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A LITERATURE-BASED STUDY OF THE BARRIERS TO AND ADVANTAGES OF SMALL-SCALE MANUFACTURE OF CHARGE CONTROLLERS AND LAMPS FOR PV SYSTEMS IN DEVELOPING COUNTRIES

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ABSTRACT

Low quality charge controllers and lamps are common sources of failure in solar home systems in developing countries. It is often assumed that components manufactured at a small scale in developing countries are of lower quality than imported ones. On the other hand, a number of authors have suggested that small-scale, local manufacture has the potential to improve the installation, maintenance and use of PV technology. This paper aims to identify the extent to which these different claims are warranted by documented experiences and to provide a summary of barriers to and advantages of small scale manufacture of balance of system (BOS) electronics for small PV systems in developing countries.

The PV literature has been reviewed for any accounts of small-scale manufacture of PV system components in developing countries. The review was further informed by case studies, site inspections and personal communications undertaken by the author, as described in (Bruce 2007). The implications of local manufacture for the successful commercialisation of the technology, and the implications of both project-based and cash-based implementation models for the success of local manufacture have been examined. The results of the literature review are presented in this paper.

INTRODUCTION

A number of studies have summarised lessons learnt or key barriers to success of photovoltaic (PV) projects (Barnes & Floor 1996; Cabraal *et al.* 1996; Lorenzo 1997; Lorenzo 2000; Martinot *et al.* 2000a; Martinot *et al.* 2000b; Nieuwenhout *et al.* 2000; van Campen *et al.* 2000; Wilkins 2002; IEA 2003a; Nieuwenhout *et al.* 2004). Many case studies of PV diffusion and use have also been published. According to these sources, main barriers to the successful commercialisation of PV in developing countries fall within the following categories:

- High upfront cost,
- Low quality of the hardware,
- Poor technical capability in system design, installation, maintenance and use of the technology,
- Unsuccessful organisational structures in projects and programmes,
- Inadequate market institutions resulting in poor information flows and contract enforcement.

It has been suggested that the local manufacture of PV system components can contribute to a more sustainable use of the technology via improved technical knowledge and skills, availability of spare parts, access to information and potentially lower cost (Acker & Kammen 1996; Gillett & Wilkins 1999; Mulugetta *et al.* 2000; Green 2004; Kumar *et al.* 2005).

Local manufacture has the potential to mitigate problems in relation to some of the above issues, whereas others represent particular barriers for small-scale manufacturers. In this paper, the PV literature is reviewed in order to identify barriers and advantages to local manufacture, the implications of the characteristics of PV markets for local manufacturers and to suggest how local manufacture of PV system components may be supported.

This review is primarily concerned with charge controllers and lamps, which are the most common electronic BOS used in solar home systems. The main function of a charge controller is to regulate charge to the battery in order to protect it from damage due to overcharging. Fluorescent lamps are most commonly used in solar home systems. The electronic lamp ballast provides a very high frequency waveform of around 20kHz to excite mercury vapour in the tube. Vervaart & Nieuwenhout (2000) provide a useful review of these components.

THE ROLE OF LOCAL MANUFACTURE IN DEVELOPMENT

Micro, small and medium-sized enterprises, often as part of the informal economy, provide the majority of employment in developing countries (Overseas Development Institute 2002). Small scale enterprises[1] have the potential to enhance the livelihoods of the poor, who are often isolated from the processes of modernisation and industrialisation (Khosla 1994), via:

- Employment, income and livelihood diversification
  Small scale industries are generally more labour intensive than larger enterprises (Albu 2001) and are able to generate employment more suitable to women (Islam 1992). Rural enterprises can provide employment in rural villages, preventing migration to urban areas (Panditrao 1994), helping to keep rural wages higher and reducing livelihood vulnerability to seasonal or disaster-related variations in agricultural output or employment opportunities (Davis 2004).
- Resource use and keeping money in the local economy
  Small enterprises employ skills, entrepreneurial talent and savings (Aftab & Rahim 1987), often more productively than agricultural activities. They may therefore be drivers of economic growth in rural areas. When producing goods and services for external markets, they may bring money into the local economy, while production for local use prevents leakages to pay for externally produced goods.
- Providing technology for the poor
  The modern sector usually does not receive sufficient market signals to induce the development of tools and technologies suitable for the rural poor. Small scale manufacturers therefore have a role to play in providing this technology. Since small scale manufacture does not require standardisation in product and process design (Krishnaswamy & Reddy 1994), where technologies need to be adapted, repaired or maintained locally to suit local conditions and activities; small, local manufacturers are well placed to provide them in a cost effective and sustainable manner.

[1] Small scale enterprises are defined for the purposes of this paper as those that are small in size, operate locally, utilise local resources and produce products for local markets using relatively small amounts of capital and simple production methods.

