THE I3A FRAMEWORK – ENHANCING THE SUSTAINABILITY OF OFF-GRID PHOTOVOLTAIC ENERGY SERVICE DELIVERY IN INDONESIA

M. Retnanestri[1,2], H. Outhred[1], S. Healy[1]

[1]The University of New South Wales, UNSW, Sydney NSW 2052, Australia
[2]STTNAS Jogjakarta College, Babarsari Jogjakarta 55281, Indonesia
E-mail: m.retnanestri@unsw.edu.au; h.outhred@unsw.edu.au; s.healy@unsw.edu.au

ABSTRACT

This paper describes the outcomes of an interdisciplinary PhD research project that combined social and engineering perspectives on the sustainability of off-grid Photovoltaic Energy Service (PVES) delivery in rural Indonesian communities without access to an electricity grid. The I3A (Implementation, Accessibility, Availability, Acceptability) Sustainable PVES Delivery framework was developed in this project as a holistic integration of three main theories: Sustainable Development (SD), Social Capital (SC), and Diffusion of Inovation (DOI), which combined with the WEC (World Energy Council)'s three energy goals (3A), was used to assess the sustainability of three off-grid PVES case studies from Lampung, West Java and Nusa Tenggara Timur (NTT) provinces respectively. The project methodologies included literature research, qualitative field research where PVES had been installed and interviews with a wide range of PVES stakeholders. A key conclusion was that, to be sustainable and equitable, off-grid PVES projects should be implemented in an institutional framework that provides sound project management and addresses PVES accessibility (financial, institutional and technological), availability (technical quality and continuity) and acceptability (social and ecological). Drawing on those insights, ways to enhance off-grid PVES delivery in rural situations in Indonesia are recommended. The outcomes of the PhD research project have since been used as the basis for a successful Australian Development Research Award (ADRA) grant application involving collaboration between UNSW and Indonesian institutions. A companion paper discusses the structure and objectives of the ADRA project and early outcomes from that project.

RESEARCH BACKGROUND & OBJECTIVES TO ADDRESS OFF-GRID PVES SUSTAINABILITY ISSUES IN THE INDONESIAN CONTEXT

The objective of this interdisciplinary PhD research project was to combine engineering and social perspectives to investigate and recommend ways in which photovoltaic energy system (PVES) could contribute to improving the sustainability of the lives of Indonesians in off-grid rural situations. In 2005, almost 50% of Indonesia's population, equivalent to approximately 110 million souls, had no access to electricity supply (PLN 2006). The archipelagic nature of Indonesia constrains the full extension of the national electricity grid to remote areas and PVES has been seen as one of the solutions. Since the 1980s, approximately 10 MWp of PV power has been installed across Indonesia for powering lighting, water pumping, communications, health care etc. However, many

PVES projects have failed and PVES remains inaccessible to many remote Indonesian communities.

PVES is a technological intervention involving hardware, software and hardware (IIASA 2006) in which:

- Hardware refers to the photovoltaic panels, battery and associated balance of system equipment as well as the end-use equipment required todeliver valued energy services such as lighting, communications or refrigeration.
- Software refers to the information and skills needed to design, install, operate, maintain, decommission and reinvent[1] the hardware and/or its use.
- Orgware refers to the institutional context that facilitates the sustainable development and application of PVES.

Successful application of PVES faces financial, technical, social and institutional barriers because the software and orgware dimensions of the technology are important in that context and must be simultaneously and effectively addressed. The following key findings from fieldwork in Indonesia in 2003 and 2005, summarize the prospects and issues for PVES sustainability in Indonesia (Retnanestri 2007):

