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Photovoltaics and Development

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23.1 ELECTRICITY AND DEVELOPMENT

23.1.1 Energy and the Early Man

Survival has always been the main preoccupation of mankind. For many thousands of years, food, shelter and protection against harsh weather and wild animals were the primary requirements of early man. In the early days of humanity, people spent most of their time hunting and gathering, and hence, energy cycles in primitive societies were extremely simple: human energy was put into the pursuit of game and the manufacture of tools and weapons; wood collection to keep the fire burning for cooking while at the same time providing warmth and lighting was also an important activity. Food from the hunt was the basic fuel for human energy and the leftover animal grease also contributed to heat and light the shelter to maintain a suitable microclimate.

Over the years, early man incorporated new options to fulfill the basic requirements of survival, and at the same time altered the energy cycles of primitive society. Gardening was added to fishing and hunting as a source of food. Additional human energy had to be put into planting, weeding and harvesting. Products from gardening provided a more predictable source of food energy for humans and the basic feedstock for raising domestic animals, which in turn became the source of high quality protein and eventually an additional source of power. Gardening evolved into agriculture, which, along with animal husbandry, eventually displaced hunting as the main activity for survival. At some point in time, domesticated animals were incorporated to take away from humans the burden of load-pulling and back-carrying.

A time came when technology was developed to simplify everyday productive activities. Along with the dawn of progress came larger and larger requirements for

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energy. It is estimated that early man had a daily energy consumption rate of around 2500 kilocalories [1]. Later on, in primitive agricultural societies, which already had some domestic animals, this rate was around five times as large [2]. By the time of the low-technology industrial revolution in the mid-1800s, per capita daily consumption of energy reached 70 000 kilocalories in England, Germany and the United States [3]. During that period fuel wood and coal constituted the main sources of energy with smaller contributions from petroleum and hydropower. In the last quarter of the twentieth century, the dominant energy sources switched to petroleum, natural gas, nuclear energy and coal, while the average per capita consumption of energy in industrialized nations rose to over 230 000 kilocalories per day [3], two orders of magnitude larger than that of primitive man!

23.1.2 Let There be Electricity

With the early studies on electricity in the nineteenth century and the eventual development of the electric power industry, around 1882, the face of the Earth was changed forever. Electric lighting began flooding the cities at night and electric motors became the main source of power in factories. Earlier, in 1846, long distance communication had been made easier and faster with the introduction of the electric telegraph. Over the years, many inventions based on electricity increased the productivity in factories and made life at home easier and more comfortable.

Modern life became an endless chain of activities and events, fuelled by electricity: the alarm clock to wake people up in the morning, followed by the news on television or on the radio, the electric shaver and the hair dryer, the coffee brewer, the blender and the microwave oven or the electric stove, the refrigerator, the air conditioner, the computer, and so on and so forth. Electricity has also been the main element in improving the quality of basic services for the well being of people, such as clean water, education, medical care, entertainment and modern means of information and communication like the Internet.

23.1.3 One Third of Humanity Still in Darkness

Unfortunately, even today, not everybody has the fortune of enjoying all the benefits of progress: about one-third of humanity lacks access to electricity and, therefore, to a large number of electricity-based services and commodities. Around two billion people, mostly in the so-called developing countries, have remained in the earlier stages of human development, and still rely on wood fire, animal grease or kerosene lamps to light their paths and their homes at night. Modern means of communication and entertainment are either not known to them or are a distant possibility. Millions of people die every year from drinking polluted water, while others suffer from the lack of basic medical services. Illiteracy denies millions of people any possibility of gaining access to better opportunities. As hard as it may seem to believe, at the onset of the twenty-first century, with all the technology mankind has been able to create, survival is still the name of the game for millions and millions of people in remote rural areas of the world.

Reasons for such disparity are manifold, but certainly access to reliable, affordable and high-grade energy sources is one of them. The direct relationship between the per capita energy consumption and human development is well established, as can be observed in a number of studies [4, 5]. What is not too clear is what form of energy, how much of it and for what applications, is required to break the vicious circle of under-development. However, experience shows that a little electricity properly applied could help resolve many of these ailments of society.

23.1.4 The Centralized Electrical System

Electricity is certainly the most sophisticated and flexible form of energy in use today around the world. But it has some drawbacks: electricity has to be used almost immediately after it is generated, as storing it may be expensive, time-limited and inefficient, and in the current scheme of supply, it has to be transported over long distances from the point of generation to the point of use, which can be inefficient and unreliable, especially when these two points are too far apart from each other in places lacking support infrastructure.

In the early days of the electric power industry, electricity was generated right at the point of use. Around 1880, even street lights in places like Paris and London had their own individual generators [6]. Electricity was also then mostly generated using local and renewable sources of energy. Water wheels originally used in the factories to mechanically power process machinery, were later retrofitted into prime movers to turn electric generators, which in turn began powering electric motors in the late nineteenth century.

As the demand for electricity increased because of industrial and urban growth, and the distance between the point of generation and that of use became increasingly large, electric companies searched for new ways to deliver their services within good profit margins. Engineering research focused on alternatives to increase the power and hence the scale of the generating stations and the carrying capacity of transmission lines. Thus, the concept of economies of scale was introduced in the electric power industry, which for over one hundred years has influenced decision making for new investments in electric systems.

Since the generating units grew in size, electric companies oftentimes found themselves with excess generating capacity at the end of the construction of a new plant. The need to recover their investment in this excess capacity frequently motivated them strongly to look for new customers. Transmission and distribution lines were extended to reach the new customers, so an extensive grid was eventually created. Sometimes when demand was nonexistent, it was artificially created. For such purpose, donation of appliances was, at times, made by the electric company to the customer.

23.1.5 Rural Electrification

At some point in time, agricultural processes were identified as potential applications for electricity and, consequently, the lines began to be extended into the rural areas. Here, the density of potential clients and the intensity of electricity use was not as large as in the cities or the industrial centers; therefore investments in grid extensions became hard to recover, so new institutional and financing mechanisms were developed to support the operation. Official rural electrification programs were introduced in the most advanced nations, an initiative that eventually trickled down to the developing countries.

As rural electrification proved beneficial to developed societies, early policy planners felt that the same or similar benefits could be achieved in developing societies. Thus, a major effort was undertaken in the 1960s and early 1970s to extend the electrical lines into the rural areas of developing countries. However, by the end of the twentieth century only a few developing nations had reached an acceptable degree of electric grid coverage in rural areas. The rest could not advance much as a result of a number of problems faced by the electric utilities, including lack of capital to finance additions of capacity and grid extensions. Thus, the process of rural electrification through grid extensions in many developing nations stalled to the point that the problem of rural electrification again became a major political issue around the world.

23.1.6 The Rural Energy Scene

Life in many rural areas of the world is no different today than it was centuries ago. Even energy cycles resemble those of early man, although with the introduction of some modern elements. Firewood remains the main source of fuel in most rural communities, in spite of the alarming deforestation, dangers to health and the amount of work needed to collect it. In most places firewood is used mainly for cooking followed by shelter heating and lighting. A good reference point at hand is the case of Mexico, one of the most advanced economies in the developing world. Here, firewood consumption in 1997 represented around 2.7% of the total energy supply, a share that is larger than that of coal and nuclear electricity taken together and almost equal to that of hydroelectricity [7].

Candles and votive candles are more convenient than firewood for lighting, as they provide a more steady and whiter light, and can easily be carried from place to place, thus serving as a portable means for lighting pathways at night. Candles are frequently available in nearby towns, are not too heavy to carry in moderate quantities for long distances, and can be stored for long periods of time. Almost the same can be said for kerosene, which can be used in rudimentary lamps for lighting, although its availability may be more geographically restricted than that of candles. Getting either candles or kerosene requires money, which imposes an economic burden on poor rural families, while their use poses the risk of fire due to the flammable nature of the materials oftentimes used in the construction of rural houses.

23.2 BREAKING THE CHAINS OF UNDERDEVELOPMENT

23.2.1 Electricity Applications in the Rural Setting

The current patterns of energy use in rural areas show that the provision of small amounts of energy, especially electricity, changes the lifestyles of the rural population significantly. Energy applied to improve quality of life of the population may be a good first step to break the chains of underdevelopment. Applications such as lighting, clean water supply, entertainment and communications, preservation of vaccines and other medical supplies and means for modern education are usually welcome by governments, aid development agencies and the rural communities themselves. A number of tasks at home, mostly done by women, such as the provisioning of water, grain grinding, clothes sewing and others, could be made easier with the provision of small amounts of electricity.