- The development of local capabilities
  The use of technology requires, but also enhances the capabilities of entrepreneurs, their employees and users of the technology, increasing livelihood options for poor communities. In particular, local manufacture may help to develop and improve the capabilities for after-sales service of the product (Krishnaswamy & Reddy 1994).

ACCOUNTS OF LOCAL MANUFACTURE OF PV BOS

The manufacture of balance of system (BOS) components for remote applications in developing countries is primarily carried out by small enterprises, often in developing countries (Vervaart & Nieuwenhout 2000), although in many countries, the components are imported from other developing countries (Kumar & Bhattacharya 2005) and components for use in large projects are often imported from developed countries.

Table 1 summarises the instances of local manufacture that have been described in some detail in the literature and which are reviewed in this paper.

Table 1: Summary of Projects Reviewed and Sources

PROJECT & SOURCES	DESCRIPTION
Instituto de Energía Solar (IES) Bolivian Altiplano project (Aguilera & Lorenzo 1996; Huacuz & Gunarante 2003)	A project carried out in the Bolivian altiplano from 1988-1993 included the establishment of rurally-based manufacturing of balance of systems components in a small town of 50 families, 45 km from La Paz. Circuits and casings for simple series charge regulators with MOSFET switches and 18W fluorescent lamps were manufactured on the basis of designs from the Institute of Solar Energy in Madrid, Spain. These were installed locally within the project.
GEF/World Bank assisted China Renewable Energy Development Project (CREDP) (Stone *et al.* 1998; Cabraal 2000; Li 2003; Cabraal 2004; ter Horst & Zhang 2005)	Technical specifications for modules, charge controllers, inverters and DC lights developed through project. National PV testing facilities established and national component and system standards adopted. 50% of the cost of testing was covered by CREDP for businesses whose components complied. Hefei University of Technology was contracted to provide design assistance to Chinese manufacturers to improve the quality and performance of their products to meet the standards. R&D grants and business development services were provided to manufacturers.
Indonesian Local Manufacture and National Programme supported by Fraunhofer ISE, TüV Rheinland, GEF/World Bank Indonesia project and ECN, Netherlands (Fitriana *et al.* 1998; Nieuwenhout *et al.* 2004)	Fraunhofer ISE and TüV Rheinland assisted government authorities to establish a test centre for the certification of PV components and systems to be installed in a collection of projects under a national 50MW programme. Technical specifications were developed for the project and problems with the designs of local component manufacturers were identified by ECN. The manufacturers did not implement the changes straight away due to low demand at the time, and some of the changes made led to passing certification but poor performance in the long term.
Local Manufacture in Kenya (Hankins 2000; Duke *et al.* 2002; Jacobson & Kammen 2005; Moner-Girona *et al.* 2006)	Kenya has one of the largest cash markets for PV products worldwide. There are as many as 20 companies involved in the manufacture of 12V lamps and charge controllers and three battery manufacturers in Kenya. In 2000 more than 90 percent of the batteries, 30–50 percent of the lamps, and 10 percent of the charge regulators used in local solar home systems were manufactured locally.

Kiribati and Tuvalu utility model supported by the EU (Gillett & Wilkins 1999; Tani 2003b; Wade 2003)	Local utilities have been established with the support of the EU in Kiribati and Tuvalu. Senior technicians manufacture charge controllers, DC-DC converters and night-lights locally using designs provided by EU. The circuits are designed using an open circuit board to be repaired or refurbished in the field. External and internal training courses and on the job training has built technical and management capacity. Local field technicians collect fees and perform regular maintenance, while senior technicians visit twice a year to address electronics problems. The designs for the BOS have been improved over time.
RET-Asia projects in Bangladesh, Cambodia, Vietnam, Lao, Nepal and the Philippines, supported by SIDA (Sweden) and coordinated by AIT (Asian Institute of Technology, Thailand) (Ibrahim 2005; Kumar & Bhattacharya 2005; Kumar *et al.* 2005; Samy & Sovanna 2005; Sayalath & Theuambounmy 2005; Trinh 2005)	In each country, any local manufacturers were identified, products were tested, designs were improved and new ones developed to suit local requirements and to be manufactured and repaired locally with available parts. Standards, testing facilities and research capability were established by Local Government agencies and/or NGOs, which then supported commercialisation by local manufacturers in most of the countries, or manufactured them themselves. Manuals and training for technicians and users as well as technology transfer; seminars and fellowships between institutions in participating countries were used to disseminate knowledge.
Solar Power and Light Company (SPLC) Sri Lanka supported by the Sri Lankan ASTAE World Bank Program (Cabraal *et al.* 1996; Huacuz & Gunarante 2003)	In the late 1980s, Solar Power and Light Company (SPLC) manufactured PV modules, 12V lamps and charge controllers domestically. Other solar PV firms, NGOs and government programs involved with the Sri Lankan ASTAE World Bank Program purchased the modules at wholesale prices.
Zimbabwe GEF Solar Project and JICA (Japan) intervention (Mulugetta *et al.* 2000; IEA 2003a; Tani 2003a)	Standards and testing facilities were established in the 1990s with the assistance of the Danish Technical Institute. Local manufacturers that were able to comply qualified for subsidies and manufacturing, installation and maintenance training. Existing smaller companies often were unable to qualify and therefore to benefit from the subsidies and training, while unsustainable larger companies only operated as long as the subsidies existed. JICA therefore later supported selected charge controller and lamp manufacturers to improve their designs and quality control, but manufacturers could not achieve the required quality within the project timeframe and the controllers were eventually replaced with a Japanese manufactured model.

