDI score for this dimension of 71%, while that of MHPP-Tulabolo Timur is 43%. The principle of equal-distribution promotes equitable access to electricity for all of the villagers by providing subsidies, even though it weakens the profit of the MHPP. The environmental dimension becomes the most sustainable dimension, with the SDI scores for PVPP-Pelita Hijau and Tulabolo Timur being 96% and 86%, respectively, due to the MHPPs' reliance on environmentally friendly renewable energy. The main challenge is in raising awareness of clean cooking energy and maintaining catchment areas to ensure the availability of water. In terms of management, PVPP-Pelita Hijau is relatively better off than MHPP-Tulabolo Timur, with SDI scores of 89% and 69%, respectively. The strength of Pelita Hijau is in its advantage of capacity building, good relation with the government and community participation, although there is an inability to reduce the high non-technical losses. For MHPP-Tulabolo Timur, the institutional weaknesses can be illustrated by their low share of staff with appropriate education and auditing. However, sustainability is a matter of development over time. Data from a single evaluation is therefore not sufficient for assessment of sustainability. Information about the trends of the indicators would lead to considerably improved possibilities to assess sustainability [18].

4.3. Impact of socioeconomic factors on the sustainability indicators

The amount of electricity consumed by the customers will determine the amount of capacity factor (DNT1). It is specified by the share of electricity consumed by all households, business units (ECD4), and public facilities (SOD1 and SOD2). The choice of each household in electrical appliances and energy practices can be seen in Table 2. The relationship between the socioeconomics of customers and their electricity consumption can be explained by the energy culture framework. The majority (56%) of customers of PVPP-Pelita Hijau use their spare time (when not working) to watch TV, and rest fill their free time by chatting with family. The majority (56%) of customers of PVPP-Pelita Hijau instead prefer chatting with family or neighbors as a religion teaching activity over watching TV. The customer income of PVPP-Pelita Hijau is relatively higher than that of PVPP-Pilolaheya, as is the average number of family members. With more family members, customers of PVPP-Tulabolo Timur require a greater number of lights. The level of household income is one of the factors that affect the willingness to pay (WTP) for electricity. Customers' willingness to pay and the price structure of electricity relate to profitability indicators (ECD1), the share of profits for re-investment (ECD2), tariff lag (ECD3), and non-technical loss (IND5). Customers of PVPP-Pelita Hijau generate economic indicator scores that are 16% higher. In practice, there is an understanding in the community that PVPP electricity is a grant and that the electricity tariff is not commercially motivated, as well as an emphasis on the social aspects of both of the PVPPs. This electricity tariff makes consumers less concerned with power consumption that is visible from the villager habit of turning on the lights following MHPP operating hours, although in daytime the lights remain on. Campaign/socialization practices related to the use of electrical energy in a more efficient and more productive manner is still lacking. People's choices for fuel for lighting and cooking are associated with indicators of the share of electricity use as a replacement for other sources of energy for lighting and cooking (END3 and END4). All customers prefer to use electricity for lighting. There is a hope getting better and more practical lighting will make them prefer PVPP electricity over the regular lighting that they used previously, such as kerosene lamps and water wheels. The use of kerosene as a fuel for lighting requires higher costs. An average consumption of 8 L per week will cost USD 8/month, very expensive when compared to their monthly dues of only USD 2.73/month. Electricity from traditional water wheels requires intensive care. The user must provide the extra time to go to the river to take care of it. The cost savings in terms of time and effort are perceived by the villagers with the lighting from the MHPP electrical service.The use of wood as a cooking fuel is a hereditary habit that is taught by parents. As many as 62% of PVPP-Pelita Hijau respondents and 6% of PVPP-Pelita Hijau respondents express a preference to use electrical energy for rice cooking. Practices of gathering and burning biomass fuels for cooking have been identified as posing specific threats to the environment e most notably deforestation and global warming and hence are regarded as being environmentally unsustainable. Constant exposure to smoke from biomass fires is also seen as putting local populations at risk of contracting acute respiratory infections, a threat which is regarded as one of the most serious health problems facing poor countries. Customers of PVPP-Pelita Hijau have better education and awareness and show a better understanding of the dangers of wood-burning smoke. All of the respondents of PVPP-Pelita Hijau revealed that they believed that cooking with wood would not harm their health. Mastery of Photovoltaic technology by local communities is a result of the formation and normalization of knowledge and interaction with the 'agent' of technology providers (the government and NGO). Capacity building through training is conducted related to the indicators in the institutional dimension. In order for a PVPP to be sustainable, Photovoltaic technology should be fully integrated into the culture of the village. The education and knowledge of the staff/manager are very necessary, especially for operators to maintain and repair damage as it occurs. Managerial ability is also necessary to be able to manage administration, such as bookkeeping and making the right decisions. Trained personnel become part of the village's cultural assets. This highlights the importance of avoiding the dropout syndrome (IND3) because, if trained technicians leave their posts, continuing operation of the photovoltaic technology may be placed at risk if they were the only holders in the village. Management with a high sense of PVPP ownership will persist. Sense of PVPP ownership can be seen from the participation of customers, including the timely payment of the electricity bill indicator (IND5) and also the participation of the community to maintain the PVPP facility. To run an PVPP sustainably, the management team needs sufficient financial means to cover maintenance costs and management salaries. Income for the PVPP management team is generated from the electricity tariff collected. Sensitization and establishment of a tariff system was required to highlight community participation by paying for their PVPP electricity.