Electricity for the household is at the top of the shopping list of rural communities. A house with electricity is a symbol of status. Beyond that, electrical lighting facilitates movement at night inside the house, helps prevent accidents, eliminates the need for kerosene and other combustible materials for illumination (thus avoiding the risk of fire and health-damaging fumes), helps spot poisonous insects and other wild animals that could be a threat to humans, and helps respond instantly to critical situations in case of accidents or illness. Furthermore, illumination of external areas such as the streets and meeting points also helps promote social interaction and a number of after-hours outdoor activities.

Electricity in the house also makes modern means of entertainment a more realistic possibility. The rural telephone system gives people the opportunity to keep in touch with their families in other parts of the world, and to call for help in case of an emergency. Electricity also gives the opportunity to use modern means of getting information and imparting training, using VCRs, satellite links, computers and even the Internet.

23.2.2 Basic Sources of Electricity

With the introduction of the transistor radio and the handheld flashlight dry cells became a favorite means to provide light and entertainment in rural areas. Dry cells can be purchased in many places and are easy to carry. Thus, many rural families spend substantial amounts of money buying them. Transistor radios play an important role in the life of remote communities, not only because they bring music and entertainment, but also because radio broadcasting in many places carry important messages such as warnings of floods, instructions on health practices and other valuable services, such as family to family message delivery. Some countries have even set up radio stations with regional broadcasting in the locally spoken native language or dialect, when it is different from the official national language.

New forms of entertainment, such as portable televisions, VCRs and tape players, have increased the demand for electricity in many rural communities. Because of this, dry cells prove to be expensive and hence many users in rural areas not connected to the grid have resorted to the car battery as the power source for their needs, including home lighting. Car batteries are widely available in rural areas of many developing countries. They are rechargeable, and because of their relatively larger power capacity, they can be applied to a wider variety of services; they last longer and may turn out to be cheaper per unit of service delivered than dry cells. Recharging car batteries, however, requires a primary source of electricity. Where motorcars or tractors are available, people use them to recharge batteries. Otherwise, they are carried over long distances to the nearest source of electricity for recharging. However, batteries are heavy and burdensome to carry, so transport to the point of recharging is sometimes done on the backs of animals and sometimes on the backs of humans. There have been cases of local entrepreneurs setting up micro businesses to offer battery-recharging service. For this, batteries are collected, taken to the point of recharging, recharged and then returned to the owner. This operation however, requires some infrastructure such as roads and means for transportation, not always available in rural areas.

As the economic power of families increases, so does the need for electricity. Dry cells and car batteries are no longer sufficient, so people in many places put political pressure on electricity authorities to extend the grid to their communities, or individually resort to the use of small gasoline-fuelled generator sets. Small generator sets have the advantage of supplying alternate current of the right voltage, so that conventional appliances can be used. But their service is usually restricted to a few hours a day, because of the increasing cost of operation and maintenance of the equipment.

Experience shows that even when grid electricity is available, people in rural areas normally use it to light a few bulbs and perhaps to power small radios or typically black and white TV sets. Most people in rural areas lack the money needed to buy larger electric appliances, such as refrigerators and washing machines, or are simply not acquainted with them. Hence, because the number and size of appliances now in use is small, rural electrification represents an important niche of opportunity for the application of photovoltaic technology.

23.3 THE PV ALTERNATIVE

Photovoltaic (PV) technology nowadays is considered one of the most appropriate options to electrify dispersed population in remote places [8]. From an engineering point of view, modularity is perhaps the single most attractive feature of this technology. It allows designers to tailor electricity-generating systems as small in capacity as a few watts, or as large as many megawatts to suit specific needs, just following basic rules of electrical engineering. This feature combined with the suitability of the technology for autonomous operation, producing electricity with locally available sunshine, plus other characteristics such as lightweight, low-maintenance requirements and long useful life, has led people to consider photovoltaics as an attractive option for rural electrification. Ever since the technology was applied to power space satellites in the mid 1950s, the concept of reliable electricity generation for remote applications was firmly established. Terrestrial applications were developed with the basic idea of powering loads in remote places, where the cost of extending the grid was just too high. Today, hundreds of thousands of PV systems have been installed around the world to substitute for candles and kerosene lamps, gasoline- or diesel-powered generating sets, or even for unreliable grid extensions. The types of applications of PV technology in remote areas range from telecommunications, lighthouses and alarm systems in certain industries, to domestic applications and delivery of basic services. Leisure applications, such as sailboats and mountain cottages now carry PV panels to provide the required amounts of electricity, instead of noisy and smoky combustion engines. Even the petroleum industry, which is nowadays the basis for the world's energy supply, is using photovoltaics to supply electricity in offshore rigs or to power remote valve stations in oil and gas ducts.

The advantages of PV technology for rural electrification were demonstrated through a number of early projects in the period between 1968 and 1977 in Niger, Mexico and India. Applications included PV powered educational television, telephones, medical dispensaries and boarding schools for native Indian children. This early work demonstrated not only the technical viability of the systems but also the benefits to the user [9–11]. Some of these installations are still operational and in good condition, although with the limitations of a 30-or-so-year-old technology. Unfortunately, a critical mass of early projects was never achieved as to make a noticeable impact on society, and the lessons derived from the few projects on record have mostly fallen into oblivion. Only the notion that the technology was too expensive and not too reliable, has prevailed over the years among many decision makers, in spite of the tremendous progress PV technology has made in recent years in terms of cost, efficiency and reliability.

Progress in materials technology, electronics and PV systems engineering, along with a drop in price of the main components of the PV system and a better understanding of the needs and expectations of the rural people, have resulted in a large variety of ideas, proposals and technological schemes to use photovoltaics as a source of electricity to promote human and economic development in rural areas of the developing world. A large number of applications have been identified for PV systems in rural areas, some more mature than others in technical terms, but all facing similar problems to enter the rural market on a massive scale.

23.3.1 PV Systems for Rural Applications

PV systems for remote applications typically include three basic elements: one PV panel that converts solar radiation into electricity, a means to store the electricity produced by the PV panel, which is normally an electrochemical battery, and an electronic device that helps control the flows of electricity within the system, thus protecting the battery by properly dispatching available energy. A variety of devices capable of using electricity to provide comfort, entertainment and other services for the benefit of the user are then attached to the PV system by means of the electronic charge controller (ECC). Figure 23.1 shows a schematic diagram of a general PV system. Depending on the application, some elements of the PV system may not be necessary, as is the case of the battery in water pumping systems.

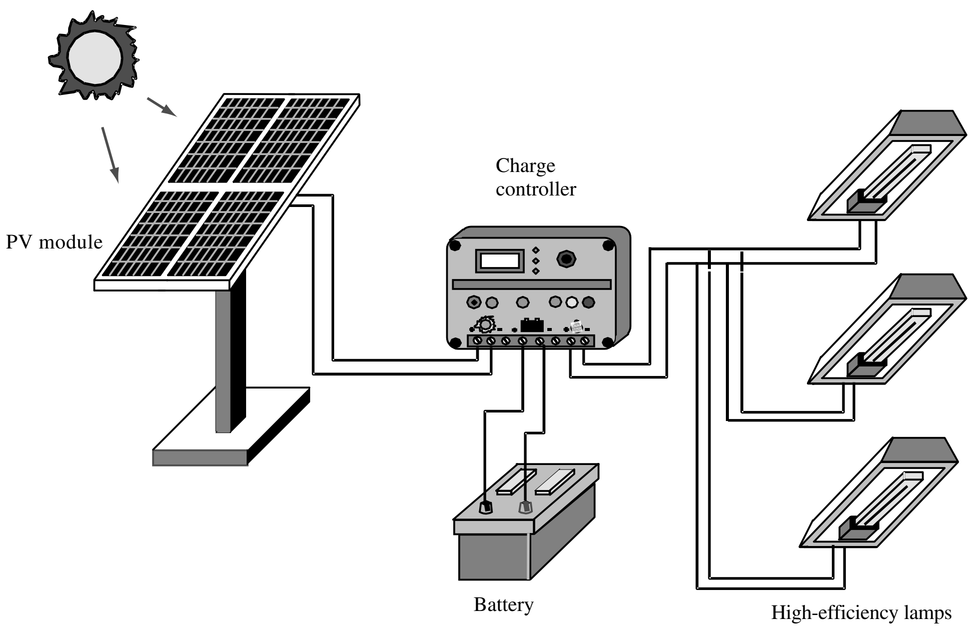

Figure 23.1 Schematic diagram of a general PV system

PV systems can be designed and built in the stand-alone mode, in which photovoltaics is the only source of electricity, or as hybrids, in which photovoltaics is combined with other sources of electricity, such as wind generators, small hydropower stations or combustion generators. PV hybrids are normally built to take advantage of other locally available renewable energy resources while at the same time improving the economics of the application. Photovoltaics can be installed in the so-called "disperse" mode, in which each individual application carries a full PV system as its source of electricity (just as it used to be in the very early stages of the electrification process in the late 1800s). Larger PV systems can be built to feed isolated electric minigrids, as is done today with diesel gen-sets in many parts of the world. Since PV panels produce relatively low-voltage direct-current electricity, a minigrid system requires additional components, such as DC/AC inverters and step-up transformers, to yield the right characteristics of the electricity on the user's side of the grid. Hybrid systems are also more complex to integrate, since different types of electricity can be produced by the different generating units that are included in the system. Figure 23.2 shows a number of possible configurations of PV systems, for most of which practical examples can be shown.

