Off-grid Photovoltaic Applications in Indonesia: An Analysis of Preliminary Fieldwork Experience

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Abstract - *During the past two decades photovoltaic (PV) power has been introduced to remote communities in developing countries as a means of remote area electrification. In Indonesia, approximately 5 MWp of PV power has been installed to date in the various provinces for powering lighting, water pumping, ice making, communications, health care, etc. Of the 5 MWp PV lighting systems contributed 1.8 MWp. Despite the massive number of PV power installations questions remain as to how PV installations can contribute to the sustainability of the lives of rural Indonesians who do not have access to grid electricity. This paper introduces a study of the sustainability of off-grid PV applications being carried out in Indonesia. In this study, these questions will be explored in relation to off-grid electricity supply by analysing how villagers and islanders, and on a larger scale present and future generations, might harvest benefits from the implementation of PV in off-grid applications. This is intended to scope a potentially broader study focused on the use of PV power systems as a means of rural energy development by, for example, facilitating income generation and broader improvements in social welfare. Some findings from preliminary fieldwork are presented and used to identify key issues for further analysis.*

1. INTRODUCTION

As of 2001, 82% of the total 60,049 Indonesian villages have been electrified, however only 52% of households have actually been electrified leaving approximately 25.6 million Indonesian families (approximately 108 million souls) without electricity (PLN, 2002). The fragmented geography of the Indonesian archipelago together with an uneven population distribution has created problems extending the nation's power grid. Off-grid PV systems are therefore considered a solution for remote area electrification and a number of photovoltaic rural projects have operated in Indonesia since the 1980s. To date approximately 5 MWp (ACE, 2000) of PV power has been generated from various residential and public PV applications including PV for lighting, water pumping, communication, health care, ice making, etc. Villagers have responded positively to these PV installations and have acknowledged an improvement in their lives (see for example CADDET, 1999; Reinders, 1999; Van Campen, 2000). However has PV provided 'raw fish' into the hands of the villagers or has it provided the 'fishing tackle' for them to 'fish' and improve their lives? Many questions arise here as to: in what ways has PV improved the life of rural Indonesian people? Can PV become a tool for rural development making rural life more attractive? Have all the potential applications of PV that may deliver service to rural people been identified and implemented?

Since the 1980s approximately 5 MWp of PV power has been installed through the following project phases and by involving a number of agencies: [1] Experimental, [2] Pilot/Demonstration, [3] Multiple Demonstration and [4] Semi-Commercial phases. During the 1979-1986 Experimental stage, a number of PV systems including water pumping, desalination, ice-making, telecommunication repeater and buoy light systems were installed. During 1988-1993, the second phase, 1,600 PV systems were

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installed in Sukatani and Lebak, West Java as pilot projects. Proceeding further to the multiple demonstration stage, the Banpres (Presidential Aid) project was launched in 1990 with the goal to install 3,140 PV systems in 13 Indonesian provinces to be completed in 1991. The Dissemination Phase commenced in 1992 whereby approximately 30,000 PV systems (such as vaccine refrigerators, rural telephones, solar boat systems and street lightings) had been installed by various agencies throughout Indonesia by 1997. In 1997 the Government of Indonesia (GOI) launched the "50 MWp One Million Roof Programme" whereby AusAID (with 36,400 PV units), the Bavarian government (BIG-SOL[2]) and the World Bank/GEF have all committed to participate. In addition, a revolving fund has been generated from the Banpres and AusAID projects making it possible to install a further 2,100 units in Kolaka, North Molucca and Natuna islands. (Source: BPPT, 1999; DGEEU, 2003; Djamin, 1997; MOC&JICA, 2002).