THE COST AND QUALITY OF LOCALLY MANUFACTURED BOS

Although PV is often the cheapest option for rural electrification over the life cycle of the system, the high upfront cost of the hardware is one of the major barriers to the diffusion of the technology in developing countries. Poor quality hardware has frequently been emphasised as a cause of system failures, and it is often assumed that the quality of locally manufactured components will be lower than imported ones (Stone *et al.* 1998; Ling *et al.* 2002). The following sections review the evidence from the literature to see whether cost and quality of PV systems is impacted by local manufacture of BOS.

Local Manufacture and High Upfront Costs

The cases reviewed here indicate that local manufacture is cheaper than the imported product in many cases, including the Bolivian altiplano project (Aguilera & Lorenzo 1996), Brazilian manufactured lamps (Zilles *et al.* 2000), Kenyan batteries and lamps (Acker & Kammen 1996) and Bangladeshi charge controllers and lamps, which were 50% cheaper (Kumar *et al.* 2005). In the RET-Asia project, the local products were designed to be simpler and therefore cheaper. Local manufacturers in Kenya and China benefited from avoidance of transport costs, sales tax and import duties (Acker & Kammen 1996; Stone *et al.* 1998; Hankins 2000). However, local manufacturers often need to use imported components, and in some cases become the sole importer of electronics in the country, such as in Bolivia (Aguilera & Lorenzo 1996). They are therefore vulnerable to changes in the value of the local currency, which was problematic in Zimbabwe (Mulugetta *et al.* 2000) and import duties, which was problematic in Sri Lanka (Huacuz & Gunarante 2003).

Local Manufacture and Hardware Quality

Within this literature survey, the quality of locally made BOS components has been found to be mixed. The quality of local components was found to be initially inadequate in many of the RET-Asia countries that had existing manufacturing, such as Nepal, Bangladesh and Vietnam. Quality of locally manufactured products was also found to be poor in Indonesia (Fitriana *et al.* 1998) and in the case of Brazilian-made charge controllers (Zilles *et al.* 2000). However, locally made products in Bolivia performed equally to those made in Spain (Aguilera & Lorenzo 1996) and better reliability was recorded for locally manufactured lamps than imported ones in Brazil (Zilles *et al.* 2000). Locally made components in Kiribati also recorded low failure rates (Gillett & Wilkins 1999). During development of new products through the RET-Asia project, high failure rates were experienced (5% for charge controllers and 15% for lamp ballasts in Bangladesh and 2% for charge controllers in Vietnam), but failure rates were insignificant after designs and components were improved on the basis of field monitoring and user feedback (Ibrahim 2005; Kumar *et al.* 2005). Components from Kiribati and Vietnam have been exported to other developing countries on the basis of their good reputation (Gillett & Wilkins 1999; Trinh 2005).

There are also numerous examples of poor quality imported components in rural electrification projects (Wilkins 2002; Nieuwenhout *et al.* 2004). For instance, in Zambia, imported prepayment devices and batteries were found to be poor quality and 28% of imported lamps were found to have malfunctioned after a few years (Gustavsson & Ellegard 2004). 20 projects which had some analysis of failure modes were reviewed by Bruce (2007), and where it could be confirmed that the components were either locally manufactured or imported, the failure rates were recorded. Imported and locally made components were reported to be of poor quality in an equal number of projects. However, the perception that small manufacturers are unable to produce products of sufficient quality remains and high quality is likely to be difficult for them to achieve without assistance.

Problems Related to Design of Charge Controllers and Lamps

Most small controllers used in developing countries are simple, low-cost on/off charge regulators, which require a relatively small amount of electronics. These are often hand-built by small-scale local manufacturers to suit diverse markets (Vervaart &

Nieuwenhout 2000). Many problems with charge controllers have been caused by inappropriate design, such as inappropriate settings for low voltage and high voltage disconnect; frequent fuse breaking or insufficient fusing and polarity protection, causing failure of the product with connection of incorrect polarity; consumption of too much power; inability to carry the rated current; and deep hysteresis (cycling between disconnect and reconnect) (Kumar *et al.* 2000; Mulugetta *et al.* 2000; Katic 2002; IEA 2003a; Varadi *et al.* 2003).

