IEA INTERNATIONAL ENERGY AGENCY

Pico Solar PV Systems for Remote Homes

A new generation of small PV systems for lighting and communication

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

Report IEA-PVPS T9-12:2012

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IEA PVPS Task 9

Report IEA-PVPS T9-12: 2012

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Foreword

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD) that carries out a comprehensive programme of energy co-operation among its 23 member countries. The European Commission also participates in the work of the Agency.

The IEA Photovoltaic Power Systems Programme (IEA-PVPS) is one of the collaborative R & D agreements established within the IEA and, since 1993, its participants have been conducting a variety of joint projects in the applications of photovoltaic conversion of solar energy into electricity.

The 23 participating countries are Australia (AUS), Austria (AUT), Belgium (BEL), Canada (CAN), China (CHN), Denmark (DNK), France (FRA), Germany (DEU), Israel (ISR), Italy (ITA), Japan (JPN), Korea (KOR), Malaysia (MYS), Mexico (MEX), the Netherlands (NLD), Norway (NOR), Portugal (PRT), Spain (ESP), Sweden (SWE), Switzerland (CHE), Turkey (TUR), the United Kingdom (GBR) and the United States of America (USA). The European Commission, the European Photovoltaic Industry Association, the US Solar Electric Power Association and the US Solar Energy Industries Association are also members. An Executive Committee composed of one representative from each participating country or organization heads the overall programme. The management of individual Tasks (research projects / activity areas) is the responsibility of Operating Agents. Information about the active and completed tasks can be found on the IEA-PVPS website www.iea-pvps.org

Task 9, Deploying PV services for regional development, addresses the use of PV as a means to enhance regional development – both for rural electrification applications and more broadly in the urban environment. The Task achieves this by developing partnerships with appropriate regional and national organizations plus funding agencies, and carrying out work on specific applications of interest and relevant business models.

Noting that some 1.5 billion people have no electricity grid connection and perhaps not even its prospect, this Task 9 report demonstrates that solar pico PV systems can help in providing a few essential energy services. However, the provision of this initial level of service with pico solar PV systems does not imply that these populations should be considered electrified. Governments should take a facilitating role in the area of pico PV services, focusing on quality assurance, reliable information and education. Donor bodies can also play an indirect but important role.

Acknowledgements

This report received valuable contributions from several IEA-PVPS Task 9 members and other international experts. Many thanks are due, in particular, to Anjali Shanker, Peter Ahm, Alex Arter and Georg Bopp.

Abstract

The concept of pico PV systems and their application in real-world circumstances are explained. The importance of understanding the dynamics of the demand side of this market is clearly elaborated, as are the nature and supply of the products, their economics, and experience with various business models. There are clear lessons for the roles that should be played by governments, donor bodies and others in the markets for pico PV products and services, essentially as providers of appropriate institutional frameworks and information.

Executive Summary

Photovoltaics (PV), and other renewable energy technologies, can significantly contribute to economic and social development. About 1.5 billion people worldwide still do not have access to electricity and to the clean water, primary health care, education and other basic services that often depend on access to electricity.

Solar pico PV systems have experienced significant development in the last few years, combining the use of very efficient lights (mostly LEDs) with sophisticated charge controllers and efficient batteries. With a small PV panel of only a few watts essential services can be provided, such as lighting, phone charging and powering a radio. Expandable solar pico systems have entered the market. Households can start by buying a small kit, later adding an extra kit, allowing extra lights and services to be connected and even a small TV to be considered.

The majority of the 1.5 billion people mentioned above will have no grid connection for years to come, perhaps never, and for them solar pico PV systems can help in providing a few essential energy services. But it should also be realized that rural inhabitants usually prefer a grid connection, in order to watch colour TV and to iron their clothes when they want. Despite the provision of this initial level of service with pico solar PV systems, they should still be considered non-electrified and the so-called "solar trap" should be avoided.

"Governments should take a facilitating role in this area, not directly interfering in the market. Governments should focus on quality assurance schemes, dissemination of reliable information and education of consumers."

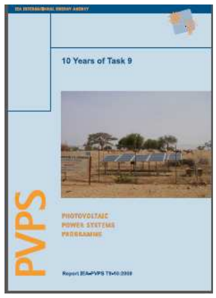
Two decades ago solar lanterns were the dominant products but with a number of technical problems, such as poor mechanical and electrical design, insufficient light output and bad quality of the LEDs. Testing has improved the new generation of pico systems, with a rapidly growing number of manufacturers and products.

