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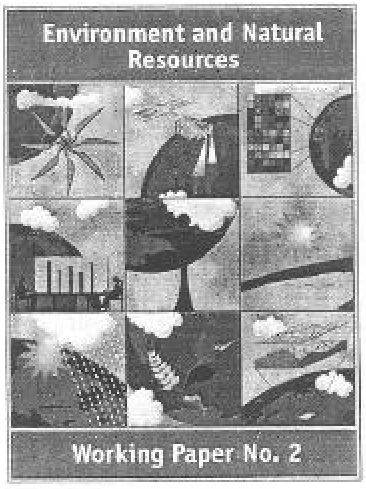

SOLAR PHOTOVOLTAICS FOR SUSTAINABLE AGRICULTURE AND RURAL DEVELOPMENT

by

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Solar photovoltaics for sustainable agriculture and rural development
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Abstract

Solar photovoltaic (PV) systems have shown their potential in rural electrification projects around the world, especially concerning Solar Home Systems. With continuing price decreases of PV systems, other applications are becoming economically attractive and growing experience is gained with the use of PV in such areas as social and communal services, agriculture and other productive activities, which can have a significant impact on rural development. There is still a lack of information, however, on the potential and limitations of such PV applications.

The main aim of this study is, therefore, to contribute to a better understanding of the potential impact and of the limitations of PV systems on sustainable agriculture and rural development (SARD), especially concerning income-generating activities. It is, in fact, of paramount importance to identify the potential contribution of PV to rural development in order to gain further financial and political commitment for PV projects and programmes and to design appropriate PV projects.

One of the main lessons learnt through this study is that success of PV programmes is significantly enhanced when an integrated strategy is followed. Solar photovoltaic systems, through their flexibility in use, offer unique chances for the energy sector to provide “packages” of energy services to remote rural areas such as for rural health care, education, communication, agriculture, lighting and water supply. It is hoped that this document contributes to the generation of ideas and discussions among the different institutions involved in providing these services to rural areas and thereby to an "informed" decision on the PV technology option.

Keywords: solar energy; photovoltaic; rural development; income generation; agriculture; aquaculture; livestock

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Cover photo:
Solar photovoltaic panel for the operation of a water pump to pump water from the river in the background into the multi-purpose garden. This system is part of an FAO project focused on forest and village territory management near the Senegal River, in the northern region of Senegal (Dagana and Podor). The project provides organizational and technical training. The multi-purpose gardens have become rather popular in villages of those departments. The villagers, particularly groups of women and young men, lay out a garden, around which they plant trees for protection against the wind and the sun. All kinds of horticultural products that can improve local living conditions are grown in these plots, usually situated on the edge of the village. The characteristics of each garden depend on the local situation and the imagination of the persons in charge. Some even have beehives. A course on agrarian studies has been included in the school curriculum in Podor to explain the multi-purpose gardens in the village.
Author: I. Balderi, 1995

Foreword

Energy is an important input for the provision of basic human needs and services, such as cooking, water supply, lighting, health services, communication and education. It is also an essential input for the enhancement of rural production and food security, through land preparation, fertilization, irrigation, agro-processing, conservation and transport. In many rural areas of developing countries, energy needs are, at present, predominantly supplied in the form of traditional biomass fuels, human and animal labour. This inequitable scenario severely limits many rural people from enhancing their agricultural productivity and quality of life.

The Food and Agriculture Organization of the United Nations continues to promote the achievement of sustainable agriculture and rural development (SARD) as task manager of Chapter 14 of Agenda 21. The present study aims to contribute to this process by assisting the Organization's member countries in their transition to more sustainable rural energy systems. FAO recognizes the solar photovoltaic (PV) system as a technology that is already providing energy services in many sites around the world, mainly at the household level, and draws attention to its potential in fostering new income-generating activities and higher agricultural productivity.

One of the main lessons learnt through this study is that the success of PV programmes is significantly enhanced when an integrated strategy is followed. Solar photovoltaic systems, through their flexibility, offer unique opportunities for the energy sector to provide "packages" of energy services to remote rural areas, for example, for health care, education, communication, agriculture, lighting and water supply. It is hoped that this document will contribute to the generation of ideas and discussions between the different institutions involved in providing these services to rural areas and thereby to an "informed" decision on the PV technology option.

The authors are greatly indebted to all who assisted in the completion of this study and its final report. A range of people from development agencies, industry, NGOs, universities and colleagues from FAO contributed significantly with ideas, data, experience and critical comments. Special thanks go to all those who responded to the survey launched in preparation for the study. The authors are particularly grateful to Ms Cecelski and Mr Sinha for their fundamental and constructive comments.

FAO hopes that this study will contribute, even in a small way, to a much-needed change in the energy scenario of rural areas in developing countries and, in particular, to the integration of PV systems in agriculture and to the integration of agriculture into ongoing PV programmes.

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Abbreviations and Acronyms

AC	Alternating Current
BCS	Battery Charging Station
CDM	Clean Development Mechanism
CFL, FL	Compact Fluorescent Light or Fluorescent Light: efficient low-energy consumption lights often used with PV systems
DC	Direct Current
DOE	Department of Energy, the Philippines
ESCO	Energy Service Company
EU	European Union
GEF	Global Environment Facility
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit, Germany
IFAD	International Fund for Agricultural Development
LCC	Life Cycle Costs, *refers to the calculation of total costs of a system or technology over its lifetime, including costs for investment, fuel, operation and maintenance. Generally results are presented as annual costs to facilitate comparison between technologies with different lifetimes.*
LPG	Liquid Petroleum Gas
MREP	Mexico Renewable Energy Programme, Mexico
MSIP	Municipal Solar Infrastructure Project, the Philippines
	National Electrification Authority, the Philippines
NEC	North Eastern Council, India
NREL	National Renewable Energy Laboratory, USA
PRESSEA	Promotion of Renewable Energy Sources in South East Asia, Indonesia
PRODEEM	Programa de Desenvolvimento Energético de Estados e Municipios, Brazil
PV	Photovoltaic, *refers to direct conversion of sunlight into electricity through semiconductor material*
SARD	Sustainable Agriculture and Rural Development
SELCO	Solar Electric Light Company
SELF	Solar Electric Light Fund, USA
SHS	Solar Home System, *refers to a typical application of PV systems for lighting and radio/TV in households, especially of developing countries*
WHO	World Health Organization
Wp	Watt-peak, *refers to a standard measure of output for PV modules: peak power of a PV module under standard test conditions*

Executive Summary

The main aim of the present study is to contribute to a better understanding of the potential impact and of the limitations of solar photovoltaic (PV) applications on sustainable agriculture and rural development (SARD), with a special attention to the effects on income-generating activities and social welfare.

Outline of the document
The results of this study are presented in such a way that readers can select to go directly to their areas of highest interest. Chapter 1 presents the introduction and objectives. Chapter 2 provides the background to this study. Chapter 3 contains the main results of this study and presents the major applications of PV systems in rural areas and their (potential) impact. The Chapter is organized by sector of rural society (household, social and communal services, off-farm productive activities and agriculture), and further subdivided into main applications. Some illustrative examples are worked out in text boxes. Chapter 4 summarizes the findings and highlights some of the most important suggestions and lessons learnt to use the opportunities of PV systems for SARD. The annexes contain more detailed information on a number of issues discussed in the document, such as a package of recommendations to promote PV for SARD, the survey questionnaire and a list of references.

Chapter 1
Chapter 1 identifies the objectives and scope of the study, clarifying its limitations and stressing the need for a better understanding of the potential contribution of PV applications to rural development and the need for further research, in order to gain further financial and political commitments for PV programmes.

Chapter 2
The important links between energy, sustainable agriculture and rural development are briefly discussed in the first Section. Energy is seen as an important input to the development process, not as an end in itself, but as a means for providing necessary services in the different sectors of rural society: households; agriculture; off-farm productive activities (cottage industry and commercial services); and communal and social services (for example, potable water, health care, education). Section 2.2 briefly discusses the experiences with electrification in the context of rural development. Section 2.3 gives an overview of technical and organizational developments in relation to PV rural electrification. Section 2.4 describes more explicitly some of the lessons learnt in three decades of PV applications, especially regarding institutional aspects and the current and emerging markets for PV systems.

Chapter 3
On the basis of surveys, literature, project documents and interviews with practitioners and key players in the PV field, the most important applications are discussed, both in terms of present use as in terms of (potential) impact, focused on productive applications in rural areas of developing countries. The following is a brief synopsis of this discussion.

Solar Home Systems (SHS) are still the dominant PV application in rural areas of developing countries and their main use is for lighting and radio/TV in households. Some studies report that there is little evidence for direct economic impacts by SHS on households; other studies indicate an increase in income generating activities and make reference to time savings and extension of the day due to SHS. This “surplus time” is sometimes used for productive activities such as sewing, basket weaving and handicraft making. In other cases this “surplus time” is used for facilitating household chores, homework, education and recreational activities. In addition, indirect economic benefits often arise from improved access to information, and increased quality of life standards related to household electricity services.

Many PV projects have been and are being implemented for **social and communal services**, such as provision of potable water, health centres, education and communal centres. PV has often shown to be the most cost-effective solution for improving such services in remote, unelectrified areas of developing countries. Through these services, PV systems can have a significant impact on the lives of *all* rural inhabitants, provided attention is paid to the access of the most marginalized groups to these services. At times, the provision of social and communal services is also able to spark the provision of income generating activities.

Small solar systems also help develop **off-farm productive activities** in many countries, such as bars, restaurants, rural cinemas, telephone shops, technical and artisanal workshops, by powering small tools and appliances (drills, soldering irons, blenders), lighting and radio/TV. The installation and maintenance of PV systems and sales of PV electricity has been shown to contribute to rural employment creation. In this sector, there is scope for further investigation of the potential for PV/wind and PV/diesel hybrid systems.

PV systems are also increasingly being used for **agricultural applications**. Some of these applications, such as livestock watering and PV electric fences are already widely available commercially. Applications such as PV-powered drip irrigation systems are finding increasing niche markets. Interesting applications such as pest control, aeration pumping for aquaculture, fish and poultry lighting have to be investigated further to prove their replicability. Successful examples exist of PV/diesel and PV/wind hybrid systems to economically power agricultural applications that have a higher energy consumption.

Chapter 4

The last chapter summarizes the findings. These findings have led the authors to believe that the time is now ripe to advance to a new phase of "**PV beyond the light bulb"** directed at fully exploiting the potential of PV systems for SARD, reaching wherever feasible the electricity demand beyond households lighting. Recommendations are presented to facilitate the implementation of the opportunities this presents, including a call for intensified cooperation between institutions from the energy, agricultural and rural development sectors to take up these opportunities. While recognizing that the main responsibility for action lies with national development authorities, the role of technical cooperation agencies such as FAO in supporting these national efforts is addressed.

PV applications, and especially those for productive activities, have considerable potential to serve both environmental concerns (e.g. climate change) and improve the situation of the inhabitants of impoverished rural areas in developing countries. Reference is made to FAO’s commitment to tapping this potential in the process of promoting sustainable agriculture and rural development in developing countries. As a follow-up to the conclusions and recommendations to this study, it is recommended that FAO actively looks for cooperation and alliances with other interested parties.

The preparation and publishing of the present study represents an assurance of the interest of FAO to assist its member countries in taking advantage of the opportunities offered by developments in the PV field for sustainable agriculture and rural development. Recalling the importance of cross-sectoral programmes as a strategy to maximize the benefits of PV applications, the study will hopefully contribute to underscoring FAO’s role in promoting the integration of PV systems in agricultural development programmes and of agriculture into ongoing PV programmes.

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1. Introduction and objectives

1.1 Introduction

Rural energy is generally recognized as an important element of rural socio-economic development, not as an end in itself, but through the demand for the services made possible through energy inputs, such as potable water pumping, extension of the day by lighting and cooking. As a general trend, an increasing energy demand - both in quantity and quality - is highly correlated with socio-economic development. Yet, the rural populations of many developing countries have been excluded from most of the benefits of economic development and the transition to better (quality) energy services. Little seems to have changed since rural energy issues and problems were first raised in the late 1960s; traditional energy sources (fuelwood, biomass residues and human and animal power) continue to be the main and often the only energy resources available for millions of rural families, with well-documented limitations and effects on rural well-being in such fields as health, food security and agricultural production[1].

Agenda 21, resulting from the 1992 United Nations Conference on Environment and Development, calls for a "rural energy transition". FAO was made task manager of Chapter 14, dealing with Sustainable Agriculture and Rural Development (SARD), which points out the need for such an energy transition as a means to effectively improve the socioeconomic conditions of rural populations, especially as a requirement for "increased productivity and for income generation". The same emphasis on energy as a means not as an end, is applied in the present study, which focuses on the potential of solar photovoltaic (PV) systems for use in agriculture and rural development, especially for income generating activities, as a basis for sustainable rural development.

Over the last decades PV has shown its potential as a technology for decentralized rural electrification and as a means to improve access to electricity in rural areas of developing countries. Impressive advances have been made in the technical as well as in the organizational, economical and financial fields. PV systems are now being integrated in large rural electrification programmes in different parts of the world (Argentina, India, Mexico, South Africa, United States, and Zimbabwe). In general, PV technology is reaching commercial maturity and the growing investments in new production capacity are expected to create the conditions for further price drops and higher competitiveness[2]. Programmes and studies now address the issues related to large-scale market development in rural areas: access to affordable credit, local market infrastructure for installing and servicing PV systems, and mechanisms for conducive local policy-making. Most of the attention is directed towards the so-called Solar Home Systems as the most proven PV application, but with uses limited to lighting and audiovisual media. Continuing advances in PV technology and decreasing prices are creating new opportunities for other applications of PV with a greater and more sustainable impact on rural development.

On the basis of anecdotal information, it can be concluded that a rising number of such applications are being used, but little systematic information on this is available, especially concerning income generating activities.

[1] see for a detailed discussion on rural energy and development FAO/WEC, 1999
[2] International PV prices are decreasing to about US$ 3 per Wp, from more than US$ 10 per Wp in the 1980s.

1.2 Objectives and scope of the study

The main objective of this study is to contribute to a better understanding of the potential impact and of the limitations of PV systems on sustainable agriculture and rural development, especially concerning income-generating activities.

It is in fact of considerable importance to identify the (potential) contribution of PV systems to rural development in order to gain further financial and political commitment for PV projects and programmes.

The following research questions were defined:

- ♦ What are the major applications of PV systems at present - especially activities related to income generating activities?
- ♦ What potential impact do these systems have?
- ♦ What advantages and disadvantages do these systems have in comparison to alternative technologies?
- ♦ What is the status of the different applications in terms of extent of use and replicability (in terms of technical potential and economic competitiveness)?
- ♦ What lessons can be learnt from literature, key persons and project reviews on how to maximize the impact of PV systems on rural development?

The present document is the result of a desk study based on a survey done with PV project managers, on a review of literature and project documents, and on interviews with key persons.

The study also aims to contribute to the understanding of the following premises:

- ♦ Small loads from PV systems can be carriers of rural socio-economic development. Specifically, the PV option is investigated as an input to rural income generating activities and as a tool for powering applications with high value added in terms of their social benefits content.

- ♦ A number of specific applications of PV systems for productive uses can have high replicability. Technical maturity is not enough though, it must be complemented with support mechanisms for their diffusion (policies, awareness programmes, private sector support, marketing strategies, rural financing mechanisms).

- ♦ At least a portion of the power produced by solar home systems, mainly used for lighting and TV/radio, is nowadays also powering hidden household-level economic activities.

2. Background

2.1 Rural energy and rural development

Rural people are still an important majority in most developing countries and according to statistics will continue to be so until far into this century. Although many of these countries have had significant economic growth during the last decades, these figures are national averages; they mask the economic disparities and the lack of access to necessary basic services by the poor, especially the rural poor. Rural areas generally harbour an unequal share of poverty, especially in developing countries. Rural areas often suffer from a lack of attention on the agenda of national and international authorities since most of the political and economic attention is given to industry-driven economic growth. Apart from the unfairness to such a big mass, it also represents an enormous amount of missed human capital. Furthermore, it should be realized that it is the rural areas where many of the resources originate (e.g. water, food, biomass energy) that are essential to the society as a whole. Especially in many developing countries, rural areas and their natural and human resources are the cornerstones of the economy and should therefore be a major focus on the development agenda.

In 1991 FAO defined a framework for the Sustainable Agriculture and Rural Development (SARD) as part of its mandate to better the conditions of rural populations and improve agricultural productivity: "... the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable".

An elaborate discussion of the role of rural energy in the SARD-framework is beyond the scope of this document. However, it should be pointed out that energy plays an important role in many basic human needs and in agricultural and economic development in rural areas. Some examples of important activities requiring energy inputs in different rural sectors are:

- agricultural sector: irrigation, land preparation and fertilization;
- household sector: lighting, food processing and conservation, cooking;
- rural industry and commercial services sector: lighting, processing;
- community and social services: water pumping, refrigeration for health centres, lighting of communal buildings. [3]

This study is focused on solar photovoltaic (PV) systems, which can fulfil only a part of rural energy needs. As has been noted before, most PV programmes have given attention to the so-called "Solar Home Systems" as the most proven of PV applications. With continuing advances in PV technology, decreasing prices and growing experience in the organizational aspects of introducing this new technology, many other applications of PV have shown their potential. This promises to open the door for a greater contribution of PV systems to rural development .

[3] please also refer to FAO/WEC (1999) and FAO (1999) for a more detailed discussion on the important links between energy, rural development and agriculture (both as consumer and producer of energy)

2.2 The rural electrification challenge: experiences and impacts

Most countries have launched rural electrification programmes, which are usually based on the extension of the national grid, especially in the 1970s and 1980s. Coverage of this grid varies considerably between countries, but is often low in rural areas. From table 1 it can be derived that although percentage-wise considerable progress has been made, in absolute terms still almost two billion rural people in developing countries are without access to electricity.

Table 1 Rural population and electrification trends

	1970	**1980**	**1990**
World population	3 600	4 400	5 300
Developing countries rural population	2 600	3 000	3 200
Rural residents with access to electricity	610	1 000	1 400
Rural residents without access	2 000	2 000	1 800
Percentage rural access	**23%**	**33%**	**44%**

source: Davis (1995) in FAO/WEC (1999)

The level of success of these electrification programmes has been a topic of strong debate. While in some cases these have been very successful and have actually changed the face of rural areas, in others success is considered very relative. There are many reasons behind this complex situation. Apart from the enormous numbers of rural inhabitants of developing countries not yet electrified, the challenge of rural electrification is increased by a few specific characteristics:

- wide dispersion of potential consumers in rural areas with low levels of demand;
- demand concentrated in a short period of the day (generally early evening hours) leading to relatively high peak capacity and low load factors;
- high levels of power loss (up to 25 percent), including theft;
- limited purchasing power of consumers regarding electricity and appliance costs;
- difficult billing, maintenance and servicing circumstances.

Because of the above-mentioned characteristics, in many instances rural electrification is not a financially attractive investment and requires government subsidies. Several reviews have been carried out, especially in the 1980s and early 1990s, on the impacts of rural electrification programmes[4]. Annex 3 presents an overview of such studies. In general the conclusion is that the impact of rural electrification is not what it has often been claimed, and that the success of rural electrification follows and supports socio-economic development, rather than the other way around.

Schramm (1993) concludes that grid electrification, though versatile when installed, is the most expensive of energy investments and that, in principle, all energy requirements that can be met by grid extension, can also be met by the right mix of energy supply options (PV, kerosene, woodfuel, diesel, wind). Recent trends in many developing countries include Electricity Sector Reform Programmes, often based on deregulation and privatization. In these emerging structures new rural electrification projects are implemented with a tighter focus on their economic feasibility. In the search for the least-cost rural electrification choice, decentralized energy options are being increasingly considered as an alternative option to

[4] a.o. Fluitman, 1983, Pearce and Webb, 1987, Desai, 1988, Foley, 1990, and Munasinghe, 1990: listed in Ramani, 1993; Schramm, 1993

traditional grid extension. These decentralized technologies have new advantages, but also some limitations, especially regarding scale and load (see also Section 2.4).

In recent years attention has risen again regarding the issue of rural access to electricity supply and regarding the relation between energy (electricity) and poverty. Cecelski (2000) reviews several "success factors" in widening rural access to electricity, including subsidies, credit and leasing options for PV systems. Cecelski acknowledges that even under these circumstances, rural electrification is still not likely to reach more than 50-75 percent of the rural population and is more likely to benefit the less-poor. Increasing attention to poverty alleviation has brought the issue of impact of rural electrification back on the agenda, but very few empirical studies convincingly demonstrate a linkage between energy and poverty. If there is a linkage to the poor, it is generally through increased employment and income generating opportunities. Improved communal services such as water supply and improved health care (vaccine refrigeration), have the potential of benefiting all rural inhabitants providing that careful consideration is taken to the access of the marginalized groups.

In line with the above, this study does not pretend to promote PV as a panacea for solving rural poverty problems: PV is generally still an expensive technology. Regarding agricultural and other income generating activities, it is realized that the most disadvantaged, subsistence farmers will generally not be able to afford PV systems. PV systems do, however, provide some particular advantages that make them interesting for several “niche”-applications. With continuing advancement in PV prices and technology, the size and number of niches will grow.

2.3 The dynamics of the PV rural electrification

From early on, PV and other renewable energy systems have been seen as alternatives for grid extension, as their small and modular character makes them particularly suitable for remote, dispersed populations with low and scattered energy demands. The developments of PV technology for rural electrification can be roughly described in three phases which represent the dynamic from the very first demonstration efforts in the 1970s, to a wider dissemination of (especially) solar home systems as pre-commercial pilot projects in the 1980s, to finally reach a large scale commercialization stage in the 1990s.

1970s: PV demonstration projects

During the 1970s an increasing interest grew for experimentation with the use of solar systems for stand-alone rural electrification. Most of these were demonstration projects with medium-sized PV systems for uses such as water pumping and community centres. Because of their demonstration character the focus was often to test technologies, and out of context with real local needs and conditions. It has often been said that these activities were not clear as to what they were demonstrating and to whom. Many projects failed due to the introduction of “hardware without software” i.e. overlooking the needs of local technical training, local maintenance service, user education and awareness programmes[5]. In addition, most of the demonstration projects were full donor financed projects, presenting no financial commitment for the beneficiaries, thereby diminishing their sense of ownership and responsibility. The results proved that local participation is essential in the success of technology introduction, including financial participation at least in the coverage of the maintenance and operating costs. Similar failures were recorded in the initial experience with decentralized electrification

[5] Barozzi, Guidi, 1993

with stand-alone diesel generators, which carry the additional problems related to high fuel and maintenance requirements. The defaults and lessons in project design were documented extensively[6], providing a basis for later initiatives in PV rural electrification.