Solar home systems (SHS) are perhaps the most popular of all the PV applications. An estimated 500 000 to 1 000 000 such systems have been installed in rural communities around the world [12]. Systems for basic lighting generally include one small, 10 to 40 W PV module and a small battery, enough for one to four points of light (normally compact fluorescent lamps). Larger, 50 to 100 W PV panels and batteries of around 100 Ah open the possibility of feeding other electric appliances, such as transistor radios, tape recorders and small TV sets. Even larger PV systems can support complete sets of domestic electric appliances, just as in any urban house, but the price of such systems is at present prohibitively expensive for a poor family. The smallest SHS are direct substitutes for dry cells and other ancient means of lighting a house, and a form of using electrochemical batteries without the need of sending them elsewhere for recharging.

Quality and efficacy of communal services can substantially be increased when relatively small amounts of electricity are available on site. This can be done by photovoltaics. Schools can be supplied with modern audiovisual means, educational television, and even the Internet, as shown by the project *aldea solar* in Honduras, supported by UNESCO, the Honduras Ministry of Education and the Council for Science and technology (COHCYT) of Honduras. In Mexico, over 13 000 PV powered telephones now link tens of thousands of people in remote communities with the rest of the world, through terrestrial PV powered transmitting stations and satellite links [13]. In Cuba, the Ministry of Health has implemented a system of rural clinics powered by photovoltaics, which has been operational for a number of years [14]. PV powered technologies to disinfect water have already been tested and field-demonstrated in countries of Africa and Latin America in a recent project financed by the European Commission [15]. A large number of PV water-pumping projects have been implemented around the world, and many examples of other PV powered communal services and applications can also be found (see for instance: [16–20]).

A large number of possibilities to apply photovoltaics for productive activities in rural areas of the developing countries can also be envisioned. Small irrigation, cattle watering, grain grinding, small handicrafts shops and other similar activities that require

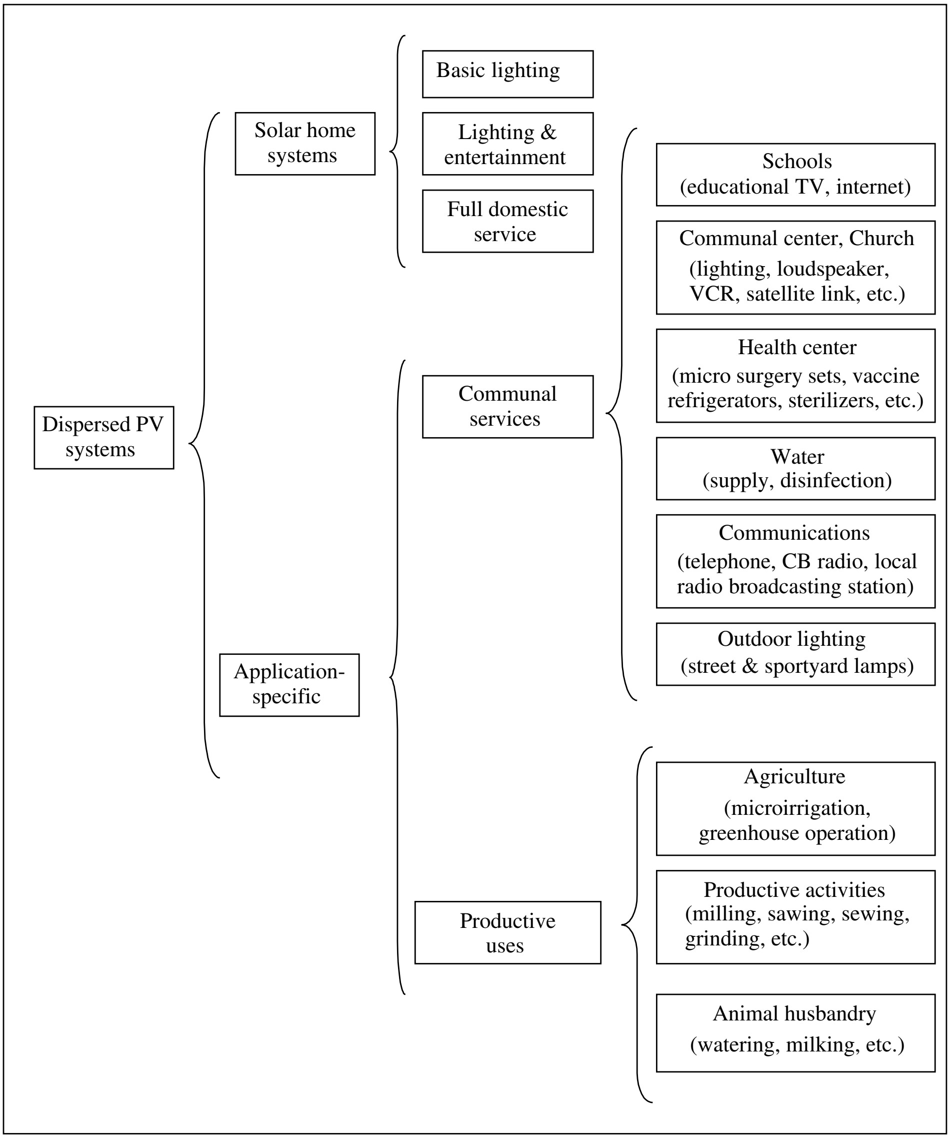

Figure 23.2 Possible configurations of PV systems

relatively small amounts of electricity can now be powered by photovoltaics to increase productivity and foster economic development.

23.3.2 Barriers to PV Implementation

For most urban people around the world, electricity comes into their homes just like magic: it is there, instantly and reliably at the touch of the switch. Few individuals make a conscious connection between their appliances and the electrical pole in the street, so paying their monthly bills is perhaps the closest they get to the electricity business. But even fewer people realize the technical and administrative complexities behind the process of generation, transmission and distribution of electricity that allows factories to run and people to enjoy the benefits of modern services.

Understanding the physical principles that turn primary energy into electricity belongs to a small group of technical elite in the universities, research centers and electric companies. For the layman, it makes little difference whether primary energy is hydropower, nuclear power, fossil fuels or solar energy. Thus, the fact that electricity can be locally produced using the sunrays as the primary source of energy, with no wires connecting to remote and unknown places and facilities, would be of significance only to the most knowledgeable people. It is interesting to know that PV users in native communities in many parts of the world make a cosmogonist connection between electricity and their ancient god, the Sun. Thus, for most of these people PV technology is an appealing means to get a long-awaited service.

However, after learning about photovoltaics people are inclined to ask why is it that with so many virtues and so many advocates, PV technology has only reached one-tenth of a percent of the world's rural population with no access to the grid? The answer is found in the number of barriers a new technology such as this has to overcome to fully enter the market. In the case of photovoltaics, some such barriers are well known, others still unknown; some technical in nature and others having to do with institutional, social and financing issues. Just as conventional electricity is generated, in large and distant facilities, transmitted and then distributed to reach the individual consumer, so is PV technology produced in a small number of facilities in Europe, Japan and the United States, transported across the continents and distributed to reach the final user in very remote rural areas. And at each step a number of operations need to take place, which involve different degrees of complexity and cost. Therefore, bringing the PV solution to those sites where the grid has not been able to reach can be a very difficult task, unless such barriers are successfully removed.

23.3.3 Technical Barriers

PV systems are claimed to be reliable and long lasting. This is true and proven insofar as the PV module is concerned, but not every component of the system's balance has the same degree of technological maturity. In both, stand-alone and hybrid systems, batteries are perhaps the weakest links. Batteries are exposed to overcharging and over-discharging, which usually reduce their useful lifetime. Batteries also demand a fair amount of attention and regular maintenance, albeit relatively simple. However, even the simplest technical tasks may prove to be complicated in rural areas where a high degree of illiteracy and a lack of familiarity with modern technology, and with electricity in particular, is more the rule than the exception. The problem with batteries arises in part because of the fact that the lead-acid technology now in use, available for over one hundred years, was not specifically designed for use in PV systems. Adaptations of the current technology into what is now called *solar batteries*, and development of new battery types, such as nickel-metal hydride [21], promise to ease many of the current problems.