The most common problem resulting from poor design of lamp ballasts is tube blackening (Vervaart & Nieuwenhout 2000), which shortens the life of the tube and is usually the result of asymmetric waveform, inappropriate frequency, voltage fluctuations or voltage spikes. In addition to tube blackening, lamps have been found to still draw current when the lamp has failed; have no reverse polarity or short circuit protection; cause radio frequency interference; and have high power consumption (Kumar *et al.* 2000; Katic 2002; Corkish *et al.* 2004).

The quality of the design of lamps and charge controllers is critical to ensuring good performance and long life. Achieving good quality designs requires a high degree of skill in design and testing of electronics. However, small local companies do not always have enough highly educated technicians available. Young graduates in electronics prefer to work for large organisations and usually do not want to work in rural areas. As a result of lack of skilled personnel and isolation from other enterprises and organisations, many local manufacturers use old circuit diagrams, often based on poor designs (Vervaart & Nieuwenhout 2000). However, small manufacturers have been able to access quality designs from universities, technical institutes or NGOs in most of the projects described in Table 1.

Problems in the Manufacture of Charge Controllers and Lamps

In addition to the problems related to poor design described, many failures of electronic BOS components have been attributed to one or more of the following factors (Vervaart & Nieuwenhout 2000):

- Unreliable components, such as poor quality printed circuit boards, transistors and fluorescent tubes found in Bangladesh and Vietnam (Kumar *et al.* 2005),
- Specified components not available locally where designs are from international organisations,
- Insufficient quality control during manufacture, and poor workmanship, leading to risk of short circuits, which was problematic in Zimbabwe (Tani 2003a).

The processes involved in BOS manufacture are simple, including identifying electronic components (resistors, capacitors, ICs, diodes, transistors), soldering them onto PCBs, winding transformers and constructing the housings for the electronics. Quality control is more challenging and its importance may be overlooked, as was the case for Zimbabwean manufacturers (Tani 2003a). Although small-scale manufacturers are unlikely to be able to design their own circuits, they must have a detailed understanding of the operation of the circuit and quality control procedures so that they are able to test, troubleshoot and repair. Quality control also requires specialised equipment and is labour intensive. If these barriers can be overcome, however, quality control can make manufacturers more cost effective. In China, manufacturers who accessed assistance through the World Bank/GEF Program improved their product quality with no additional cost, some even decreasing costs (de Villers 2005).

LOCAL MANUFACTURE AND LOCAL CAPABILITIES

Inadequate local capabilities in system design, installation, maintenance and use have led to the premature failure of many PV systems in rural areas of developing countries (IEA 2003b). Projects & programmes in particular tend to have inadequate links to local communities and therefore inadequate local availability of spare parts, skilled personnel and funding. Local manufacture has the potential to impact linkages with users and technicians and the availability of spare parts, and to improve local capabilities for installation, maintenance and use.

Spare Parts Availability and Appropriate Products

The local manufacture of BOS components has resulted in better local availability of spare parts in Brazil, Kiribati & Tuvalu (Gillett & Wilkins 1999; Zilles *et al.* 2000), and has resulted in products which are better suited to local requirements (Acker & Kammen 1996), such as low-power white LED lamps for poor users in Bangladesh and Nepal and a colour TV adaptor for users in Vietnam (Kumar & Bhattacharya 2005). In the cases of Kiribati and Tuvalu and the RET-Asia countries the locally manufactured products were designed to be more easily repaired in the field (Gillett & Wilkins 1999; Kumar & Bhattacharya 2005).

Local Technical Skills

In Kiribati and Tuvalu (Gillett & Wilkins 1999), in Bolivia (Aguilera & Lorenzo 1996), and in the RET-Asia project countries, technical capabilities for maintenance and installation were enhanced by local manufacturers, who interacted closely with technicians. In the RET-Asia project, user training helped to reduce the incidence of calls for maintenance (Kumar & Bhattacharya 2005).

The training of local technicians is undertaken in most projects, but a full time technician job relies on a minimum number of systems in a small geographical area. Rural technicians, once trained, may find better employment in urban areas. Where local manufacturing staff are also involved in maintenance and repair, such as in Kiribati and Tuvalu, more permanent specialised employment may be provided, even in small markets. Local manufacture can therefore increase both the capability and availability of maintenance technicians.

CHARACTERISTICS OF PV MARKETS AND IMPLICATIONS FOR LOCAL MANUFACTURE

The success of local manufacture and commercialisation of PV system components and the satisfaction of social and business goals is strongly impacted by the way that the technology is delivered, including the financing, installation, after-sales service and training, and the linkages between actors in the value chain. This section discusses the impacts of the two main types of PV markets (project-based and cash-based) on local manufacturers.