Governments should take a facilitating role in this area, not directly interfering in the market. Most importantly, governments should not provide product subsidies and should also gradually eliminate kerosene subsidies. Governments should focus on quality assurance schemes, dissemination of reliable information and education of consumers. Donors can also play an indirect role by funding programmes to educate target groups, helping to guarantee a minimum level of system quality, and supporting micro-credit schemes. They should also avoid subsidizing equipment.

The costs of the smallest systems are between USD 10 and USD 50 - in reach for a growing part of populations living in remote areas. These costs are in the same range as those of simple mobile phones, which can be charged by the solar PV system. With payment plans through the mobile phone developing quickly, it is envisioned that a "marriage" between the mobile phone and the pico solar PV system could be very productive, and support financing of the PV system.

1. Introduction

Photovoltaics, and other renewable energy technologies, can significantly contribute to economic and social development. About 1.5 billion people worldwide, many of whom live in isolated areas, still do not have access to electricity or to clean water, primary health care, education and other basic services, all of which are largely dependent on access to electricity.



In 1998 the IEA PVPS Executive Committee decided to form a new Task to more effectively address these issues. This was the very first IEA activity targeting non-OECD countries. In its first ten years, from 1999 to 2009, **Task 9** dedicated its activities to the development of *'PV services for developing countries'*. Recommended Practice Guides were produced covering issues such as programme design, institutional frameworks, sources of financing and business models, quality management and capacity building. The lessons learned were summarized in the publication "*10 years of Task 9*".

Responding to both the demand from various organizations, governments, banks and development agencies as well as to rapid technological developments, the scope of Task 9 has been broadened in 2010 to '*Deployment of PV Services for Regional Development*'. Its activities cover:

- PV for rural community needs
- PV for mini-grids and hybrid systems
- Integration of PV in the urban environment
- Large scale PV systems

This publication on *'Pico*[1] *Solar PV Systems for Remote Homes'* has been written in response to challenging new developments in small PV systems. Their PV panel capacity is usually a few Watt-peak, but can be as small as 0.3 Wp or up to 10 Wp, thanks to dramatically increased energy efficiency of appliances and, in particular, the spreading of LED lights. They are equipped with a rechargeable battery and a charge controller, and provide either light only (solar lanterns) or also additional electrical services. These services include: power for a radio, a music player, and charging a mobile phone. Recently expandable solar pico systems have entered the market. Households can start by buying a small kit serving small loads, such as two lights and a radio. Gradually they can add an extra kit, so extra lights and services can be connected and even a small TV can be considered. Their costs are much lower than those of Solar Home Systems, so a much larger market can be reached, with simpler business models.

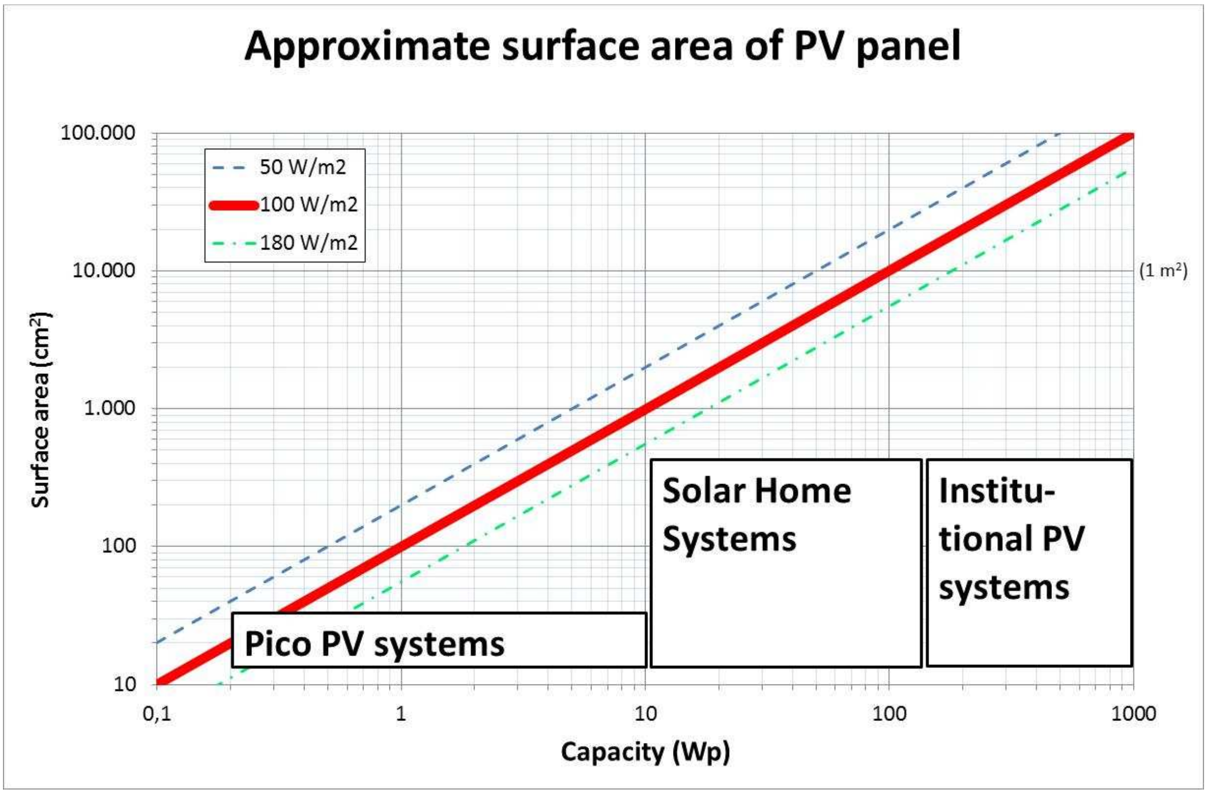
This creates a larger role for the private sector and implies a different role for government agencies, banks and donors. Ensuring proper quality of the products and educating the future users on the benefits of replacing their dirty kerosene-burning lights, candles and throw away batteries are major tasks. Women are an important target group in these respects. The preferences of these users are clear: the system should give a bright light, be affordable, multipurpose (lighting two rooms, charging a phone), portable, easy to use, safe, secure and have a long battery life.