1980s: Dissemination of SHS by grassroots non-governmental organizations (NGOs) and small private dealers
In the 1980s new approaches were developed to introduce small solar systems on a more sustainable basis. This was made possible, in part, by a significant decrease in production costs. NGOs and grassroots groups, such as the pioneering ENERSOL and ADESOL in the Dominican Republic, initiated a new approach of rural electrification based on the analysis of rural household energy demand and spending power, and on the observation that rural areas often present a very dispersed energy demand for small loads (especially lighting and audiovisuals). These PV projects aimed at demonstrating that SHSs could substitute costly and low quality energy sources (candles, flashlights, kerosene lamps, car batteries) that households use to fulfil their need for lighting and audiovisuals. It was found that many rural households are used to spending 5-15 percent of their monthly income for such energy sources. SHSs were shown to provide a higher quality and safer option as long as the households' small monthly energy expenditure could be used for servicing a credit scheme or leasing plan. In addition to the provision of rural credit to overcome the barrier of the high SHS capital cost, the approach included a component of support to the local service infrastructure, with capacity-building and training of local technicians/entrepreneurs, of fee collection mechanisms and user education. These NGO-driven pilot projects were replicated in many countries with various degrees of success. The Solar Electric Light Fund (SELF), for instance, had established pilot projects in over ten countries by the end of the 1980s.

A similar successful experience with small scale SHS commercialization was conducted by local PV dealers that started to target the cash sales segment of the market (5-10 percent of most affluent rural families). In some countries also the less affluent households could be reached through consumer credit and low cost maintenance service. In Sri Lanka, for instance, Suntec Ltd. was able to locally assemble and sell hundreds of SHSs, establishing distribution partnerships with local NGOs and the Singer sewing machine network of over 400 shops. In Kenya, Solar Shamba was established in 1985 as the first local PV systems integrator and besides reaching the rural SHS cash sales, was one of the first PV companies to target other rural electricity end uses, such as the solar powered sewing machines. In Zimbabwe, the first cell of a private market for rural PV system was born in 1981 with Solarcomm, a subsidiary of a large local industrial group. After handling some government projects in telecommunications and water pumping, this PV company started to service the SHS market and by 1988 was able to initiate local modules assembly with Canadian technology.

1990s: Lessons learned and applied in wide-scale dissemination
At the end of the 1980s, the development lending and donor institutions started to take up the lessons learnt in the field, and by the mid-90s various initiatives were launched to scale up into large commercialization programmes and government sponsored SHS programmes. The principal lessons learnt from experiences in the 1970s and 1980s to create a sustainable solar PV market in rural areas can be summarized as follows:

- project design originating from participatory assessment of the energy needs and present energy expenses;

[6] Among others Amado, Blamont, 1992

- establishment of rural credit models and effective fee-collection mechanisms;
- establishment of infrastructure for distribution, installation, maintenance and repair of PV systems;
- training of solar technicians and capacity-building for solar dealers/micro-enterprises.

With these lessons in mind SHS projects multiplied rapidly. It is estimated[7] that around 500,000 SHSs had been installed worldwide by 1996 with an estimated annual installation of at least 80,000. As the size of the potential rural PV market became evident, a clear sign of the shift to a fully commercial era for SHSs was that some of the most prominent practitioners from the NGO sector started profit ventures, attracting private investor capital. Soluz Inc., for instance, was created as a spin-off of the non-profit NGO ENERSOL and started to target the Latin American market; and in 1997 SELCO International was created on the experiences of SELF with subsidiaries in China, India, Sri Lanka and Vietnam.

In Kenya the solar (cash sales) market took off after 1987, when 12 Wp amorphous panels were introduced for less than 100 US$. At present at least 15 private PV systems distributors and more than 100 agents are presently operating in Kenya with a total of about 50,000-70,000 SHS installed, despite the fact that "solar is still punished through tax and duty schemes that may increase the price of solar systems by as much as 44%" (v/d Plas, Hankins, 1997). A similar growth has been experienced in Indonesia, where the Government and institutional donor money[8] supported the growth of a thriving private SHS market and led to examples such as the Sudimara Company, that after reaching a size of 200 employees in a network of 45 regional service centers each installing up to 3000 SHS annually, stimulated the interest of several international utilities in buying the company (Wouters et al., 1997).

In some instances SHS programmes were initiated and carried out by the public sector with a subsidized approach and some private sector involvement at the implementation level. In Mexico, for instance, one of the first subsidized large programmes was launched in the late 1980s by the Government and the national electricity utility (CFE) as a “least cost” rural electrification plan - the so-called Pronasol programme. Wherever the PV option for basic service could be introduced more economically than grid extension and with the acceptance of the rural communities, the CFE would issue tenders for PV suppliers to install and maintain the SHSs, for which the users would pay a fixed monthly service fee. By the end of 1998 more than 40,000 SHS had been installed[9]. The level of effectiveness reached through this programme and its financial sustainability have been subject of debate, but Pronasol paved the way for other government-sponsored large scale programmes. Similar public PV programmes have now been started in Argentina, China, India, Morocco and South Africa with varying degrees of subsidies and of private sector involvement.

In parallel with the effort to scale up the commercial dissemination of SHSs, this third phase of PV rural electrification triggered a growing attention for other solar PV applications for communal use. The typical example is the dissemination of vaccine refrigeration units for rural clinics, which today have a code of quality standards certified by the World Health Organization (WHO). In parallel, other communal PV applications such water pumps, lighting sets for rural schools and street lights started to become more standardized as typical products for rural communities. These larger PV systems have mostly been channelled

[7] Village Power 1997
[8] World Bank, Dutch Development Assistance, the E-7 group of utilities and others
[9] Wouters e.a., 1997

through development programmes, but this type of market is slowly stimulating private demand for such applications.

During the 1990s a new basic product was developed for the poorest customers: the portable solar lantern. Although technical problems are still reported, mainly on the battery storage management, these small units have experienced a large market penetration. According to 1996 sales estimates, more that 110,000 units had been sold worldwide, totalling more than 0.6 MW of installed power and making it one of the fastest growing PV markets (Maycock, 1998). This market segment is still expanding also through a growing number of examples of local manufacturing.

Solar battery charging stations (BCS) are another interesting PV application that was further developed in the 1990s to service the market segment of low income rural households who cannot afford to purchase a SHS even with access to credit. Such systems have been installed in several countries including Colombia, Mali, Morocco, the Philippines, Thailand, Senegal and Vietnam. In Thailand, for instance, a Government-sponsored programme has installed over 1000 BCS between 1988 and 1998 (Lew, 1998). The customers only have to pay the charging fees as the BCS facility is owned by the Government and managed via a local committee. The model builds on the widely existing practise of recharging car batteries and allows customers to gradually upgrade and buy a solar panel in a later stage, if so desired. The local operation of BCS units creates local employment opportunities and potential business for local entrepreneurs.

Finally, PV village mini-grids and other larger PV systems have come to receive renewed attention, after being under demonstration since the 1980s. Such large PV systems are not yet able to compete economically with stand-alone diesel generators[10], but hybrid PV/diesel and other hybrid systems have made considerable progress and are worthwhile investigating further. Where the local conditions make fuel supply unstable and expensive, the fuel, operation and maintenance cost savings deriving from the PV/diesel hybrid option become economically significant. On this basis the International Fund for Agricultural Development is financing an island mini-grid in the Maldives designed for supply of household power and for a number of small productive activities. In Asia a company named Synergy has installed Wind/PV/diesel hybrids for village power on the basis of the significant capacity of such systems to satisfy village electricity including productive uses. Examples of PV/wind systems come also from Argentina and Brazil[11]. Opportunities seem also to exist for retrofitting remote diesel mini-grids with PV (and/or Wind), an idea under investigation in countries such as Brazil, Morocco and the Philippines. In Morocco, for instance, Noor Web together with ENEL (Italian national utility) performed a feasibility study for the retrofitting of Diesel-based mini-grid with solar PV.

2.4 PV rural electrification: barriers, institutions and markets

The lessons learnt over three decades of use of PV systems for rural electrification have also given insight into the potential and limitations of PV technology to reach rural populations - both in terms of technology and in terms of organizational requirements (see table 2 for an overview). One of the lessons learnt is that to fully exploit this potential, several institutional changes are necessary in the energy sector to give the private sector a larger role and stimulate the creation of sustainable PV markets.

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[10] An attempt to a comparative cost benefit analysis with diesel mini-grids is contained in GTZ (1995).
[11] Village Power 1997

Table 2 Overview of potential and limitations of PV systems

Area	Potential	Limitation	Result
Equipment and investment	Flexibility: easy scaling from a few Wp upward	High investment costs per unit (Wp)	PV mainly competitive in low energy use range in remote, unelectrified areas Need for financing mechanisms (also due to low capital availability in rural areas)
Operation and maintenance	Reliability: low maintenance and supervision needs and costs	Need for back-up or storage for use at night and in days of low insolation Battery is weak part of PV system[12]	PV systems often competitive on life cycle cost basis
Organization	Easy integration in user 'packages' adapted to users' needs[13]	Higher involvement of user necessary for PV projects more than for grid extension projects	Need for institutional changes in the energy sector for PV rural electrification projects
Environmental implications	Environmentally friendly: low emissions of CO_2 and other emissions compared to fossil fuel based systems	Disposal of battery is a major environmental issue	Possible (co)financing from climate change funds

source: FAO survey and literature review

As with the introduction of every new technology, barriers are encountered when trying to introduce PV systems in rural areas, many of which have to do with the characteristics of PV technology. A more general aspect of the introduction of a new technology is the need to buildup a new infrastructure for dissemination of information, promotion, distribution and installation. A detailed description of these barriers[14] is beyond the scope of this publication, but can be summarized in:

- information barriers: lack of familiarity with PV technology and lack of promotion;
- financing barriers: high initial costs of PV systems and lack of finance mechanisms (affordable credit);
- institutional barriers: regulations, monopolies, import tariffs, subsidies, quality standards;
- scale and cost barriers: lack of sufficient market base to warrant private investment; and lack of local infrastructure for installation and maintenance (increasing cost and lowering reliability).

It should be noted that such barriers often create a vicious circle: high investment costs, lack of financing mechanisms, low volumes of sales, high transaction costs[15], lack of

[12] Investigation in alternative storage systems, e.g. water tanks (for water pumping systems) or ice (for refrigerators and freezers) promises to contribute to solving this problem at least partly.

[13] PV systems offer the possibility to design and install "'packages"' tailored to specific uses, such as refrigeration for health care centres, lighting and communication for schools, community and other public buildings. This facilitates the integration of energy services in development programmes such as health care, water development, agriculture (livestock watering, irrigation) and education. Subsequent standardization of such "packages" contributes to user friendliness and simplifies long-term maintenance. Another trend is the development of factory-standardized products such as solar lanterns, solar lighting kits and egg-incubators, creating 'off-the-shelf', easy-to-install products that can be sold through a wide range of distribution channels. Both the trends of tailor-made design and standardization/integration will continue to exist in parallel.

[14] Discussed in detail in many publications, e.g. Erickson, Chapman, 1995; Northrop et al, 1995; Cabraal et al., 1996

[15] Transaction costs include costs involved in setting up distribution, installation and maintenance infrastructure, promotion and other overhead costs.

infrastructure**,** lack of familiarity and lack of political commitment and adequate policies. From the point of view of the (potential) rural PV user this means: difficulties in gaining access to information on PV technology, higher costs, and more difficult access to spare parts and repair services. Economies of scale can be reached with higher volumes of sales, but investment in developing such markets brings risks and is only reasonable to the investor if there is a prospect of solid future markets.

Institutional aspects of PV rural electrification
Several approaches to tackling these barriers have been pursued. The case of Kenya shows the exemplary difference between a monopolistic power company focused at grid extension, but not capable of reaching the vast majority of rural people, and a private sector developing a solid market for small PV systems. Many cases in between these two extremes exist where public and private sector can and do cooperate in developing rural PV markets. The detailed discussion of different institutional arrangements is beyond the scope of this publication[16]. Such public-private sector cooperations in rural electrification have become more prominent since many countries have initiated power sector reforms stressing deregulation, decentralization and privatization. PV has shown to have considerable potential in this context and slowly PV has entered onto the agenda of rural electrification programmes. Many of these projects include a subsidy component, because rural electrification is still often recognized as a basic government service. A general complaint is that subsidized projects tend to distort existing private PV market infrastructure. Recent projects try to take these considerations into account.

A few of the latest examples of public-private cooperation in rural electrification are based on the granting of concessions to private companies, but under strict state controlled conditions. Such arrangements include the concessionaire's right (and obligation) to offer electrification services to a certain rural area, including installation, user education and servicing of the systems. These approaches try to combine the flexibility of private sector operations and the creation of a large customer base (“critical mass”), with the public interest approach of rural electrification projects. The least-cost technology is generally used and PV is often the preferred option for electrifying dispersed rural dwellings. As in 'traditional' rural electrification projects, the end user generally only pays a small down-payment (installation costs) and a monthly consumption fee. Examples of such approaches come from countries such as Argentina, Chile, Morocco and South Africa. In some cases not only household electrification is part of the concession, but also the electrification of community services and public buildings. This helps create a critical mass of PV systems.

Such PV electrification schemes generally involve various amounts of subsidies by governments, national and international donors. In some cases renewable energy systems receive a higher subsidy. A noteworthy source of such subsidies is from funds related to climate change mitigation efforts. If well designed, PV rural electrification projects can contribute both to the reduction of greenhouse gas emissions (by replacing fossil fuel based electricity) and to the development of rural areas. Several PV projects have already received considerable funding from such sources. At present such funds are provided by the Global Environment Facility (GEF) and other national and international donors, but in the future it is expected that mechanisms such as the Clean Development Mechanism (CDM) will give rise to high private investments in such projects. This would help considerably to bring down investment costs and help to attract additional (loan) capital.

[16] Discussed in e.g. WB/ESMAP, 2000

Markets for rural PV applications in developing countries

When stressing the importance of private sector involvement in PV rural electrification, it is important to know in which direction markets for rural PV applications are developing. The general trend for PV rural markets is to grow at the same or slightly faster pace than global PV markets. Global annual PV shipments grew from 48 MWp in 1990 to 126 MWp in 1997: an average of 14.8% p.a. In the same period the "world off-grid rural" market (mainly in developing countries) grew with an average of 17.9 % p.a. (Maycock, 1998). It is difficult to give exact estimates of the markets for different rural PV applications. Annex 4 discusses in detail data from various sources on these markets for rural PV applications. The different sources coincide in the conclusions that the major rural PV markets will be:

- Solar Home Systems (major part in developing countries);
- Communications (both in developing and industrialized countries);
- Water pumping (mainly in developing countries).

On the basis of such market estimates as discussed in annex 4, the European PV Industry Plan (EC, 1996) defined the following priority applications and markets outside Europe (mainly developing countries):

- Solar Home Systems;
- Health care systems;
- Solar pumps.

3. PV for sustainable agriculture and rural development

3.1 Instruments and outline of results

3.1.1 Activities and instruments

To address the research questions described in Chapter 1, a survey questionnaire was designed and sent to key persons in PV projects and commercial PV companies to ask their ideas and opinions on the potential and impact of PV systems for rural development. The views and experiences of these resource people gave a clear outline of impact and potential of different PV applications; and provided a solid basis for continuing research. The complete survey questionnaire can be seen in annex 5. To complement the survey a search was made for existing information, studies, research and publications on promising PV applications and projects. More than one hundred project documents, case studies and reports were reviewed (see annex 1 bibliography). Finally, statistical data was found on present and potential markets for various PV applications.

For the analysis of impact and potential of PV applications, a division is made by sectors of rural society: households, social and communal services, off-farm productive uses and agriculture. In the area of agriculture and off-farm productive applications an economic criterion (cost-comparison and cost-benefit analysis) is deemed of utmost importance to establish the viability of PV applications. In the household sector the quantification or monetization of impacts is far more difficult and the search should be more for beneficiaries' opinions on the impact, supplemented by a cost comparison with other technologies.

It is also important to note the special case of electricity needs for social and community uses such as reliable drinking water, rural schools and clinics. Considering that these goods are basic needs or services whose impact is significant but difficult to quantify or monetize, there needs to be a shift in emphasis from cost-benefit analysis to cost comparison of delivering the same service with different technology options comparing cost-effectiveness. An important issue then becomes the availability of (public) investment capital for such social investments and the political prioritization of such investments. As mentioned in Chapter 1, rural areas generally suffer from lack of political commitment and priority in this area.

An important point to underline is that the detailed financial and economic analysis of rural PV systems goes beyond the scope of this study. For in-depth financial and economic cost–benefit analysis, comparison would be needed between PV systems and other decentralized and grid options on a country and even case-to-case basis (Guidi, 1997). The survey responses do not go into enough detail to make such comparisons possible. Generalization of such case comparisons is difficult, especially when it comes to applications involving different climates, soils, crops, user-techniques and energy prices. With the help of survey data and literature it is possible, however, to give some direction as to what PV applications make economic sense and under what conditions.

3.1.2 Outline of results

Forty-three completed questionnaires were received with a concentration of responses from Latin America and Asia (see annex 2). It should be noted that, obviously, the study does not pretend to have a representative sample of responses on which to base conclusions. The survey responses were used as an indicator for impacts and applications, and served to identify other material on the most promising and interesting areas. Together with the additional secondary material a rich picture could be created of the potential impact, most promising applications and required organizational structures.

Table 3 shows an overview of the survey responses on the uses of PV systems in their projects or business. Note that projects and businesses often involve different applications. More than one application could be filled and therefore the uses total up to more than 100 percent. The table shows clearly that "lighting, TV, radio and other household uses" with the so-called Solar Home Systems (SHS) is the dominant use of PV systems, which is confirmed by literature. Other major applications are for retail shops, cafes and restaurants. Communal use of PV for health centres and community buildings is also a major application. Of the agricultural applications, PV pumping for livestock and irrigation dominate. The prominence of radio and cellular phone communication is confusing, because this category often includes both PV systems used for repeater stations (which do not necessarily directly benefit rural areas), and systems for radio communication by development projects, health centres, rural telecom authorities and private investors (which benefit rural areas more directly).

Table 3 Uses of PV systems (percent of survey respondents)

PV pumping (irrigation)		30 %
Livestock watering		9 %
PV pumping (potable water)		35 %
PV water purification		12 %
PV electric fences		16 %
Lighting of poultry /livestock		14 %
Office equipment (computers, etc.)		16 %
Radio or cellular phone communication		42 %
Health centres (refrigeration, lighting, etc.)		44 %
Veterinary service (refrigeration, lighting, etc.)		9 %
Refrigeration (household, retail store, agricultural products, meat, dairy, fish, etc.)		16 %
Lighting, TV, radio, small appliances for commercial services (retail shop/cafe/restaurant)		47 %
Lighting, small power tools for micro-enterprises (repair shop, handicraft)		19 %
Lighting, TV, radio, etc. for household use		81 %
Tourist facilities (lighting, TV, refrigeration of lodges, hotels, etc.)		21 %
Lighting and audiovisuals for schools and other community buildings		37 %
Street lighting		28 %
Others, namely:	telemonitoring (irrigation)	2 %
	advertising kiosks	5 %
	lighting for fishing	5 %
	portable lanterns	1 %

source: FAO-survey

Another question referred to the area of impact of the installed PV systems. Table 4 shows an overview of the responses.

Table 4 Impact of PV systems on different rural sectors (percent of survey respondents)

Agricultural productivity	35 %
Off-farm productive uses: rural and cottage industry, commercial services and small business development	40 %
Social and community services	60 %
Households	81 %
Other (productive) activities, namely: billboards/advertising	5 %

source: FAO-survey

Again, the majority of respondents noted the impact on households, (mainly SHS), but 60 percent of the respondents also saw impacts on community and social services and more than a third on agricultural or other productive activities. As a combined group, more than half of the respondents (56 percent) saw an impact of PV systems on productive activities (agricultural and/or off-farm productive activities).

The combined sources of survey, literature, project documents and interviews resulted in overview of the uses of PV with a significant (potential) impact on income generating (productive) activities and rural development - as shown in table 5.