Local Manufacture and Project-Based Diffusion

Projects and programmes constitute around a third of the total market for PV in developing countries (Nieuwenhout *et al.* 2001). Projects can more easily guarantee quality of PV systems through centralised procurement and testing of components, but often result in more expensive and imported hardware, money spent on the wages of foreign consultants and administrators, and a limited number of designs approved by the project developers, which may not suit the preferences of the users. The participation of locally based NGOs, such as Grameen Shakti in the RET–Asia project in Bangladesh, conversely, facilitated support for local entrepreneurs, locally appropriate financing, fee collection, and technology (Ibrahim 2005).

Small enterprises face high barriers to participating in projects and programmes, due to prohibitively strict standards, complex or costly administrative procedures, fiscal procedures, the complexity of tendering processes, or contracts that are too large. Small firms may not have the capability to achieve high technical standards, or the financial or administrative capabilities to comply with procedures. For example, in an ESCO pilot project in Zambia, local suppliers could not participate due to the long guarantees and credit periods required (Gustavsson & Ellegard 2004). In Zimbabwe, small manufacturers were unable to meet the quality requirements (Mulugetta *et al.* 2000). Favouritism for known brands or influential suppliers may also be a barrier to the selection of local enterprises for projects or programmes. Large-scale schemes may exclude the many small, financially weak, firms that have local knowledge and commitment and often end up delivering the services on behalf of larger suppliers. IEA’s (2003b) report on capacity building recommends that regulatory frameworks need to consider barriers to new entrants and unfair competition.

Projects inherently have a limited life. There has been little success in establishing self-sustaining markets after projects, even where the market is not saturated (de Villers 2005). Uncertainties in PV markets resulting from project cycles impede investment in labour and equipment. Enterprises often need to recruit temporary staff for projects and may find it difficult to develop a skilled trained workforce. Many small enterprises are not able to cope with this variability and will often need to have other business activities to sustain them when PV demand is low.

While projects may aim to promote the use of good quality hardware, systems installed through projects often fail in the medium or long term after the support for installation and maintenance is removed (Nieuwenhout *et al.* 2004). The instability of markets, subsidies and technical support has detrimental effects on the reputation of the technology and local manufacturers.

Local Manufacture and Diffusion via Cash-Markets

Many systems are sold in cash-sales markets without any maintenance agreement or user training. The retailer often has very little capability in installation and maintenance, since it is common for PV to be one of the many products they sell. Since small enterprises are often at risk of going out of business, users may be left without any after-sales service.

While projects may not provide long-term market stability, and may have poor linkages with local communities, they can provide financing and the training to build capabilities locally. The provision of finance to the poor users of PV systems and to small enterprises involved in retailing, servicing or manufacturing systems is likely to be inadequate without intervention, because of the high risks and transaction costs of providing credit to poor and dispersed customers with little ability to make repayments. In cash markets, small manufacturers generally have no access to the finance or training required to provide products at an appropriate quality and cost and may therefore be unfeasible. Small-scale manufacturers also face market barriers related to preferences for brand names or imported goods. Unfair competition in the form of dumping by larger suppliers, both national and international has also been reported (de Villers *et al.* 2004).

SUPPORTING SMALL SCALE PV COMPONENT MANUFACTURE

The World Bank/GEF and RET-Asia programmes previously described have attempted to improve the quality of local PV system component manufacture through the establishment of standards, local testing facilities and support for compliance with standards. Certification and improved components improved the confidence of Chinese consumers in PV systems and increased the willingness to pay for higher priced, better quality products (Li 2003).

While the introduction of standards provides incentives for manufacturers to improve, in many cases, such as in Zimbabwe, small manufacturers have not been able to qualify for these programmes, resulting in their collapse and encouraging unsustainable larger companies to enter the market (Mulugetta *et al.* 2000). The absence of a sufficiently large market in Indonesia prevented manufacturers from realising their improved designs (Nieuwenhout *et al.* 2004), while project timeframes in Zimbabwe were too short for manufacturers to improve their designs sufficiently (Tani 2003a). In Indonesia, products which passed testing were sometimes not robust and did not perform well over the long term in the field (Nieuwenhout *et al.* 2004).

Poor financial management of the dissemination of locally manufactured PV components has caused problems in Bolivia (Huacuz & Gunarante 2003) and Tuvalu (Gillett & Wilkins 1999). Attempts at small-scale module manufacture in Nepal and Zimbabwe have failed due to inadequate infrastructure (power supply) and insufficient financial capital respectively. Complementary capabilities in business skills and financial management are clearly required by small-scale manufacturers, but there is very little information available in the literature in relation to these requirements.

In order to nurture local manufacturing, the introduction of standards should involve consultation with existing local manufacturers and be combined with financial assistance, design assistance and capability building from research through to maintenance and use. It should also be recognised that time and iterations are needed to improve the design and production capabilities of small-scale manufacturers. The development of research capabilities in the RET-Asia countries facilitated the development of appropriate designs, testing services and high quality technician training. Regional networking has also proved effective in transferring new product designs and building capabilities via training courses and seminars in Vietnam and Nepal, delivered to technicians and engineers from other RET-Asia countries (Shestha *et al.* 2000; Kumar & Bhattacharya 2005). Engineers also undertook research at the Asian Technology Institute in Vietnam.