Despite the massive number of PV installations and the considerable support and initiatives provided by the government, to date the PV market remains small compared to its technical potential, which is projected at 900 MWp (IEA, 1999). Lack of access to finance, inadequate after sales service and inadequate institutional infrastructure are common barriers for PV market acceptance in developing countries (Cabraal et al, 1996). PV is also still alien to the local socio-economic culture in rural communities. In some cases in Indonesia, where the arrival of grid electricity has made the PV systems redundant, PV modules have been sold in a second hand market. The presence of a second hand market demonstrates growing willingness to pay in rural communities and raises interesting questions as to whether local innovation in the use of PV is occurring. Without proper controls, of course, the presence of a second hand market might also encourage theft.

2. PROJECT DESCRIPTION AND METHODOLOGY

The research project discussed in this paper is a combination of social and engineering research that is intended primarily to examine the sustainability of PV systems as a means of rural electrification. The primary objective of the project is to study how PV can contribute to the sustainability of the lives of rural Indonesians who do not have access to grid electricity, by considering social, economic, institutional, technical and environmental dimensions. These dimensions will be explored in relation to off-grid electricity supply by analysing how villagers and islanders, and on a larger scale present and future generations, might harvest benefits from the implementation of PV in off-grid applications. This is intended to scope a potentially broader study focused on the use of PV as a means of rural energy development by, for example, facilitating income home generation and broader improvements in social welfare. An earlier paper (Retnanestri et al, 2003) describes the current institutional framework for off-grid applications of PV in Indonesia. This paper summarises that material and then discusses the outcomes of preliminary fieldwork undertaken in late 2002 and early 2003.

The methodology of the project will include literature research, field research in villages where PV systems have been installed, and interviews with key stakeholders. The field research is intended to investigate villager expectation and degree of satisfaction, PV system performance, experience with the care and maintenance of PV systems, experience with failure and replacement of PV systems, and monitoring protocols. The interviews will be used to identify the costs, benefits, and values associated with the PV system as well as a potential alternative PV design for income-generating activities in rural areas.

As part of the research project work plan, preliminary fieldwork was undertaken during the period of December 2002 – March 2003. This field work included visits to governmental institutions, donor agencies, PV industries, universities, NGOs and PV sites in West Java and Lampung province (in the Sumatra island), which are active in the PV implementation in Indonesia. The intent of the visits was to learn from their experiences and to identify key issues to be explored in the survey phase as well as to select villages to be surveyed. In the following sections, sustainability issues in off-grid PV applications in Indonesia will be discussed by presenting and analysing some relevant findings from the preliminary fieldwork.

[2] The Bavarian-Indonesian Joint Solar Project.

3. SUSTAINABILITY ISSUES IN THE OFF-GRID PV APPLICATIONS IN INDONESIA

3.1. Socio-Economic Dimension

Villagers have responded positively to the introduction of PV systems. Findings from the preliminary fieldwork suggest that:

- PV systems have been used for economic activities, which is a measure of the acceptance of PV into rural life;
- PV systems have been kept as back up power after grid connection, which is a measure of user satisfaction with PV reliability;
- PV users are willing to invest in bigger capacity systems, which is a measure of user's enthusiasm;
- Some revolving funds have been generated from past government projects, which is a measure of financial sustainability.

In some cases however, where the arrival of grid electricity has made the PV systems redundant, PV modules have been sold in a second hand market. As previously discussed, this raises interesting questions as to whether local innovation in the use of PV is occurring.

The author intends to study the acceptance and perception of PV and the social and economic development to which it has contributed. Despite the massive number of the PV systems installed in the various areas of Indonesia, many questions still remain regarding socio-economic development for instance lifestyles, education, economic activities and social activities at night, which add value and create benefits making village life more attractive and potentially reducing migration to urban settlements. The socio-economic sustainability of PV installations can be assessed from answers to the following questions:

- Is the direction of the PV investment economically sustainable?
- As part of rural development as a whole, does PV contribute to improving the economic performance of rural communities?
- Has PV helped in alleviating poverty by creating job and income opportunities?