Solar pico systems have seen a strong development in the last few years because they combine the use of very efficient lighting (mostly LEDs) with sophisticated charge controllers and efficient types of batteries, particularly lithium-ion batteries. With a small PV panel of only a few watt-peak, essential services such as light and phone charging can be provided. With the traditional rural 60 watt incandescent bulbs of only a few decades ago this would have been impossible. On the other hand it

[1] The addition "pico" just refers to a small PV system, below 10 Wp. In physics "pico" is really very small: in a pico-second (10^{-12} sec) a photon at light speed travels only 0.3 mm! But in hydropower systems for example a pico-hydro station has a power below 5 kW.

should be realized that solar pico systems can only play a niche role for specific purposes. Also rural inhabitants usually prefer a grid connection, so they can watch colour TV, use powerful music systems and iron their clothes when they want. But the majority of the 1.5 billion people mentioned above will have no grid connection for years to come, or perhaps never, and for them the solar pico systems may help in providing a few essential energy services. As a matter of fact, in a number of regions, these systems are being sold as simple off the shelf consumer appliances. ***However, providing this initial level of service does not imply that these populations should be considered "electrified".***

The graph below provides an indication of how small the PV panels of pico systems are, compared to the panels of Solar Home Systems and larger institutional systems. A value of 100 Wp/m^2 (roughly 10% efficiency) represents a reasonable estimate for small multi-crystalline cells. The graph shows that a 10x10=100 cm^2 panel has a capacity of about 1 Wp. Crystalline PV cells are more efficient (up to 180 Wp/m^2), hence smaller for the same capacity, and amorphous PV cells are less efficient (50-60 Wp/m^2), hence roughly doubling the panel size.



2. Development of small PV systems for rural applications

2.1 A brief history

One of the earliest PV systems in a rural setting was installed in Chile in 1960. In the early seventies the UN promoted so-called “integrated energy systems”, combining solar, wind and biomass resources, and distributing the electricity via a regular grid system in the village. A classic example is the Sri Lankan village of Pattiyapola, where in 1975 UNEP initiated a Rural Energy Demonstration Centre, with solar PV, wind turbines and biogas system [Gunaratne, 2002]. In practice these systems gave unreliable service because they were poorly designed, demanded too much maintenance and, most importantly, were more or less forced upon the village inhabitants [Lysen, 1994]. In mountainous regions in Colombia the German government supported the introduction of thousands of solar lighting and telecommunication systems in the early 1980’s.

Individual solar PV systems for rural applications were introduced in the 1980’s more or less independently in the Philippines, the Dominican Republic and Indonesia [Lysen, 1994].