Table 5 Inventory of PV systems for sustainable agriculture and rural development

TYPE OF PV APPLICATION	TYPICAL SYSTEM DESIGN	EXISTING EXAMPLES
Applications in the agricultural sector		
Lighting and cooling for poultry factory for extended lighting and increased production	50-150 Wp, electronics, battery, several TL-lights, fan	Egypt, India, Indonesia, Vietnam, Honduras
Irrigation	900 Wp, electronics, small DC or AC pump and water tank	India, Mexico, Chile
Electric fencing for grazing management	2 - 50 Wp panel, battery, fence charger	USA, Australia, New Zealand, Mexico, Cuba
Pest control (moth)	Solar Lanterns used to attract moths away from field	India (Winrock Intl.)
Cooling for fruit preservation	PV/wind hybrid systems or 300-700 Wp PV with DC refrigerators (up to 300 lt.)	Indonesia (Winrock Intl.)
Veterinary clinics	300 Wp, batteries, electronics, refrigerator/freezer, 2 TL-lights	Syria (FAO project)
Cattle watering	900 Wp, electronics DC /AC pump, water reservoir	USA, Mexico, Australia
Aeration pumps for fish and shrimp farms	800 Wp, batteries (500 Ah), electronics, DC engine, paddle wheel, for 150 m^2 pond	Israel, USA
Egg incubator	panel up to 75 Wp, integrated box + heating element for hatching 60 eggs	India (Tata/BPSolar), Philippines (BIG-SOL project)
Crop spraying	5 Wp, sprayer	India (southern states), but cancelled from product package by BPSolar
Applications in cottage industry		
Tailor workshop	50-100 Wp system with DC lights and electric sewing machine	Several countries (i.e. NREL projects)
Electronic repair workshop	50-100 Wp for DC lights and soldering iron	Bangladesh (Grameen Shakti project) India, Indonesia
Gold jewellery workshop	60 Wp system with DC lights and soldering iron	Vietnam (SELF project)
Bicycle repair workshop	80 Wp system for DC lights and DC small drill	Conceptual: Vietnam - Ha Tinh Province (IFAD project)
Handicrafts workshop (small woodwork, bamboo, basket weaving, etc.)	60-100 Wp system for DC lights and DC small tools	Nepal, Vietnam

Trekking/eco-tourism lodges	Solar lanterns, SHSs and larger PV systems for lights and refrigeration	Nepal, India, Peru, Trinidad and Tobago
Pearl Farms	0.4 - 1 kW PV systems to power craft workshops with drills, pumps, lights & compressor	Examples in French Polynesia (Solar energy)
Applications in the commercial service sector		
Village cinema	100-150 Wp system with DC lights and Colour TV + VCR or satellite	Dominican Republic (ENERSOL project), Vietnam (Solarlab), Honduras
Battery charging stations	0.5 - 3 kWp systems with DC battery chargers for kWh sales to households and micro-enterprises	Morocco (Noor Web), Philippines (NEA), Senegal, Thailand, Vietnam (Solarlab), India, Bangladesh
Micro-utility	50 Wp, electronics, battery, 5 -7 TL ("rented out")	India, Bangladesh (Grameen Shakti project)
Rent-out of solar lanterns for special occasions (weddings, parties, reunions)	Solar lanterns (5 - 10Wp)	India (NEC) as part of a youth programme
Lights, radio/TV and small appliances such as blenders for restaurants, shops and bars	20-300 Wp, electronics, battery, appliance, invertor (if necessary)	many countries, incl. Karaoke bar in Philippines (NEA)
Trekking/eco-tourism lodges	Solar lanterns, SHSs and larger PV systems for lights and refrigeration	Nepal, India, Peru, Trinidad and Tobago, Mexico
Cellular telephone service	A 50 Wp System with 2 lights and a socket to charge cellular phone batteries	Bangladesh (Grameen Shakti project)
Computer equipment in rural offices	8- 300 Wp systems powering lights, fax, TV, etc.	Bangladesh, Costa Rica, Chile
Internet server for E-commerce	Integrated in multifunctional solar facility (> 1 kW)	West Bank (Greenstar project)
Applications for basic social services		
Health clinics	150-200 Wp, electronics, deep-cycle batteries, small refrigerator/freezer	Many countries (WHO standards)
Potable water pumping	1 - 4 kWp, electronics, pump, reservoir (generally no batteries needed)	Many countries, e.g. large project in Sahelian countries (EU-project)
Water purification	PV to power UV or ozone water purifiers (0.2-0.3 Wh/litre)	Many countries, e.g China, Honduras, Mexico, West Bank
Water desalination	1 - 2 kWp needed to power reverse osmosis or other water desalination units for $1m^3$ per day	Italy, Japan, USA, Australia, Saudi United Arab Emirates
Internet server for telemedicine	Integrated in multifunctional solar facility (> 1 kW)	West Bank (Greenstar project)
Schools and Training centres	PV systems for powering lights, TV/VCR, PCs	many countries: China, Honduras, Mexico, the Philippines,
Street light	35/70 Wp, electronics, battery, 1 or 2 CFL	India, Indonesia, the Philippines, Brazil

source: FAO-survey and literature review

The most illustrative cases and their lessons are highlighted in text boxes in the sections that follow. These sections are organized by sector: Section 3.2 covers the household sector. Section 3.3 explores applications of PV systems for community and social services. Section 3.4 discusses the potential of PV for off-farm productive uses. Section 3.5 deals with the use of PV in agriculture.

3.2 PV for rural households: Solar Home Systems

The Solar Home System (SHS) is the dominant application of PV in rural areas of developing countries and this is reflected by the 81 percent of survey respondents who are involved in such projects. As described earlier (see Section 2.3), the SHS option has been disseminated though a variety of market and social policy approaches which have been analysed in a vast range of literature. Existing studies cover well the enabling conditions for a successful commercialization or dissemination, but generally do not carry an analysis of the implications on rural development. This Section aims to summarize what is known in this field. SHSs have made their impacts mainly at the household level, which, for analytical purposes, can be roughly divided into impacts that can be quantified economically and in impacts that can more easily be described under the heading "quality of life" or welfare impacts (paragraphs 3.2.1 and 3.2.2 respectively). In paragraph 3.3.3 important gender aspects of these impacts will be highlighted.

A general comment on the SHS performance is that they generally provide a reliable source of electricity. This reliability offers a guarantee of continuous service, especially when the alternative is grid connection with frequent supply interruptions or diesel/gasoline/kerosene options that depend on unreliable access to fuels - situations that occur all too frequently in rural areas. This reliability is generally highly appreciated by SHS users but further research is needed to assess the intrinsic (economic) value in terms of the rural development process.

Apart from trying to evaluate the impact of SHS "from the outside" and trying to objectively do cost-benefit analysis, rural inhabitants do their own cost-benefit analysis when they make a decision to buy an SHS. The number of SHSs installed is therefore an indication of end-users' cost-benefit analysis. As a derivative of this, studies into the "willingness to pay" can be used as a *proxy* of such cost-benefit analysis. For instance, studies on the PV market in Kenya, where most of SHSs installed are sold by commercial companies, show that 50,000 - 70,000 SHS have been installed, more than 90 percent by cash sales and that when grid extension is not a realistic option, 70 percent of the PV system owners would be willing to spend an average of US$390 for expanding the power rating of their SHS (Van der Plas, Hankins, 1997). Other SHS project experiences report that SHS users are willing to pay double their traditional energy monthly spending to obtain the high quality lighting service.

3.2.1 Impacts of SHS on household economics

In the introduction to this Section it was said that, for analytical purposes, the impact of SHS could be divided between economic and "welfare" impacts. In reality these impacts cannot be divided so easily; in fact the impact on household productive activities overlaps considerably with the impact on *off-farm productive activities* as discussed in Section 3.4.

Many studies conclude that there is little or no evidence of direct economic impact by SHS (e.g. Cabraal, 1994; Wamukonya, Davis, 1999). Other investigations, however, show that SHSs also support household economic and income generating activities for some end-users, as indicated in a recent study conducted in Nepal on a sample of 250 SHS users: 13 percent of the interviewed men and 11 percent of the interviewed women perceived an increase in income generating activities due to the introduction of SHS (AEPC/DANIDA,1999). These activities most often include sewing, basket weaving and other small artisanal activities. Several other examples exist, but there seems to be a lack of research devoted to analysing this home economics sector. Often these examples reveal a link with productive activities conducted by women (see paragraph 3.2.3).

The evaluation of surplus time due to time savings and prolonged hours of light offers another indicator of the (potential) impact that SHSs have on income generation. As for surplus time, the referred Nepal study indicates that 93 percent of respondents realized a surplus of over 1.5 hours per day. Other project reports also mention the effect of prolonged hours of light, ranging from one to two hours a day (Richter, 1999; Wamukonya, Davis, 1999). This “surplus time” is not necessarily dedicated to productive activities, as field observations record also an increase in activities such as TV watching, homework, socializing and reading. Other (often female) activities include more time for household chores, attention to children and homework; activities that are generally not called productive, but not less valuable. "Surplus time" is therefore an easily quantifiable impact indicator and can easily be linked with the (potential) impact on income generating activities.

An interesting trend in this context, is that the average size of SHSs purchased in the developing world is growing, as indicated in interviews with representatives of the PV industry. Larger systems should introduce "excess power" beyond lighting and audiovisuals (the main SHS uses). If this trend is confirmed and supported by decreasing PV system prices, there could be a higher potential for impacts on household economics. There are, for instance, some examples from projects being implemented in China, where the installation of larger PV systems (100-300 Wp per family) and PV/wind hybrids led to an increase in productive uses. The monitoring results show that at least 50 percent of end-users use home appliances for time and labour savings and a typical domestic appliance, the washing machine (with cold water) is introduced not only as washer for laundry but as an effective centrifuge machine to separate butter from milk with considerable time saving gains (Richter, 1999). Another more widespread example is the introduction of simple electric sewing machines: their usual energy requirement is about 50-75 Wh/day for a sewing machine of 80W power rating. These applications can easily be powered by slightly increasing the size of PV systems for lighting and radio/TV (the marginal costs of 10-20 Wp extra power are low) and cannot only save time but can also create more productive tailors.

It is worth mentioning that another rudimental indicator is sometimes used in SHS impact analyses which measures at least a portion of the economic impact related to the savings on energy expenditures such as kerosene, butane gas and candles. Savings can be considerable: reported savings in Kenya amount to US$10 per month.[17] Most Kenyan households initially invest in small 10-12 Wp panels and in these cases pay-back periods are as low as 1.5 to 2 years (v.d. Plas, Hankins, 1997). For larger PV systems, households have shown to be willing to pay several times their monthly energy expenditures for the increased service.

An example from Inner Mongolia (China) highlights the economic value of TV/radio use to access information on weather forecast (see text box 1). In addition, market reports delivered via TV/radio and the access to a telephone service are reported as ways for rural people to access valuable information on the price of their produce.

[17] A study conducted in Nepal (Koirala, 1998) on a sample of 85 SHS users reports that kerosene consumption dropped from 6.38 litres to 1.86 litres per household per month, with an average saving of 60 percent of lighting fuel. Other research findings give estimates from 50 to 80 percent decrease in household kerosene use (Schweizer-Ries, 1998).

Text box 1 The economic significance of weather forecasts for inner Mongolian households

As recently reported in a solar/wind project evaluation report (Richter, 1999), findings show that at least 80 percent of adult community members listen to the weather forecast for productive purposes. The families interviewed state that access to TV/radio has a positive impact both on quality of life and rural income. The weather forecast is most important for the herdsmen and has a positive impact on herd productivity because it reduces the risks in herd management. Cattle can be protected and brought home when a storm is announced. The weather forecast helps plan dates for sheep shearing, avoiding the health risks of shearing when cold and rainy. Newborn lambs can be properly protected in unusually cold weather if cold weather is known to be arriving. When rain is announced hay can be moved indoors. Knowing that rain will arrive can also help save labour and water by avoiding unnecessary watering of the fields. When a herdsman knows that insufficient rain is announced, cash can be set aside for buying animal food as during dry periods the grasslands cannot provide enough fodder for the animals.

The weather report also has an impact on the activities of shop owners. Fruit and vegetables should not be ordered if there is going to be a sudden drop in temperature as they could freeze during delivery. Stock keeping of other foods is also dependent on the weather as during heavy rain the roads to the town close. Knowing this in advance helps shop keepers to plan accordingly as otherwise they would not be able to return to the Sumu (home) for a few days, resulting in income loss. If the shop owner knows that there has been enough rain, then he knows that grass is abundant and that herdsmen will have income to spend.

source: Richter 1997; Richter 1997a; Richter 1997b

Another important effect of SHS diffusion is the local employment related to the technology transfer and commercialization of SHSs. The dispersed markets for SHSs lead to the creation of decentralized, local support infrastructure and therefore it is argued that SHS installations generally stimulate rural employment more than conventional grid extensions (see also Section 3.4).

3.2.2 Welfare impacts of SHS

The following paragraphs summarize information on the (potential) impact of SHS on social welfare, collected through the survey and through the review of literature. A distinction is made between the impacts of the two main services provided, lighting and audiovisuals.

Social Welfare Impacts of Lighting Service

Studies on SHS introduction usually mention that there is a general effect related to the provision of basic lighting service in terms of improvements in *quality of life* at the households level (Hankins, 1993). About 81 percent of the survey respondents indicated that the solar systems had an impact on the household quality of life. The quality of lighting output coming from well-designed SHS is much higher than the lighting from kerosene lamps - 400 lumens for a 8W high efficiency solar lamp vs. 60 lumens from a kerosene lamp. The linkage between provision of quality lighting and household increase in social welfare can be summarized in the following often reported effects (AEPC, DANIDA, 1999):

- extended housework schedule;
- time and labour savings;
- increased reliability and convenience in energy use;
- decrease in indoor pollution;
- decrease in accidental fire;
- improved health and hygiene;

- improved education;
- increase in leisure time activities.

The results of the survey confirm that electricity for lighting and TV/radio has several impacts on the quality of life at the household level, especially related to education and homework (79 percent of respondents) and related to recreational activities (77 percent of respondents).

Table 6 Household improvements due to PV electricity (% of all respondents)

Work/education/homework in the evening		79 %
Better recreation possibilities (TV/radio, reading, etc.)		77 %
Better health conditions (refrigeration, no smoke, no danger of fire)		42 %
Time liberation, especially for women		44 %
More pride/self-esteem/positivism		56 %
Improvements in housing coinciding with installation		40 %
Others, namely:	➢ possible use as a mosquito repellent power supply ➢ elimination of the use of primary cell batteries	5 %

source: FAO-survey

Social Welfare Impacts of Audiovisuals Service

The use of SHSs for audiovisuals (radio, TV) can bring the benefits of more access to information and entertainment to the rural villages, but negative impacts are also reported in this context. It is argued that TV programmes can create negative impacts in the realm of what could be called "preservation of traditional, cultural values". TV watching is sometimes said to create expectations about (urban) lifestyles, disenchantment with rural life, especially in the young, and thereby to contribute to rural-urban migration (e.g. Saupin, 1996). In the referred study, it was also found that some villagers who were beneficiaries of solar battery charging service in Thailand expressed the concern for the new habit of staying up late at night watching TV, with a negative impact in terms of decreased amount of time devoted to sleeping.

Other field studies report, however, that users feel that “we have conditions almost like in the city with light and TV” (Richter, 1997b). Some of the survey respondents also indicate that PV projects help to slow down rural-urban migration. Finally, TV and VCR can become important tools in delivering adult education and training programmes as highlighted in paragraph 3.3.3.

3.2.3 Gender-related aspects of SHS impact

An important aspect of household electrification that has only recently come to the forefront, is the different impact on men and women. The feedback from several studies suggests that there is a higher impact on women and children than on men (e.g. Cabraal, 1996). The former spend more time at home, performing indoor activities, and thus enjoying more the lighting and audiovisuals services from a typical SHS. It is often noted that the quality lighting helps women to do household work more efficiently and children to study after dark[18]. Examples from several countries show that handicrafts, sewing and embroidery are activities that women carry out at home and that access to electricity translates into productivity gains due to factors such as better work schedule management, higher quality lighting, and extended working hours.

[18] One field study reported that the number of hours of lighting per day decreased after SHS installation, which was interpreted as an indicator of more efficient conduction of home work.

Despite this tendency for higher impact on women, marketing and financing of SHS is generally targeted towards men as the main decision makers on monetary investments. Training in operation and maintenance is also mostly directed at men, although women are often the ones that spend most time with the systems and are therefore more regularly confronted with failures and imperfections. The experiences of Grameen Shakti (Bangladesh) and Genesis (Guatemala) show that women can be reliable investors in and caretakers of SHSs and that these systems can help them increase their productivity considerably (see also Section 3.4). The example of the former also proves that women are more reliable repayers of loans.

As for benefits related to improved health and hygiene, an impact study from Nepal, indicates especially that women and children (95 and 91 percent respectively) felt increased benefits. A study from China highlights gender specific impacts related to SHS and wind/solar home systems related to the use of time and labour saving home appliances, such as the electric blower[19] for cook stoves: at least 80 percent of interviewed end-users state that electricity has made housework easier and faster for women (Richter, 1999).

Other researchers on energy and gender issues underline the areas of potential impact on which future project design should put higher emphasis: time savings in water collection by energizing water pumping; ease of domestic work and increased women productivity via use of small appliances such as blenders and commercial lighting; and health improvements via water purifiers and small DC fans to remove smoke from kitchens (Cecelsky, 2000).

The experience of the Himalayan Light Foundation in Nepal (see text box 2) is a good example of where SHS commercialization, micro-enterprise development, productive uses and gender aspects meet via an unusual source of private financing (eco-tourism industry).

[19] An indication on labour savings related to use of electric blower is given in the following terms: “with the electricity supply food preparation is easier and faster because women can use an electric blower instead of using a hand driven one to keep the fire in the oven/stove burning” (Richter, 1999, p. 57). The substitution of the hand driven blower for heat control during the cooking process can save labour for one person, because traditionally one person had to just steadily power the hand blower.

Text box 2 Linking eco-tourism to solar rural electrification and the development of women
The Solar Sisters project is an example of how rural electrification and micro-enterprise development can take place through a linkage with the growing eco-tourism market, whose revenues serve to finance the initial investment costs. A volunteer programme managed by Stephanie Davis and run through the Himalayan Light Foundation (HLF), is bringing affordable solar lighting to rural villages in Nepal. HLF is a non-governmental organization created to bring renewable energy to Nepal's rural population. Each volunteer subsidizes as well as installs one 36 Wp solar electric system. The participants receive a two-day intensive training on solar installation during which they stay with local families and are provided with translators and technicians to monitor the participants' progress. The US$1,500 programme fee includes the system, the training course, accommodation and all travel inside Nepal. The Solar Sisters programme mainly focuses on Nepali women although the interest stands in creating income-generating activities for the benefit of the entire community. In March 1999 the first project was begun where the group installed four 36 W systems into homes of women who were involved in bringing income into the home through handicraft production. The systems benefited the families in a variety of ways. The solar light made it possible to work into the evening as well as begin early to prepare products for the local markets. The children benefited by being able to help out at home as well as read and study at night. There are currently four programmes planned for each year and in October 1999 the volunteers travelled to Terathum in Eastern Nepal to install solar systems in a weaving workshop that employs forty women. As the electricity grid does not reach this region, the women have difficulty sewing the detailed embroidery with insufficient lighting. In areas where women would not usually be involved in activities outside their domestic duties, it is important for them to use the skills that will empower them both socially and financially.

With the current Government subsidy, solar home systems are only available to 22 of the 75 districts. Out of the 22 regions, it is only the wealthiest villagers who can afford the SHS and there is a restriction on groups purchasing systems together. The Solar Sisters programme is accessible to those who are excluded by Government subsidy programmes because they allow the villagers to use the solar panel itself as collateral. If the villagers fail to make payments to HLF (each payment reflects the individual's normal expenditure on kerosene and batteries), the system is removed. The villagers are more comfortable because they are not risking land and possessions by taking out loans. Because the photovoltaic systems are helping to create a better standard of living for the families, their reliability is also impacting education, employment, and social empowerment of the entire village. In addition to longer working hours, schools are able to offer night classes, which can lead to a higher literacy rate and in turn more possibilities of employment and income. With several photovoltaic system manufacturers emerging in Kathmandu over the past few years, over 2,500 systems have been installed in Nepal and are proving to be successful in the villages.

source: Davis, 1999

3.3 PV for social and communal services

As mentioned in Section 3.1, 60 percent of the respondents indicated an impact on social and community services, especially through improved health facilities, education and community centres as shown in table 7.

Table 7 Type of social and community services stimulated with PV (% of all respondents)

(Improved) health facilities	47 %
Education	51 %
Training centres (professional, farmer)	21 %
Public lighting	33 %
Drinking/tap water (including water pumping, purification and desalination)	26 %
(Improved) veterinary services	5 %
Community centres/religious centres (churches and mosques)	47 %
Telecommunications	37 %

source: FAO-survey

Table 8 shows that the impacts indicated by the respondents are more or less equally distributed among the different categories.

Table 8 Impact of PV systems for social and community services (% of all respondents)

Better quality courses/training	30 %
More involvement and participation in community development activities	35 %
Productive activities/handicrafts (in the evening)	35 %
Courses/classes/training or homework in the evening	37 %
Better opening hours shops, restaurants, etc.	28 %
Liberating time of villager for other activities, especially for women	35 %
Better communications and/or information	40 %
Higher health standards	37 %
Improvement of local natural environment	19 %

source: FAO-survey

Note that 35 percent of respondents mention that the communal PV systems are also used for productive activities in the evening. No details are available on how many hours, what kind of work and how much more income could be derived from these activities. The use and economics of PV systems for such productive uses is illustrated in more detail in Section 3.4. Most of the impacts of social and community applications of PV are difficult to quantify. In the following paragraphs the main uses of PV systems for social and community services will be discussed and impacts will be supported with figures and examples from literature.

3.3.1 PV for health care

Vaccine refrigeration

Vaccine refrigeration and ice-pack freezing are the best-known and most common applications of PV in rural health clinics. This equipment is used in immunization programmes around the world. Failing reliable refrigeration (along the whole chain: from manufacturing to transport to the point of use), the potency of vaccines is lost. This is, however, generally not visible to the health worker, endangering immunization programmes even more. In the most remote health clinics ice-pack freezing is also necessary to carry the vaccines to remote villages in coolers.

The frequently used kerosene refrigerators have no reliable temperature control. Studies by WHO in Mali[20], for example, have shown that kerosene refrigerators exceeded vaccine storage temperatures more than 35 percent of the time - an experience common in many other countries. Kerosene refrigerators are also unfit for ice-making. Liquid Petroleum Gas (LPG)

[20] ITPower/WHO Mali, 1990; quoted in WHO 1993

and electricity-main refrigerators do have reliable temperature control and can make ice-packages, but LPG and electricity supply in many rural areas of developing countries is highly unreliable. An additional advantage of PV fridges is their high reliability: a WHO study in three African countries showed a mean time to failure of 3.5 years and concluded that this had improved the long-term reliability of the Cold Chain/Immunization Programmes considerably. PV refrigerators had also permitted serving more remote areas, thereby increasing access to rural health services. It was also concluded, however, that despite high reliability, the costs of maintenance in remote areas was still too high and that the mean time between failures should be raised to seven years. Another option would be to share the costs of servicing more widely with other applications outside the health services.

Other applications
Electric lighting greatly improves accessibility and quality of (emergency) care at night. Also radio communication can greatly improve rural health care services, by providing full-time communication with medical back-up staff. Recently experiments have been done with remote access to medical databases by internet connection, providing a valuable knowledge source for rural medical personnel. In most instances PV is the only or most cost-effective energy source for these applications. Other medical appliances that can be run on PV systems are nebulizers, centrifuges, sterilization and water treatment equipment.