Out of 207 million Indonesians in 1998, 63% lived in rural areas (PRC, 1999). These rural inhabitants are generally farmers, artisans, craftsmen, fishermen or small-scale traders. Many occupation-related questions arise here such as: Has PV helped households to generate income from their business activities? What PV designs are best suited to facilitate the local economy (eg. agricultural and off-farm productive activities)?

Some findings from the preliminary fieldwork

1. **Financing Scheme:** For the purposes of financing, it has proved useful in Indonesia to classify potential users into three segments in accordance with their economic standing: [1] Under developed, [2] More developed and [3] Developed economic standing (Dasuki & Prasodjo, 1995; Djamin, 1997). This segmentation is used to define the level of financial assistance required and hence the payment scenario. Demonstration schemes are appropriate for the first two user segments (eg Banpres, AusAID and BIG-SOL projects whereby the end-users pay instalments for up to a ten year period) while semi-commercial schemes are more appropriate for the third segment (eg the World Bank/GEF project whereby customers pay larger down payments with a shorter period of instalment payments of up to 3 years). In demonstration schemes, villagers purchase PV systems through a revolving fund scheme that is supported by either government or donor assistance and is administered by the village cooperatives unit namely *Koperasi Unit Desa* (KUD). In semi-commercial schemes, the end users purchase the PV system directly from the PV dealer to whom the World Bank/GEF provides a subsidy of US$ 2/Wp. It is important to asses the financial sustainability in each case: Is the financing scheme economically sustainable taking into account its possible influence on future PV market development particularly as some people already consider PV projects to be a gift from the government (PSG, 2002)? Have the semi-commercial schemes achieved self-funding status? Or is further assistance required? It should be

noted that PV reaches the consumers through a chain of agents and distance involving significant operational cost for site surveys, installation and transportation fees and training for operators and consumers. In the demonstration projects, these costs are paid by the government (Djamin, 1997).

2. **The current status of Sukatani, the pilot PV village –** In 1988, 102 PV lighting systems were installed in the village of Sukatani, West Java as a pilot PV village programme (CADDET, 2000). The project at Sukatani was well monitored and periodic site audits of the technical and social aspects were conducted (Reinders, 1999). Studies of Sukatani including its financial management were well documented and the users have expressed a positive response towards the systems. Some fifteen years after its inception, and even when grid electricity arrived at Sukatani in 2001, the users have kept their PV systems for back up power when the grid fails. When comparing Sukatani, a model PV village, with others, a question arises as to how similar the outcomes will be elsewhere in Indonesia particularly in regard to project management, monitoring and the impact that PV has had on the local community.

3. **PV lighting systems for economic activities**: PV applications directed at supporting economic generating activities have been installed such as BIG-SOL solar boat lighting and the *Tamyangsang* (egg incubator and indoor/outdoor lighting for chicken barns) projects in East Java, and PV systems for fish floating nets lighting in West Java. In the village of Jangari, West Java, PV systems have been installed at the fish floating nets on the Cirata dam. There are a large number of fish floating nets on the lake that are owned by local and remote entrepreneurs. It is practically impossible for the grid to reach these nets. Battery and diesel engines have been used to fulfil the electricity needs which unfortunately polluted the lake environment. Since 2000, the net owners have purchased PV systems under a semi-commercial scheme and there are now hundreds of PV modules on the roofs of huts to support these economic activities.

Figure 1a. (left) PV installations in Sukatani village, West Java, fifteen years after its inception. 1b. (right) PV systems installed on a hut roof of a fish floating net at Cirata dam, in the Jangari village, West Java.

4. **PV for back up power** – As in Sukatani, PV systems are used in the village of Badak, Central Lampung, in the Sumatra island, as back up power when the grid fails. Grid electricity powered by diesel fuel generators is now available in the remote village of Badak however a number of households installed PV modules on their roofs as back up power as the diesel power fails frequently and also to save on expenditure on grid subscription.