In the **Philippines**, the Philippine-German Solar Energy project (1982-1988) started with a 13 kW plant for a small village but that was not found to be economic for wider dissemination. In the second phase the project installed 100 home systems on Burias Island. A prospective owner had to make a down payment of USD 140 and 36 monthly payments of USD 13.
In the **Dominican Republic**, former Westinghouse engineer Richard Hansen introduced “PV Home Lighting Systems” via his NGO Enersol Associates. In April 1984 the first PV system was installed in Bella Vista. Right from the beginning the owners had to pay for the system: USD 10/month, over four years. Soon a local solar credit fund was created (ADESOL), with seed money from USAID, and from the monthly instalments paid by its clients new systems could be bought. Local entrepreneurs were trained for the servicing and sales of new systems.
In **Indonesia**, Jan van Rooyen and Rob de Lange of R&S (a Shell company) in 1988 introduced the first “Solar Home Systems (SHS)” in the village of Sukatani, 130 km from Jakarta [Lysen, 2006]. It was the result of a fruitful cooperation between the Indonesian government (Research & Technology and Cooperatives), the Dutch government (DGIS) and R&S.

Fig 2.1 Solar Home Systems in Sukatani, Indonesia (1988)

In Sukatani a typical Solar Home System consisted of two PV panels (two by 40 Wp) on a support structure, a 100 Ah (12 V) battery in a box, charge controller, cables, three TL tubes (10 W, 6W and 6W), and a black-and-white TV (12 W). The system produced an average of 230 Wh/day.

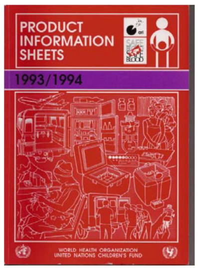
Interestingly, there was a large difference in approach between the introduction processes in Africa on the one hand and in Asia and Latin America on the other. In Africa, the panels were sold on the market for cash - as early as 1978 Jan Nijland of CETECO started selling solar panels on the African market, primarily in Cameroon. The panels, firstly expensive crystalline types, but later the cheaper amorphous panels, were directly connected to batteries as a charger, without any charge controller, using only a blocking diode. A nightmare for engineers, but it worked (for a short time). In Asia and Latin America the PV lighting and SHS systems were introduced via donors and NGO’s. The systems were usually properly engineered, with panels on tall masts, charge controllers, home wiring and a battery in a box. Because of their relatively high costs, they required special financing packages and fee collection [Adib Rana, 2001].

Presently a few million Solar Home Systems (SHS) have been installed in remote areas in developing nations. One of the most successful SHS programmes has been realized in Bangladesh, where about one million SHS systems have been installed up to 2012. This has occurred as a consequence of both strong government support via the Infrastructure Development Company (IDCOL) and by financial support from donor agencies such as the World Bank, KfW, GTZ, and ADB. Micro-finance institutions, so-called Partner Organizations (PO), finance the loans, install and maintain the solar systems and collect the fees [Wiese, 2010]. Investments for these SHS are of the order of 10 €/Wp, and hence € 500 for a typical 50 Wp system [Reiche, 2010].

2.2 Lessons learned from the deployment of Solar Home Systems for households

The experience of more than 25 years of working with PV systems for rural applications has taught important lessons. A few relevant reports with many "lessons learned" are mentioned in the references: [Foley, 1995], [Cabraal, 1996], [Loois, 1999], [Krause, 2004]. One of the success factors is good technical quality of the components [Preiser K. 1995], [Thermie B, 1998].

Despite some early successes, the level of competence required for the operation and maintenance of PV systems has been seriously underestimated in the 1980s and 1990s. Consequently many projects failed and PV often received a bad reputation. A key lesson is that the institutional setting of the project and the long-term commitment of the stakeholders are vital for the success of the PV project. The technology usually gives fewer headaches [Finucane, 2010].



Regarding PV services in rural areas, an exception is probably the introduction of **solar vaccine refrigerators** by the World Health Organization. WHO approached the issue professionally: they created norms, standards and test procedures, nominated test laboratories, and published lists with approved products. Still, problems were encountered with operation & maintenance and ownership of the PV systems in rural clinics. Also, the responsible Ministries of Health often lacked the budgets to sustainably invest or maintain the systems [Ahm, 2011].

The Solar Energy Institute of Madrid University has a dataset on field performance of 50,000 of **solar home systems** in Sub-Saharan Africa, Latin America and the Caribbean. The data reveal that (a) reliability and (b) appropriate sizing are the main challenges for PV-based rural electrification. Sizing PV systems for national electrification programmes is an important but also inherently difficult and often political process. The size of system installations needs to be determined based on demand—which in turn needs to balance three often conflicting viewpoints from: (i) international financial institutions, often oriented toward basic needs and cost-benefit analyses; (ii) end-users, who often list TV viewing the highest priority; and (iii) engineers, who typically determine standardized need levels and system sizes. The convergence of these three viewpoints is vital for success [World Bank, 2012].