- **Institutional:** Successful PVES installation has involved the establishment of local electricity institutions (software and orgware), which are indicators of the strengthening of local institutional capacity. However, in some cases, the lack of follow-up field assessment and local capacity to adapt PVES to local conditions has led to inadequate project performance and eventually PVES failure.
- **Financial:** Some revolving funds have been generated from past government projects and PVES has been used to support income-generating activities, which are indicators of financial sustainability. However, off-grid PVES delivery is characterised by scattered markets that are expensive to service and PV modules remain expensive. Thus, first-cost barriers remain to wide-spread PVES deployment. On the other hand, the energy service model can exhibit lack of transparency and poor financial management.
- **Technological:** Domestic manufacturers of balance of system components and PV panels have managed to penetrate the market and even export to other developing countries. However, inadequate after-sales service infrastructure and spare parts availability, poor installation practices and inadequate warranties undermine PVES continuity.
- **Social:** Given the right conditions, PVES has improved rural community well-being by providing access to clean water, good quality lighting, telecommunications and infotainment and has supported job creation, which together can improve community wellbeing and improve energy security. Thus off-grid PVES can be a useful vector for energy service delivery to facilitate Sustainable Rural Development (SRD). However malfunctioning PVES hardware imposes externally derived problems on communities that in some cases can lead to social fragmentation.
- **Ecological:** PVES can be environmentally friendly and noise-free, enhance sustainable rural development and contribute to the greenhouse gases (GHG)

---

[1] Reinvention refers to the degree to which an innovation is changed or modified by users to fit their situation (Rogers, 2003, p17).

mitigation strategies as well as reduce the need to transport fossil fuels, in itself a GHG emitting activity. However, inappropriate waste disposal can undermine such worthwhile objectives.

The I3A (Implementation, Accessibility, Availability, Acceptability) framework was developed as a holistic approach to investigate PVES delivery sustainability and the extent to which PVES can contribute to improving the sustainability of the lives of Indonesians in off-grid rural situations, considering institutional, financial, technological, social and ecological dimensions, simultaneously addressing issues related to the hardware, software and orgware aspects of PVES delivery.

This paper describes the I3A framework, its conceptual background and its practical application in Indonesia. The outcomes of this PhD research project have since been used as the basis for a successful Australian Development Research Award (ADRA) grant application involving collaboration between UNSW and Indonesian institutions, described in a companion paper that discusses the structure and objectives of the ADRA project and early outcomes from that project (Retnanestri et al 2008).

RESEARCH DESCRIPTION & METHODOLOGIES

The research project discussed in this paper combined social and engineering research methods and qualitative fieldwork to develop a systematic approach to achieving good PVES delivery outcomes. The methodologies of the research include literature research, qualitative field research in villages where PVES has been installed and interviews with a wide range of PVES stakeholders in Indonesia (involving 150 respondents from governmental institutions, donor agencies, PVES industries, NGOs, and PVES sites).

CONCEPTUAL BACKGROUND OF THE I3A FRAMEWORK

PVES delivery refers to a process of transferring PV systems from providers to users, involving a short term activity focused primarily on using the provider's external software and orgware to install the hardware (the delivery and installation of the PV system hardware), followed by a long-term activity relying more on the community's local software and orgware (the continuing PVES operation and its ongoing operating role in delivering energy services). The I3A model, referring to an Implementation that maintains PVES Accessibility, Availability and Acceptability, is used to investigate PVES sustainability by assessing PVES delivery objectives, the delivery process and mechanism (considering both the PVES hardware and its stakeholders or PVES orgware), the resources required, the outcomes to be achieved, and the ongoing energy service following installation of the hardware.

The I3A framework, see Figure 1, was developed as a holistic integration of three main theories: Sustainable Development (SD)[2], Social Capital (SC)[3] and Diffusion of

[2] "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p8).
[3] Dynamic resources in both structural & cognitive terms (network, trust, norms, reciprocity) that, subject to the ways in which they are used, may increase, decrease or remain constant overtime (Retnanestri 2007).