5. **Domestic PV industry – PV Distributors:** Since the inception of PV in Indonesia many PV distributors have been actively involved in the industry primarily through governmental projects. They have responded to customer demands and market activity by setting up outlets at local regions and then inviting local entrepreneurs to join in their marketing networks and even fill small quantity orders. The payments have sometimes been very flexible particularly for customers with irregular or seasonal income. Figure 2a shows an example of a sales structure where PV systems

are delivered from the distributor to the end-users through a chain of Area Sales, Outlet, Senior Canvasser, and Canvasser at the local level. At the Cirata dam in the village of Jangari, outlets of two different PV distributors in the vicinity provided customers with immediate after sales service. In contrast the nearest PV outlet in Lampung was located at a great distance from the end users resulting in high operational costs for installation and after sales service.

BOS Manufacturers: Apart from the solar module all PV equipment such as module supports, cables, charge controllers, lamps and luminaries are produced domestically. Many PV distributors also assemble imported PV modules and manufacture the balance of system (BOS) components. A major manufacturer in Jakarta has exported its BOS products to many developing nations such as Sri Lanka, Nepal, India and Bangladesh. While their existence has demonstrated an active local industry involvement, it has yet to be proved that these activities directly alleviate poverty.

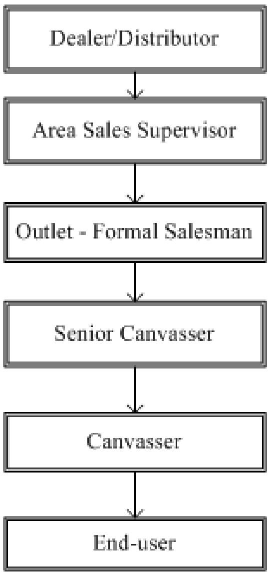

Figure 2a (left). A typical sales structure; 2b (right). A PV outlet in the village of Jangari displaying a set of PV lighting systems.

6. **PV second hand market** – There are local entrepreneurs which are active in selling used PV systems in Lampung. The entrepreneurs collected used PV modules from the relocated government projects in Sulawesi, Java and other islands when the arrival of grid electricity made the PV systems redundant. A used PV module is valued between IDR 500,000 to 1,000.000 (AUD 100-200). After being repaired and provided with new lamps and battery, a complete PV system will be valued at approximately IDR 2,500,000 (AUD 500). With the advent of the second hand market, questions arise as to the value of PV system and the implications of the presence of the market itself such as: why are owners selling their PV systems, (as the reasons could include technical or financial difficulties) and why are others willing to buy second hand systems when the quality and warranty may be in question. The existence of the second hand market raises other questions worthy of further investigation such as theft, reparability, spare component availability and the labour required for repair.

For PV to be socially and economically sustainable, it is imperative that PV is incorporated into the local socio-economic culture of the remote Indonesian societies. The widespread diffusion of the motorcycle is an example whereby a new technology can be widely accepted when it produces needed local jobs and strengthens the local economy. A motorcycle unit is far more expensive than a PV unit. It is proven that motorcycles have created economic opportunities such as the *ojek* (motorcycle) taxi, and the creation of many business derivatives such as spare parts and service workshops, fuel retail outlets and tire repairs. Similarly it is imperative for PV to be a productive investment for remote societies that they can find important for their economies rather than just a product merely for amenities.

3.2. Institutional Framework

Rural PV projects involve many institutional stakeholders, including government agencies (cooperatives, transmigration, technology development, planning, energy, and banking)[3], sponsoring bodies/donors[4], and local communities. As an example, figure 3 illustrates the network operation of the "50 MWp One Million Roof" rural electrification program. The diagram shows both the program and fund flows of the project agreements, their operation and monitored activities. Many questions about institutional capacity arise from the operation of this network of stakeholders: Is this the best form of cooperation and does it work effectively? Is this institutional framework sustainable? What should be the role of each agency in each phase of decision making, project implementation, post-project monitoring, PV training, education and dissemination? Should end-users be more actively involved in project design and planning? If so, how can this be achieved?