SHS also face other problems, mostly in the charge controllers and the lamps, basically as a result of an industry that has until now had an uneven degree of development (for a detailed discussion on charge controllers, see [22]). Two schools of thought seem to underline the issue: simple, sturdy, low-tech, low-purchase-cost devices against high-tech, sometimes a bit complex and perhaps lower life cycle–cost devices. The issue is not easy to resolve, especially with so little systematic information coming from the field on the performance of such devices. Taking into consideration that rural areas in developing countries are far from being mature markets for photovoltaics (and for many other goods) and accounting for the illiteracy of the rural population, consumer choice will hardly be a useful parameter to resolve the issue, especially if one considers that a large number of PV rural electrification projects are still being carried out in the "technology push" mode.

The suitability of photovoltaics as a solution to the rural electrification problem is being taken for granted by many advocates of the technology. Unfortunately, few studies seem to have been carried out to assess the performance of SHS now in the field, in a systematic and comprehensive manner. At this stage of technology implementation, information from the field is vital as a feedback mechanism to gauge the efficacy of the PV solution, to improve the chances of overall success and to assure long-term sustainability. Field surveys, however, tend to be expensive, especially where the most remote and isolated communities are concerned, and availability of funds for monitoring and evaluating SHS projects in the field is not obvious.

A 35-man-month field study was recently completed in Mexico, in which 1740 SHS installations (out of around 60 000 installed with government financing) in most regions and communities included in government programmes were evaluated. The study had a three-fold purpose: to assess the physical and operative condition of the systems, to probe the degree of satisfaction of the users and to evaluate the efficacy of measures previously implemented to make the projects sustainable. Preliminary analysis of the information gathered in the study shows that from the technical point of view things look good with most SHS samples performing well (for more details on these results, see [23]). But there are reasons to believe that as systems age, the results may change, unless corrective measures are taken.

Introducing photovoltaics in rural areas of developing countries is an innovative exercise in society, with the particularity that a space-age technology is being adapted for operation in a sector of society living, in many cases, at least five hundred years in the past. From this perspective, it is hard (and even dangerous for project sustainability) to ignore the strong connection that must be established between the technology (hardware) and the user. For even the most sophisticated, well-designed and perfectly built piece of PV technology is bound to fail sooner than later, if the ground for seeding it is not properly prepared. This means information, training and local capacity building on the user side, as well as user involvement at every step of the process to make them aware of the important role they play in the solution of their own problems. Similar considerations can be made in connection with the environment (social and physical) in which the PV system is bound to be installed. For instance, anecdotic and written information from the field points to the fact that some PV components designed and built with technical criteria prevailing in advanced, cold countries are not performing well in the tropics where it is most needed. Reasons for this are many, but their discussion is outside the scope of this chapter.

Alternative technical schemes to the SHS as a means to provide basic electricity services in rural areas are being tested. Battery-charging stations, where a large central PV array is installed to recharge batteries brought in by the user, who pays a fee for the service, is one such scheme advocated by a number of people. The rationale behind this scheme is that peasants in many parts of the world already use battery-charging points distant from their homes. It is also argued that microbusinesses could develop in remote areas to enhance the chances of sustainability of the electrification process and so, several projects of this kind are underway in various countries. However, recent field studies reveal [24] that this alternative also has several shortcomings, which are forcing project officials and users to switch to SHS as a substitute to the previously used PV battery-charging stations.

The preceding discussion was meant to point out the fact that even though engineers and industries will most likely solve the remaining technical problems facing PV technology for rural applications before this market enters into its mature stage, a number of more complex issues at the technology-user interface remain to be understood and dealt with. The cause–effect diagram of Figure 23.3 is an attempt to show the variety of factors leading to a failed system, and consequently a dissatisfied user. In the long run, the degree of user satisfaction will determine the level of acceptance of PV technology as the solution to the problem of rural electrification.

Technical standards, design guidelines and other elements for quality assurance of PV systems are also important for the sustainability of PV rural electrification projects. A number of these elements are being developed in institutions, professional societies and international organizations around the world. Most of them, however, focus mainly on pure technical (hardware) issues, as is the case of the recommended specifications of the organization Global Approval Program for Photovoltaics (PV GAP) and the standards

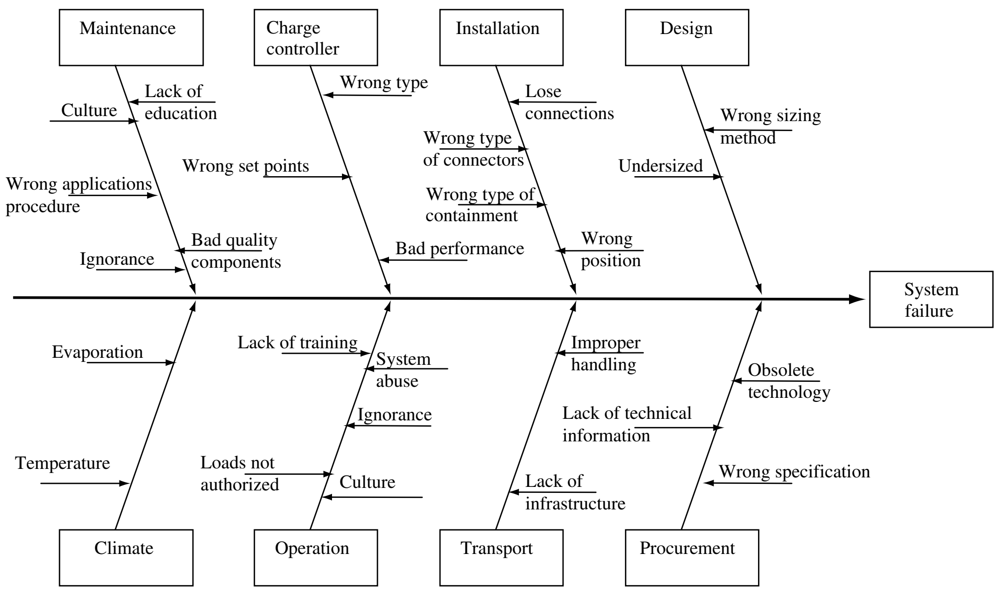

Figure 23.3 Cause–effect diagram showing a variety of factors leading to a failed system

issued by the International Electrochemical Commission (IEC) Technical Committee 82, and little attention is being given to the soft and organizational aspects of the problem dealt with in other works [25, 26].

23.3.4 Nontechnical Issues

23.3.4.1 Initial cost

It is common knowledge that for a commercial operation to be sustainable in the modern economy, a flow of goods has to be properly matched by a counter flow of money. Sunrays striking on the roofs of houses are free, but equipments to turn solar energy into electricity, and to transform this electricity into needed services, are not. PV manufacturing companies invest in factories and raw materials, pay wages to their workers and taxes to their governments and are obliged to deliver revenues to their shareholders. All expenses plus profits essentially set the base price of their products. In a second step, PV components from different companies are transported to specific points for systems integration. In turn, packaged systems are fed into the distribution channels for retailing and final installation where the end user wants them.

By the time a PV system is installed on the user's premises, its base price has increased a number of times. So, people need money to get their systems installed. Considering the low capacity of the peasants in rural areas to pay for goods, a set of important questions emerge when one considers photovoltaics as the solution to the rural electrification problem. Are people willing to pay for the system? How much can they afford to pay? What mechanisms can be instrumented to make systems more affordable? If people cannot pay, should they remain in darkness or should somebody come to their rescue? What roles can governments and development agencies play? And even when people can pay, should they bear the full system cost, even at this early stage of technology introduction when many companies are still building their infrastructure and learning how to manufacture, integrate and market the systems, so that their transactions costs are a lot higher than they should be? These are not trivial questions considering that, for the miracle of full-scale rural electrification to happen, around 300 000 million US$ must, in principle, flow from the poorest regions of the world to the modern sector of society so that PV systems can flow in the opposite direction.

23.3.4.2 Breaking the initial cost barrier

Consequently, since solar energy, the fuel used by PV systems is free and systems are, at least theoretically, low maintenance and long lasting, system cost is commonly seen as the main stumbling block for the introduction of photovoltaics. A number of schemes have been tried over the past decade in search of an effective way to remove this barrier. Most of them can be grouped into three categories: the *social route*, in which poverty alleviation programs and other socially driven mechanisms are used by governments and bilateral aid organizations to make funds available for the purchase of PV systems in favor of the least privileged people; the *fiscal route*, in which taxes, import duties and other fiscal levies are removed to lower the local price of the PV system, thus making it somewhat more affordable for the final user, while at the same time facilitating the creation of a local market; and the *business route*, in which banks, private companies and entrepreneurs are devising and testing a number of schemes to make financing available for the purchase of the PV system, thus helping to create a market for photovoltaics at the same time. One way or another, currently each of these routes somehow benefit from the intervention of governments, multilateral organizations and lending institutions. On the other hand, boundaries between these routes are not necessarily clear-cut, so that combined or coexisting schemes are not uncommon.