Inovation (DOI)[4], combined with the three energy goals (3A, Accessibility, Availability, Acceptability) of the World Energy Council (WEC, 1999). The SD dimensions (institutional, technological, financial, social and ecological) are essentially descriptive and used as underlying principles. The DOI theory is an operational concept, which, in this context, describes a process of PVES delivery that takes into account the attributes of the PVES system (advantages, complexity, etc.), assigns appropriate stakeholder roles and acknowledges their interests in a way that promotes PVES acceptance and reduces the risk of its discontinuance. SC acts as a mediator between the conceptual and operational levels ensuring social inclusion (civic engagement and active stakeholder participation) during the implementation process, taking into account the shared values of all stakeholders (norms, trust, and reciprocity) to achieve mutual benefits from PVES delivery. SC can be viewed as a resource, a stock or an asset to be used in the PVES delivery process, or as an outcome that can be enhanced by PVES delivery. The overall objectives of the I3A framework are to acknowledge the interests of all stakeholders, maximize equity, assure PVES service continuity and institutionalize PVES by utilizing and enhancing pre-existing community resources to leave the host communities with the capacity to meet their evolving needs, such that PVES can contribute to sustainable rural development. The premise of the I3A framework is that to be sustainable and equitable, PVES projects should be implemented in an institutional framework that addresses PVES accessibility (financial, institutional and technological), availability (technical quality and continuity) and acceptability (social and ecological), by assessing the I3A components shown in Figure 1 and detailed in Table 2.

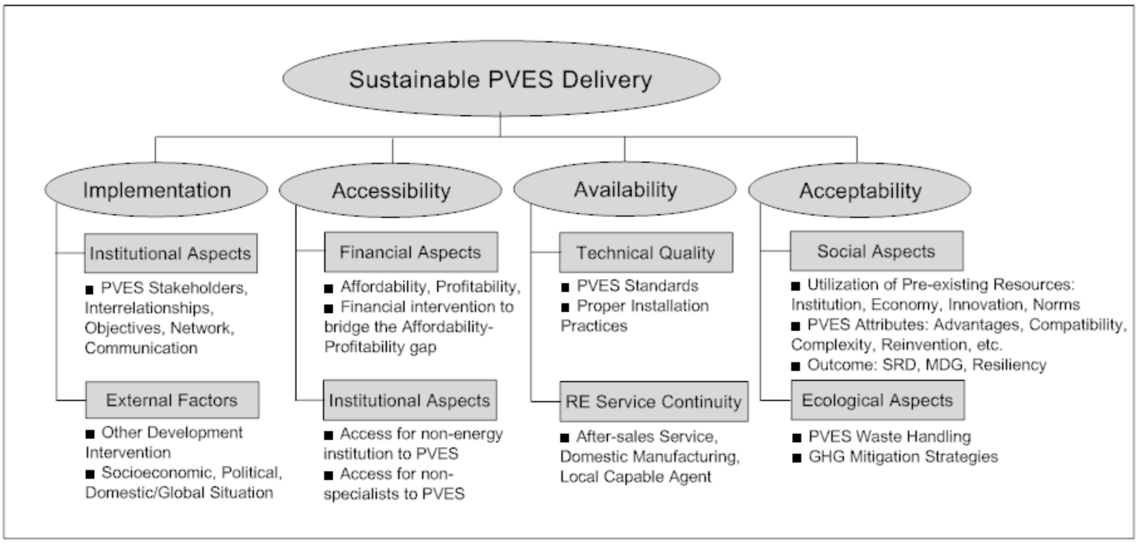

Fig.1: The I3A Model: Sustainable PVES Delivery Framework

USE OF THE I3A FRAMEWORK AS AN ANALYTICAL AND DESIGN TOOL

The I3A model can be used either as an analytical tool or a design tool. The Implementation (I) component assesses or guides the implementation of the PVES project taking account of the stakeholders and their relationships (viewed as a social

[4] "The process in which an innovation is communicated through certain channels over time among the members of a social system" (Rogers, 2003, p5).

system and as PVES orgware). The 3A serve as sustainability benchmarks or key measures that assess the extent to which PVES accessibility, availability and acceptability has been or can be at least maintained and preferably enhanced over time to leave the community with capacity and resources to socially innovate to meet evolving needs beyond hardware installation. See Figure 2.