Local standards and testing laboratories have made compliance more affordable than international standards and allowed standards to be increased incrementally via the introduction of interim standards in Nepal (Katic 2002). In addition, sales tax and import tariffs on parts and materials required by manufacturers should be avoided. In general, attention should also be given to the impacts of PV project design on small enterprises. Long-term electrification programmes and smart subsidies that can be removed or targeted are preferable to short-term projects.

CONCLUSION

This paper has identified roles for small-scale manufacture in development. The small-scale manufacture of BOS in developing countries specifically has the potential to reduce leakages from the local economy in the form of payments for energy services, savings in foreign currency and possibly development of an export industry. Locally manufactured PV products are often cheaper and better adapted to serve the local market than imported ones.

Although there is only a small amount of literature documenting experiences with small scale manufacture, there is evidence to suggest that the local manufacture of PV system components can potentially address some of the barriers to sustainable PV rural electrification via improved local knowledge, skills, access to lower cost maintenance and spare parts through the interactions of manufacturers, technicians and users in close geographical and social proximity. It should be noted that local maintenance capabilities have been improved only where there have been good linkages between technicians and manufacturers. Designs that are more easily repairable have also facilitated better local maintenance.

However, the quality of locally made BOS has been found to be inadequate in many cases. The evidence available suggests that quality control, product design and business capabilities are challenging for small enterprises. They are also likely to be particularly affected by the small and dispersed markets for PV, market fluctuations, and lack of access to markets, especially projects and programmes which may have challenging quality, warranty, credit and tendering requirements.

Support for local manufacture has been primarily related to the introduction of standards and the support of manufacturers in compliance with them. Although some manufacturers have been able to improve their products and expand their markets through these programmes, small manufacturers have been disadvantaged by these programmes in many cases and issues related to market size, project timeframes and lack of complementary capabilities have prevented them from benefiting from these interventions. The RET-Asia program, which emphasised the development of local research capabilities and regional technology transfer, has better supported local manufacturing.

Because of the paucity of information available on the small-scale manufacture of BOS in developing countries, this review may have provided an incomplete picture of the factors which impact capability building. There are almost certainly a number of other factors that impact small PV manufacturers, such as low levels of financial and physical capital, isolation from value chains and poor infrastructure. If the benefits of local manufacture are to be realised, there is clearly a need for a better understanding of the determinants of capability building in small-scale PV manufacturers in developing countries.

REFERENCES

Acker, R. H. and Kammen, D. M. (1996). "The quiet (energy) revolution : Analysing the dissemination of photovoltaic power systems in Kenya." Energy Policy **24**(1): 81.

Aftab, K. and Rahim, E. (1987). "The Emergence of a Small-Scale Engineering Sector: The Case of Tubewell Production in the Pakistan Punjab." Journal of Development Studies **23**(1): 60-76.

Aguilera, J. and Lorenzo, E. (1996). "Rural photovoltaic electrification programme on the Bolivian high plateau." Progress in Photovoltaics: Research and Applications **4**(1): 77 - 84.

Albu, M. (2001). International Strategy for ITDG's work with Manufacturing Enterprise: Improving Livelihood Opportunities from Small-scale Manufacturing and Processing Enterprises, Intermediate Technology Development Group.

Barnes, D. F. and Floor, W. M. (1996). "Rural Energy in Developing Countries: A Challenge for Economic Development." Annual Review of Energy and the Environment **21**(497-530).

Bruce, A. (2007). Capability Building for the Manufacture of Photovoltaic System Components in Developing Countries. School of Photovoltaics and Renewable Energy Engineering. Sydney, Australia, The University of New South Wales. **PhD Thesis**.

Cabraal, A. (2000). Building on Experience: Assuring Quality in the World Bank/GEF-Assisted China Renewable Energy Development Project. 16th European Photovoltaic Solar Energy Conference. Glasgow, U.K.

Cabraal, A. (2004). Improving Quality and Building Capacity for Private Provision of Rural Energy Services: The China Renewable Energy Development Project, The World Bank.

Cabraal, A., Davies, M. C., et al. (1996). Best Practices for Photovoltaic Household Rural Electrification Programs - Lessons from Experiences in Selected Countries, ASTAE World Bank.

Corkish, R., Bruce, A., et al. (2004). Small Photovoltaic Systems in Rural Nicaragua. ANZSES Solar 2004. Perth, Western Australia.

Davis, J. R. (2004). The Rural Non-Farm Economy, Livelihoods and their Diversification: Issues and Options. Chatham, U.K., Natural Resources Institute.

de Villers, T. (2005). Strategies to increase the confidence in PV and expected impact on the PV Market. Tackling the Quality in Solar Rural Electrification, TaQSolRE.

de Villers, T., Watchueng, S., et al. (2004). Successful PV SHS project in developing countries? barriers and way foreword. 19th European Photovoltaic Solar Energy Conference. Paris, France.