Not everyone in rural areas is necessarily poor or totally dispossessed. Some people live in remote places for convenience, either because their source of income is attached to the natural resources locally available, or because they prefer living in a cleaner and quieter environment than in the city. They do not have electricity from the grid, simply because they are too far away, but they usually rely on gasoline or diesel-fuelled gen-sets for their electrical service. These people, however, could easily purchase a PV system without any financial assistance, if one was made available to them. This is already a good market that is being tapped in a number of countries, such as Spain, Colombia, Mexico and others. On the other hand, some estimates indicate that between 25 and 50% of people living in remote places could purchase a SHS provided some sort of financial assistance was available to them [27]. This is a substantial market in its early stages of development; to tap this market a number of schemes are being tried by private entrepreneurs and multilateral development organizations, as is the case in Kenya, Zimbabwe and the Dominican Republic. However, the poorest of the poor, representing the largest portion of the world's rural population, can hardly ever afford to buy their own PV systems.

23.3.4.2.1 The business route

For those in need of financial assistance, two alternative models are being tested. One focuses on the sale of the PV system (the sales model), the other on the sale of the electricity produced by the system (the service model). Both models have advantages and shortcomings and both involve flows of money beyond the control of the PV user.

In the sales model, the PV system is purchased on credit by the user, who becomes the owner and takes over the responsibility of system maintenance and replacement of parts. Money for the transaction is usually borrowed by the user from a set of different sources, which may include the system supplier, a finance institution, or any other type of credit organization such as a revolving fund or a local microfinance operation. In any case, money is obtained at a cost, which adds to the cost of the PV system, and is paid back in periodic installments under prearranged terms and conditions. However, this additional cost is what entitles the user to the benefits of electricity, albeit in small quantities. This model is preferred by those who like the social status of system ownership and are willing to assume the task of maintaining the equipment and the responsibility for replacing damaged or worn out parts.

People not willing to take any risks, may opt for the service model, in which the supplier retains ownership of the PV system, or of some parts thereof, and then charges some monthly fee for the electricity delivered to the user. The supplier maintains the system and becomes responsible for providing the user with electricity, according to system capacity. Following the current practice, this kind of service can be provided through a regulated concession, an unregulated open market provider or a community-based provider.

Needless to say, the risk assumed by the service supplier also has a cost, which reflects on the monthly fee charged. According to some estimates, the added monthly fee for service over a period of 10 years could double the life cycle–costs of the same PV system when purchased on credit [27]. Current PV projects in the fee-for-service model show a large dispersion in the amount of the monthly fee charged to individual users. A number of factors may be responsible for this. For instance, some projects may involve some sort of subsidy, and in other cases, service suppliers may not follow the same rules to define the scope of their responsibility: some may retain responsibility over the PV module and charge controller only (the least troublesome parts of a SHS), while dumping on the user the responsibility of replacing the battery (the weakest link in the system) and the lamps.

Selecting a particular route for a given project is not a matter of personal preference only. The landscape is very important and has to be taken into account, since a number of its elements influence this choice, including local social and energy policies officially established in each country. For instance, some countries do not allow private sale of electricity, so that the fee-for-service model could not be applied, unless prevailing laws and regulations are changed as necessary. Low rural population density, difficult access to the communities, long distances from the supply centers and complex logistics to deliver goods and collect fees, can make both fee-for-service and financed sales schemes difficult to implement and geographically limited. In many cases, monthly fee/payment collection may be an expensive task, due to the time and effort it may take for the supplier or the service men to reach the customer. This fact has already been noted by PV companies operating in Sri Lanka, for instance [27]. Timing is another important factor, considering that people may not be home when the fee collector arrives, and that many peasants have money only during the postharvest period. Such difficulties have led some utilities, for many years, to give up on monthly fee collection from remote clients connected to their grids, basically because of very small bills and comparatively larger billing expenditures. Thus, unless fee collection schemes better adapted to the local conditions can be found, one can theorise that the fee-for-service and purchase models will be applicable basically to the most accessible and higher density rural communities. The fraction of the rural population meeting these criteria in many countries seems to be inversely proportional to the degree of rural electrification by grid extensions.

Local culture and idiosyncrasy are two additional elements to be considered for the choice of a delivery model. The notion of common property embedded in many native communities or the lack of familiarity with commercial practices, or even with money, could lead to unsustainable operations in many rural areas. Some academicians studying the process of introduction of PV systems in rural communities, argue that freedom from any financial burden is one of the most cherished values for rural people, and hence could be an important barrier for them to take on any financial obligations. Hence, government intervention may be indispensable at some point to deliver the PV solution in which the business route cannot be applied.

Over the past ten years delivery models in the business route have been tested through a number of projects financed by the GEF and the World Bank in various countries. A recent review [12] of the GEF solar PV portfolio suggests the following emerging lessons, warning that it is still too early to draw definite conclusions:

- Viable business models must be demonstrated to sustain market development for solar photovoltaics.
- Delivery/business model development, evolution and testing require time and flexibility.
- Institutional arrangements for project implementation can greatly influence the value of the project in terms of demonstrating viable business models and thus achieving sustainability.
- Projects must explicitly recognize and account for the high transaction costs associated with marketing, service and credit collections in rural areas.
- Consumer credit can be effectively provided by microfinance organizations with close ties to the local communities if such organizations already have a strong history and cultural niche in a specific country.
- Projects have not produced adequate experience on the viability of dealer-supplied credit under a sales model, and no project in the portfolio appears set to provide such experience.
- Rural electrification policies and planning have a major influence on project outcome and sustainability, and must be addressed explicitly in project design and implementation.
- Establishing reasonable equipment standards and certification procedures for solar home system components that ensure quality service while maintaining affordability is not difficult, and few technical problems have been encountered with systems.
- Substantial implementation experience is still needed before the success of the service approach can be judged.
- Postproject sustainability of market gains achieved during projects has not yet been demonstrated in any GEF project: it is too early in the evolution of the portfolio.

23.3.4.2.2 The social route

Governments can act in several capacities along the social route. Financing the purchase of SHS for poor people is perhaps the most critical one, although consumer protection and market regulation are also of importance. Government financing of SHS is seen by some as an unnecessary nuisance that distorts the market and creates dependence in the user's minds (users will not buy once the government has provided systems for free, goes the argument). Most critics of government intervention seem to forget that rural electrification has been historically subsidized by governments not only in developing countries but also in some of the most advanced nations. In that sense, there is no reason to think that PV rural electrification has to be different altogether, as it is only the technology base that is changing; the rest of the landscape remains the same.

Direct government financing of photovoltaics for rural electrification is not necessarily a bad thing. Up to now, the largest volume of SHS installed around the world has been realized through government or donor-led programs. Government intervention may help aggregate markets, reduce transaction costs and, if properly done, can create a better setting for quality assurance and local industry development. At least, this has been the experience with government-financed PV projects in Mexico, where proper institutional mechanisms were implemented for this purpose, and as a result, a local industry has also emerged around government-financed projects, which now produces locally and exports balance of system components [13, 28–30]. In this case, money provided by the government is seen as an instrument to promote local development. Over 2500 rural communities have been electrified in Mexico with photovoltaics following this model, and it is interesting to note that in many of them people have instrumented a variety of cost-recovery and money-making mechanisms, which allows for system maintenance and additional communal projects.

A number of governments from developing countries are considering the social route to deliver PV-based electricity to rural areas. Policy setting and definition of financing mechanisms are usually the first steps in this direction. Examples can be found in several Latin American countries [31]. Some examples are discussed below.

In Bolivia, Article 61 of the Electrical Law establishes that the State is responsible for the electrification process in smaller localities and in rural areas that cannot be served by private interests. Resources to finance such projects must be provided by the State, through the National Development Fund. The Executive must also propose energy policies and strategies to foster the use of alternative energy sources.

A similar mandate can be observed in Colombia, where Law 143 urges the State to provide basic electrical services to lower-income families in rural areas and to make funds available to cover necessary subsidies in this respect. The Energy and Gas Regulatory Commission is obliged to protect the rights of the lowest-income people, while the Colombian Institute for Electrical Energy has been mandated to prepare the National Energy Plan for regions not served by the grid, including the use of alternative energy systems in substitution of fossil fuelled generating systems.