Finally, remote, unelectrified rural communities have notorious difficulty to recruit and keep trained medical staff. PV systems providing light, music, TV and communication can be important incentives for professional staff (also teachers, extensionists, etc.) to make life in rural areas more amenable.

Status
The use of PV systems in rural health care[21] started in the 1970s, when the World Health Organization (in collaboration with UNICEF, USAID, and national governments) started evaluating the use of PV for vaccine refrigeration. Rapidly it became clear that PV powered refrigerators were a reliable technology for vaccine refrigeration. Large-scale programmes were introduced in Indonesia, Myanmar, Peru, Uganda, Zaire, and many more countries. WHO (1993) estimates that a total of 1.36 MWp had been installed in the health sector up to 1992, the majority for vaccine refrigerators (54 percent), another 35 percent for lighting and 10 percent for other health applications. The same study estimates the total solar PV health market at 125-257 MWp. A study by the European Commission (EC, 1996) estimates the same market at 112 MWp (see also annex 4).

Barriers, experiences and innovative approaches
PV for the health care sector has proven to be reliable and functional, especially for vaccine refrigeration, but PV also has its drawbacks, mainly due to the high initial investment costs and need of qualified maintenance. Though the high reliability lowers maintenance frequency (and costs), for isolated systems such maintenance can become inhibitively costly. Slowly more integrated approaches are being experimented, both referring to broader applications within the health centre (lighting, communications, etc.) and to other applications in the community at large. The underlying motivation of this approach is that by supplying a number of services with PV, a critical mass can be created to sustain a local infrastructure of installation and maintenance. This can also motivate households to invest in PV systems, broadening the base even further. Another reason for developing alternative approaches is that

[21] source: NREL, 1998; and WHO, 1993

health care in many developing countries is often under-funded and rural clinics often lack operating funds[22]. In several pilot projects income generating activities – such as video theatres and battery charging stations - have been integrated into PV rural health clinic electrification and have succeeded in generating significant funds for operation and maintenance (see text box 3).

Text box 3 PV for health care: an integrated approach in Colombia

Four rural communities in the Province of Chocó, on the Pacific Coast of Colombia utilize PV systems to provide health care services of vaccine refrigeration, lighting, communications, and medical appliances. Each of the four communities established community councils to create micro-enterprises to generate funds for maintenance of the PV systems. The community councils received PV systems to power micro enterprises including four video theatres, two battery charging stations and the sale of PV powered lanterns. Four churches also received lighting systems. Two technicians were selected from each community and were trained in the installation, maintenance and repair of the systems.

Apart from the improvements in health services (vaccination, nightly service and health education), additional income was generated (US$335-655 per community in a period of nine months), mainly through the sale of tickets to the video theatre and the battery charging. The income was put into a maintenance fund for the systems. The future of these kinds of successes on a larger scale depends very much on innovative financing, investment and development of a private market for energy.

source: NREL, 1998

3.3.2 PV for drinking water supply

Water is a basic necessity and a reliable supply of clean water can reduce the amount of water-borne diseases (especially in children); it can contribute to an increase in health, hygiene and convenience and can help liberate time for other activities, especially for women. The supply of drinking water is often one of the top priorities of villagers lacking such services. Great progress has been made in the supply of safe drinking water: in 1961 an estimated 10 percent of rural families in developing countries had access to safe drinking water; by 1997 this was 75 percent. However, an estimated one billion people are still without access to safe drinking water supply[23].

Status

Since the 1970s PV systems have been applied for village water pumping projects and, after many failures, PV pumping has proven itself a very reliable and in many cases cost-effective solution. A study by GTZ (Posorski, Haars 1995) in seven countries concluded that PV pumping systems for drinking water are technically feasible and economically competitive in the range of small diesel pumps (1-4 kWp solar systems). However, the variability of country and site-specific factors is very large, including personnel (operator) and construction costs for storage. This makes evaluation on a country-to-country basis necessary.

[22] source: NREL, 1998, but mentioned more often as a reason for failure of infrastructure investments

[23] source: UN Human Development, Report 1997; WHO/UNICEF Water supply and Sanitation Sector Monitoring Report; August, 1993

Table 9 Financial viability of PV pumping systems (in 1993)

	Argentina	Brazil	Indonesia	Jordan	Philippines	Tunisia	Zimbabwe
1 kWp	■	■		■	■	■	■
2 kWp	■	░		■	░		■
4 kWp	■	░		■	░		

■ = competitiveness of PV pumping systems with normal credit terms
░ = competitiveness of PV pumping systems with special credit arrangements
source: Posorski, 1995

Table 9 shows the differences in financial viability, comparing diesel to PV pumping systems. Only in Indonesia PV pumping systems are not financially competitive under any type of credit arrangement. Since 1993 prices for PV systems have lowered around 40 percent (Maycock, 1998); a similar comparison made at present prices would therefore result in a further increased competitiveness of PV pumping systems.

It is difficult to assess the total number of PV water pumping systems installed worldwide; different numbers are claimed in literature. WHO (1993) cites 24,000 PV pumping systems installed as early as 1992, while Posorski (1995) claims more than 10,000 PV systems for pumping drinking water[24]. Data of European and American sources suggests that between 8 and 12 percent of annual PV module production (in MWp) goes to water-pumping applications (see annex 4); projected on total global installed PV capacity, this would bring the total installed capacity of PV pumping systems at 100-150 MWp. A study by the EC (1996) estimates the potential market for PV potable water pumping in developing countries at 2,643 MWp, based on basic needs.

Experiences and barriers
Although PV water pumping has proven itself both from an economical and technical point of view, several of the same barriers exist as for other PV applications, including high initial investment cost and lack of infrastructure for installation and maintenance, which increases costs and hampers reliable operation. As with PV systems for the health care sector, lack of funds for operation and maintenance have been a problem in many pumping programmes.

Major lessons can be learnt from the many PV pumping projects around the world. For example, a major PV pumping project in the Sahel (Programme Regional Solaire - financed by the European Union), installed more than 1,000 pumping systems (1.3 MWp) in the early 1990s. After initial problems, the PV pumping technology proved itself reliable and cost-effective in the range of small village water supply systems. The equipment itself was financed by the EU and national governments, but one of the major barriers in the programme was the organization and financing of system maintenance. In the end the concept of payment for water by the villagers was largely accepted as a means to create a maintenance fund.

Another interesting aspect that resulted from the project's evaluation was that, apart from drinking water for the villagers, most systems also provided water for cattle and for small vegetable gardens. In individual cases this could run up to 80 percent, but more normally this would be in the range of 10-20 percent. Suggestions have been made[25] to include such additional uses of drinking water in the project design (as long as the well provides sufficient water). The marginal costs to increase the system size slightly are relatively low and the

[24] discusses systems of 1-4 kWp, which would result in a total installed pumping capacity of 10-40 MWp
[25] personal communication with Mr. Fraenkel, ITPower

additional income from these activities could help pay for the operation and maintenance costs.

3.3.3 PV for schools, community and other public buildings

The importance of basic education for development, but also of specific training in fields such as agriculture, sanitation and health, goes uncontested, as it allows people to strengthen their skills and abilities; to become more productive; and to feel empowered by knowledge on the world around them. Many studies (e.g. cited in WB, 1999) have shown that, also on the (macro)-economic level, education is one of the best investments, outstripping many investments in physical capital. Energy can make only a small contribution to this, but as more effective (and efficient) teaching methods are developed, simple (electrically powered) audio-visual aids can have a high impact on the access to, and quality of, education. These aids can vary from the advanced (distant learning through the internet or with interactive software) to audio-visual aids (such as video) supporting classroom and training programmes, to cheap and effective distant learning methods for basic adult education programmes transmitted by radio and cassette (see text box 4). In all cases adequate lighting can help extend the "learning" day.

As in the health care sector, the observation is often made that basic lighting and audiovisuals can also help professionals working in remote areas to increase their standard of living and motivate them to stay. Also it allows them to prepare classes at night and stay informed, through radio and TV, which should have their effect on the quality of classes.

In remote rural villages, schools and other community centres (churches, mosques) are often a focal point for the community, with great potential for the integration of community development and educational goals. Basic lighting in the evening can facilitate after-dark activities like community reunions, adult education, religious activities and festivities. Of the cases in the questionnaire involving PV systems for community centres, schools and other public buildings, around 35 percent mentioned productive activities as one of the evening activities in these centres, mainly relating to sewing and handicrafts making. These buildings are often the only buildings in a village that have good quality lighting.

Status

The variety of end-uses (lighting, radio, TV, video, etc.) makes it difficult to generalize about the economics of these applications, but PV powered electricity is often the most cost-effective solution for low-power devices in remote, unelectrified villages. Some major programmes have been focused on integrating PV in schools and other public buildings, e.g. in Bolivia, Brazil, India and South Africa, but it is difficult to make an estimate of total installed power. Many systems are also installed on an individual basis by churches, schools and communities themselves.

The EC (1996) estimates the potential PV market for the education sector in unelectrified rural areas of developing countries at 2,657 MWp (see annex 4).

Text box 4 PV electricity for adult education programmes in Honduras

In several rural development projects of FAO in Honduras, education has been identified as an important priority by the target population. The regular basic education programme has not succeeded in providing a literacy basis for large parts of the population (especially adults, but also children). Cooperation was sought with a nationally developed adult education programme (EDUCATODOS, financed by USAID) that is based on radio or cassette lessons and textbooks, which are studied in self-help groups, supported by a facilitator (mainly for logistical help, external motivation and examinations.). The programme is hugely popular in many communities that FAO assists. In the area of Southern Lempira alone about 160 groups are functioning, consisting of approximately 1,600 students in six different level classes. People have classes five to six nights a week and the vast majority pass their exams.

Because most adults are occupied in the day-time, preferred class hours are after dark. Groups are supplied with a cassette player (cassettes being highly preferred to radio lessons because of the possibility to listen to parts of the message again), pressurized kerosene lantern and a regular supply of dry-cell batteries, kerosene and alcohol. The pressurized kerosene lamps showed regular problems of broken glass, mantels and clogged tubes because of dirt.

In 1998 solar lanterns were introduced as an experiment in four villages. In 1999 during the first evaluation participants judged the solar lanterns superior to the pressurized kerosene lanterns: easier to handle (no filling, pumping, pre-lighting with alcohol; no weekly trips for alcohol and kerosene), better quality light (softer to the eye), no noise, no smoke, and no danger of fire. No problems were encountered.

In 1999 22 small PV systems (24 - 40 Wp) were acquired, with the help of donations from PV manufacturers, and installed in schools and community centres. Community groups were organized and trained to maintain the systems, to organize the use of the building and to raise money for maintenance and spare parts. The communities also paid 10-15 percent of the investment costs, having a choice between a 24 or 40 Wp system.

At the time of writing all systems are functioning satisfactorily. The buildings/systems are being used for adult education programmes (replacing kerosene lamps, use of kerosene, alcohol and dry-cell batteries), community meetings, festivities, etc. Several communities have also established a community shop for basic groceries in the same building with a PV-powered light facilitating longer opening hours at night.

The education programme itself has been evaluated thoroughly (Steenwyk 1997, 1998 and 1999). The programme was found to have a significant impact on income (on average US$41 more income for every study year per participant) against costs per participants (state-financed) of US$28. Traditional basic education costs US$100 on average per participant. Other important impacts of the programme include benefits such as higher self-esteem, improved health, improved civil participation, increased knowledge of reproductive health, and increased school performance of their children (the last two especially related to women). Although these benefits cannot all be accounted to the solar systems, they do make it possible to impart these classes at night. The solar systems also provide the same service at a lower cost (LCC) and higher commodity, while the bigger systems provide far more service. Discussions are presently ongoing with the Ministries of Energy, Education and the Social Investment Fund (FHIS) to include such small community-based systems on a nation-wide basis.

source: Steenwyk, 1996; Steenwyk, 1997; Steenwyk, 1998; FAO, 1999

3.3.4 Other social and communal uses of PV systems

Public and street lighting
Public and street lighting in rural villages is a common application of electricity in conventional grid extension programmes. The main impact is the increased feeling of safety at night. People have come to expect such benefits of rural electrification programmes. In several PV rural electrification programmes in developing countries, public lighting is included. In some cases public lighting is used to extend opening hours of markets or to work after dark, as in the example of fishing villages in the Philippines, where the fish is prepared after dark, making it possible to extend the fishing day and therefore increase the catch (see text box 5). Another example comes from Gosaba island (Sunderbans, India) where rickshaw-pullers put money together to buy an electric street light for the central rickshaw stand near the ferry, to increase their visibility at night and improve their services (Sinha, 2000b). As with all communal PV uses, public lighting systems require careful planning of maintenance and servicing to guarantee their adequate functioning during their lifetime.

Telecommunication
As described in annex 4 telecommunication makes up a large share of the market for PV panels. The larger part of this share, however, goes to repeater stations and other infrastructure for general support of telecommunications networks, of which rural areas gain little direct benefits. Urban based mobile telephone networks, for instance, often have repeater stations that are situated on mountain tops in rural areas, but this does not necessarily indicate rural inhabitants benefit from this in a major way. Without the necessary support infrastructure, these installations are as useful to rural inhabitants as a high voltage transmission line that passes through an unelectrified village. This support infrastructure is limited by a balance between the amount of investment and expected connections, just as in ground-based telecommunication systems. Continuing advances in radio and especially mobile telephone communication, have considerably lowered investments in support infrastructure, especially for remote, hilly and otherwise inaccessible areas. PV is by far the preferred and most reliable power source for most remote telecommunication infrastructure. Single radio-connections and mobile phones can be run on small solar panels (10 to 50 Wp). The reliability and easy maintenance of PV systems also makes these services more reliable.

Many of these mobile networks run on a for-profit basis, but in other cases national governments invest in telecommunication to connect remote rural areas to the rest of the country. Many telecommunication connections are based in development projects, hospitals and other (semi-)public institutions, where they make invaluable contributions to improved services (varying from logistical arrangements to medical consultations and emergencies). If telecommunication is open to the public, rural inhabitants not only use them for social purposes, but also for productive purposes, such as the example of Philippine fishermen who can check fish prices in the city, before selling their catch to intermediaries, thereby greatly improving their bargaining power (see also text box 5). These telecommunication services often prove so popular, that in many rural areas of developing countries, private telephone “shops” have proven quite profitable to local entrepreneurs (see paragraph 3.4.3).

PV battery charging stations
Another type of PV system that is finding increased communal application is the PV battery charging station. Many rural inhabitants already use old car batteries for TV and a single light, charging them in electrified villages at considerable distance and price. Solar battery charging stations provide an intermediate level between these “conventional” battery charging

practices and a privately owned solar system. Gradual improvement in the battery system at home (improved light fixtures, charge control) often results in the acquisition of a small solar panel on the longer term. Most experiences with solar battery charging stations have been with government-subsidized programmes, often managed by community groups. However, decreasing prices and continuing project experience, have opened solar battery charging as an option for investment by local entrepreneurs (see also paragraph 3.4.3).

Integrated PV projects for communal and social services
An example of a project where different social and communal needs are addressed simultaneously through the installation of PV systems is described in text box 5. The project shows among others, that if well organized, such "integrated" projects can create synergies. By installing different PV "packages" simultaneously the same servicing structures can be used for all packages, increasing efficiency and lowering costs. Moreover, the increased awareness for PV systems is likely to increase demand for SHSs and other private solar investments that can then be met by the existing structures. Similar examples come from Bolivia (PROPER, 1996) and Brazil (MME, 1998).

Text box 5 Municipal Solar Infrastructure Project (MSIP). the Philippines
The Municipal Solar Infrastructure Project (MSIP) is a major project in the Philippines that is being executed in the framework of the Government's Social Reform Agenda (SRA), a programme to deliver social and economic benefits to its remotest people and support for local government structures. It will provide benefits to over one million people and is being led by the Department of Interior and Local Government (DILG). The US$30 million project was signed in 1997 and is financed by a concessional loan from the Australian Export Finance and Insurance Corporation (AEFIC) and a grant of around US$7 million grant from the Australian Agency for International Development (AusAid). BP Solar Australia has been contracted to be responsible for project implementation, including project management, preparation of villages, community development and training, finance, equipment supply and installation, and building of a maintenance infrastructure.

The objective of the project is to improve the quality of life in remote towns and Barangays identified by the SRA by upgrading and extending the level and quality of services offered by local government units and providing basic inputs to the rural development process: clean water, improved health facilities, improved educational capability, improved community infrastructure, better communications. It includes the use of over 1,000 PV systems, consisting of about 14 different types of "service packages", in over 400 different communities in the regions of Mindanao and Visayas. For these regions, conventional grid electrification was deemed not possible in the short or medium term.

Rather than the provision of solar home systems, the priorities were community-based solutions such as: health centres (vaccine fridge system, lighting, solar lantern), community water supply (pump, storage, distribution), school (lighting, TV/video), community safety (area lighting), municipal halls (lighting, ceiling fans, AC outlets, telecommunication equipment), Barangay hall (lighting system, DC outlet).

Project development and preparations started in 1994. After the official project signing, 1997 was used mostly in project planning and mobilization, 1998 saw community preparation and installation commenced. 1999, 2000 and beyond are seeing the project move from supply and installation into delivering the user benefits and servicing. Adequate community participation, training and set-up of local structures for servicing are to safeguard sustainability of the project. Fees for maintenance and part-payment of the systems are collected on a community basis according to what community members can afford. A solar committee is elected in each community that helps the people decide which package suits them best. They also supervise the collection of the fees and any necessary maintenance by the trained local solar technicians.

The installed community PV systems also help to stimulate productive and income generating activities. Most of the communities in the areas of Visayas and Mindinao have an economy based on aquaculture. The markets, the fishermen's wharf and communal areas were lit to help extend the working day and thus to aid the processing of the fish for the market. The supply of telecommunications packages means that local fishermen can call fish markets in Manila to verify prices and ensure they get the "right price" for their fish when the boats from Manila come to bargain for their catch.

source: PRESSEAwebsite; DOE website; AEN, 1997; personal communication with BPSolar

3.4 PV for off-farm productive uses

The analysis of PV electrification programmes, through the survey and through analysis of project documents and interviews with experts, shows there is a growing number of off-farm productive activities among rural people whose productivity depends on or may be enhanced by the input of electricity[26].

Among these activities there are a number that can be efficiently powered by small solar systems, thus creating an opportunity for productive use of solar electricity. As indicated in Section 3.1, the survey found that about 41 percent of the respondents are of the opinion that PV systems have produced an impact on cottage industry[27] and commercial activities, and small business development. The relevance of small PV systems for productive uses is, however, limited to the provision of power for off-farm activities that require little power input. PV systems are not an option for energy intensive activities such as in rice mills and other agricultural processing. One of the premises of this study is, however, that *"Small loads from PV systems can be carriers of rural socio-economic development."*

Off-farm productive activities can be classified in: cottage industry, commercial sector and in the new but growing service sector, that is, the activities related to recreational services and utility services (electricity delivery, communication services). A final contribution of PV to income and employment in rural areas is the PV installation and servicing business itself.

Table 10 summarizes the breakdown of income generating activities identified from the survey findings. The impact on small retail shops, recreational services (bar, cinema) and handicraft and sewing workshops is most often reported (28, 19 and 21 percent respectively), while a more limited experience is reported with such pioneering activities as battery charging stations and telephone centres (16 and 12 percent respectively).

Table 10 Businesses created or improved with PV (% of all respondents)

Retail shops/restaurant/bar	28 %
Rural cinema (TV/video-business)	19 %
Battery charging	16 %
Telecommunication shops (mobile phone shops)	12 %
Repair/technical shops	16 %
Handicrafts/sewing workshops	21 %
Tourism (hotel, lodge)	16 %

source: FAO survey

Table 11 shows an overview of survey responses qualifying the major types of development impacts derived from the solar electricity input for productive activities. The results indicate that respondents most often identify the benefits of lighting, which allows longer working and opening hours (35 percent). A lower but significant percent of respondents indicated the impacts consisted of higher productivity (21 percent), increased quality of service due to

[26] As well synthesized recently: "Rural development specialists are now more conscious that not all rural dwellers are farmers, and even the farmers derive a large part of their income from non-farm activities. For non-farm activities to thrive in rural areas, there must be a decent rural infrastructure and probably a decently educated rural labour force. Energy is part of the required rural infrastructure. That is, in brief, the linkage between rural development and energy (Wiens, 1999).

[27] This term indicates small scale processing or artisan manufacturing where manual work is still the value added factor.

higher attractiveness for customers (23 percent), and more employment (19 percent) followed by the creation of new home/cottage industry productive activities (16 percent).

Table 11 Impact of PV on business activities (% of all respondents)

Longer working hours/longer opening times	35 %
New business opportunities through use of new equipment (power tools, telephone, etc.) or new, more marketable products (e.g. handicrafts)	16 %
Higher productivity	21 %
Better quality products (higher price)	5 %
More sales	14 %
Better quality service (e.g. more attractive business through provision of light, music, cold drinks, etc.)	23 %
Creation of home/cottage industries	16 %
More employment	19 %

source: FAO survey

3.4.1 PV for cottage industry and commercial businesses

One of the most commonly reported examples of productive use in rural businesses is related to the prolonged working hours due to lighting. Lighting is reported to improve also the quality of the productive activity and to attract more customers, according to the nature of the business. In the survey, 28 percent of respondents indicate that retail shops, cafes and restaurants were created, stimulated or improved by the provision of solar electricity. Apart from lighting in such businesses PV provides power for music, TV and simple devices such as blenders. The survey responses do not go into enough detail to derive data on income generation from these activities, but examples can be found in literature. A store in the Dominican Republic experienced a 60 percent increase in daily sales due to the provision of light and radio (Cabraal, 1996). A monetary evaluation of the impact that quality lighting and availability of TV mean in rural areas was done in China: a restaurant run in Inner Mongolia increased its revenues by US$722 in six months (Richter, 1997a).

The information gathered from the survey also shows the potential for using solar systems in small technical workshops (16 percent of the respondents). Often electronic repair shops are reported to receive benefits from some electricity supply. They can easily power monitoring devices and small tools such as the soldering irons, which can improve the quality of repair and the productivity of the workshop with very limited power demand[28]. An example of this is the case of a gold jewellery-making laboratory in a village of the Mekong Delta (IFAD, 1998). As indicated in the inventory of applications, repair workshops have made use of solar electricity for powering small drills, employed, for instance, in bicycle repair shops. Such low-power DC tools can also improve the quality and productivity of handicrafts, such as in woodwork and bamboo craft workshops.