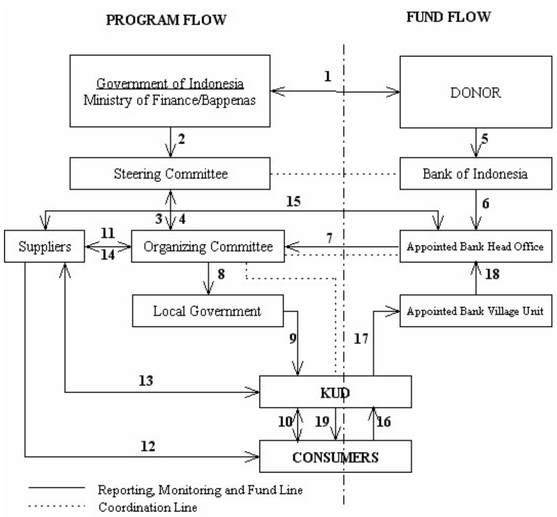

Figure 3. Organizational structure of "50 MWp One Million Roof" PV rural electrification project. Legend: 1 - Loan agreement; 2,3,4,8,9 - Program coordination from government to localities; 10,11,12,13,14,19 - Contract arrangement; 5,6,7,16,17,18 - Fund flow. Source: (Dasuki & Prasojo, 1995).

Upon the loan/grant agreement between GOI and donor (1), operational guidance is given to a Steering Committee (SC) (2) and an Organizing Committee (OC) (3) whereby the OC reports back on the project implementation (4). The committee is chaired by BPPT and composed of key governmental institutions such as Directorate General of Electricity and Energy Utilisation (DGEEU), Ministry of Cooperatives (MOC), Ministry of Transmigration, etc. Funds are transferred to the Bank of Indonesia (BI) in USD note (5) and passed to the Appointed Bank in IDR notes (6). Allied with Local Government (LC), the OC determines the program, the location and the KUD (8). They also conduct pre-surveys to select eligible villages (9), sign contracts with Suppliers for system procurement (11) and authorize banks to disburse payment to Suppliers (14,15), the operational fees of which are paid by the appointed bank (7). KUD assesses the potential customer's suitability and the successful customers then sign Lease-Purchase contracts with KUD (10) to have their systems delivered, installed and commissioned by the Suppliers and OC Technical Team (12). Users pay their credits to KUD (16) who then deposits these payments to the local bank (17). These funds are later transferred to the appointed bank (18). KUD also provides service and system maintenance to the customer (19) supported by the Suppliers. (Source: Dasuki & Prasojo, 1995).

KUD is a central institution whose role is to oversee the administration of the projects at the village level, collecting PV payments and providing spare parts and a maintenance service. Several questions arise from this: Does KUD have sufficient management capacity to play this central role? Are there appropriate regulations and penalty mechanisms to ensure timely collection of payments?

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[3] The governmental agencies include BPPT (the Agency for the Assessment and Application of Technology), MOC (Ministry of Cooperatives), Ministry of Transmigration, DGEEU (Directorate General for Electricity and Energy Utilization), Bank of Indonesia.

[4] For instance AusAID, E-7, GEF, UNESCO, World Bank.

The experimental project at Sukatani demonstrated good financial management and book-keeping practices. However, proper financial documentation is not always been the case for other projects. The Banpres project for instance, upon the implementation of the regional autonomy or decentralization in 1999; Depkop (the Department of Cooperatives, which is responsible for coordinating KUDs) is no longer updated on the KUD's progress activities in payment collection and maintenance service at local level[5]. Therefore to obtain records on KUDs' activities one needs to contact the provincial/regional Depkop or alternatively to the KUDs directly. However, 'institutional memory' issues are also emerging. An anecdotal report mentioned that the successor of the KUD board in Kolaka, Sulawesi encountered difficulties continuing the PV system service and management when taking over the role from the previous board as adequate transfer of knowledge did not occur[6]. This resulted in the unavailability of trained technicians and spare parts which eventually lead to non-payment from the users. When end users observed that there were no consequences on non-payment this issue became contagious.