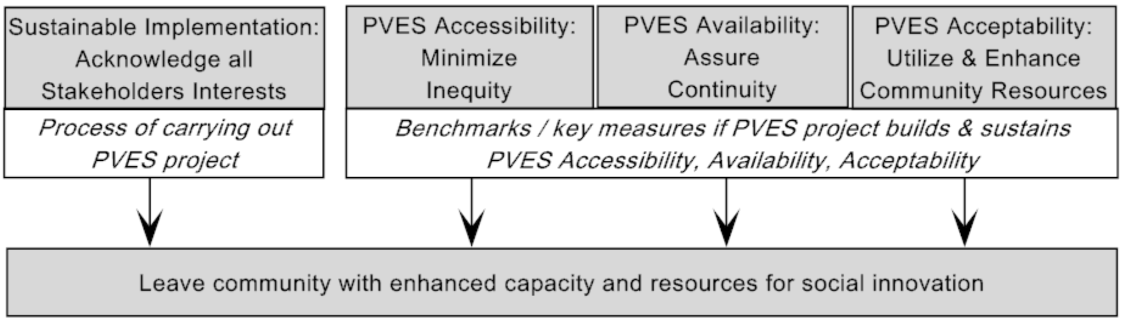

Fig.2: Use of the I3A framework as an analytical or design tool for a PVES project

As an analytical and design tool for a PVES project, the I3A framework is used in two steps: First, a PVES project is assessed/designed by breaking down PVES sustainability into five dimensions: - institutional, financial, technological, social and ecological sustainability as listed in Table 1. Secondly, the PVES sustainability issues are transposed into the I3A framework and assessed using the I3A components listed in Table 2, to ensure that project design and implementation acknowledges the interests of all stakeholders, maintaining accessibility to minimize inequity, availability to ensure energy service continuity and acceptability by utilizing and enhancing local community resources.

Tab.1: Sustainability questions for PVES analysis

Institutional Sustainability: Is the institutional framework for PVES delivery sustainable? What should be the role of each body in project design, project implementation, post-project monitoring, PVES training, education and dissemination? Does the project leave the community with sufficient capacity for on-going socially beneficial innovation after it has been completed? Have all the potential applications of PVES that may deliver service to rural people via non-energy service delivery chains been identified and implemented? Does the environment in which a PVES project is implemented enable the project to operate sustainably?
Financial Sustainability: Is the arrangements for PVES investment financially sustainable? Are there appropriate regulations and penalty mechanisms to ensure timely collection of user payments? Considering the diverse segments of the target communities, are questions of equity acknowledged and addressed?
Technological Sustainability: Have orgware, software and hardware dimensions of PVES technology been adequately addressed? How has the provision of PVES system quality, proper installation practices, component guarantees and after sales service been maintained? How have villagers dealt with the operation and maintenance of PVES systems, and system failures such as electronic components and batteries? Have there been any user innovations aimed at either enhancing PVES capacity or adapting it for different uses, or repairing failures?
Social Sustainability: Can PVES become a tool for sustainable rural development? Has PVES provided short term or long term benefits to the villagers to improve their wellbeing? Does the project provide, and leave on completion, the community with resources for on-going socially beneficial innovation to meet evolving community needs?
Ecological Sustainability: PVES produce wastes such as electronic components, cables, batteries, etc. Has waste management at the local level been adequately facilitated? By how much have CO_2 emissions& other ecological impacts been reduced? Does PVES function well under the local physical environment?