The powering of tools for off-farm activities with small PV systems encounters obvious limits on the power supply side: the larger the electricity demand, the higher is the chance for diesel or gasoline-run gensets. This is similar to the case of refrigeration: small energy efficient units (up to 200-300 lt.) can be powered with a small PV supply, but when the demand is for large refrigeration units the PV option often becomes too costly.

[28] A small soldering iron rated at 30 Watts of power (Hankins, 1995), will only require 20 Wh/day as it is typically turned on for only 40 minutes per day.

The economic viability of larger PV systems for cottage industry has to be studied in each particular circumstance, but in general decreases in comparison with the diesel generators, when electricity demand grows. Larger PV applications exist and would need to be monitored. Large solar systems of up to 1 kWp, for instance, are used for powering pearl factories in French Polynesia, where power is needed for lights, drills and pumps. In this segment of power supply, however, a growing interest is being devoted to hybrid power solutions, integrating PV and/or Wind power with diesel generators to back up a battery bank. This option is worth exploring as an environmentally and economically sound supply of remote electricity in cases where the energy demand density is more concentrated and where the fuel supply is costly. In Indonesia, for instance, a wind hybrid system for ice- making is helping fishermen market their catch better (Kadyszewsky, 1998). Under the Mexico Renewable Energy Programme (see text box 10), Sunwize Energy technologies in conjunction with the State Government of Chihuahua, introduced a PV hybrid ice-maker in a cooperative of 70 fishermen families. The 2.4 kW PV array, backed by a propane generator for continuous power, is able to produce up to 500 kg of ice per day and enables the cooperative to store their fish and sell the product directly to the urban markets. Such promising examples are already in place and growing in number[29], showing their contribution to rural income generation. What is needed, however, is a thorough analysis in terms of their life-cycle cost-benefit performance compared to the diesel-only option, including analysis of environmental issues and an investigation of the applications with the highest value added.

3.4.2 PV for service businesses

One of the simplest examples of rural income generation with PV is the sale of electricity: a sort of rural electric micro-utility. Traditionally the more affluent families in the villages who own a small diesel generator sell electricity to their neighbours. A recorded example of such a "micro-utility business" with a PV system is now being monitored in Bangladesh (Barua, 1998), where Grameen Shakti is financing a solar system for a shop owner who in turns sells lighting service to the neighbouring shops producing an extra income of about US$12.5 per month (see text box 7). The diffusion of village-size solar battery charging (BCS) stations is another instance of micro-utility which generates rural income and employment. The solar BCS is usually managed by a local entrepreneur, local cooperative or an Energy Service Company (ESCO). The profitability of such PV enterprises has to be assessed in each specific rural market and is related to the applicable local charging fees, to the accessibility and cost of a diesel battery charging alternative and to the investment cost financing. In Morocco, the studies of a local private ESCO Noor Web show that a franchising model could be implemented to create a centrally owned and managed network of village entrepreneurs running 1 kWp BCSs. Most of the past PV BCS projects, however, have been implemented within government subsidized programmes (e.g. in Colombia, the Philippines, Senegal, Thailand and Vietnam) with charging fees often too low for generation of revenues able to cover more than the operation and maintenance costs. As described earlier (Section 2.2), this appears to be a promising option but there is a gap in knowledge on the conditions enabling this rural micro-utility model as a fully commercial option.

Another promising PV-powered service business is the rural telephone service. Today, solar powered satellite telephone booths developed by Iridium and Motorola provide the service to remote areas in 80 different countries (Sancton, 2000). Sizeable investments characterize the new remote area markets of large multinational telecommunications companies, which are

[29] According to Synergy, a company which designs and installs hybrid systems, the demand is raising and talks are under way to finance and install such hybrid systems in Bangladesh in cooperation with Grameen Shakti.

introducing innovative *wireless local loop* systems in several developing countries such as in Mexico, Pakistan, Peru, Tanzania and Zimbabwe. In such markets and in the internet service markets, renewable energy is promising to play an increasing role. The rural development implications of internet-based communication services can be interesting and touch on both rural income generation due to e-commerce and on social benefits related to innovative services such as telemedicine and distance learning. An experiment underway in Palestine sponsored by Greenstar Foundation is summarized in text box 6 and offers an idea of the potential impacts of projects integrating multifunctional solar powered village telecommunication centres.

Recreational service businesses are expanding in many rural areas and they are usually dependent on a small electricity supply for powering lights, colour TV, videos and music systems. These solar system applications often build on (and replicate) local past experience with the sale of TV service by an affluent family owning a small kerosene or diesel generator. In Vietnam, for instance, Solarlab, a local solar systems integrator, installed over 50 community centre systems that are equipped with lighting, TV/VCR, music and battery charging service. When the local operator is able to acquire good videocassettes, these centres experience success in selling the tickets for films together with snacks and drinks, thus contributing to the cash flow of the battery charging service.[30] In the Philippines recreational services have flourished with solar power for karaoke systems.

The experience reported from PV projects in Inner Mongolia (China) includes some estimates of the additional income from recreational activities as shown in table 12 (Richter, 1997a, 1999).

Table 12 Additional income created by recreational activities powered with PV

Type of recreational activity	**Additional income (in US$) and frequency of service**
Business presenting video films	Ticket of 8 cents/person, run once a week
Business running a dancing hall	Ticket of 8 cents/person, run 2 times/week, US$ 5/6 per week

source: Richter, 1997a

[30] source: personal communication with Ms Li Huang Tó, director of Solarlab, Ho Chi Min City, Vietnam.

Text box 6 Greenstar initiative: merging PV electricity with information technology and micro-enterprise development in Palestine

Greenstar Foundation, is a non-profit organization committed to bringing solar powered services to developing countries and to places where a centralized electrical power grid is not available. Some of the organizations involved in this pilot initiative are the National Renewable Energy Laboratory, the United Nations Development Programme, an internet company and a solar PV manufacturer.

With an investment of about US$25,000, Greenstar recently electrified a school and community centre in the remote, off-grid village of Al Kaabneh in Palestine. The typical layout of the solar system is a large PV array mounted as a roof of a container, which becomes the solar powered facility. The school roof easily powers lights, a copier, a multimedia computer, and shortly a satellite dish and a water purifier. Greenstar Foundation places a special focus on the sustainable rural activities that can be supported by the telecommunication technology, thus calling for use of solar electricity as “smart electrons”.

In Al-Kaabneh, Greenstar has helped to identify an array of local products, which can be offered on the world market by this Palestinian community. They include musical instruments, pottery, ceramics, glassware, and tapestries that are unique to the area, carry special historical significance because of their origin in the Dead Sea area, and will be of interest to 150 million worldwide Web consumers because they can be in direct contact with the people who produce the products as well as being part of a renewable energy project. This is an example of a “virtual” sustainable development initiative in which solar energy, telecommunication and e-commerce merge to provide the tools for a remote community social and economic welfare improvement. By emphasizing local products that are marketed internationally, the programme is giving maximum control to the local community and strengthening traditional communities.

A second important application employed in the Al-Kaabneh village is an ultraviolet light water purification system, developed at Lawrence Berkeley Laboratories, which is durable, easy to use and can be locally manufactured. The operation of such a system for 12 hours per day can bring to the purification of about eight million litres of water annually at very low cost[31].

Besides electronic commerce and water purification, other solar powered services identified by Greenstar include the telemedicine and distance learning services through the telecommunication network, cellular communications (since the beginning of the experiment the number of cellular phone owners has jumped from 1 to about 20), vaccine cooling, manufacturing and agricultural support services.

source: North, 1999; Gay, 1998

[31] Assuming a per capita drinking water requirement of 10 litres per day, a single UV light water purifier could serve about 2 200 villagers at a cost of about 14 cents per person per year.

Text box 7 Solar kWh for rural micro-enterprises in Bangladesh

Established in 1996, Grameen Shakti is a leading organization in the renewable energy sector in Bangladesh, which was set up by the Grameen Bank, one of the leading financial institutions worldwide for micro-credit to the poor. The Grameen Bank, which was founded by Muhammad Yunus, revolutionized poverty alleviation efforts by offering small loans to poor entrepreneurs, primarily women. Members join the bank in groups of five with an agreement that if any member does not keep up with payment, the others are not able to receive loans. This micro-credit model based on liability groups has led to 98 percent loan recovery rates. Recently, within a US Government aid programme which will provide US$84 million to encourage renewable energy in Bangladesh and the South Asia Region, USAID provided US$4 million for a Grameen Shakti five-year renewable energy programme, to support the promotion and marketing of PV solar systems for rural electrification of small enterprises.

Grameen Shakti had installed 1,244 solar systems by August 1999 with a total installed capacity of over 55 kWp and reached a sales volume of 100 systems per month. With a plan to install a total of 6 000 systems within the next three years, Shakti will expand its network of 19 branch offices in rural Bangladesh. A PV system customer pays 25 percent of the system cost as down payment and the remaining 75 percent can be paid with two years with an 8 percent service charge. The PV systems marketed are also directed to build up some micro-entrepreneurs or household income generating activities. As a result of electricity generation, the following benefits have been recorded:

- extended working hours;
- extended selling and shopping hours;
- increased income in micro-enterprises led by women, including basket-making, electronic repairs, carpentry workshop, tailoring, food stores, fish net weaving;
- development of local technical expertise for selling, maintaining and servicing the solar power systems.

Table 13 A summary of PV powered micro-enterprises in Bangladesh

ENTREPRENEUR	TYPE OF SYSTEM	ENERGY USE	ESTIMATED EXTRA INCOME
Mr Hanif	17W solar module, two 7W fluorescent lamps	for lighting a diesel operated saw mill	US$20.00 per day
Mr Manik	34 W solar module, two 7W fluorescent lamps, an outlet for TV and radio and a soldering iron	for repairing the electronic appliances in his repair shop	US$25.00 per day
Mr Umor	50W solar module, six 7W fluorescent lamp	selling solar power to the shopkeepers	US$12.50 per month
Mr Shah Alam		cellular phone service; no other communication alternative exists	

As summarized in table 13, the following are some examples of micro-enterprises powered with solar energy and the first results of a monitoring exercise indicate the extra income earned due to the electricity supply.

Mr. Hanif, who is a saw mill owner, with the help of solar light, can work at night (four extra hours/day) which increases the working capacity of the mill so that the villagers are getting their timber delivered in time, hence increasing the number of customers. He is able to work an extra four hours a day and the total system cost was US$270 on which he made a 25 percent down payment. An additional indirect result is the increase in employment and in workers income.

In the village of Dhalapara, Mr Manik uses solar power to test the appliances of his electronic repair shop and again, the light allows him to work at night. With a soldering iron he is also able to provide a higher quality repair service for appliances (such as TV, radio, cassettes and emergency lights).

In Kormel-Batar, Mr Umor has bought a solar system with six lamps one of which he uses for his shop and five of which he rents to neighbouring shops. This is an example of micro-utility model because the other users are also selling more and the customers are feeling easy to shop at night. Besides his utility income of US$12.50 per month (he charges a fee of US$2.5 per lamp/month), the indirect impact is that the income of the shops is also increasing due to the attractiveness of the solar lighting.

Mr Shah Alam uses solar energy to provide customer telephone service in a rural area named Nabinagar. The villagers have a large communication network all over the world.

All of these examples make the life of the shopkeepers and the other villagers easier. The extended working hours increase the business, the income of workers, the employment opportunity as well as social status. The Grameen Shakti electrification experience is also showing that there is an impact on women. Solar power, as reported, has provided a better environment for women by eliminating the health hazard kerosene lamp and by giving housewives some income-generating activities such as basket weaving and tailoring. It also ensures women security at night and improves the children's education by extending their studying hours.

source: Barua, 1998

3.4.3 PV micro-enterprises

An additional source of rural income and rural development is found in the rural market infrastructure for the deployment and servicing of SHS and other PV systems. The existing PV electrification programmes show that their success is consolidated when the commercialization of PV systems and the after-sale service is managed in a decentralized manner, through networks of solar technicians and rural micro-enterprises. In Morocco, for instance, Noor Web, a local solar company, created a network of village shops run by local entrepreneurs who offer battery-charging service and sell SHSs. Soluz in Central America, SELCO in India, Sudimara in Indonesia, China, Sri Lanka and Vietnam are just a few well-known examples of a growing number of privately run ESCOs that rely on a network of rural offices and promoters, thus offering a new employment opportunity to rural villagers. A general rule often quoted by practitioners is that each entrepreneur has to install and service a minimum of 100-200 SHS to make this solar micro-enterprise development a sustainable venture.

Text box 8 ENERSOL experience supporting solar micro-enterprises in the Dominican Republic

Francisco Fria, now a solar PV micro-entrepreneur in the Dominican Republic, completed three levels of the *Micro-entrepreneur/Business Associate Programme* organized by ENERSOL, a non-profit organization dedicated to solar-based rural electrification. Part of this NGO's work is focused on solar micro-enterprise support and training, thus creating a local technical and managerial capacity for the solar PV service infrastructure. With the commission from his first cash sale of a PV home system, Fria was able to obtain a small inventory for his PV enterprise, named Energía Solar del Nordeste, and provide subsequent systems on credit through local NGOs such as the Asociación de Desarrollo de la Provincia Duarte, the Asociación de Desarrollo de Espallat, and ADESOL. The cost for the end users is a 30-50 percent down payment, the rest of which is covered in monthly payments over less than two years, usually within eighteen months. After some years of operations Energía Solar del Nordeste has successfully installed many PV systems for household lighting and TV use but also for productive uses for customers such as small grocery stores, cafeterias, community centres and village cinemas. Other systems sold include medical dispensaries. An indicator of the quality of Fria's enterprise is that it has experienced about 90 percent rate of satisfaction.

source: personal communication with ENERSOL, 1999

Examples of local manufacturing activity of components for PV systems are also reported in several countries. In the Dominican Republic in 1992, for instance, a village-based company named Industria Eléctrica Bella Vista was already manufacturing simple charge controllers (Barozzi, Guidi, 1993) (Guidi, 1993). In countries such as China and India PV lanterns are locally manufactured. Solar modules assembly and the local manufacturing/assembly of charge regulators and solar lamps is taking place in several countries as well, often with the core business of satisfying the demand in rural areas, creating the conditions for the birth of networks of rural micro-enterprises for the distribution and after sale service of such systems.

3.5 PV for agriculture

As indicated in Section 3.1, 35 percent of respondents indicated an impact on agriculture, mainly through activities in irrigation, livestock watering and electric fencing as shown in table 14.

Table 14 Agricultural activities stimulated with PV (% of all respondents)

Irrigation	23 %
Refrigeration of crops/meat/fish/dairy/other	2 %
Lighting (poultry, livestock)	9 %
Water pumping for fish farming	5 %
Water pumping for cattle drinking	19 %
Pest control	2 %
Electric fencing for grazing management	14 %
Light for fish processing	2 %
Light for fishing	5 %

source: FAO survey

Table 15 shows that the main impacts indicated by the respondents were increased productivity (including higher yields, lower losses and faster production) and improved natural resource management.

Table 15 Impact of PV systems on agriculture (% of all respondents)

<table>
<tr><td colspan="2">Higher productivity (higher yield)</td><td>28 %</td></tr>
<tr><td colspan="2">Lower losses (death rate) or faster production</td><td>16 %</td></tr>
<tr><td colspan="2">Better natural resource management</td><td>19 %</td></tr>
<tr><td colspan="2">More land to be cropped</td><td>7 %</td></tr>
<tr><td colspan="2">Multiple crops per year</td><td>12 %</td></tr>
<tr><td colspan="2">New, more marketable product</td><td>12 %</td></tr>
<tr><td colspan="2">More animals can be raised</td><td>16 %</td></tr>
<tr><td colspan="2">Better quality product (higher prices/more sales)</td><td>19 %</td></tr>
<tr><td colspan="2">Access to more profitable markets (e.g. through conservation of product for transport)</td><td>0 %</td></tr>
<tr><td rowspan="2">Others, namely:</td><td>Safer fishing</td><td>2 %</td></tr>
<tr><td>Cost savings through production instead of purchase of forage (micro-irrigation)</td><td>2 %</td></tr>
</table>

source: FAO-survey

Although the survey responses do not go into sufficient detail to be able to do in-depth cost-benefit analyses and they are too few to serve as a representative sample, with the help of literature it is possible to make general comparisons for the economic competitiveness of different applications. The main agricultural uses of PV for agriculture are discussed in the following paragraphs and an attempt is made to outline the conditions under which PV is already or potentially cost-competitive.

3.5.1 PV pumping for irrigation

FAO (1986) summarizes the potential of irrigation water for agriculture:

- increase of land area brought under cultivation;
- improvement of crop yields over rain-fed agriculture by three or four times possible;
- increase in cropping intensity;
- reduction in drought risk, which produces improved economic security;
- introduction of more valuable crops.

Irrigation of small-holdings is likely to become increasingly important and widely used in the next decades, especially in developing countries, because of increasing population pressure and because the majority of land-holdings are small, particularly in Asia and Africa. Studies have also shown that small land-holdings are often more productive, in terms of yield per hectare, than larger units.

This being said, the pumping technology - be it PV, electric or diesel - cannot be credited entirely for all of the above-mentioned (potential) impacts. The successful introduction of irrigation is mostly dependent on improved farming techniques and market access, and the pumping technology is but one factor. However, new developments in water-conserving irrigation practices favour irrigation technologies, such as drip- and micro-irrigation that coincide well with the characteristics of PV pumping and provide many advantages.

Traditional irrigation techniques, such as total area flooding, typically involve low-frequency application of large amounts of water to reach excess saturation of soils. Optimal conditions occur only briefly in transition from one extreme condition to the other. Not only is much of the water wasted, but this practice also contributes to the degradation of land through water-logging and soil salinization, especially in arid climates (FAO, 1997). Ideally, new irrigation techniques should convey water in closed conduits to avoid seepage and pollution, and allow pressurizing the water. Water can be delivered directly to the root zone by means of drip emitters, micro-sprayers and porous bodies placed at or below the soil surface. Small daily applications of water allow the flow of the water to the plant to become more constant, lowering water stress and allowing increased yields and simultaneous conservation of water. Fertilization can also be applied through these systems, allowing optimization of these inputs. Low-pressure, constant or daily irrigation, coincides very well with the characteristics of PV systems. Additionally, when well applied, water flow to the plant can become nearly the exact rate of water usage by the plant and the water storage properties of soil become less important. New lands, until recently believed to be unsuited for irrigation, can be brought into production, e.g. coarse sand or gravel type soils and steep slopes. However, these irrigation techniques also have shortcomings, including the danger of short-term interruption of irrigation (whether by neglect, mechanical failure or water storage), which can quickly result in severe stress to crops.

The impacts mentioned most in the survey regarding PV irrigation projects were higher production and multiple crops. Less mentioned were new crops and the exploitation of new lands. Apparently PV irrigation projects focused on the optimization of existing lands and crops with a known market rather than experimenting with new crops or new lands.

Status and economics

The survey responses do not show enough detail to make cost-benefit analysis possible. Many different figures exist in literature on the comparison of PV and other pumping technologies. All agree on the fact that investment costs in PV pumping equipment are much higher than the alternatives (diesel, electric), but on a life-cycle basis, PV pumping can be economically more competitive. The relative advantage of PV pumping is in the low-water use and low pumping head (low power) range. Other advantageous aspects are low-maintenance and high reliability (if projects are well designed and organized). PV pumping is therefore very suitable for drinking water supply in remote unelectrified villages and often the least-cost solution on the basis of life-cycle costing. Also, for livestock watering, PV pumps are often the least-cost solution and widely used.

Since irrigation often takes part only part of the year, the demand for water is more variable, with peaks in a specific period. PV pumping systems have to be oversized to meet these peak demands, which makes them under-utilized for other months. Such water requirements for part of the year favour powered pumps that require a low initial investment, such as diesel pumps. This disadvantage of PV systems for seasonal irrigation could be cancelled out, if additional uses for the PV power supply could be found for the non-productive part of the year (when irrigation is not required). Hahn (1998) summarizes under what site-specific conditions the use of photovoltaic pumps for small-scale irrigation can offer economic advantages over competing technologies:

- arid/semi-arid climate;
- no access to the public power grid;
- problems with the maintenance of diesel pumps and the supply of fuel for their operation;
- low pumping head (maximum of roughly 30 metres);
- small field sizes (maximum of three hectares);
- cultivation of high-quality crops for secure markets;
- use of water-conserving and energy-saving methods of irrigation (e.g. drip irrigation);
- high degree of system utilization through adoption of permacultures or systematic crop rotation.

PV pumping systems are particularly well-suited for water- and energy-saving methods of irrigation such as drip irrigation because of their advantage in the low-energy range. This has particular advantages in areas with water scarcity, but requires extra training in the use of improved irrigation techniques, especially in regions where little experience exists with such improved techniques. The Indian example (see text box) shows that with proper training and management large savings on water and fertilizer can be made, with raising crop performance. Hahn mentions, however, that considerable work still has to be done on the optimization of PV pumping for irrigation, including several practical aspects, such as:

- optimization of PV driven low-lift pumps: developments in the field of PV powered drinking water supply have focused primarily on borehole pumps with relatively substantial pumping heads; PV irrigation is more competitive for low-heads and surface water pumping, where less experience exists;
- design and optimization of low-pressure drip irrigation systems with appropriate filters and fertilizer feed mechanisms.

Many of the same advantages and barriers that apply to PV systems in general, also apply to PV pumping systems. A specific characteristic of PV pumping systems is that they generally do not need a battery for back-up, but can use a water tank for storage[32], reducing investment and maintenance costs and increasing system reliability. High system reliability is particularly important in combination with water saving irrigation techniques.

As indicated before, niche markets for PV irrigation pumping systems are limited to relatively small field sizes, but in general small-scale farmers have little capital available[33]. This increases the need for adequate financial support mechanisms. In India the Government used a combination of subsidy, credit and technical support to promote PV irrigation pumping. An important conclusion from this programme is that technical and agronomic assistance should

[32] an alternative under investigation is "direct injection" (Hahn, 1998): i.e. the direct application of PV-pumped water to the plant, without the need of a water tank. In such a system set-up the soil functions as a type of water reservoir.