Thus it is important to asses the institutional sustainability of the PV implementation in order to ensure that PV is delivered within a framework that accommodates and allows for project monitoring and evaluation for the best interests of PV stakeholders and in particular the end users as the beneficiaries.

3.3. Technological Dimension

As a newly introduced technology, PV could entail a cultural gap between the system and the users which could lead to poor performance or shorter life of PV systems in spite of long life guarantees from the PV manufacturer. The transfer of technology without sufficient transfer of knowledge will leave PV alien to the users and could thwart the potential advantages of PV's contribution to energy services delivery to rural communities. To assess whether PV can be technologically sustainable, it is imperative to investigate how the PV users are handling the maintenance of PV systems. Questions arise as to their introduction of proper maintenance habits particularly when failures occur to the PV components and there are unfortunate consequences from improper handling of PV wastes such as electronic components, cables, batteries and lamp tubes. Issues concerning quality assurance, quality of installation and user intervention, for instance 'innovation' practices aimed at either enhancing the system's capacity or repairing any failures, are also part of the equation.

Case studies - Lampung, Sumatra island: Typically, a PV system is rated at 45-50 Wp and generates 240 Wh/day under an average solar irradiation of 5kWh/m^2/day (CADDET, 1999). A PV lighting system for domestic use commonly comes in a package as illustrated in Figure 1a. It comprises of a PV module, a 10A electronic charge controller, a 12V 70 Ah rechargeable battery, three 6-10 W fluorescent lights and connectors for audiovisual appliances. The PV module is supported from a roof beam, and lamps are commonly located in the terrace, in the living room and in a bedroom. In Lampung the battery and electronic controller are usually located in the living room above the television allowing regular condition monitoring of the charge state and acid level of the battery by family members. A preliminary observation in Lampung indicated that many end users found that the PV lamp was too bright for sleeping and could also attract the unwanted attention of thieves to their homes. Consequently the users still use traditional kerosene lamps after 10 pm effectively eliminating the energy saving feature of the PV system and raising their energy expenditure as they are now paying for both fossil fuel and PV instalments. One user attached motorcycle bulbs to the installation to reduce the illumination but unexpectedly found they actually consumed more energy exhausting the stored PV energy very quickly.

This case indicates that despite the innovative approach of bringing the PV closer to the users' culture, a cultural gap still exists between PV and the users. A PV system with a more flexible package for instance by including smaller wattage lamps for night light might solve the problem. More importantly, adequate information concerning system features and performance must be explained to the users prior to a transaction to ensure customer satisfaction and avoid disappointment.

[5] Source: Personal communication with Depkop, Jakarta, 23/01/03.
[6] Source: Personal communication with BPPT, Jakarta, 15/01/03.

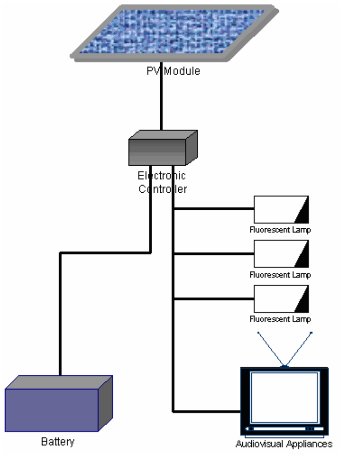

Figure 4a (left). A common PV lighting system package. Figure 4b (middle and right) PV lighting system installations in Lampung, Sumatra: The battery and the charge controller are located in the living room allowing practical observation of the charge state and the acid level of the battery by family members.

There are anecdotal reports of panels being relocated by local people for charging telecommunication equipment. This illustrates the villagers' ability to innovate using PV but may, of course, also raise the possibility of theft.