Tab.2: PVES sustainability assessment using the I3A framework components

Implementation: Acknowledgement of all Stakeholders Interests - **Institutional:** Looking at PVES social system (stakeholders, objectives, interrelationships) in the delivery process. Stakeholders' interrelationship can be vertical (top-down), horizontal or hybrid. For good PVES project outcomes, it is necessary to create a civic network that acknowledges the interests of all stakeholders, encourages their active participation and promotes self reliance. - **Enabling environments:** Looking at the external factors affecting PVES delivery
Accessibility: Minimize PVES Inequity. Accessibility assesses PVES equity issues from the financial, institutional and technological perspectives. To improve PVES accessibility and the ability of rural communities to meet their future energy needs in an autonomous fashion, facilitators need to understand the communities' prior socioeconomic situation and technological capability. - **Financial:** Affordability, profitability and equitable access to PVES, delivery model appropriate to the market segment (more commercial to less commercial). - **Institutional & Technological:** Access for local institutions, non-energy institutions and non-PV specialists to PVES financing, skills and network
Availability: Assure PVES Service Continuity. Availability focuses on the quality & continuity of energy service supply necessary to maintain confidence in PVES & providers. Users may discontinue the use of PVES if availability is too low. Robust PVES hardware is essential to withstand various physical conditions in the field. Equally important are sound local institutions, local capable agents and well-informed users to maintain PVES availability throughout its technical lifetime. **- Technological:** Technical standards, proper installation practices, domestic manufacturing, spare parts **- Institutional:** After sales infrastructure, local institution, local capable agent, user education
Acceptability: Utilize & Enhance Community Resources. Acceptability focuses on the extent to which PVES can acculturate into local life, strengthening rural socioeconomic culture & promoting ecological care to facilitate SRD. **- Social:** Local requirements vs. PVES attributes (advantage, compatibility, etc), utilization & enhancement of local community resources (institution, economy, innovation), PVES contribution to SRD **- Ecological:** GHG mitigation aspect as well as PVES suitability to local physical environment

The I3A framework was used to analyse three off-grid PVES case studies in Lampung, West Java and NTT provinces in Indonesia, as discussed briefly in the following sections. See Retnanestri (2007) for a more detailed discussion of the analysis.

CASE STUDY 1: AN ORGANIC SHS MARKET IN LAMPUNG PROVINCE

The self-reliant organic Solar Home System (SHS) market in Lampung province emerged as a result of the 1997 Indonesian financial crisis that caused the pre-existing formal market to collapse, leaving thousands of its customers, who had installed SHS since the 1990s, stranded without after sales service. The self-reliant market then evolved in an organic fashion, whereby the former sales representatives and technicians of a failed PVES company saw business opportunities to offer spare parts and maintenance services. Both the entrepreneurs and the customers relied on their own investment in this informal, private SHS sales model, in which both new and second-hand PV modules are now traded.

- **Implementation Aspects**

The organic, informal SHS market institution facilitated the horizontal network for information sharing. SHS Users and Providers (the entrepreneurs) had a high degree of familiarity with SHS and were able to make flexible transactions, negotiating the payment terms and the content of the SHS packages.

- **Accessibility Aspects**

Accessibility was maintained by the use of second hand modules, flexible system configuration (for example buying SHS without a battery charge regulator (BCR) to save approximately A$20) and payment terms (made on a seasonal basis for example). However the poorest segment of the villagers remained unable to access SHS.

- **Availability Aspects**

No formal SHS standards were used other than practicing the skills and knowledge obtained since the 1990s. Local capable agents made profitable businesses out of maintaining service continuity (for example spare parts sales, electronic repair and battery maintenance). Users bypassed the BCR and substituted for it, for example by managing load according to weather condition (eg use less load following cloudy days), enabling them to prolong battery life (up to 5 years).

- **Acceptability Aspects**

SHS has been part of the ongoing activities of the local people who have demonstrated a high degree of technical reinvention (BCR bypass, system configuration) and social innovation (job creation, SHS is used beyond lighting purposes for swallow bird farming, users wanted PV-powered radio for working at field, donation to community facilities, strategy for reducing fire risk hazard from kerosene wick lamps, etc) indicating SHS acculturation into local life.