[33] in contrast to extensive live-stock farming, where farmers often have large herds (i.e. capital) but need several small wells to make rotation of livestock possible. See next paragraph. See also text box Mexico Renewable Energy Programme.

preferably be offered to farmers from one source (one institution) to facilitate the introduction of PV powered drip irrigation systems and improved irrigation techniques (see text box 9).

Text box 9 Indian experience in PV pumping for irrigation

The Indian PV programme - as part of a renewable energy programme - is one of largest and oldest in the world. Started in 1975, it shifted its focus to rural applications from 1982 onwards. The programme (and number of PV installation) received a major boost in 1992 when a revolving credit fund was introduced, coinciding with the privatization of deliveries. By 1999 more than 39 MWp had been installed, including applications for telecommunications (still around 50-60 percent of installations), lighting (home and street), solar lanterns, vaccine refrigerators and pumps.

The Ministry of Non-conventional Energy Sources (MNES) has deliberately targeted the agricultural sector in its RE-policy. A major part of Indian agriculture (approximately 30 percent) is under irrigation and another 30 percent is estimated to have irrigation potential. The Indian Government has always stimulated the use of electricity for pumping with subsidized connection costs and electricity tariffs (up to 80 percent subsidy). This led to high electricity consumption for irrigation (25 percent in some states; Baktavatsalam, 1998) and contributed to a growing gap between generation capacity and demand of up to 40 percent in some states. Scheduled power cuts of up to 75 percent of the day in peak summer months had become a regular feature in some states, besides unscheduled power lay-offs, e.g. by overloading of transformers. Finally, due to scarcity in material, connections for irrigation pumps had waiting periods of up to three years. In 1992 a demonstration programme for Solar PV pumps for agriculture and other uses was introduced. With the aid of subsidies and soft loans PV pumps were introduced in several phases. At the end of the first phase, in 1995, 463 pumps had been installed. 81 percent of the users expressed satisfaction with the overall performance of the system. At the end of March 1997 a total of 1 816 pumping systems had been installed: 58 percent for irrigation and agriculture; 30 percent for horticulture; and 12 percent for other uses (including pisci-, aqua- and silviculture). By the end of 1999 a total of 3 100 pumping systems had been installed**.**

The most common irrigation system is a 900 Wp surface mounted pump, costing around US$6 250 (including electronics, pump and installation excluding irrigation equipment) [34]. At present, financial incentives include a soft loan (5 percent) and a subsidy of US$3 per Wp up to US$5 000. For the described 900 Wp-system, this would mean a subsidy of approximately 40 percent. MNES also supports training programmes on operation and maintenance and water management aspects of the PV pumping systems. These cover the actual users, local technicians and rural youth.

The experiences in this programme can be described as mixed. The installation of more than 3 100 PV pumping systems has led to a wealth of experience both in the technical, financial and organizational field. Most of the installed systems are working satisfactorily and niche markets for the use of PV irrigation systems seem to be increasing, mainly for horticulture and other high value crops and in combination with water saving irrigation techniques. The adequate use of, for example, drip irrigation systems can save both water and fertilizer, increase production and augment the viability of PV pumps (due to lower water, i.e. energy demand). Research conducted by the Central Plantation Crops Research Institute (India) led to the conclusion that through such irrigation techniques the use of Nitrogen fertilizer could be reduced to 1/3, phosphatic fertilizer to 1/10 and potassic fertilizer to 2/5. In addition to an 80 percent reduction in fertilizer expenses, crop performance improved (Hart, 1998). With the aid of appropriate financing mechanisms, private sector companies have been included in the project, laying the basis for sustainable markets. On the other hand, markets are developing much slower than anticipated and high investment costs continue to be a major obstacle for the widespread use of such systems. Appropriate subsidy and financing mechanisms will continue to be necessary for the time being to lower this barrier. The experience has also shown that the introduction of PV technology must be combined with adequate technical support infrastructure and training programmes in improved agricultural and irrigation practices, including adequate field preparation, correct water management and selection of adequate (high value) crops. A final conclusion from this experience is that the above-mentioned technical and agronomic assistance should be made available to the farmers from one source (one institution) to facilitate the adoption of PV-powered irrigation equipment and improved irrigation techniques.

source: Sinha, 1998; Sinha, 2000; Hart, 1998; MNES, 1999

[34] source: Sinha, 2000

Table 16 Progress of installed PV systems in India (cumulative)

PV systems	December 1995	March 1996	October 1996	March 1997	March 1998	December 1998
Street lighting	20 000	30 569	31 042	31 149	33 196	33 633
Home lighting	1 000	42 845	45 524	47 824	70 144	85 350
Solar lanterns	0	88 920	89 718	101 531	177 998	198 482
Power plants (kWp)	20	923.30	949.20	949.20	955.20	1 012.20
PV pumps				1 816*	2 481	2 787

* These figures pertain to installations until December 1996
source: Ramana (1998); MNES (1999)

3.5.2 PV for livestock watering

As livestock operations improve, watering places in addition to natural water sources become necessary. Effective watering systems are also needed to protect watercourses and to improve the availability of good quality water. PV pumping for cattle-watering is one of the alternatives that is gaining prominence in off-grid areas. Of the survey responses involved in cattle-watering, the main positive impacts mentioned are: increased cattle production on existing lands (both of milk and meat), and improved natural resource management. Literature[35] mentions two categories of potential effects of *uncontrolled* access to a watercourse (lacking a watering alternative like PV water pumps):

- impact on the watercourse itself, including damage to vegetation and water banks and faecal contamination adding pathogens and excessive nutrients to the water;
- impact on herd health, including reduced water intake, injuries to legs and hooves and increased water transmittable diseases.

Improved pasture management practices such as rotational and strip grazing require a flexible watering alternative. Such systems should encourage uniform nutrient distribution over the pasture and reduce trampling and overgrazing near watering areas.

Status and economics
PV powered pumps are one of the alternatives for improved livestock watering systems. PV systems have the advantages of mobility, little maintenance and no need for supervision or fuel supply. A specific characteristic of PV pumping systems is that they generally do not need a battery for back-up, but use a water tank, which reduces maintenance and increases system reliability. However, investment costs in PV systems are high, which makes them mainly attractive for large herds. A problem often mentioned is the vulnerability to stealing and/or damaging of the systems in remote, unattended locations.

Though investment costs are high, PV pumps for livestock watering are widely commercially available and mature markets exist in countries such as Australia, Brazil, Mexico, USA and Western Europe. In USA many electric utilities now offer PV pumps as an alternative to grid extension, including mobile units and lease-options. The logic of this is shown with an example in table 16 from a utility study into livestock watering and other potential markets for PV (UPVG, 1994/5), showing a cost comparison between a PV pump and grid extension for a pump one mile from existing electrical distribution system.

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[35] e.g. NBDARD, 1999

Table 17 Cost comparison of livestock watering pump through PV or grid extension

	Installation Costs (US$)	Annual Operating Costs (US$)	Total Costs (US$)	Lifetime (years)	Life Cycle Costs (annual) (US$)
Conventional service	10 701	1 036	11 737	30	910
Photovoltaic service	4 350	355	4 705	20	420

Source: UPVG, 1994/1995

The total market for solar pumping for livestock watering in USA alone is estimated at 30-40 MWp (UPVG, 1994/5). The Mexico Renewable Energy Programme has been promoting the use of PV pumping for livestock watering in Mexico as one of the most attractive PV applications (see text box 10). The Mexican market for these systems was estimated at US$297 million[36]. The advantage of the livestock sector in countries like Mexico is that many large cattle-owners exist that manage their cattle on an extensive basis: they still need several small pumping systems to make continuous rotation of their cattle possible.

Text box 10 Mexico Renewable Energy Programme

The Mexico Renewable Energy Programme (MREP) is managed by Sandia National Laboratories (USA) for the US Agency for International Development (USAID) and the US Department of Energy (USDOE). It aims to promote the use of renewable energy systems, enhance economic and social development in Mexico, create new business opportunities for US industry and off-set greenhouse gas emissions. The focus is on rural, off-grid productive uses of renewable energy systems in off-grid areas, mainly solar and small-scale wind. Productive uses include water pumping for irrigation and/or livestock, communication and lighting for eco-tourism facilities. The MREP complements programmes by the Mexican Government mainly focusing on Solar Home Systems.

It is a cooperative effort between governmental and non-governmental institutions from Mexico and USA, including the Mexican Commission for Energy Savings (CONAE), the National Solar Energy Society (ANES), the Center for Energy Research of the National Autonomous University (UNAM), the Shared Risk Trust Fund (FIRCO), Winrock International, New Mexico State University (NMSU) and ENERSOL Associates. Fundamental elements of the programme are: building of partnerships with national and local organizations, capacity-building, technical assistance, implementation of pilot projects, replication and monitoring. In order to lower perceived risks by end-users costs of initial installations are shared (up to 70 percent), but the element of cost-sharing is gradually lowering. Also the technical assistance element is slowly reduced due to the effect of capacity-building.

Since its start in 1994 the Programme has invested around US$10 million. Until the second half of 1998 180 pilot renewable energy projects had been installed, totalling more than 100 kW: 66 percent PV water pumping, 17 percent PV Electrification; 3 percent PV Communication; 1 percent PV/wind hybrid electrification; 3 percent wind water pumping and 10 percent wind electrification. The majority of the water pumping projects were primarily intended for livestock watering, although many involved mixed-uses including community water supply and small-scale irrigation. In many cases installations sponsored by MREP were followed by non-sponsored installations; exact data is difficult, but research in four areas where the Programme has been active since the beginning has shown that 15 kWp of programme sponsored installations have been followed by 49 kWp of non-sponsored installations.

Lessons learnt in the process are among others:

- the essential need for building partnerships with local organizations for capacity-building and financing mechanisms;
- the need to focus resources and efforts: rather do one thing well than many things poorly; most efforts were focused at the use of PV and small-scale wind energy systems;

[36] Sandia, 1998: 42 430 systems at US$7 000 average. One system per 200 heads of cattle. The publication does not mention the size of the systems, but using the sizes used for the Mexico Renewable Energy Programme (850 - 1 000 Wp), would bring the Mexican market also at 30 - 40 MWp.

- development issues must be integrated with, even given precedence over technology push; originally the project started from the perspective of business opportunities for US Industry and CO_2 mitigation, but quite early it was recognized that a development perspective was needed to connect to demands of farmers;
- pilot projects are a tool, not an end: a tool for capacity-building (hands-on experience), promotion and establishment of credibility for the new technology;
- one of the most critical areas is facilitation of financing mechanisms;
- though direct installations would have resulted in more system installations; only under the above-mentioned conditions can the foundations be laid for growing, sustainable markets.

Based on these experiences, FIRCO and the Ministry of Agriculture developed a proposal for a nation-wide project of renewable energy for agricultural applications with the aim to install more than 1,200 systems. This proposal has resulted in a US$ 31 million World Bank and GEF-supported "Renewable Energy for Agriculture Project", due to commence operation in mid-2000.

As part of the MREP-project a market study was done for renewable energy systems in Mexico and a total potential market for RE applications (mainly solar) of US$1 037 billion was identified (source: Sandia, 1998):

Application	**potential market in million US$**	**comments**
Rural electrification	511	projects difficult to fund
Potable water	135	
Livestock watering	297	- best agricultural application for RE - capacity to pay exists with majority of ranchers
Small-scale irrigation	94	- market for small-scale irrigation does not yet exist, but pilot projects are well-warranted -best opportunities high-value crops that can be efficiently produced in small plots

Rural electrification represents 50 percent of the potential market, mainly through solar home systems, but it is commented that projects are at present difficult to fund, because the state is in a process of privatization and rural customers have limited resources. The next biggest market is livestock watering, where large ranchers have a far higher capacity to pay. Small-scale irrigation is identified as another interesting agricultural application of renewable energy systems, but more doubts are expressed on the capacity to pay in this sector. Finally other applications like PV fencing are mentioned in the study, which are commercially viable but negligible markets in terms of Wp (small applications of PV).

source: Sandia, 1998; Sandia, 1999; Sandia 1999b

3.5.3 PV for aquaculture and fishing

For nearly 20 years, aquaculture has been the fastest growing food producing sector in the world, increasing from 1.45 kg per capita in 1984 to 4.9 kg in 1997. Today, aquaculture production accounts for almost a third of the total world fish production. Since 1984, aquaculture production in developing countries has been growing more than five times as fast as in developed countries[37]. Commercial fish and shrimp farms need to power aeration pumps and other uses. Aeration of the water increase oxygen levels, which contributes significantly to productivity. Many of these farms are in remote, off-shore locations. Much of the power demand is at present provided by diesel generators, which are costly to operate and present an ecological hazard, especially close to vulnerable aquatic eco-systems. For small applications (aeration pumps) PV can be an economic solution. For higher energy consuming applications PV/diesel hybrid systems can be an option. More research would be needed into the economics of these PV applications. It is difficult to estimate present use and potential global market size of such aeration pumps, but the Utility Photovoltaic Group (UPVG 1994/1995) estimates a potential market of 30-35 MWp for PV pond and lake aeration in USA alone (see

[37] source: FAO fact-files, 2000

also annex 4). The Mexico Renewable Energy Programme has also identified aquaculture as one of the market niches for PV and other renewable energy technologies in Mexico (Sandia, 1998).

Another potential area for PV in unelectrified fishing communities is on-shore refrigeration of fish and ice-making before transport to nearby markets. Because of the high-value of fish, this might be an interesting application, but in general PV refrigerators are still not cost-competitive with gas and kerosene alternatives. For smaller sized refrigerators (household size), developments in low-energy consuming compressors and improved insulation techniques are bringing cost-competitive PV refrigeration within reach (see paragraph 3.5.4). But the high energy demands of larger refrigerators does not make PV a competitive option, even on the medium term. Examples exist, however, of hybrid diesel/PV and wind/PV systems that provide a more competitive solution for such situations, for instance in Indonesia and Mexico (see paragraph 3.4.2).

Lighting for fishing is mentioned as another use of PV: both as light for fishermen and as underwater-light for attracting fish. This use of PV lighting improves safety and increases yields. In Indonesia such a "solar boat lighting system" has been developed comprising a PV system, three fluorescent lights for boat lighting and an underwater lamp to attract fish. The system's capacity is 100 Wp. This system is still under experimentation, but a smaller one (50 Wp, without the underwater light) has already proven successful; 175-225 of such smaller have been systems installed. [38] Similar experiences come from the Philippines.

3.5.4 PV refrigeration of meat, dairy and other products

PV powered refrigerators and freezers are used on a wide-scale for health clinics mainly because of their high-reliability and low-maintenance and the extreme importance of reliable conservation of vaccines in immunization programmes. Cost-wise PV refrigerators are still not competitive with other off-grid alternatives like propane or kerosene fridges. A major problem is that most electric refrigerators are not designed to be powered by PV systems and have a high energy consumption. The few refrigerators that are made for PV use are expensive, partly because of the low volumes of sales. Also they tend to attract high import tariffs on importation in many developing countries, even if PV panels have a special, low tariff. In some countries, such as Brazil, attempts are made at developing local PV refrigerators.[39]

For the medium term, interesting research is being done on low-energy use refrigerators with Stirling compressors and vacuum-insulation. Stirling compressors have the advantage of being able to be in constant operation with an output that can be easily modulated (compared to traditional compressors that turn on or off depending on the need for cooling). This mode of operation avoids the high current peaks that occur when "normal" compressors turn on and off. Together with simple technologies to store "cooling energy" in ice, rather than in batteries, this makes it possible to run such refrigerators directly from PV panels, avoiding the costs of batteries and increasing system reliability.[40] Additional work is being done on improved insulation. Since energy insulation losses generally make up 75-80 percent of energy demand in refrigerators[41], improved insulation has considerable effects on energy

[38] source: PRESSEA website and personal communication with M. Damin, 2000
[39] personal communication with J. de Winter, ETC Energy Consultants, Leusden, The Netherlands, 2000
[40] source: Berchowitz, 1996
[41] the remaining energy demand being caused by the opening and closing of the refrigerator

consumption. Increasing insulation thickness with the present foam-insulation techniques, is limited by the amount of space being occupied by insulation. New developments in the field of Vacuum Insulation Panels combine high insulation with limited thickness. These innovations have been shown to work in demonstration models, but it will take considerable time before they will be on the market and at affordable prices.

The two developments sketched above indicate an increased attention for affordable PV refrigerators. The results of these developments will pay-off firstly for household-size refrigerators with possible uses for small businesses such as restaurants and bars. For use in dairy, fish and meat processing, larger refrigerators are generally necessary, increasing energy consumption and losing the competitive edge of PV systems. Examples exist, however, of hybrid PV/diesel and PV/wind systems to power larger refrigeration systems, for instance in Indonesia and Mexico (see paragraph 3.4.2).

A final application of PV refrigeration in the agricultural sector is the cooling of vaccines for veterinary use. The same considerations as for vaccine cooling in the health care sector are valid here: a high emphasis on reliability and low-maintenance, making cost considerations less important. Many examples exist, such as an FAO-managed project on Rangeland Management in the Syrian Steppes (FAO, 1999).

3.5.5 PV electric fences

Livestock farmers in many remote areas need power for electric fences. Electric fences often prove more cost-competitive in the long run than fixed barbed-wire fences especially in countries where labour prices are relatively high. For remote areas the use of grid electricity is often too expensive due to the long lines to be extended. Such electric fences are often powered by stand-alone batteries. The addition of a solar panel extends the lifetime of the battery and avoids the costs for time, transport and charging. In many cases the use of PV electric fences is therefore the least-cost and most convenient solution. Apart from cost-effectiveness, the most mentioned advantage of PV electric fences is that they facilitate pasture management.

A PV fence charger basically consists of a set of electronics that is capable of delivering short (in the order of 0.0003 seconds), high-voltage voltage shocks (5 000-7 000 Volt depending on the animal). Power consumption is low because shocks are short and only occur when animals touch the fence. The chargers can be powered with grid electricity, 12V-battery or even dry-cell batteries for the smallest units. PV panels make it possible to use these fences in off-grid areas without the need of supervision or battery charging. A PV fence charger (including panel and battery) costs around double the price of a grid-connected alternative (excluding line extension)[42]. Small, integrated PV fence units exist with a small solar panel, battery and the necessary electronics to power, often used as mobile units for small fences (up to a few km).

PV electric fences are widely commercially available from companies in countries such as Germany, New Zealand and USA. Survey respondents reported experiences with PV electric fences from: Australia, Brazil, Cuba, India and Mexico.

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[42] for instance: a PV fence charger to power 15 km of fence costs around US$400 F.O.B., while a grid-connected alternative costs around 200 US$ F.O.B. (excluding line extension to the grid).

3.5.6 Other applications of PV for agriculture

Poultry lighting

Several scattered cases have been identified in which solar systems were used to provide light for poultry (both meat and egg production). Using light extends the day and increases the growth of poultry and the production of eggs. Another important factor for poultry farms in some areas is heat to reduce the mortality rate of chicks. In conventional poultry farms "heat" lights are used to provide both heat and light. Such heat provision with PV would be too costly, because these heat lights consume large amounts of electricity (100 W or more). Alternatives for heat could be solar water heaters or other ways of low heat provision. In other (hotter) areas, there is more need for ventilation, which can more easily be supplied with PV powered electric fans. More investigation would be needed to ascertain whether this type of PV application makes economic sense and is replicable on a wider scale.

Pest Control

One case study has been identified[43] in which solar-powered lanterns were used for trapping a specific pest (Red-Headed Hairy Caterpillar or RHC) in the Deccan region of India. An NGO, Centre for World Solidarity (CWS), introduced this application in its programme for ecological pest control. The RHC is widely spread in semi-arid South and Central India and affects various rain-fed food and commercial crops. The parent of RHC is a moth with a complicated life cycle and emergence pattern (four to five emergence peaks a year). Often pesticides are used to control the moth, but with consequent harmful environmental effects and growing pesticide resistance. CWS started experimenting with light bulbs hanging over a bucket of soapy or kerosenated water. If lights are placed in the fields at night after a heavy rain, which is when the moths emerge in great numbers, most moths are attracted by the light, fall into the water and drown before laying eggs. Solar lanterns proved far more effective, economic and safe than extending a cable into the fields. In 1998 Winrock India funded a trial on 100 acres of land using Indian produced solar lanterns. In the test year (1997-1998) the damaged area was brought back from 44 to 8.2 percent. More research is needed to test the viability of this pest control method, its applicability to other pests; and to establish its potential for replication.

[43] source: Winrock REPSO magazine, Vol 3, No.3 1998

4. PV for SARD: Findings and recommendations

In Chapter 3 the most important PV applications were discussed - both in terms of present use and in terms of (potential) impact - with a special focus on productive applications in rural areas of developing countries. This chapter summarizes these findings and describes ways to design programmes and projects that optimize the impact of PV systems on sustainable agriculture and rural development.

4.1 Findings

Solar Home Systems (SHS) are still the dominant PV application in rural areas of developing countries and their main use is for lighting and radio/TV in households. The evidence of the impact of SHSs on household economics is mixed: some studies report that there is little evidence of such direct impacts; others make reference to time savings and extension of the day due to SHSs. This “surplus time” is sometimes used for productive activities such as sewing, basket weaving and handicraft making. A detailed survey of SHS-users and non-users in Nepal concluded that 13 percent of the men and 11 percent of the women perceived an increase in income-generating activities due to the introduction of SHSs. In other cases this “surplus time” is used for facilitating household chores, homework, education and recreational activities. The acquisition of SHSs generally results in savings on other energy expenditures (especially kerosene), but this is often more than compensated by the additional expenditures on SHSs (for example, payments on loans, maintenance). Rural people's willingness to pay several times their “normal energy budget”, is a clear sign of the value they attach to the improved services of SHSs. Often mentioned aspects include: decrease in accidental fire, improved quality lighting, improved education, improved access to information and improved health/hygiene.

Women and children are often found to be the main users of SHS, because they spend more time in and around the house and they are also more confronted with system failures. Still most marketing, financing and training efforts are directed towards men. Slowly this appreciation is trickling down to the practitioners of PV and having its impact on training programmes and projects. A trend noticed is the widening of delivery mechanisms for PV electricity, including leasing, which improves the access of lower income groups to these services. Another trend that is detected is the growing system size of PV installations in developing countries. Examples show that this can translate into more power becoming available for other uses than lighting and radio/TV, for example for items such as electric sewing machines.