For PV to be technologically sustainable, answers to the above questions are therefore imperative to ensure that PV delivery to the villagers is more than a technocratic solution (Reid, 1999) delivered by a top-down approach which is inherently either centralistic or corporatist, and departs from local culture. Such a path eventually leads to further problems rather than a solution. Delivering PV to the remote communities in a building block fashion may be more effective than as a finished product because it would allow users to use PV in a way that meets their needs. In addition, it is of prime importance to investigate the most effective PV design whose features include a high degree of robustness, flexibility and adaptability to accommodate communal needs, given that communal gatherings (such as village meetings, *selamatan* –traditional gathering to celebrate birth, promotion, harvests, as well as to commemorate deaths, wedding parties, etc.) usually occur in the evening.

3.4. Environmental Dimension

PV systems provide a source of electricity for villagers to power their lighting, black and white TVs, radios and telecommunications. Before the introduction of PV, the villagers used fossil fuel energy such as kerosene for lighting, dry-cell batteries for radios and automotive batteries for TVs. In some villages and small towns diesel engines are used to meet the energy needs of community gatherings. Provided that the World Bank/GEF project is successful in Indonesia, it is anticipated that their PV project alone would abate approximately 2.2 million tons of CO_2 (PSG, 2002) from the reduction of kerosene and diesel fuel use. However, PV systems can also pose threat to the environment if their waste products are not handled properly.

The villagers main source of energy for cooking and heating is kerosene and fuel wood. The wood is obtained from home gardens, upland fields and forests. In Indonesia, boiling water before drinking is a common practice. Larsen (2000) reported that 1.8 billion cubic meters "is burned directly as wood fuel each year in developing countries" leading to deforestation. Coupled with the PV applications, solar technologies such as solar disinfectant (SODIS), low-cost solar water heaters, solar ovens and solar cookers would reduce the use of wood fuel, deforestation and CO_2 emissions.

In order to examine the environmental sustainability of PV applications in Indonesia, we need to answer the following questions: From the perspective of the replacement of fossil fuels: how much will CO_2 emissions and other negative environmental and health impacts be reduced? What would be the cost savings from avoiding the purchase of fossil fuel compared to the purchase price and the transportation cost of PV systems? In handling PV system wastes such as electronic components, cables, batteries or lamp tubes, how have the villagers been informed about the consequences of improper waste handling and disposal, especially the inorganic and toxic wastes, and what the effects are on human health? Is there any proper recycling program for handling PV waste products?

4. FUTURE PLAN

In the substantive research phase the current findings on PV implementation will be utilised to design a survey instrument and develop survey methodologies as well as nominating the villages to be surveyed. A broad spectrum of stakeholders will be interviewed, including users (villagers and islanders), manufacturers and representatives of the main institutional bodies. These will include KUDs, government agencies and local government. The survey is intended to investigate villager requirements, expectations and degrees of satisfaction, PV system performance, care and maintenance issues relating to the PV systems, monitoring protocols, as well as identify the costs, benefits, and values attributable to the installation of the systems, and a potential alternative more flexible PB design better able to cater to rural community needs. Because Indonesia consists of many islands with different ecosystems and cultures, villagers from different geographical areas will be studied to identify as broad a range of socio-economic issues as possible.

5. CONCLUSION

The research project discussed in this paper is a combination of social and engineering research that is intended primarily to examine the sustainability of PV systems as a means of rural electrification by considering the social, economic, institutional and environmental dimensions of system sustainability. The authors believe that for PV to be sustainable in off-grid applications in Indonesia, it is imperative that PV is delivered to rural Indonesians in an institutional framework that accommodates the interests of all stakeholders. PV is best viewed as an enabling technology able to strengthen the rural socio-economic culture, promote care for the environment, and from which they can earn their livelihood. For PV to be technologically sustainable, it is imperative that PV delivery to the villagers is more than a technocratic solution which is inherently centralistic or corporatist and departs from local culture. Of prime importance is the investigation of a PV design with a high degree of robustness, flexibility and adaptability to accommodate rural communal needs.

6. ACKNOWLEDGEMENT

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