Fig.3: The SHS organic market in Lampung Province, Sumatra. From left: 1) A farmer who had owned SHS since 1991 purchased a second SHS package. 2&3) The SHS technician displaying spare parts in his outlet and demonstrating a simple SHS current-voltage (I-V) testing. 4) An SHS user discussing SHS with neighbours. (Photos: M Retnanestri 2005).

CASE STUDY 2: THE WORLD BANK/GEF SHS PROJECT IN INDONESIA

The 1997-2003 World Bank/GEF SHS semi-commercial project, implemented in Lampung, West Java and South Sulawesi provinces, provided a 20% consumer subsidy, enacted SHS standards and facilitated the certification of Indonesian PVES testing facilities. The initial sales target was 200,000 SHS units but the project was severely affected by the 1997 Asian financial crisis, resulting in only 8,054 sales by project end (GEF 1996 and PSG 2004 in Retnanestri 2007).

- **Implementation Aspects**

This project involved six Jakarta-based SHS dealers who operated in Lampung, West Java and South Sulawesi by establishing rural outlets. This centralized project focused more on the supply side than the demand side, by providing technical assistance, increasing manufacturing capacity and exporting Balance of Systems (BOS) components. The providers determined the SHS package and payment terms and this vertical network did not allow users to be active participants.

- **Accessibility Aspects**

Accessibility was maintained by providing a 20% subsidy (USD 2/W_p) from the GEF, which was aimed at making SHS more affordable to users and more profitable to providers. Even so, only the wealthier segment of villagers could afford to buy an SHS. Following the completion of the project, sales declined forcing rural outlets to close down, thus financial dependency on subsidy had not been eliminated.

- **Availability Aspects**

Users were protected by internationally complying SHS standards. Domestic SHS standards enacted and testing facilities accredited. Continuity was maintained with the establishment of rural outlets that continued to operate during the project period, but raised a question about future availability of after sales service. User familiarity with SHS varied, in some cases resulting in user disappointment from overselling. Loss of battery storage capacity within 6 months after installation resulted in users deciding to bypass the BCR.

- **Acceptability Aspects**

In general users acknowledged SHS benefits (more practical, more reliable compared to the grid, improved quality of life, less use of kerosene and diesel fuel, creating jobs during project implementation) but there were also cases where SHS remained alien (lamps too bright to sleep at night, fear that brighter light provoked observation by thieves). The banking system remained unpopular (villagers preferred to keep their money under the pillow rather than depositing it in a bank, villagers preferred to spend their time working in the field rather than travelling to a bank office located a distance away from the village, the credit administration process involving a letter of recommendation from the head of the village was seen as disclosing a financial hardship to others ((Dian Desa 2003 in Retnanestri 2007)). Resolving this required an innovation in a non-technical dimension during project design and implementation for the local people to acculturate SHS in their lives.

Fig.4: The WB/GEF SHS project. 1&2) Cirata Lake, West Java: A 50 Wp SHS installed on a hut roof of fish floating net powering lighting and telecommunication to support economic activities, and an outlet displaying SHS. 3) Lampung Province: The battery and the BCR are located in the living room allowing practical observation of charge state and acid level of the battery by family members. (Photos: M Retnanestri 2005).

CASE STUDY 3: THE PLD CONCEPT IN NTT PROVINCE

The *Pengelola Listrik Desa* (PLD), or village electricity management formed from among the users, was initiated by the 1997-2000 E7 project as a CDM test-wise tool, facilitated by the locally based Womintra NGO (E7 in Retnanestri 2007). A PV-Wind-Diesel hybrid system was installed in Oeledo village, Rote Island. The PLD concept was later replicated in other parts of NTT, including Pusu village, in which 150 SHS units were installed during 2003-2005 (Retnanestri 2007).