The key to guaranteeing reliability is appropriate technical specifications, national lab testing procedures and reception tests, early field inspections, and an in-depth field evaluation after one year of operation. The lack of lasting maintenance structures is a significant weakness of PV system service delivery in many programmes. This can be resolved by implementing large-scale programmes with high densities of PV systems, encouraging significant levels of business to support specialized local companies capable of offering professional O&M services and training for local technicians. These issues have been extensively covered in the following "Recommended Practice Guides" published by PVPS Task 9:

1. Institutional Frameworks and Financial instruments for PV Deployment in Developing Countries
2. PV for Rural Electrification in Developing Countries: Programme design, planning and implementation
3. Summary of models for the implementation of Solar Home Systems in Developing Countries
4. Financing Mechanisms for SHS in Developing Countries. The role of financing in the dissemination process
5. A Guide to Capacity Building Requirements
6. The Role of Quality Management, Hardware Certification and Accredited Training in PV Programmes
7. 15 Case studies

This has been the approach adopted by the Moroccan utility ONE that has engaged in a very large-scale solar PV programme, offering 100 Wp systems to households on a fee-for-service basis including full maintenance of the system and battery replacement. ONE provides an upfront subsidy and private operators, subsequent to competitive bidding, are given an exclusivity area for collecting the fees and servicing – with a certain level of density, thus providing the right conditions for mobilising skilled staff and carrying required spares.

Laos and Cambodia, with grant support from the World Bank GEF programme, have engaged in large programmes (more than 15,000 SHS) providing 20 Wp to 50 Wp individual SHS to remote rural households. An upfront subsidy is provided by the national governments who then offer the customers the possibility of paying back a lease over a period of between four and ten years, depending on the scheme - implying monthly payments ranging between one and five dollars – a leasing scheme with the household owning the system at the end of the period and having to replace the battery. Though all conditions for success seem to have been gathered on paper, reality has proven more difficult: customers are indeed informed of the battery replacement issue, but cannot afford to pay cash for the replacement, hence make do with a 30 minute service unless financing is available to replace the battery. Though concentration over an area of a minimum number of SHS is essential to ensure viability for the service provider, as one goes deeper into rural areas households are more and more scattered and the cost of servicing and payment collection becomes higher and higher, leading to a situation where the cost of monthly collection ranges from 25% to 70% of monthly payments. Bringing down these costs can be achieved effectively by bringing down frequency of collections from a monthly basis to two monthly or even quarterly; by mobilising a village level representative, who also has to be trained for trouble shooting [IED, 2012; IED, 2008].

Mobile banking or phone-based systems have been considered but face difficulties for this market segment because phone coverage is not always available in these remote areas and end users do not necessarily have phones. And when they do, they are often not literate enough to manage the long string of numbers needed to be inputted, and simply do not accept the idea of sending off an amount of money without getting a physical receipt. Finally, the equipment represents a significant proportion of the belongings of the remoter household segments and they definitely want to have a physical contact with a person in charge of the systems.

2.3 Solar lanterns and pico PV services

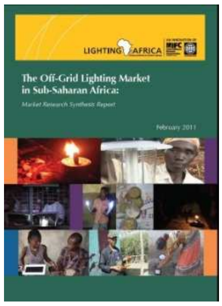
Quite a variety of **solar lanterns** have arrived on the market, first equipped with CFL's, and later also with LED's. The GTZ report of May 2010, "*What difference can a Pico PV system make?*" gives a comprehensive analysis of small PV systems, with a focus on solar lanterns[2].

The majority of the more than 50 types of solar lanterns are manufactured in China, followed by India, USA and Germany. Laboratory tests of lanterns, carried out by the Fraunhofer Institute for Solar Energy ISE [Pfanner, 2011] demonstrated the following main technical problems:

- Poor mechanical design and workmanship
- Missing over-current protection of the LED
- Poor electrical design
- Insufficient light output
- Bad quality of the LEDs
- Solar panels and batteries did not show nominal values
- Defective protection of the battery
- Defective ballast for CFLs or LEDs

As a result they recommend a detailed test procedure and a series of technical requirements (see sections 4.1 "Demand" and 5.4 "Quality") to improve the quality and the sustainability of the lanterns.

The **Lighting Africa** programme of the International Finance Corporation (IFC) and the World Bank covers many of these issues, by rigorously testing the various lighting products on the market [Pfanner, 2011] and publishing those that pass the quality standards, training technicians, helping the development of markets, and helping the private sector with removing barriers.
Their recent market analysis report, for example, contains a wealth of information on present use of off-grid lighting products, and on markets and prices [Baker, 2011]. The report gives clear indications regarding the preferences of the users:



- the system should give a bright light,
- be affordable,
- multipurpose (lighting two rooms, charging a phone),
- portable,
- easy to use,
- safe and secure
- and have a long battery life.