V. CONCLUSION

Analysis of PVPPs shows that there are sustainability in technical, social, environmental and institutional dimensions, but it is lacking greatly in the economical sustainability dimension. The economic sustainability is facing great difficulties, as the project has no financial scheme in place. The issue that requires attention for sustainability to be achieved is the electricity tariff. The strengths of these projects are the technical client-relation, i.e. daily operation service and availability service, the equity of distribution of public benefits for all of the community. The The cultural backgrounds, including the societal and economic characteristics of the clients, have a relation with the sustainability of the project, mainly with regards to the electricity consumption pattern, income, and education both formal and informal.

Furthermore, the awareness and knowledge of clients to apply proper tariff, to develop productive end use and to fully integrate the photovoltaic technology into the client culture will increase the project sustainability. Government and non-government organizations have roles to play in making sure the necessary knowledge and technical skills are in place, especially in the first year of operation. A further study should multiply the number of photovoltaic power sites to investigate and understand deeply the analytic relationship between the sustainability of an electrification project and its driving factors.

REFERENCES

Brandt, Patric, Anna Ernst, Fabienne Gralla, Christopher Luederitz, Daniel J Lang, Jens Newig, Florian Reinert, David J Abson, and Henrik Von Wehrden. 2013. “A Review of Transdisciplinary Research in Sustainability Science.” *Ecological Economics* 92. Elsevier B.V.: 1–15. doi:10.1016/j.ecolecon.2013.04.008.

Costanza, Robert, and Herman E Daly. 1992. “Natural Capital and Sustainable Development.” *Conservation Biology* 6 (1). Wiley Online Library: 37–46.

Dempsey, Nicola, Glen Bramley, Sinéad Power, and Caroline Brown. 2011. “The Social Dimension of Sustainable Development: Defining Urban Social Sustainability.” *Sustainable Development* 19 (5). John Wiley & Sons, Ltd.: 289–300. doi:10.1002/sd.417.

Giddings, Bob, Bill Hopwood, and Geoff O’brien. 2002. “Environment, Economy and Society: Fitting Them Together into Sustainable Development.” *Sustainable Development* 10 (4). Wiley Online Library: 187–96.

Hopwood, Bill, Mary Mellor, and Geoff O’Brien. 2005. “Sustainable Development: Mapping Different Approaches.” *Sustainable Development* 13 (1). Wiley Online Library: 38–52.

Laliyo, Lukman. 2016a. “Rekayasa Implementasi Teknologi Tepat Guna Melalui Pengembangan Model Pembelajaran Untuk Menumbuhkan Budaya Pemanfaatan Energi Terbarukan Pada Masyrakat Daerah Terpencil.” Gorontalo.

———. 2016b. “Transdisciplinary Study on Solving Problems of Sustainable Usage of Renewable Energy in Bone Bolango Regency, Gorontalo Province: A Case Study on Isolated and Poor Community in Mongiilo Village.” In *Transdisciplianary Research on Environmental Problems in South East Asia*, 120.

Mauser, Wolfram, Gernot Klepper, Martin Rice, Bettina Susanne Schmalzbauer, Heide Hackmann, Rik Leemans, and Howard Moore. 2013. “Transdisciplinary Global Change Research: The Co-Creation of Knowledge for Sustainability.” *Current Opinion in Environmental Sustainability* 5 (3). Elsevier: 420–31.

Sauvé, Sébastien, Sophie Bernard, and Pamela Sloan. 2016. “Environmental Sciences, Sustainable Development and Circular Economy: Alternative Concepts for Trans-Disciplinary Research.” *Environmental Development* 17. Elsevier: 48–56.

Statistics of Bone Bolango Regency. 2016a. *Bone Bolango in Figures 2016*. Suwawa. http//bonebolangokab.bps.go.id.

———. 2016b. *Bulago Ulu Subditrict in Figures 2016*. Suwawa. http//bonebolangokab.bps.go.id.

Wertz-kanounnikof, Sheila, and Metta Kongphan-apirak. 2008. "Reducing Forest Emissions in Southeast Asia." http://www.cifor.cgiar.org.