Fig.5: From left: 1) The PV-Wind-Diesel hybrid system (21.8kW-10kW-20kVA) installed in Oeledo village, Rote Island/NTT. 2&3) PLD Pusu: A SHS subscriber whose also a weaver of West Timorese traditional fabric now able to work for longer hours and earn more. 4) Monthly SHS payment session at PLD Pusu office, in which the traditional weaving products were displayed for sales. (Photos: M Retnanestri 2005).

- **Implementation Aspects**

The combined vertical (in terms of technical design) and horizontal (in terms of project implementation and ongoing operation) project design consolidated the differing interests of the investing parties (the G7 countries) and the host community. Involvement of local communities and a local capable institution (NGO) to act as facilitator was instrumental in achieving a successful project outcome.

- **Accessibility Aspects**

The donor provided capital investment for the equipment and project implementation, and users paid the operation, maintenance and energy usage on monthly basis. The project was accompanied with rural economy empowerment to tap local economic potential enabling them to pay for the electricity regularly. Significance revenue was generated but not sufficient to refinance a similar investment.

- **Availability Aspects**

Availability was maintained by the use of PVES complying to international standards and the availability of a local institution to maintain the continuing operation of PVES. The use of foreign equipment created dependency on outsourced repair.

- **Acceptability Aspects**

PVES has become part of ongoing village life with more and more villagers wanting access to PVES to achieve the perceived benefits (social gathering, better quality of lighting, avoid fire hazard from kerosene lamps), however care should be taken to avoid strengthening social hierarchy (for example adding to women's domestic tasks).

CONCLUSIONS AND RECOMMENDATIONS

The I3A framework can shed light on the extent to which off-grid PVES can contribute to improving the sustainability of the lives of rural Indonesians by applying the following criteria:

- Sustainable implementation: Promote a civic PVES social system by acknowledging the interests all stakeholders, encouraging their active participation, and enhancing self reliance.
- PVES accessibility: Build user autonomy so that users have the capacity to participate actively, with access to PVES financing, skills and networks, thus maximizing PVES equity.
- PVES availability: Ensure availability both during and after project completion with a paradigm shift from emphasising the hardware to emphasising the software and orgware dimensions of technology.
- PVES acceptability/acculturation: View PVES as an enabling technology focusing on using the PVES to enhance pre-existing local resources.

The main limitation of the I3A model is that it requires substantial effort to implement. However, this investment may be necessary to achieve good outcomes regardless of the approach used.

REFERENCES

IIASA (undated), What is Technology?, www.iiasa.ac.at

PLN, (2006), PLN Statistics 2005, PT PLN (*Perusahaan Listrik Negara*/The Indonesian National Electricity Utility), Jakarta.

Retnanestri, M., (2007), The I3A Framework – Enhancing the Sustainability of Off-Grid Photovoltaic Energy Service Delivery in Indonesia, PhD Thesis, http://www.library.unsw.edu.au

Retnanestri, M., Outhred, Tugino., Astuti, B., Rezavidi, A., Prastawa, A., (2008), An ADRA Research Project to Overcome Barriers to Renewable Energy in Rural Indonesia by Community Capacity Building Using the I3A Framework, a paper submitted to the ISES-AP-2008 Conference, Sydney 25-28 November 2008.

Rogers, EM., (2003), The Diffusion of Innovations, Fifth Edition (1962, 1971, 1983, 1995, 2003), Free Press, New York, ISBN 0-7432-2209-1.

WCED, (1987), Our Common Future, The World Commission on Environment and Development, Oxford University Press, New York, ISBN 0-19-282080-X

WEC, (1999), "Achieving Equitable Access to Sustainable Energy", World Energy Council, Available Online: http://www.worldenergy.org/wec-geis/

BRIEF BIOGRAPHY OF PRESENTER

Dr Maria Retnanestri completed her PhD degree at the School of Electrical Engineering & Telecommunications, the University of New South Wales (UNSW), Sydney, Australia, in November 2007. Currently she is a Research Associate at UNSW funded by the Australian Development Research Award (ADRA) 2007 to identify ways to overcome barriers to renewable energy for sustainable development in developing countries.