World Bank and IFC are now looking at expanding and developing a "Lighting Asia" programme.

The question which can be asked here is, given the multiplicity of products developing at all quality and price ranges, should these systems not simply be considered as **consumer products**, offering a different perspective for their deployment? Though some products may indeed be of poor quality and with a very limited lifetime, they also tend to be cheap with entry prices as low as USD 5.

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[2] The results of the GTZ Solar Lantern Test can be found at: http://www.gtz.de/en/themen/umwelt-infrastruktur/energie/4552.htm

Technology and innovation in this market segment seem to be definitely beating the pace at which state of the art testing and standards become available; as by the time the documents are made available a new generation of products is already on the market!

Combining LED technology and mostly very efficient end use equipment, a new generation of pico PV systems are now entering the market, offering the tremendous advantage of modularity. Rather than having to find a way to finance the full cost of a SHS with the 50 Wp panel plus appliances – either by way of cash or through some financing mechanism - the idea now is to use extremely efficient end use appliances thus decreasing the power requirement to 30% or 50% of what was previously required. By first selling the panel, central system and basic appliance to a customer, they can then progressively buy additional appliances and add panels and battery in series, to a service level approaching that of a SHS. These very recent technical developments offer a totally new realm of perspectives in terms of services including lighting, audio-visual, telephone charging, radio and TV.

Nonetheless, it remains important to state that these services should not be considered as a full substitute for grid quality electricity, as we shall see in the next chapter.

3. The Clients

3.1 Clients want the service of electricity and prefer the grid

Designers and engineers do their utmost to develop energy systems, such as a PV system, with the highest performance and longest lifetime. They usually have some notion of the harsh conditions in which their equipment must function, but generally they are not aware of the type of clients using their products and in which type of markets their systems will be sold and serviced.

A client generally has no interest in a PV system or in electricity per se, but only in the **service** that the electricity of the system can deliver.

The client wants light in the night, a recharge for his mobile phone, or wants to watch TV. This is equally true for clients in so-called developed countries as well as for clients the remotest regions of a developing country. The benefits of having access to electricity in a rural area are most clearly expressed by a pious American farmer in a rural church in the early 1940s: "*Brothers and sisters, I want to tell you this. The greatest thing on earth is to have the love of God in your heart, and the next greatest thing is to have electricity in your house*" [Zomers, 2001].

Fig 3.1 Solar phone charger in Africa

There are stories about an African lady who bought a solar system and an iron at the same time. She may be laughed at, but it clearly shows what this client wants: to be able to iron clothes. The difference between a 1,000 watt iron and a 1 watt radio seems obvious for an engineer, but for most people (even in developed countries, it should be mentioned) it is simply irrelevant.

All inhabitants prefer to have a connection to an electricity grid, simply because it allows them to draw more energy per day and, when needed, a high peak power for the ironing, music systems, colour TV or refrigeration that come with increasing living standards. But it is fair to say that for millions of rural inhabitants the grid will not reach their village, let alone their home, for many years to come and probably never. Solar PV systems provide some of the energy services they require, but it should be made very clear to the users what the limitations (but also the benefits) are of pico solar systems.

3.2 Pre-electrification

When solar systems are introduced in a remote village, it is sometimes called 'pre-electrification'. In other words: a technology which is temporary, and villagers only have to wait a few years before the real thing arrives: a grid connection. Inhabitants have solar panels connected to their roof, electrical wiring installed in their homes, and lights fixed to their ceiling. But after some time they discover that it means that the village will have to wait longer, very much longer, before the electricity grid is extended to their village. It is called: "**the solar trap**". A typical example is the village of Pattiyapola, Sri Lanka, mentioned already in section 2.1. Even when the systems malfunctioned after some time, it took the villagers several years to get a regular grid connection by the Ceylon Electricity Board. So, there is a natural tendency to resist pre-electrification with PV systems (or wind or biomass systems, for that matter).

In addition there is the effect of mobility; people tend to move, particularly the younger generation. If it is difficult to remove the solar home system from their old house and install it again in their new house, this is not an incentive to invest in the (often expensive) system.

These arguments are favourable for the promotion of the small portable PV systems. They are much cheaper than Solar Home Systems and also portable; they can simply be moved to another house and used as a backup when the (frequent) failures of the grid occur. As a consequence, a pico PV system can hardly be labelled as 'pre-electrification' and should not delay a possible future grid connection. Hence, deployment of pico PV systems should be treated as a market driven approach of consumer products and not be considered as regular electrification.