Many PV projects have been and are being implemented for **social and communal services**, such as refrigeration, communication and lighting for health centres; provision of potable water; and basic lighting for schools and communal buildings. In many cases PV has shown to be the least-cost solution to improving such services in remote areas of developing countries. With relatively small investments, PV systems can have a significant impact on the lives of *all* rural inhabitants through these improved services, providing that access to these services by marginalized groups is accounted for. One of the important lessons learnt in such projects, is the importance of adequate community organization and financing of operation and maintenance. Successful examples exist where some kind of income-generating activity is integrated into the communal service to contribute to a fund for operation and maintenance (for example, by running a small village cinema or battery charging station, by selling produce of small irrigated plots).

Small PV systems also help develop **off-farm productive activities** (both cottage industry and commercial services) in many countries, by powering small tools and appliances (drills, soldering irons, blenders), lighting and radio/TV. These activities include bars, restaurants, rural cinemas, technical and artisanal workshops. The amount and diversity of these PV applications for off-farm productive activities is enormous (see table 4 for an overview), but too little information was found to quantify this potential. Often these activities take place at home and are therefore difficult to distinguish from other home activities as described under the SHS-section. The example of Grameen Shakti in Bangladesh, shows that a systematic approach of small credits and capacity building for local entrepreneurs can make PV systems a valuable input for micro-enterprise development. Other off-farm productive activities that are increasingly powered by PV systems are telephone services and the sale of electricity itself: more and more local entrepreneurs and community groups run solar battery charging stations or sell electricity in other ways. Finally, the servicing and installation of PV systems themselves is often based on networks of solar micro-enterprises that are often situated close to their source of business in rural areas, creating more local employment.

There are also a growing number of uses of PV for **agricultural productive applications**. Water pumping (for livestock watering, irrigation as well as potable water) has gained prominence, representing around 12 percent of yearly global PV production and one of the major rural PV markets in developing countries (estimates range up to 19 percent, see annex 4). PV systems are often already the most economic solution for watering livestock in remote, unelectrified areas and are widely commercially available. Though still needing optimization, the combination of PV pumps with drip and other “efficient” irrigation techniques promises an economic solution for irrigation of horticultural and other high value crops with less water and fertilizer, even for lands that were formerly judged as unsuitable for irrigation. Other agricultural PV applications in wide use are PV electric fences. Interesting applications that still need to prove their replicability are: aeration pumps for aquaculture, pest control, fish and poultry lighting. Small PV vaccine refrigerators are used extensively in the human and veterinary health sectors, mainly because of their high reliability. Developments in PV refrigeration could bring household refrigerators in reach within the short to medium term. Larger refrigerators (for example for conservation in dairy, meat and fish production) still demand too much energy to be economically powered with PV. Successful examples exist of hybrid PV/diesel and PV/wind systems for refrigeration and other higher energy consuming applications.

4.2 Recommendations towards integrated PV electrification programmes

The findings of this study have led the authors to believe that the time is now ripe to advance towards a new phase of "PV beyond the light bulb". This does not exclude PV lighting in general, but stresses the necessity (and potential) of looking beyond SHSs towards other PV applications and to the impact they can have on rural development. PV electrification is not a panacea for all rural development problems and is still hampered by high costs, but as shown in the preceding chapters, a growing number of PV applications is becoming economically viable and has a significant impact on rural development. To exploit the full potential of PV in areas such as agriculture, rural education and health care, there is a need for adequate policies and for improved collaboration among institutions from the energy, agricultural, health, education and other sector organizations involved in rural development. Annex 6 presents a package of recommendations, directed at promoting such policies and cooperation with the aim to use the opportunities that PV systems offer in contributing to sustainable agriculture and rural development.

As mentioned in Section 2.4, barriers are being encountered in trying to fully exploit the potential of PV, which often act in a vicious circle: high investment costs, lack of financing mechanisms, lack of infrastructure**,** lack of familiarity, low volumes of sales, high transaction costs and lack of political commitment and adequate policies. The growing experience in PV project organization, combined with reforms in the energy sector, have opened the possibility of a new type of rural electrification project, which could perhaps help solve the problems mentioned. Several “integrated PV electrification programmes” try to *simultaneously* address energy (electricity) needs in different sectors of rural society (for example, households, education, agriculture) by offering different PV systems tailored to the different needs. Such integrated projects promise to deliver synergies in terms of infrastructure, promotion and familiarity of the technology by combining PV markets to create a critical mass, thereby contributing to overcome barriers and creating sustainable markets. Examples discussed earlier in this publication are the Municipal Solar Infrastructure Project in the Philippines (paragraph 3.3.4), the Indian PV programme (paragraph 3.5.1) and the Mexico Renewable Energy Programme (paragraph 3.5.2).

While creating critical mass, such projects have the potential to maintain the flexibility and modularity of individual PV installations tailored to different (local) needs. This creates the opportunity for a gradual and participatory approach to rural electrification projects and allows such projects to focus on prioritized energy needs of communities, for instance water pumping, improved health care, street lighting or household electrification. As a result of the focus on individual, prioritized installations, the development impact of such installations are much easier to evaluate. Furthermore, initial installations (including local capacity-building and infrastructure development) can provide a base for future expansion according to needs and demands, either through projects or private acquisition by individuals. PV therefore allows rural electrification that is able to follow and support the rural development process.

As described in previous sections, the diversity of PV applications also results in a range of impacts on rural development, which combined, might add up to a more significant and sustainable impact - or, as a respondent to the survey carried out in preparing this study pointed out: *"We need to have reasonable concentration of systems in a given area, stimulating the establishment of local technical support. Social applications can highly improve impact of PV systems but use in the households can help to establish significant clusters."*

Many of the projects reviewed also note that the impact of PV systems is greatly improved if the PV systems themselves are delivered in combination with training programmes for effective use of appliances, for example, training for improved irrigation techniques (India, paragraph 3.5.1), livestock extension (Mexico, paragraph 3.5.2), integration in health care centres (Colombia, paragraph 3.3.1), microenterprise support and microcredit (Section 3.4) and educational programmes (Honduras, paragraph 3.3.3). “Packages” can be developed for each sector, including the energy component (PV system, installation training and servicing) and the application component (appliance, training in use).

The institutional arrangements for implementing such integrated approaches can differ from country to country and sector to sector. The provision of PV systems for basic services would logically appear to be a government prerogative, where energy organizations can work together with organizations from the education, health and other sectors to develop "social service packages". The installation and servicing can be contracted to public or private energy companies. The electrification of households can be included in such contracts (for example, concessionary approach), including government subsidies, but could also be left to the free market where individual companies compete at the level of the end-user. Similar arrangements can be made for the provision of PV systems for agricultural and other productive uses in cooperation between energy and agricultural organizations. PV systems adapt easily to these different types of institutional arrangements.

4.3 Final remarks

It can thus be concluded that PV applications, and especially those for productive activities, have considerable potential to both serve environmental concerns (e.g. climate change) and contribute to the achievement of sustainable agriculture and rural development. All stakeholders involved in the dissemination and use of these applications need to play their respective roles in order to achieve that potential. It is hoped, in particular, that international cooperation agencies, including FAO, commit themselves to assisting developing countries in making use of this potential, particularly in the process of promoting sustainable agriculture and rural development.

The preparation and publishing of the present study represents an assurance of the interest of FAO to assist its member countries in taking advantage of the opportunities offered by photovoltaic systems for SARD. Recalling the importance of cross-sectoral cooperation to fully maximize this potential, the study will hopefully contribute to underscoring FAO's role in promoting the integration of PV systems in agriculture, and of agriculture into ongoing PV programmes. It is also recommended that FAO actively looks for cooperation and alliances with other interested parties.

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Annex 2: List of completed questionnaires

Name	Organization	Project/business and location
Mr H. V. Joshi	Vistar Electronics P Ltd., India	Solar distribution company, India
Mr Julius Koli	Community Management and Training services-East Africa	SHS project, Kenya
Akanksha Chaurey	Tata Energy Research Institute, India	Several projects, India
Asma Mesnaoui	NOOR Web S.A., Morocco	Solar Rural Electrification, Province of Taroudant, Morocco
Mr B. van Campen	FAO - Honduras	PV for community buildings and education, Honduras
Ms Beatriz Cancino Madariaga	Departamento Ing. Mecánica, Universidad Técnica Federico Santa María	SHS and community systems project, Camarones, Chile
Mr Bob Schulte	Ecofys, The Netherlands	Solar Market Development Programme, The Gambia
Mr E. Buchet	GERES, France	Project decentralised electrification in Kagera, Tanzania
Mr Claudio Moises Ribeiro	CEPEL-Centro de Pesquisas de Energia Elétrica, Brazil	US/Brazilian PV Rural Electrification Pilot Project, Brazil
MrDaniel B. Waddle	NRECA International Ltd., USA	Various PV projects in Bolivia, Guatemala, Bangladesh and Costa Rica
Dr. Salifou Bengaly	SINERGIE SA, Mali	Projet Femmes -Energie -Developpement (FED), Mali
Dr. Salifou Bengaly	SINERGIE SA, Mali	PV electrification of 10 Health Centres, Mali
Dr. Lu Aye	IDTC, Dept. of Civil & Environmantal Eng,Univ of Melbourne, Australia	Various PV projects in Australia
Ms Fabienne Karhat	Fondation Energies pour le Monde, France	Pilot Programme for Rural PV Electrification in Bangladesh
Mr Guilherme Caldas Bahia	Secretaria de Infra-Estrutura de Pernambuco, Brazil	Lus do Sol, Pernambuco, Brazil
H. Harish Hande	SELCO Photovoltaic Electrification (P) Ltd., India	Solar distribution company, India
Ing. Manuel Contijoch	Fideicomiso de Riesgo Compartido, Mexico	Energía renovable en la agricultura, Mexico
Ir. Patrick J.N.M. van de Rijt	Shell Solar Energy B.V., the Netherlands	Xinjiang demonstration village, China
Mr Jayantha Nagendran	DFCC Bank, Sri Lanka	Energy Services Delivery Project & Credit Programme, Sri Lanka
Ms Jeanette Scherpenzeel	Biomass Technology Group bv, the Netherlands	Rural electrification by 10,000 Solar Home Systems, Bolivia
Mr John Rogers	Soluz S.A. de C.V., USA	PV rural electrification (leasing), Honduras and Domincan Republic
Mr Jorge Henrique Greco Lima	Centro de Pesquisas de Energia Eletrica (CEPEL), Brazil	PRODEEM Social PV programme, 7 states of Brazil
Mr Jose Maria Blanco	Biomass Users Network - Central America Office, Costa Rica	SHS projects in Central America
Mr Juan Fransisco Gómez Cristiani	Ministerio de Energia y Minas, Guatemala	PV Rural Electrification, Guatemala
Mr Juan José Chacon	NRECA , Guatemala	School Lighting in Chachahualilla village, Guatemala
Mr Juan Vadillo Astrurias	Fundacion Solar, Guatemala	SHSs in La Oscurana, Guatemala
Ms Lisa Büttner, Mr Chris Rovero	Winrock International, USA	Mexico Renewable Energy Program, Mexico

Mr Mark Hankins	Energy Alternatives Africa, Kenya	WB ESMAP PV SHS Financing Project, Kenya
Mr Wisdom Ahiataku-Togobo	Renewable Energy Department, Ministry of Mines and Energy, Ghana	Kpasa off-grid rural electrification Project, Ghana
Mr Ned van Steenwyk	Soluciones Energeticas, Honduras	Solar distribution company, Honduras
Mr Peter JM Konings	PT Mambruk Sarana Interbuana, Indonesia	Solinvictus II, 20,000 SHSs Indonesia
Mr Phil Covell	ENERSOL Associates, Inc., USA	Honduras Health Clinic Electrification, Honduras
Prof. Amrit B. Karki	Consolidated Management Services (Nepal) P. Ltd.	Pilot Project on Solar PV Pumps for Micro-Irrigation System, Nepal
Prof. Amrit B. Karki	Consolidated Management Services (Nepal) P. Ltd.	Socio-economic Study of Solar Home Systems Target Groups, Nepal
Mr Roberto Zilles	Instituto de Eletrotécnica e Energia-USP, Brazil	Potable water pumping in the state of Sào Paulo, Brazil
Mr Roberto Zilles	Instituto de Eletrotécnica e Energia-USP, Brzail	ECOWATT, leasing-project for SHSs
Mr Rubén Ramos Heredia	Centro de Investigaciones de Energía Solar, Cuba	Evaluation of factibility of medium-sized PV projects, Cuba
Shawn Luong	SELCO-Vietnam	Solar distribution company, Vietnam
Mr Shinji Omoteyama	The Institute of Energy Economics, Japan	Rural Electrification Project by Renewable Energy, Laos
Mr Silverio T. Navarro, Jr.	Solar Electric Co., Inc., the Philippines	Malalison Solar Battery Charging Station, the Philippines
Mr Vicente O. Roaring	Renewable Energy Association of the Philippines(REAP)	SHS-project in Abra region, the Philippines
Mr Wael H. EL-Nashar	Arabian Solar Energy & Technology Co. (ASET), Egypt	Solar distribution company, Egypt
Mr Yug Ratna Tamrakar	Solar Electricity Co. (PVT) Ltd., Nepal	Solar distribution company, Nepal

Annex 3: Review of rural electrification projects

In most countries national governments are involved in promoting rural electrification projects to reach out to more remote, rural areas. In many cases such rural electrification projects are not financially attractive investments and require subsidies. Schramm (1993) lists several of the most frequently cited reasons and objectives for undertaking rural electrification projects:

- to act as catalyst for agricultural, industrial and commercial development of rural areas, including electricity for irrigation pumping;
- to replace more costly energy sources, such as kerosene for lighting, diesel for individual motors, irrigation pumps and generators;
- to improve the quality of life through such means as improved quality of light and use of domestic electrical appliances (such as irons), resulting in time saving, particularly for women;
- to improve the standard of living of the rural poor;
- to stem migration from rural to urban areas;
- to improve security, political stability and/or correct regional imbalances;
- to redress urban/rural bias;
- to reduce deforestation by replacing firewood or charcoal.

The following is a condensed overview of several studies[44] done in the 1980s and 1990s on the impact of several rural electrification projects.

Impact on rural development and economic growth
No evidence of direct correlation between rural electrification and economic growth (leading to rural development) is concluded by either of the mentioned studies. Electricity may contribute to economic growth when introduced under the right circumstances and in conjunction with many other resources and (infrastructure) inputs.

Impact on poverty
Rural electrification does not benefit the poor, despite the use of subsidized tariffs,. Some authors conclude that rural electrification exacerbates existing pre-electrification differences by favouring the affluent that can afford electricity and appliances and that benefit most from subsidized electricity tariffs.

Impact on productivity
Although lacking conclusive evidence, there is reason to believe that rural electrification has a positive impact on agricultural and industrial productivity. Main points are:

- benefits to sugar, coffee industries
- irrigation, especially small-scale vegetable production
- refrigeration, especially for the fish, meat and dairy sector
- rural industries, where electricity is relevant (flour-mills, workshops and small craft manufacture)
- longer working hours due to lighting
- release of female-labour time for small craft and other productive activities
- dairy and livestock farming.

Impact on employment
Little or no evidence exists of a direct positive impact of rural electrification on employment. A positive impact on employment would result through general improvement in economic conditions and productivity (see above), but indications also exist for the contrary due to labour-saving technologies and increased working hours.

[44] Fluitman, 1983 - Pearce and Webb, 1987 - Desai, 1988 - Foley, 1990 - Munasinghe, 1990: listed in Ramani, 1993; Schramm, 1993

Impact on other social goods
There is a distinct effect on the quality of life, for those who can afford it, due to better lighting, recreation, improved conservation of food and availability of labour-saving devices like electric irons and flour mills (liberating female time). Electricity does not, in general, replace fuelwood for cooking. Electricity opens the possibility of improved health services, education, etc., but this potential is often limited by lack of supplies and qualified manpower.

No direct impact on population control can be established. Only where rural electrification is part of a general trend of socio-economic improvement, fertility rates are seen to drop. The views on impact on rural-urban migration are mixed. Some stress the high social impact of rural electrification, giving a great social boost, changing people’s attitudes and perceptions and increasing their expectations. Others reason that increased expectations, combined with increased communication and, possibly, reduction in employment, might even lead to increased migration.

The evidence on the impact of rural electrification on rural development is therefore inconclusive. Direct impacts or correlations are difficult to establish. There is reason to believe that rural electrification has a positive impact on productivity, quality of life and several social services. The remark is made by most authors that rural electrification has no impact by itself, but has a potential for increased productivity, improved social services and other positive impacts, if accompanied by additional inputs. For instance, higher productivity can only be realized, when a market for additional production exits or can be promoted, and when combined with complimentary inputs like appliances and credits.

Annex 4: Present and potential markets for rural PV applications

Annual PV shipments (in MWp) have grown an average of 15 percent p.a. and reached worldwide nearly 70 MWp in 1994 (EC, 1996). Maycock (1998) comes to a similar conclusion concerning the period 1990-1997: annual shipments grew from 48 MWp in 1990 to 126 MWp in 1997: an average of 14.8 percent p.a. In this period the "world off-grid rural" market (mainly in developing countries) grew with an average 17.9 percent p.a. Maycock describes this market as the "biggest opportunity" of all, although hampered by major barriers and predicts this market will take off explosively after the year 2000.

Obtaining detailed data on markets for specific rural PV applications in developing countries is difficult, but with data from American and European industry sources, a good overview picture can be created of developments in these markets. In the early 1980s the PVmarket was strongly dominated by large-scale PV applications. By the beginning of the 1990s the market for stand-alone PV applications had clearly taken the lead (see table 18). Over 1990-1994 the four largest PV application markets (in MWp) were:

- communications (both in developing and industrialized countries);
- leisure, boating and caravaning (mainly in industrialized countries);
- Solar Home Systems (major part in developing countries);
- water pumping (mainly in developing countries).

As can be seen in table 18 grid-connected systems only represented 10 percentof the PV shipments in 1990-1994 but this percentage was higher for industrialized countries (22 percent). The grid connected segment is also one of the fastest growing markets and is predicted to occupy 29 percent of annual shipments by 2010 under a business-as-usual growth scenario (EC, 1996). By 2010 the major markets would be:

- Solar Home Systems (major part in developing countries);
- grid-connected systems (mainly in industrialized countries);
- communications (both in developing and industrialized countries);
- water pumping (mainly in developing countries).

Table 18 Existing and predicted global PV module shipments (in % of Wp-shipments)

End-uses by type	**1990-1994 (average)**		**2010 (BAU scenario)**	
	% of total	**% of rural market**	**% of total**	**% of rural market**
Grid connected	10 %		29 %	
Consumer indoor	7 %		3 %	
Camping/Boat/Leisure	15 %		9 %	
Cathodic protection + military/signaling	6 %		5 %	
subtotal non-rural markets	*38 %*		*46 %*	
subtotal rural markets	*62 %*		*54 %*	
Communications	21 %	*34 %*	11 %	*20 %*
Solar Home Systems	15 %	*24 %*	23 %	*43 %*
Water pumping	12 %	*19 %*	7 %	*13 %*
Village Power	5 %	*8 %*	4 %	*7 %*
Remote houses	7 %	*11 %*	6 %	*11 %*
Other remote	3 %	*5 %*	2 %	*4 %*

source: EC, 1996

An attempt has been made to separate the rural and non-rural markets (see right column of table 18) to give an approximate idea of the market developments for different rural PV applications. Clearly Solar Home Systems, communications and water pumping remain the major rural markets. Because the communications and SHS markets are more evenly distributed between developing and industrialised countries, while the water pumping market is mainly in developing countries, the water pumping market segment is likely to be relatively larger in developing countries. It should also be noted that the communications market includes repeater stations and other applications supporting telecommunication networks (that do not necessarily benefit rural areas directly), as well as radio and cellular communication systems that are used by rural inhabitants from which they gain direct benefits.

A similar picture can be derived from American PV industry data[45]:

Table 19 End-uses of American PV module production (in percent of Wp-shipments)

End-uses by type	**1996**		**1997**		**1998[46]**	
	% of total	**% of rural market**	**% of total**	**% of rural market**	**% of total**	**% of rural market**
Grid interactive	14 %		18 %		28 %	
Consumer goods	3 %		1 %		2 %	
Transportation	15 %		15 %		13 %	
Cells/Modules to OEM[47]	7 %		11 %		10 %	
subtotal non-rural market	*38 %*		*44 %*		*53 %*	
subtotal rural market	*62 %*		*56%*		*47 %*	
Remote	31 %	*50 %*	19 %	*33 %*	17 %	36 %
Communications	17 %	*28 %*	16 %	*29 %*	16 %	35 %
Water pumping	9 %	*15 %*	8 %	*15 %*	9 %	18 %
Health	3 %	*4 %*	3 %	*5 %*	2 %	4 %
Other[48]	2 %	*4 %*	10 %	*18 %*	3 %	6 %
TOTAL shipments	**35,464 kWp**		**46,354 kWp**		**50,562 kWp**	

source: Energy Information Administration (EIA), Annual Photovoltaic Module/Cell Manufacturers Survey

In the American data-set, "remote" applications include both SHS (mainly in developing countries) and power for mobile homes and other camping/leisure uses (mainly in industrialized countries). This makes separation of "rural" and "non-rural" markets slightly more complicated. A rough estimation of market shares for different PV applications (end-uses) of American manufactures modules can be derived from table 19. The right column for each year represents estimated shares of "rural markets". These data should be interpreted with caution but the general trend is the same as for the data from the EC-study (1996). The major rural markets are "remote"(including SHSs), communications and water pumping. Water pumping (for potable water, livestock watering and irrigation) represents 8 to 9 percent of yearly PV shipments (15 to 18 percent of the "rural"market). It should also be noted that uses for the health care sector represent a solid 2 to 3 percent of total annual shipments (4 to 5 percent of the "rural" market).

Based on data as represented above, the European PV Industry Plan defined the following priority applications and markets outside Europe (mainly developing countries):

- SHSs;
- health care systems;
- solar pumps.