In Ecuador, the Law of Regime for the Electrical Sector, addresses rural electrification and financing issues for the rural sector. It also assigns priorities for the application of renewable energy in rural electrification projects and describes the structure for project identification, approval, execution and operation. The National Fund for Rural and Urban Marginal Electrification (FERUM) is the body responsible for the administration of financial resources, and is directly regulated by the office of the president.

Similarly, in Nicaragua, the Law for the Electrical Industry holds the State responsible for developing rural electrification in remote areas in lieu of interest from other economic agents. For this, the State must provide the necessary resources through the Fund for Development of the National Electrical Industry. The State is also required by the law to implement policies and strategies for the use of alternative energy sources for electricity generation.

As a last example, in Panama, Article 9 of Executive Decree 22 makes the State responsible for promoting rural electrification and for assigning an annual budget to carry out this task. Consequently, the Office for Rural Electrification was created within the office of the president, and is in charge of promoting the use of renewable energy for rural electrification projects.

23.3.5 Trained Human Resources

Adequate financing and institutional frameworks are necessary but not sufficient conditions to remove the main barriers for PV rural electrification. Properly trained human resources to develop and operate programs, and to carry out projects, are equally important. PV systems and their implementation in rural areas are frequently looked upon in a very simplistic manner by a number of people. However, disregard for the complexities behind the process has resulted in a large number of failures. One would be surprised to learn how many PV projects in rural areas around the world have not lasted but a few years beyond the inauguration date; or how many others are still not complete because a variety of logistic aspects were not given due consideration at project inception; or even how many others are under-performing as a result of faulty engineering and construction practices. Unfortunately, little reliable information from the field is available in this respect as many projects are in their first years of operation so it would be too early to draw any definite conclusions about them.

PV systems packaging is increasingly being carried out by local companies in the developing countries. This practice has its merits, since it promotes the use of local labor and materials, which benefits the local economy. However, workers are not always properly trained to carry out their duties, so that construction and installation guidelines, no matter how precise and elaborate, are not always followed. Sometimes instruction materials are not in the local language, or are translated incorrectly, and at other times they do not properly match the idiosyncratic framework of the local worker. The benefits of training local workers for industry support cannot be overstressed. An example of how far this training could go can be found in the project carried out by the Spanish Cooperation in Bolivia, where native Aymara Indians were successfully trained to assemble electronic charge controllers for SHS. This project is described in greater detail below [32].

Local distributors and vendors of PV systems frequently lack a proper understanding of the products they sell. This leads more often than not to undersized systems, to make the sale easier, or to overselling the attributes of the PV systems to be sold, creating customer expectations beyond the actual capabilities of the system. In any case, the result is customer dissatisfaction. Thus, for the PV business to grow on solid bases, the front-lines that deal with end users must be properly trained in technical, marketing, selling and business practices. This is easier said than done, as many PV businesses in developing countries are small commercial ventures embedded in other lines of activity, such as hardware stores or cattle feed stores.

Photovoltaics being a novel technology for most people, developing and implementing programs for its massive deployment is not necessarily an easy task for program managers. Assistance is oftentimes required for program formulation, and to establish the proper mechanisms for project financing, implementation and monitoring. Multilateral agencies such as the World Bank, the GEF, UNDP and others, organize workshops and seminars around the globe to disseminate best practices that could help solve this problem. Over the past six years, the Network for Rural Electrification with Renewable Energy (RIER) of the Ibero American Program of Science and Technology for Development (CYTED) has been running courses and workshops on strategies for PV rural electrification throughout Latin America. Attendees usually include officials from government agencies in charge of rural electrification, electric utilities, local financing organizations, PV distributors and salespeople, and university professors. Benefits from such training activities often translate into better-formulated programs and projects, and a more appropriate understanding of the critical elements to make PV rural electrification projects sustainable.

23.4 FOUR EXAMPLES OF PV RURAL ELECTRIFICATION

It is estimated that by the end of the twentieth century, anywhere between 500 000 and one million small PV systems have been installed to power rural homes in developing countries [12]. On top of that, tens of thousands of PV-powered water lifting pumps and other communal services, such as health centers, schools, telephones, street lamps, have been deployed through government programs, donor-led initiatives and entrepreneurial activities. Many such programs have been subject to in-depth reviews as a means to better understand the process that is taking place in the field and to harvest the lessons learned that can be applied to other projects and programs. For details, the reader is encouraged to consult available reports (see for instance, [33–36]). In this section, a few examples of PV rural electrification projects and programs are described.

23.4.1 Argentina

As part of the reform of the electrical sector in Argentina, the provincial electricity markets were divided into centralized and disperse sectors. Each sector has its own structure, its own mission and its own operational form. Then, the program to supply electricity to the rural and disperse population of Argentina (PAEPRA for its name in Spanish) was established by the government in 1994. This program has the goal of providing electricity to 1.4 million people not yet served by the grid, and to electrify around 6000 public services, all this in areas where the low-population density and the long distance to the electric grid makes it too costly to supply electricity by conventional means [37]. PAEPRA operates at the provincial level through concessions to private companies bound by contract to provide electricity services under the supervision and control of the provincial electricity regulatory body [38]. Provincial concessions are awarded through a public bidding process, in which the winning company is the one that requests the least amount of subsidy money on a per customer basis to operate. This subsidy complements the funds collected from the user under a fee-for-service scheme. Participating companies are required to have experience and technical capabilities (1) to operate and maintain electrical systems and other services, such as water supply and telecommunications in a dispersed rural market; (2) to manage electrical systems based on diesel gen-sets, photovoltaics, wind and microhydro turbines; and (3) to manufacture and supply spare parts and components for this type of system. Furthermore, selected companies must be financially healthy.

The PAEPRA program was conceived to operate supported by a loan from the World Bank, but has not moved forward as fast as originally expected for a number of reasons beyond the scope of this work. Since 1986, the Republic of Argentina has a national PV industry with a capacity to produce balance of system components and about 1 MWp per year of PV modules. The current market is based on rural applications for domestic and communal services, water pumping and telecommunications. The presence of this industry is a good element to support the program.

23.4.2 Bolivia

In Bolivia, the National Rural Electrification Program (PRONER) was established to promote and support economic development in rural areas in order to improve the living conditions and the quality of life of the population. The original objective of the program was to provide electrical services to 100 000 households in a time span of five years by means of renewable energy. The process to carry out this task is based on sustainability, by creating an appropriate institutional, financial and technological framework. This program has been under implementation since 1997, supported by an UNDP-GEF grant. The first phase of the program has the goal of installing 3200 SHS through 22 projects in five municipalities and is aimed at removing financial, institutional, technical and human resource barriers to the massive application of photovoltaics.

Bolivia has been a favorite place for international cooperation in the field of PV rural electrification. In 1988, the Spanish Agency for International Cooperation and the Solar Energy Institute of the Polytechnic University of Madrid launched a PV electrification project to bring electricity to the Aymara community in the high Bolivian plateau. Beyond the traditional objectives of a project of this kind, this particular project attempted to foster the development of a users' organization with capabilities to manage and maintain PV installations, and to be responsible for the proper continuation of the project. At the same time, emphasis was put on the creation of an industrial unit in one of the rural communities to manufacture balance of system components using local manpower and Bolivian components as a basis for future projects [39]. By 1993, a total of 1000 SHS had already been installed and the Association for Solar Electrification (AES) had been created. AES included all PV users and was the owner of all the PV installations. An accounting system was established and a team of installers and maintenance crews was trained. This project has been studied thoroughly and important lessons derived thereof [32]. By the end of its fifth year of operation, a demand for about 30 000 SHS had been created, well beyond the financial capabilities of the project. Unfortunately, several problems in the area of financial management developed within the AES once the main implementing agents pulled out from the country and the project stalled.

In another action, the US-based National Rural Electric Cooperatives Association (NRECA, now an incorporated company) launched several pilot PV projects in Bolivia to test different financial schemes. In cooperation with the local organization Rural Electricity Cooperative (CRE), 90 SHS were installed as a preamble to a further 1300 installations. CRE provided complementary financing for the purchase of the PV systems and managed other aspects of project implementation, including the selection of the users and providing technical training [40]. In cooperation with the Cochabamba Electric Company, a privately owned electricity distribution company, NRECA implemented another project to install 300 SHS in remote rural communities. ELFEC finances the purchase of the equipment and provides installation and maintenance services.

The project INTI K'ANCHAY (light from the sun) has been implemented by the local NGO Energética with financial support from the Netherlands. Five hundred SHS were to be installed in the first phase, to test a financing mechanism that eventually could be extended to cover a larger portion of the 150 000 families without electricity in the province of Carrasco [41]. Companies participating in the process are required, among other things, to supply and install the SHS according to technical norms and specifications issued by Energética, to provide guarantees according to the useful life of the individual components and to build a network of representatives at the microregion level for after-sales service. By July 1999, a total of 200 SHS had already been installed, and applications for 350 more were being processed [42].