3.3 Willingness to pay

Based on the laboratory tests GTZ supported field surveys of solar lanterns in Bolivia, Nicaragua, Mozambique, Senegal and Uganda between 2008 and 2010 [Reiche, 2010]. The initial investment costs ranged from USD 36 to USD 120, often too high for the low-income part of the population with little or no possibility for generating savings. But the monthly service costs (USD 2 to USD 9 per month) were comparable with the budget of typically USD 2 to USD 5 per month for lighting with traditional kerosene wick lamps or candles (that have both a much lower light quality and more danger associated with their use).

The purchasing limitations associated with the various lighting products strongly depend on the income class. This is clearly indicated in figure 3.2 below, derived from the Lighting Africa publication concerning expanding the role of women in the sub-Saharan lighting market [Alstone, 2011].

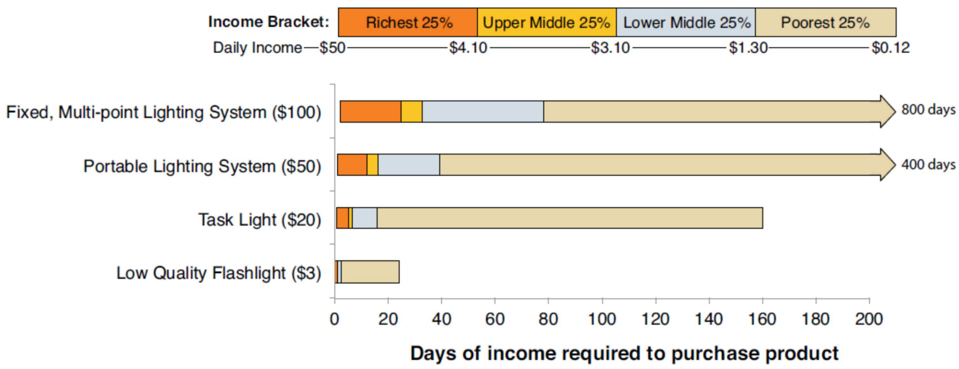

Fig 3.2 Days of income required to buy various hypothetical lighting products [Alstone, 2011]

It is clear, but will not be surprising, that the poorest part of the population will only be able to buy low quality products, and even those require nearly a month of income. Hence innovative business models will be required to reach these groups.

A related issue is the traditional role of the kerosene vendor. Rather than trying to put him out of business, it should be preferred to involve him in the business of selling modern lighting systems.

4. Power and energy: demand and supply

In all electricity supply systems, whether grid-based or autonomous, the expected power and energy demand are key parameters in the design of the system. This is even more important for a small solar PV system with a battery, given the limitations of the maximum power and the daily energy supply.

4.1 Demand

Lighting is the key demand for a small PV system. Before calculating the energy demand for lighting it is important to analyse the lighting demand in lux and lumen. More detailed information, older but still quite relevant, can be found in the World Bank paper on this topic [Van der Plas, 1988].

LUMEN, LUX AND LUMEN/WATT

The luminous flux ("light") emitted by light sources is measured in **lumens**. And if one lumen falls on a surface of 1 m^2, the illuminance on the surface is one **lux.**

A light source radiating a power of 1 watt of green light (the color to which the cones in the eye are most sensitive - a wavelength of 555 nm to be precise) has by definition a luminous flux of 683 lumens. So the theoretical maximum luminous efficacy of a green light source is **683 lumen/watt**. Incandescent lamps have a relatively low luminous efficacy of about 10 lm/W, fluorescent tubes do much better with 50 to more than 100 lm/W, CFLs are in the range of 50 to 60 lm/W. Presently warm white LEDs typically reach a little higher values, 70 to 90 lm/W, but values above 120 lm/W can be found on the market for cool white LEDs. There is further room for improvement as the company CREE Inc set a laboratory record value of 254 lm/W for a white LED in April 2012 [http://techon.nikkeibp.co.jp/english/NEWS_EN/20120423/214494/].

In our homes we can easily read a book with 100 lux or less. In Western offices the illuminance usually required is 300 lux and for special laboratory work up to 500 lux. In the GTZ publication [Reiche, 2010] it is recommended for young people in remote homes in developing nations to have a minimum illuminance level of 20 lux on a surface of at least two sheets of paper. Room lights should have a minimum luminous flux of 50 lumen, which is comparable to the brightness of petroleum wick lamp. Further, a minimum of 300 lumen is required for a household (a traditional 30 W incandescent lamp). With 100 lumen/watt LEDS, this implies that a combined power of **3 watts fulfills the minimum for all lights in a remote home**.