Duke, R. D., Jacobson, A., et al. (2002). "Photovoltaic module quality in the Kenyan solar home systems market." Energy Policy **30**(6): 477.

Fitriana, I., Kantosa, E., et al. (1998). On the Way from Sukatani to the 50 MW Programme - A Socio-Technical Analysis of Solar Home Systems in Indonesia. IEEE 2nd World Conference on Photovoltaic Solar Energy Conversion. Vienna, Austria.

Gillett, B. and Wilkins, G. (1999). Evaluation of the PREP Component : PV Systems for Rural Electrification in Kiribati & Tuvalu. Final report for the European Commission DGVIII Development, AEA Technology Environment (ETSU).

Green, D. (2004). "Thailand's solar white elephants: an analysis of 15 yr of solar battery charging programmes in northern Thailand." Energy Policy **32**(6): 747.

Gustavsson, M. and Ellegard, A. (2004). "The impact of solar home systems on rural livelihoods. Experiences from the Nyimba Energy Service Company in Zambia." Renewable Energy **29**(7): 1059.

Hankins, M. (2000). A case study on private provision of photovoltaic systems in Kenya. Energy and Development Report: Energy Services for the World's Poor. U.S.A, World Bank Energy Sector Management Assistance Programme (ESMAP).

Huacuz, J. M. and Gunarante, L. (2003). Photovoltaics and Development. Handbook of Photovoltaic Science and Engineering. Luque, A. and Hegedus, S. S., John Wiley & Sons.

Ibrahim, M. (2005). A New Paradigm in Rural Electrification in Bangladesh brought about by an Effective Extension of Solar PV: Contribution of RETs in Asia Program. World Renewable Energy Regional Conference Jakarta, Indonesia.

IEA (2003a). 16 Case Studies on the Deployment of Photovoltaic Technologies in Developing Countries. Deployment of Photovoltaic Technologies: Co-operation with Developing Countries, IEA PVPS Task 9.

IEA (2003b). PV for Rural Electrification in Developing Countries – A Guide to Capacity Building Requirements. Deployment of Photovoltaic Technologies: Co-operation with Developing Countries, IEA PVPS Task 9.

Islam, R. (1992). Chapter 1: Transfer, Dissemination and Adoption of Technology for Small and Cottage Industries: An Overview. Transfer, Dissemination and Adoption of Technology for Small and Cottage Industries. Islam, R. New Delhi, India, Asian Regional Team for Employment Promotion, World Employment Programme, ILO.

Jacobson, A. and Kammen, D. M. (2005). The Value of Vigilance: Evaluating Product Quality in the Kenyan Solar Photovoltaics Industry. Report delivered to solar industry stakeholders in East Africa, July 2, 2005.

Katic, I. (2002). Quality Assurance of Solar Home Systems in Nepal. 18th European Photovoltaic Solar Energy Conference. Rome.

Khosla, A. (1994). Effective Design and Diffusion of Rural Technologies. The technological transformation of rural India : a study prepared for the International Labour Office within the framework of the World Employment Programme. Bhalla, A. S. and Reddy, A. K. N. London, Intermediate Technology Pub.**:** 44.

Krishnaswamy, K. N. and Reddy, A. K. N. (1994). The Commercialization of Improved Technologies in Rural Areas. The technological transformation of rural India : a study prepared for the International Labour Office within the framework of the World Employment Programme. Bhalla, A. S. and Reddy, A. K. N. London, Intermediate Technology Pub.**:** 23.

Kumar, S. and Bhattacharya, S. C. (2005). Renewable Energy Development in South and Southeast Asia through a Regional Research and Dissemination Programme. World Renewable Energy Regional Conference Jakarta, Indonesia.

Kumar, S., Bhattacharya, S. C., et al. (2005). Renewable Energy Technology Promotion in Asia: Case Studies from Six Asian Countries. Renewable Energy Technologies in Asia: A Regional Research and Dissemination Programme, Asian Institute of Technology, Thailand. Funded by Swedish International Development Cooperation Agency.

Kumar, S., Bhattacharya, S. C., et al. (2000). A Status Survey on PV Systems and Accessories in Asia. World Renewable Energy Congress. Brighton, U.K.

Li, Z. (2003). Global Environment Facility (GEF) / World Bank Assisted China Renewable Energy Development Project PV Component. 16 Case Studies on the Deployment of Photovoltaic Technologies in Developing Countries. IEA, IEA PVPS Task 9 Deployment of Photovoltaic Technologies: Co-operation with Developing Countries.

Ling, S., Twidell, J., et al. (2002). "Household photovoltaic market in Xining, Qinghai province, China: the role of local PV business." Solar Energy **73**(4): 227.

Lorenzo, E. (1997). "Photovoltaic Rural Electrification." Progress in Photovoltaics: Research and Applications **5**(1): 3-27.