On the other hand, the German foreign-aid agency GTZ has promoted and supported several PV projects in Bolivia and has carried out an important promotional campaign in favor of renewable energy through the bilateral program for the diffusion of renewable energy (PROPER). Among other things, PROPER carried out activities to increase the number and capabilities of in-country personnel trained in the field of renewable energy at the professional and technical levels, including microenterprise building [43].

23.4.3 Brazil

PV rural electrification projects in Brazil started around 1992/93 with pilot cooperative projects with Germany and the United States [44]. Around 1500 SHS were installed as part of these projects in Northeast Brazil in cooperation with the local electricity distribution companies, who were responsible for systems installation, maintenance and performance monitoring. In 1994, the Brazilian Government launched an initiative to promote the use of renewable energy and the corresponding *action plan* was established in 1995, with the original goal of installing 50 MWp of PV systems by the year 2005 [45]. The program for energy development in the municipalities and the states (PRODEEM) was also launched in 1994 to deliver electricity by means of renewable energy to rural communities not served by the grid [46]. At the same time, several state governments, including Minas Gerais, Sao Paulo and Parana, launched their own PV rural electrification projects.

The PRODEEM program is coordinated by the National Department for Energy Development of the Ministry of Energy and Mines and is technically supported by the National Center for Electrical Research (CEPEL). Since 1995, three program phases have been implemented [47], with a total number of PV installations close to 2400, basically for water pumping, public lighting and other installations such as communal buildings, schools, health centers and churches. A fourth phase has been under consideration for installing about 1300 additional PV systems [48]. The process for the implementation of PRODEEM is well established and documented in the literature cited here.

The Electric Company of Minas Gerais has been actively involved in deploying PV systems, in spite of owning one of the most extensive electrical grids in Latin America, with a total length of 300 000 km. In 1989, CEMIG launched an experimental project to install PV systems for productive and domestic applications in remote places. Between 1995 and 1997, a demonstration phase of the Program of Assistance for the Rural Development of Brazil took place in cooperation with the US Department of Energy and the US National Renewable Energy Laboratory. PV systems for 70 schools and several pumping systems were installed as part of this program [49]. Plans were made to electrify 2000 regional educational centers and to install about 500 water supply systems, all powered by photovoltaics. By 1987, such pumping systems, with PV capacities between 1 and 2 kW each had already been installed [50]. General criteria for eligibility in the CEMIG program include localities farther than 5 km from the nearest electricity grid and a user density of less than 5 people per kilometer. CEMIG provides financing for 64% of the project cost, the remaining 36% being covered by the community authorities. CEMIG has also established a training center for technicians, who provide regular maintenance of the systems. Monthly salary of the technicians is covered by the municipal authorities of the region they serve [49]. A PV "pre-electrification" program was established by CEMIG in 1998 to stimulate the growth of the electrical demand in remote places, to the point where grid extensions could become economically viable. Some 500 PV systems were installed for this purpose in 1999 and another 5000 were under consideration for the following years. The rationale of this pre-electrification program is to use photovoltaics as a basis to aggregate electrical demand in rural areas. Once the critical mass has been reached, the grid would be extended to the point of highest demand while the PV installation would be moved to another location for the same purpose.

23.4.4 Mexico

About 5% of the Mexican population (almost 5 million people) has no access to electricity from the grid. A highly dispersed rural population and a rough terrain make grid extensions technically difficult and economically unviable. Several attempts were made in the late 1970s to use photovoltaics to power basic electrical services, as mentioned earlier. In 1989, the Mexican Government launched the PRONASOL program for poverty alleviation, which soon became the platform for a large-scale PV rural electrification activity. Today, over 2500 rural communities have been fully supplied with SHS through government programs, which means there are over 60 000 SHS in the whole territory. It is estimated that another 30 000 SHS have been installed outside government programs on a purely commercial basis. In addition, thousands of other PV-powered rural services have been provided, including rural telephones, schools, health centers and communal buildings.

A distinctive characteristic of the Mexican PV rural electrification program has been the active participation of the national electric utility (CFE) as technical normative agency, a central element for quality assurance and sustainability [29]. Under contract to CFE, the Electrical Research Institute of Mexico developed, in the early 1990s, a set of technical standards and specifications for project implementation. Laboratory testing and field evaluation protocols were also developed and implemented. Government-financed projects are carried out by private companies under the technical supervision of CFE and administered by an implementing agency, usually a government office. Contracts to private companies are awarded through a bidding process within the framework of the law for public works. Companies are required not only to supply the physical equipment but also to install the PV systems and train the user in proper operation and basic maintenance. The winning company must also establish a network of contact points for after-sales services.

Finance to purchase the PV systems has been mostly provided by the Federal Government, with lesser contributions from the state and municipal governments. Communities are requested to contribute to the project according to their own economic capacity. In-kind contributions, such as carrying the PV equipment to the community from the nearest point where vehicles have access, is one of the most frequent services by the community in support of the project. Funds are provided by the government as part of the patrimony for the community and, hence, no *a priori* money repayment mechanisms are established. However, communities are free to implement any fund-raising activities that can help them maintain their systems and purchase additional equipment. A popular mechanism is the so-called communal fund, in which members of the community contribute money or man-hours or both to a common fund managed by the community representatives. The communal fund is then used to maintain the PV installations and/or to implement other projects for the benefit of the community, such as water works repair, building a new schoolroom and the like. A more detailed description of the Mexican PV rural electrification program can be found in the literature mentioned in References [28, 51, 52].

23.4.5 Sri Lanka

An estimated two million households lack access to grid electricity in this country. Recent studies indicate that at least 10% of these households could afford a SHS at current prices, based on a monthly household income of Rs. 5000 [53]. A market study commissioned by the National Development Bank of Sri Lanka in 1991 indicated that a market of 360 000 households could afford a PV system [54]. However, so far only about 15 000 such systems have been sold commercially for cash through a retail network.

Many reasons have been cited for this low penetration level. As in other places, the biggest barrier for the exploitation of this market has been a lack of consumer financing. Political promises for grid extensions in rural areas and the government sponsored "Electricity for all by the Year 2000" campaign, which was perceived as *grid electricity* for all, have also been major barriers. Lack of government-level endorsement for solar photovoltaics, along with other renewables, was a hindrance to both private sector and NGO promoters. Nevertheless, four companies retail PV systems in Sri Lanka: Shell Renewables, Resco Asia (subsidiary of the US Selco), Alpha Thermal Systems and Access International. Sarvodaya SEEDS, a local NGO, provides microfinancing in partnership with some of these companies.

In the late 1980s, solar PV modules, 12-V lamps and simple electronic charge controllers were assembled in Sri Lanka by Solar Power & Light Company (SPLC), a private venture established as Power & Sun in 1986. However, manufacturing of solar modules ceased as the advantage over imported products was eroded, in part because of the high import duties on raw materials. Thus, SPLC essentially developed into a marketing organization by creating an infrastructure to market, install and maintain PV systems in rural areas. SPLC uses retailers to stock solar home systems; trained technicians and individual agents, called *corresponding agents* (CA), are used to canvass sales, install systems and provide customer service. SPLC, which has just been bought over by Shell International Renewables, has sold over 3000 PV systems directly to consumers, mostly for cash.

Apart from cash sales of SHS, there are examples in Sri Lanka of both successful and "deemed as failed" projects, using loan repayments by the consumer as the measure of success. Projects implemented with total community involvement by NGOs, such as Sarvodaya and Solanka, have been quite successful. Sarvodaya's already successful microcredit operation was adapted to market SHS, and implemented a pilot project with 250 installations through its Rural Technical Services branch, with assistance from the US-based NGO Solar Electric Light Fund (SELF, now the private company Selco) and a seed fund from a US foundation. Further activities by Sarvodaya using funds from a credit line for renewable energy provided to Sri Lanka by the World Bank, led to the installation of 300 more systems. Plans to install 5000 more within the next five years are already drawn. Sarvodaya SEEDS has become a Participating Credit Institution of the Energy Services Delivery Project. It can now access the fund directly and on-lend to customers. In January 2001, it has been reported that Sarvodaya SEEDS' lending portfolio exposure is Rs. 89 million (about US $1 million) for solar photovoltaics.