More detailed estimations of specific (country) markets for rural PV applications have been made. As discussed in paragraph 3.5.2, PV for livestock watering is already financially competitive in many areas and widely used in the USA. Many North American rural electrification utilities now offer PV

[45] The Energy Information Administration of the US Department of Energy (EIA/DOE) gathers data on the American PV industry - which represents around 39 percent of world PV module production
[46] provisional - forthcoming publication EIA/DOE
[47] OEM = Original Equipment Manufacturer, i.e. for integration in other non-consumer equipment
[48] Other uses include PV modules for uses, such as cooking food, desalinization, distilling, etc.

pumping as an economic alternative to grid extension. The Utility Photovoltaic Group (UPVG, 1994/95) estimates the potential market for solar pumping in livestock watering in the USA alone at 30-40 MWp[49]. A similar pumping market (30-35 MWp) is estimated for pond and lake aeration, mainly for fish and shrimp farming, but also for residential use. Other uses such as PV powered fences are also widely commercially available in USA and competitive, but they represent relatively small PV market shares (in MWp) because of their low energy requirements.

REPP (1998, 1999), an American think-tank on renewable energy, states that the market for such uses in developing countries is manifold the market in OECD-countries, estimated at a total market of 500 GWp[50]. They quote a global survey in the Solar Industry Journal, investigating the global market for stand-alone pump-sets, which is estimated at 10.4 GW annually representing US$6.3 billion, five times the market for stand-alone generator sets[51]. PV or PV diesel hybrid systems could serve most of these applications economically. The PV pumping market could therefore develop as one of the major rural PV markets in developing countries.

In the context of the Mexico Renewable Energy Project (see paragraph 3.5.2).a market study was done for renewable energy systems in Mexico. Water pumping and rural electrification (SHSs) were identified as similar-sized markets for RE applications (mainly PV).

Table 20: Market for RE-applications in Mexico

Application	**potential market in million US$**	**comments**
Rural electrification	511	projects difficult to fund
Potable water	135	
Livestock watering	297	- best agricultural application for RE - capacity to pay exists with majority of ranchers
Small-scale irrigation	94	- market for small-scale irrigation does not yet exist, but pilot projects are well-warranted -best opportunities high-value crops that can be efficiently produced in small plots

source: Sandia, 1998

The observation is made that in the water pumping market a larger capacity to pay exists, at least in the livestock sector, because pumping systems contribute more to income generation. This should make these markets more accessible. Small-scale irrigation with PV pumps is seen as a potential market in the medium term, because, as described in paragraph 3.5.1, PV pumped irrigation is still not as competitive as livestock water pumping and work still has to be done in system optimization (pumps, drip-irrigation systems, etc.).

Finally, in its report on the photovoltaic market (EC, 1996), the European Commission presents an estimate of the potential market for rural stand-alone PV systems in developing countries, based on the *need* for basic services and home lighting of unelectrified areas and households in developing countries. The total potential demand is 16.5 GWp, based on 1.1 billion rural people worldwide without access to electricity. The set of basic energy needs (health care, education, communication and household electrification) represent a mere 15 Wp per capita.

[49] based on a price of US$3/Wp. This price level is predicted to be reached by 2000/2001
[50] this represents ca. at 250 Wp per capita
[51] prime power only, i.e. almost continuous work; market for standby power in N. America is approx. 80 times.

Table 21 Potential PV market for communal services in rural areas of developing countries

Rural HH electrification (66%)	11,151 MWp
Water pumping (16%)	2,643 MWp
Education (16%)	2,657 MWp
Health (1%)	112 MWp
Communication (2%)	314 MWp

source: EC (1996)

These figures show a clear dominance of rural household systems, but water pumping and education represent large demands as well. It should be stressed again that these are not market figures, but estimations based on basic needs. Household electrification is likely to have to be financed mainly by the rural people themselves, who often lack the resources. The other categories can be counted as basic communal services, which governments could provide, but the key questions are: "will they?" and "is the capital available?". Many projects are being developed in this area, but they are not likely to cover this whole potential market of 16.5 GWp.

On the other hand, these figures do not take into account investments by individuals and organizations in more-than-basic-needs or the market for PV systems for agricultural or other productive uses, off-grid repeater stations or any other energy demands derived from non-basic needs.

Annex 5: Survey questionnaire[52]

STUDY ON THE IMPACT OF SOLAR PHOTOVOLTAIC SYSTEMS ON RURAL DEVELOPMENT

Filling in the questionnaire

This questionnaire is directed at key-persons – like you – involved in the organization, distribution, finance, installation and/or maintenance of PV-systems in rural areas and asks your assessment of the impact of PV-systems you are involved in or have immediate knowledge of. It is directed at both "projects" – in the sense of development projects organized by government agencies, NGOs and international organizations – and at PV-systems distributed through direct commercial sales.

If you work in more than one PV-project or market, please fill in a separate questionnaire per project or choose one (preferably the one with the largest income-generating component).

The questionnaire has been structured in 3 parts:

Part 1 (chapter 1) contains general questions on the PV-project and systems and on the general area of impact and main beneficiaries. It also serves as a selection for part2 of the questionnaire.

Part 2 (chapters 2 – 5) contains the main questions on the impact of the PV-systems on different aspects of rural development. In general, only one or two of these chapters will have to be filled per questionnaire, depending on the main area of impact.

Part 3 (chapter 6 and 7) lists questions on the organisation and financing of the PV-systems. Chapter 7 contains some open questions on your ideas/opinions of how to improve the impact of PV-systems on rural development.

The questionnaire is made in such a way that it can be printed, filled and sent by fax/mail or **filled on-screen and sent as an email attachment (preferable).** It has been designed in WORD6, but should not give any problems when reading in WORD95 or WORD97. You can send it back in all the WORD-versions above-mentioned.

Most of the questions are of a 'checklist'-nature, in which case one or more boxes should be checked. For the few open questions space has been left open in text boxes to write down your answer. If you fill in the questionnaire on screen: it is protected so only selected fields can be filled (marked gray on screen). Just click the check boxes with your mouse and see a cross appear. For open questions click on the gray area in the text box and start writing; the text box automatically expands if necessary. **Filling in the questionnaire should not take more than 30 minutes on average.**

Please feel invited to send any remarks, criticism, suggestions or questions to us. We are looking forward to hearing from you.

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Food and Agriculture Organization of the United Nations (FAO)
Sustainable Development Department

[52] The survey questionnaire was sent in English, Spanish and French. For inclusion in this publication only the english version is presented. The lay-out has been changed slightly (mainly reducing the size of the text boxes for open answers) to better fit the final document.

1.1. Personal Data			
Name of respondent			
Organization			
Address *mail address*			
Telephone no(s)		**Fax:**	
email			

1.2. If your organization is involved in different PV-projects or sells different types of PV-systems, could you indicate what the PV-systems are used for and possibly give a percentual breakdown?			
Productive uses *agriculture, rural/cottage industry, small business*		☐	%
Community/social services *village water pumping, health centers, schools, etc.*		☐	%
Solar home systems		☐	%
Other, namely		☐	%

If you are involved in more projects, markets or areas, please select one, preferably the one where the income-generating component is largest.

1.3. General project data *For projects only! Otherwise please continue with question 1.4.*	
Name of the PV-project	
Year of starting of PV-project	
Short description of the project *main objectives and target group*	

1.4. Geographical location of the PV- project or market	
Village/Town/City *if applicable*	
Region/department/ province	
Country	

1.5. Type of PV-systems used/sold *please tick box, more than one if appropriate*		
Centralized village mini-grid		☐
Solar Home System (= small system for lighting, TV/radio, etc. for home, school, bar, etc.)		☐
Other stand-alone system (pumping, refrigeration, desalination, etc.)		☐
Hybrid system PV and ☐ diesel or ☐ wind or ☐ other, namely		☐
Battery charging station		☐
Other, namely		☐

1.6. Technical data

Pls fill in separate boxes for the three (or less) main types of systems used or sold:

Voltage of system 1	12 V DC	☐	110/220 V AC	☐	**other, namely:**	☐
Total size of system 1	panels	Wp				
	batteries	Ah				
appliances or end-uses	**appliance**			**number**		
	lights					
	water pump					
	radio/TV					
	refrigerator					
	other appliances namely:					
	other appliances namely:					
Total cost of system 1 *incl. appliances & installation*			**Currency:**			

Voltage of system 2	12 V DC	☐	110/220 V AC	☐	**other, namely:**	☐
Total size of system 2	panels	Wp				
	batteries	Ah				
appliances or end-uses	**appliance**			**number**		
	lights					
	water pump					
	radio/TV					
	refrigerator					
	other appliances namely:					
	other appliances namely:					
Total cost of system 2 *incl. appliances & installation*			**Currency:**			

Voltage of system 3	12 V DC	☐	110/220 V AC	☐	**other, namely:**	☐
Total size of system 3	panels	Wp				
	batteries	Ah				
appliances or end-uses	**appliance**			**number**		
	lights					
	water pump					
	radio/TV					
	refrigerator					
	other appliances namely:					
	other appliances namely:					
Total cost of system 3 *incl. appliances & installation*			**Currency:**			

1.6. What is the PV-electricity used for? *Pls tick box, more than one if appropriate*		
PV-pumping (irrigation)		☐
PV-pumping (potable water)		☐
PV-Water desalination		☐
Livestock watering		☐
PV-Electric fences		☐
Lighting of Poultry /Livestock		☐
Office equipment (computers, etc.)		☐
Radio or cellular phone communication		☐
Health center (refrigeration, lighting, etc.)		☐
Veterinary service (refrigeration, lighting, etc.,		☐
Refrigeration (household, retail store, agricultural products, meat, dairy, fish, etc.)		☐
Lighting, TV, radio, small appliances for commercial services (retail shop/cafe/restaurant)		☐
Lighting, small power tools for micro-enterprises (repair shop, handicraft)		☐
Lighting, TV, radio, etc. for household use		☐
Tourist facilities (lighting, TV, refrigeration of lodges, hotels, etc.)		☐
Lighting and audiovisuals for schools and other community buildings		☐
Street lighting		☐
Other, namely:		☐
Other, namely:		☐

1.7. In your opinion have the PV-systems led to an impact on:
please check box(es) and if applicable proceed to indicated questions

Impact on	**check box**	
Agricultural/livestock productivity	☐	**please fill in questions 2.1 - 2.4**
Rural & cottage industry and commercial services / small business development	☐	**please fill in questions 3.1 - 3.4**
Social services and community development (community level)	☐	**please fill in questions 4.1 - 4.5**
Household quality of life	☐	**please fill in questions 5.1 - 5.3**
Other (productive) activities *please specify/describe*	☐	**namely:**

1.8. How would you characterize the main beneficiaries/users of the PV-systems?
please check more than 1 box if necessary

Profession/activity	check
small subsistence farmer / rancher / fisherman	☐
commercial farmer / rancher / fisherman	☐
professional (teacher, nurse, etc.)	☐
landless laborer	☐
self-employed	☐
artisan/craftsman	☐
small family business/shop/trade	☐
larger business/shop/trade *> 10 employees*	☐
Other, namely:	☐

2. Agricultural & livestock productivity

2.1. What kind of agricultural/livestock activities has/have been stimulated by the introduction of PV-electricity?	
irrigation	☐
refrigeration of crops/meat/fish/dairy/other:	☐
lighting (poultry, livestock)	☐
water pumping for fish farming	☐
water pumping for cattle drinking	☐
pest control	☐
electric fencing for grazing management	☐
Other, namely:	☐

2.2. What beneficial impact(s) did the systems have? *please check box(es), more than one if necessary or fill in last row if choice impact not mentioned*	
higher productivity (higher yield)	☐
more land to be cropped	☐
multiple crops per year	☐
new, more marketable product	☐
more animals can be raised	☐
lower losses (death rate) or faster production	☐
better quality product (higher prices/more sales)	☐
access to more profitable markets (e.g. through conservation of product for transport)	☐
better natural resource management	☐
Other, namely:	☐

2.3. Could you quantify these benefits? *If possible please describe quantitatively the impact indicated above, e.g. how much more income was earned or how much crops were produced/sold, etc. If necessary include additional material.*

2.4. Were there other positive or negative impacts? *If desired, please, describe any impacts not yet covered or that need further explanation.*

3. Rural & cottage industry and commercial services

3.1. What type of business has/have been created, stimulated or improved by the introduction of PV-electricity? *check box(es), more than one if necessary or fill in last row if choice business not mentioned*		
retail shops / restaurant / bar		☐
rural cinema (TV/video-business)		☐
battery charging		☐
telecommunication shop (mobile phone shop)		☐
repair/technical shop		☐
handicrafts / sewing workshop		☐
tourism (hotel, lodge)		☐
other business/productive activity, namely:		☐

3.2. What beneficial impact(s) did the systems have? *check box(es), more than one if necessary or fill in last row if choice impact not mentioned*		
longer working hours / longer opening times		☐
new business opportunity through use of new equipment (power tools, phone, etc.) or new, more marketable product (e.g. handicrafts)		☐
higher productivity		☐
better quality product (higher price)		☐
more sales		☐
better quality service (e.g. more attractive business through provision of light, music, cold drinks, etc.)		☐
creation of home/cottage industry		☐
more employment		☐
Other, namely:		☐

3.3. Could you quantify these benefits? *If possible please describe quantitatively how much more business/product sold, more production, higher price, more man-hours worked, etc. If necessary include additional material.*

3.4. Were there other positive or negative impacts? *If desired please describe any impacts not yet covered or that need further explanation*

4. Social services and community development (community level)

4.1. What kind of social or community services/ infrastructure have been offered or improved thanks to the introduction of PV-electricity? *check box(es), more than one if necessary or fill in last rowf choice service is not mentioned*	(improved) health facilities	☐
	education	☐
	training center (professional, farmer)	☐
	public lighting	☐
	drinking/tap water	☐
	(improved) veterinary service	☐
	community center	☐
	telecommunications	☐
	Other, namely:	☐

4.2. In what way has local lifestyle improved because of the introduction of PV-electricity? *check box(es), more than one if necessary or fill in last row if choice impact not mentioned*	better quality courses/training	☐
	more involvement and participation in community development activities	☐
	productive activities / handicrafts (in the evening)	☐
	courses/classes/training or homework in the evening	☐
	better opening hours shops, restaurants, etc.	☐
	liberating time of villager for other activities, especially for women	☐
	better communications and/or information	☐
	higher health standards	☐
	improvement of local natural environment	☐
	Other, namely:	☐

4.3. Could you quantify these benefits? *If possible please describe impact quantitatively, e.g. estimated no. of people helped, % less incidence of disease, working hours per week saved, etc.. If necessary include additional material. If necessary include additional material.*

4.4. Were there other positive or negative impacts? *If desire please describe any impacts not yet covered or that need further explanation.*

5. Household quality of life improvement

5.1. What is the PV-electricity mainly used for? *check box(es), more than one if necessary or fill in last row if choice end-use not mentioned*		
lighting		☐
TV/radio		☐
refrigeration		☐
Other, namely:		☐

5.2. What principal improvements have taken place in the households that now have access to PV-electricity? *check box(es), more than one if necessary or fill in last row if choice impact not mentioned*		
work / education / homework in the evening		☐
better recreation possibilities (TV/radio, reading, etc.)		☐
better health conditions (refrigeration, no smoke, no danger of fire)		☐
time liberation, especially for women		☐
more pride/self-esteem/positivism		☐
improvements in housing coinciding with installation		☐
Other, namely:		☐

5.3. Were there other positive or negative impacts? *If desired please describe any impacts not yet covered or that need further explanation*

6. Selection, finance and installation

6.1. Were any nationally manufactured components used in the PV-systems? *if yes, could you estimate the value of the nationally manufactured components as % of the total costs of the PV-system (including appliances and installation)?*	☐	**Yes, % of total system costs**
	☐	**No**
6.2. Was any local/national labor used during installation? *if yes, could you estimate the value of local/national labor as % of the total costs of the PV-system (including appliances and installation)?*	☐	**Yes, % of total system costs**
	☐	**No**

6.3. How were the PV-systems (mainly) financed? *pls tick appropriate box and fill details if necessary*		
100 % customer paid (cash)		☐
100% customer paid (credit) interest rate (%) % down-payment (%) % period of payment (years) years		☐
Leasing / fee for service		☐
Grant/gift		☐
Mix grant: % ; cash: % ; credit % ; leasing %		☐
Other, namely:		☐

6.4. Has another energy technology been considered for the same use?
Yes, ☐ generator ☐ wind ☐ grid extension; ☐ other, namely:
No ☐

6.5. Why was PV chosen in this case? *Please specify.*

6.6. Was a cost comparison done with other technical options?.
No ☐
Yes ☐, please specify costs of compared technical options

6.7. Was a cost-benefit analysis done for the PV-project? *Please specify.*
No ☐
Yes ☐, please specify

7. Impact improvement / potential of PV

7.1. In your opinion, how could the impact of projects using PV-electricity be improved? *Please describe ways to improve impact. e.g. concerning intensity of impact, type of PV-projects, diffusion to wider target group, cost-benefit*

7.2. In your opinion, what is the potential of PV for Rural Development? *If possible please describe.*

7.3. If you have any additional commentaries on the questionnaire or others, that could not be covered in earlier questions, please describe here:

Annex 6: Recommendations to promote PV for SARD

The following is a package of recommendations arising from the study, directed at promoting cooperation between institutions from the energy, agricultural and rural development sectors with the aim to use the opportunities that PV systems offer in contributing to Sustainable Agriculture and Rural Development. These recommendations are the result of an assessment of the experiences collected in this study, enriched with other discussions and inputs. They are intended to provide a set of activities for different stakeholders involved in the process of PV rural electrification and rural development. It is clear that the main responsibility for action lies with national development authorities. The role of technical cooperation agencies such as FAO is to support these national efforts.

Policy and planning

- National governmental policies need to be established to promote the important role that renewable energies in general, and solar photovoltaic systems, in particular, can play in achieving sustainable agriculture and rural development - SARD;
- these policies, of a sectoral and cross-sectoral nature, should guide the establishment of plans, programmes and targets of the agricultural, energy and environmental sectors, in particular;
- these policies should also create the appropriate environment and the necessary regulatory and normative context for the role of the private sector and non-governmental institutions;
- synergies as identified when PV applications are promoted simultaneously in various sectors of rural society, should be built into policies and programmes;
- policies in the electricity subsector should establish the role of independent power producers and the rules to be followed by both sides of the power production/purchasing equation;
- policies and programmes should also establish the nexus with international efforts to reduce CO_2 emissions and fulfil the goals and targets of the Climate Change Convention and the Kyoto Protocol;

Research and development

- Research is further needed to assess the replicability of promising PV applications and the conditions under which they are successful; and to develop approaches for assessing their cost/benefit ratio;
- further research efforts are required for the optimization of PV systems for agricultural use in order to develop complete services or product packages, e.g. optimized irrigation systems (panels, electronics, pumps and drip-irrigators) for economic irrigation and fertilization; such packages should be adapted to local agronomic, soil and water and ecosystems and should be accompanied by adequate training packages;
- such efforts should be accompanied by an assessment of the life-cycle technical and economic behaviour of these PV systems;
- other areas of continued research and development are low energy consuming appliances (such as affordable low energy consumption refrigerators) and PV/diesel and PV/wind hybrid energy systems;
- research should also include the development of quality standards, e.g. for agricultural applications, in combination with mechanisms to implement these standards;

Finance

- Rural and agricultural development banks should include PV systems as eligible for loans; the PV systems themselves can function as collateral, especillay when they are investments for productive uses; multilateral investment banks and other financing organizations may develop loan guarentee funds to support these solar loan portfolios;

- innovative financing channels should be explored; this includes the possibility of applying the Clean Development Mechanism (CDM) to PV systems; it is expected that investments in productive uses (agriculture) of PV will be easier to finance than Solar Home Systems because of the income generated by the former;

- as for many other products, equal access to credit by women is required, which would increase their chances to use PV for household and income generating opportunities;

- private sector investments can and should be attracted for financing of PV electrification programmes; international donor funds, soft terms loans and other seed capital can be used as a leverage for such private sector investments.

Demonstration, implementation and marketing

- Demonstration and promotion are required for PV applications such as drip-irrigation, cattle watering, PV electric fences and aquaculture applications as an integral part of agricultural development programmes;

- demonstration and promotion of small PV systems for small cottage industry activities are needed to increase the awareness and knowledge of PV contribution to micro-enterprise development. A possible and innovative approach could be based on *PV powered micro-enterprise development zones* or *PV business incubator approaches*, through the installation of multi-purpose or multi-service PV units, that can deliver power for income generating activities and, for example, common access to phone/fax/web;

- demonstration projects, not done in isolation, but as an intrinsic component of an implementation plan, should include all main stakeholders, including the private sector and government; results of these demonstration efforts should be made public;

- subsidies, when necessary, should be transparent, targeted and time-framed within a gradual phase-out plan; otherwise subsidies should be limited to those PV applications for basic social services such as education and health care;

Training/information/education/awareness

- Agriculture and other rural extension services should become agents to identify potential PV applications; information and training in this field is required;

- training packages are required for preparing PV installation, operation, maintenance and repair services, but also in the use of PV for various agricultural applications, e.g. improved irrigation techniques;

- particular attention should be given to information and training of women, as main users especially of household systems;

- academic curricula at all levels should be prepared and incorporated into educational programmes.

Institutions

- The complex institutional set-up behind SARD needs to be "energized" by the institutions dealing with energy, in general, and with PV systems, in particular;

- to this end, intersectoral efforts are required to bring closer the plans, programmes and policies identified above; this involves the agriculture, energy, health, education and environmental sectors in particular;

- such intersectoral collaboration is critical since small renewable energy (PV) systems can have a significant and durable impact on rural development if applied in “packages” in, for instance, agricultural production and social services (e.g. communication, water, education, health care);

- synergies as identified when PV applications are promoted simultaneously and in an integrated approach in various sectors should be built into collaborative implementation and marketing strategies;

- there is scope for developing plans of action for the integration of rural energy delivery programmes with micro-enterprise development programmes; mutual benefits could be gained: PV electricity rural markets can become a source and stimulus for both Energy Service Companies and for small “electrified” entrepreneurial activities;

- since PV systems normally require more "involvement of the end-user" than conventional grid electricity, the involvement of farmers' and other end-users' organizations in all phases of the PV programme design and implementation is critical; failure to achieve an ownership feeling will most probably lead to failure of the programme.