Lorenzo, E. (2000). "In the field - Realities of some PV rural electrification projects." Renewable Energy World(Sept-Oct 2000).

Martinot, E., Cabraal, A., et al. (2000a). World Bank/GEF Solar Home Systems Projects: Experiences and Lessons Learned 1993-2000, World Bank/GEF.

Martinot, E., Ramankutty, R., et al. (2000b). The GEF Solar PV Portfolio: Emerging Experience and Lessons, Monitoring and Evaluation Working Paper 2, Global Environment Facility.

Moner-Girona, M., Ghanadan, R., et al. (2006). "Decreasing PV costs in Africa: Opportunities for Rural Electrification using Solar PV in Sub-Saharan Africa." Refocus **7**(1): 40-45.

Mulugetta, Y., Nhete, T., et al. (2000). "Photovoltaics in Zimbabwe: lessons from the GEF Solar project." Energy Policy **28**(14): 1069.

Nieuwenhout, F., de Villers, T., et al. (2004). Reliability of PV stand-alone systems for rural electrification, Part 1: Literature Findings. Tackling the Quality in Solar Rural Electrification, TaQSolRE.

Nieuwenhout, F. D. J., van Dijk, A., et al. (2001). "Experience with solar home systems in developing countries: a review." Progress in Photovoltaics: Research and Applications **9**(6): 455-474.

Nieuwenhout, F. D. J., van Dijk, A., et al. (2000). Monitoring and Evaluation of Solar Home Systems - Experiences with applications of solar PV for households in developing countries, Netherlands Energy Research Foundation ECN and Department of Science, Technology and Society of Utrecht University.

Overseas Development Institute. (2002, October 2002). "Non-Farm Income in Rural Areas." Keysheets for Sustainable Livelihoods Retrieved August 2005, from http://www.keysheets.org/.

Panditrao, Y. A. (1994). Experiences of the Khadi and Village Industries Comission in Technology Transfer. The technological transformation of rural India : a study prepared for the International Labour Office within the framework of the World Employment Programme. Bhalla, A. S. and Reddy, A. K. N. London, Intermediate Technology Pub.**:** 113.

Samy, S. and Sovanna, T. (2005). Renewable Energy Promotion in Cambodia under RETs in Asia Programme. World Renewable Energy Regional Conference Jakarta, Indonesia.

Sayalath, P. and Theuambounmy, H. (2005). PV Accessories Development in Lao PDR. World Renewable Energy Regional Conference Jakarta, Indonesia.

Shestha, J. N., Sharma, D., et al. (2000). Application of Photovoltaic Technology in Nepal: An Assessment. World Renewable Energy Congress. Brighton, U.K.

Stone, J. L., Tsuo, Y. S., et al. (1998). "PV Electrification in India and China: The NREL's Experience in International Cooperation." Progress in Photovoltaics: Research and Applications **6**(5): 341-356.

Tani, T. (2003a). JICA PV Project - Case of Zimbabwae. 16 Case Studies on the Deployment of Photovoltaic Technologies in Developing Countries. IEA PVPS Task 9, IEA.

Tani, T. (2003b). PV Rural Electrification in Kiribati. 16 Case Studies on the Deployment of Photovoltaic Technologies in Developing Countries. IEA PVPS Task 9, IEA.

ter Horst, E. and Zhang, C. (2005). Impacts of Technology Improvement and Quality Assurance in the WB/GEF China Renewable Energy Development Project on PV industry and market development in China. 15th PVSEC.

Trinh, Q. D. (2005). Development and Dissemination of PV BoS in Vietnam. World Renewable Energy Regional Conference Jakarta, Indonesia.

van Campen, B., Guidi, D., et al. (2000). Solar photovoltaics for sustainable agriculture and rural development. Environment and Natural Resources Working Paper No. 2. Rome, FAO.

Varadi, P. F., Domínguez, R., et al. (2003). Quality Management in Photovoltaics:Quality Control Training Manual for Manufacturers. Quality Program for Photovoltaics (QuaP-PV), ASTAE PV GAP.

Vervaart, M. R. and Nieuwenhout, F. D. J. (2000). Solar Home Systems: Manual for the Design and Modification of Solar Home System Components Quality Program for Photovoltaics (QuaP-PV), ECN.

Wade, H. (2003). Summary of PV Rural Electrification Experiences in the Pacific Islands. 16 Case Studies on the Deployment of Photovoltaic Technologies in Developing Countries. IEA PVPS Task 9, IEA.

Wilkins, G. (2002). Technology Transfer for Renewable Energy: Overcoming Barriers in Developing Countries. London, Earthscan Publications.

Zilles, R., Lorenzo, E., et al. (2000). "From candles to PV electricity: a four-year experience at Iguape-Cananéia, Brazil." Progress in Photovoltaics: Research and Applications **8**(4): 421-434.

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