Solanka Sun Associates, created community level capabilities to do complete projects, including evaluation of potential customers, providing financing; designing, installing and maintaining the solar home systems; collecting repayment and managing the project with the inherent difficulties of managing projects from cities. This model has shown that success can be achieved with proper training and incentives to the operators at the village level. With the lower than commercial rates of interest provided to its customers, Solanka has targeted the lower economic category of the market, having thus far installed two projects, one with 84 solar home systems in the village of Morapathawa, and the other with 77 systems in Thorawa. This has been possible since the funds for lending have been provided as grants. However, it will be difficult to sustain this scheme with commercial level funding, unless interest rates are increased and loan repayment period is reduced. However, this will naturally exclude the current target market of this organization. Thus, the challenge for Solanka is to secure further grant funding to replicate such projects. Its biggest merit has been to prove that the village has the capacity to implement and manage PV electrification projects. Solanka had the provincial government's patronage and support when the selection of areas for implementation was made jointly. The project has an interesting feature in that the 12-V lamp units and the simple electronic controllers are manufactured at the village level. Also, a village level repair unit has been started where defective battery cells can be replaced to lengthen the life of the battery. Loan repayments to date for both projects are 100% due to the grass roots level service that is provided to users. For instance, even when a battery fails, the user immediately gets a replacement while the old one is being repaired or serviced. The Colombo-based head office focuses on long-term strategic planning and also imposes the accounting controls with audits of all accounting operations in the process of selecting recipients and collecting repayments. On the basis of the experience of these two projects, its original promoter has established a commercial solar company called RESCO as a subsidiary of Selco-USA.

A counterexample is the Pansiyagama 1000 homes project, funded by the Sri Lankan and Australian governments, which has a very low repayment rate in spite of the very favorable finance scheme applied. Hence, it can be considered a failure, although technically over 90% of the systems are still operating. This project was politically motivated, and was implemented by the National Housing Development Authority (NHDA) of Sri Lanka, which attempted to implement a "grass roots" level program. However, the top-down manner in which it was done resulted in poor community level involvement and poor management infrastructure. The systems installed were more sophisticated than the normal SHS being installed elsewhere in the country and had a typical cost ranging from Rs. 20 000 (US $571) to Rs. 32 000 (US $914), depending on the size of the module and number of lamps. This led to a monthly payment from Rs. 75 (US $2.14) to Rs. 135 (US $3.85), depending on the cost of the unit (US $1 = Rs. 35 in 1990), which turned out to be unrealistically low. According to a socioeconomic survey conducted by the Marga Institute of Sri Lanka, it was found that most households could afford to pay much more for the system. However, since the payments by households were set at nominal terms, their value has been eroding with inflation. At some point in time, the infrastructure for collecting repayments broke down as a result of bureaucratic problems, and some initial technical problems in the systems set a precedent for nonpayment, which was most difficult to break later. Some of these problems have been fixed after the NHDA handed over the maintenance and money collection duties to Power & Sun in 1991. However, the repayments remain around 50%, as the cost of collecting the money is much more than the actual collections due to the low monthly payment. This means that over-subsidizing solar photovoltaics has a negative effect on the dissemination of solar photovoltaics through the business route. This project has demonstrated that solar photovoltaics is an appropriate technology, but the implementing methodology used for the project was not sustainable and as a result was found detrimental to the commercial dissemination process of solar home systems in Sri Lanka.

23.4.6 Water Pumping in the Sahel

The Regional Solar Programme (RSP) was one of the early systematic programs to apply PV technology to solve pressing problems in the Sahel region of sub-Saharan Africa. Financed by a grant of 34 million ECU from the European Commission, to cover the cost of PV equipment and other procedures such as training, information and public awareness activities, regional coordination and technical assistance, this program was launched in 1989. The goal of the RSP was to install almost 1.4 MWp of PV modules (about 3.5% of the world market at that time) in water-pumping systems, vaccine refrigerators, community lighting and battery-charging stations. At the end of the program, a total of 626 pumping systems and 644 community systems had been installed and a wealth of lessons learned.

The principal objectives of the RSP were [55] to improve the accessibility of water in both quantity and quality, to improve the economic condition of the villagers by development of complementary resources through gardening, to reduce the time spent in procuring drinking water, to train personnel for project management, to create management groups for the solar equipment and to develop and adopt a legal framework for operation of the equipment with contractual structure of the relations between users and private companies.

Not all specific goals and objectives originally planned were fully met, but important lessons were derived. The drinking water component of the program took more than 90% of the installed PV power, so the lessons learned apply basically to this application. Solar pumping was found more affordable than diesel motor pumping, by about a factor of two per cubic meter of water. Compared to the per habitant cost of manual water rising pumps (50 ECU), borehole considered, investment on PV pumping systems was slightly higher (55 ECU), but the service quality of PV pumps was superior. Of the total installed cost, 31% was for the supply of the PV system, 11% for installation, 12% for regional activities (including coordination, quality control, tests, monitoring and the like) and 46% for the distribution network, water tower and other reception infrastructure.

One mode of management of the water supply system used in some communities was directly inspired by the management of water points equipped with manual pumps through a village water committee. This management system, however, was not effective owing to a number of difficulties, including an imperfect mastering of the accounting tools and a quasisystematic confusion of the responsibilities assigned to the principal members of the committee. Other communities preferred delegating the management of the entire system to a private-type body on a fee basis or to a communal-type body. These latter forms of management seemed better suited to the local conditions than the water committee scheme.

The idea of using PV technology to improve productivity of market gardening and farming was finally abandoned, hence the prospects of PV technology in Sahel were found in meeting specific domestic electrical needs (lighting, radios and TV sets), in pumping drinking water and in telecommunications.

23.5 TOWARD A NEW PARADIGM FOR RURAL ELECTRIFICATION

The problem of rural electrification has been traditionally handled by conventional means in a process of successive approximations. In this process, the most remote and dispersed population is attracted to larger population centers, which are then served by a mini electrical local grid, fed by diesel gen-sets or small hydroelectric generators. As the load increases, a point is reached at which extensions of the main grid become economically viable. This process is known as *pre-electrification* among electric companies and has been the basic growth mechanism of the interconnected system in rural areas. Although effective from a purely technical-economic point of view, this pre-electrification process has several downsides. From the social point of view, it forces people to leave their place of origin to create larger population centers, which in turn induces the need for the central provision of other services and puts a larger stress on the environment.

The term pre-electrification is being used nowadays by some authors in reference to PV rural electrification and, in some cases such as the CEMIG example above, the operational scheme is also being transported. However, there are a number of reasons to think that using the term pre-electrification in the context of photovoltaics is not appropriate. Furthermore, transporting the concept is bound to cancel the advantages offered by photovoltaics to create a new path for rural electrification. First, from the purely technical point of view, photovoltaics offers the possibility of supplying high quality electrical services even to the most remote sites, without the need for relocating people or eventually having to resort to grid extensions. Because of its modular nature PV systems can grow in pace with the load. Furthermore, this vision is compatible with current trends in the electrical sector toward distributed generation systems, and is supported by the development of more efficient electrical appliances, the miniaturization of electrical technologies and the progress being made in electronic devices for system supervision and load management. There are also environmental reasons that lead the notion that the local generation of electricity using renewable and nonpolluting energy resources is more convenient than building kilometers of electricity lines across ecologically sensitive areas. Local generation of electricity also offers the possibility for local management and, hence, for active community participation in the process of self-development.

On the other hand, there is evidence that the traditional electrification process based on the old paradigm of *Delivering electricity to rural people* has frequently lent itself mainly to fulfill the political need to improve the electrification statistics rather than to serve the real needs of people. Thus, it is not uncommon to observe rural communities with access to the grid, where a good portion of the households are not connected, usually because of lack of money to pay for the connection fee, or because the secondary distribution network only reaches the center of the community, leaving the rest of the population unserved. Therefore, if electricity supply is to be used as a tool for development, that is understood as increased life expectancy, more knowledge and a better standard of living [56], then the present rural electrification paradigm must be urgently changed to: "*Increasing the access of the rural poor to electricity-based services*". This set of services includes health, clean water, education, food preservation, entertainment and the possibility of engaging in productive activities.

Under this perspective, current PV rural electrification activities represent a landmark of the transition period into a new rural electrification scheme to substitute the old one with better results. However, the *new electrification* requires among other things, a new culture for electricity supply and use in rural areas, an *ad hoc* legal framework, new business practices within the electrical sector, innovative financial mechanisms, new and better technologies and appropriate institutional schemes. Thus, the actual value of programs and projects currently underway has to be weighted not only in terms of the number of PV users in rural areas, but also in terms of the benefits PV installations are bringing to the population. Also important to gauge the effectiveness of current PV rural electrification projects is the relevance of the lessons learned from them, which will allow the implementation of improved schemes for successful project replication.

This new paradigm for rural electrification should in turn be embedded in the broader concept of rural energy supply, which calls for a timely supply of useful energy in a variety of forms, so that people can have better opportunities to improve their own quality of life, to foster local economic development and to protect the environment.

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