It will be clear that because of their high efficacy the LED lamps are the perfect match for a pico PV system. An additional benefit for lighting a surface is that, because of their construction, LED lamps emit light more in a beam rather than in all directions as emitted by an incandescent or kerosene lamp.

The daily energy demand for lighting can be estimated on the basis of the number of lights, their power and the number of hours per day in use. Examples are given in table 4.1, based on LED lights with 100 lm/W.

Mobile phone charging is the next important demand for rural homes. Simple mobile phones have battery capacities of 700 to 1000 mAh[3]. As most have lithium-ion batteries, the voltage is 3.7 V and their typical battery capacity is between 2.6 and 3.7 Wh. With a charging efficiency of 90% it takes about 3 to 4 Wh to fully charge an average simple mobile phone (2 watt, 1.5 to 2 hours). Charging a smart phone roughly doubles the requirement. In the table below it is assumed that the phone is charged every day with half the required charge (or a full charge every other day). Suppliers of pico PV systems usually recommend users to charge their phones during the day, as this takes the power directly from the PV panel and consequently saves the storage loss of the battery.

Operating a small radio takes about 0.5 Watt, or about 1 Wh for two hours listening per day.

Load	**Type of service**	**nr**	**watt**	**hr/day**	**Wh/day**
study light	50 lumen	1	0.5	3	1.5
main light	200 lumen	1	2.0	2	4.0
night light	10 lumen	1	0.1	8	0.8
phone	charging (50%)	1	2.0	1	2.0
radio	sound	1	0.5	2	1.0
TOTAL					**9.3**

Table 4.1 Minimum energy demand for lighting, phone and radio

This energy can be supplied by a pico PV system of about 3 Wp, as we will see later.

A small TV (7 inch LCD) requires a power of less than 10 watt. With three hours per evening this means 30 Wh/day. This is at the edge of the possibility for a dedicated PV system of about 10 W.

More information on rural energy demand, particularly the Energy Demand Ladder, can be found in [Foley, 1995]. As a reference, although far beyond the potential of a pico PV system, three desirable rural loads can be mentioned: the refrigerator, the fan and the iron.

The energy consumption of a refrigerator depends mostly on its size, efficiency, temperature setting and the temperature of the room in which it is placed. In the literature, refrigerator consumption values of 1000-1300 kWh/year (3-4 kWh/day) are quoted [Hagan, 2006]. With proper design one should be able to reduce this to about 100 kWh/year, which is still close to 0.3 kWh/day for a refrigerator with 150 litre content [Steca, 2010]. For comparison: a typical solar vaccine refrigerator, tested for the World Health Organization, consumes 0.6 kWh/day (43 ^{o}C / 5 ^{o}C) for the refrigerator (76 l) alone. With the freezer (30 l) switched on, the consumption increases to 1 kWh/day [WHO, 2009]. The power demand of standard (compression type) refrigerators is between 50 and 100 W, depending on size.

Fans are popular, particularly in Asia. They tend to consume quite an amount of energy because (a) they run often many hours per day and (b) switching to a lower speed does not consume much less

[3] Smart phones have larger batteries (iPhone 3GS: 1220 mAh = 4.51 Wh, Samsung Galaxy S2: 1650 mAh = 6.11 Wh).

power in older fans (resistance switching). If a 50 W fan runs for 6 hours per day the consumption is 0.3 kWh/day.

Lastly, irons have another drawback - their peak power is fairly high, usually 1000 watt or more, which is very hard for a battery powered system. Their consumption can also be considerable: one hour ironing over a day, with a 1 kW iron and a duty cycle of 50%, implies 0.5 kWh/day[4].

4.2 Supply and storage

The energy and power demand, described in the preceding paragraph, has to be supplied by a PV panel connected to a storage battery via a charge regulator.
In ideal circumstances and in sunny areas each Wp (watt peak) of a fixed PV panel can produce up to 5 Wh per day (1825 Wh/yr per Wp)[5]. For a portable pico PV system the panel is not always in the best position, and sometimes even shaded for some time, so that even in sunny areas it is safer to assume a lower output ratio of about 3 Wh/day per Wp.
With a round-trip battery efficiency of about 80% (efficiency of dis- and charging electronic device included) for most batteries this implies that, if all energy is consumed in the evening or night, the practical available energy for the consumer of a pico PV system is about **2.5 Wh/day per Wp** of the PV panel. With this output ratio the size of the PV panel can be determined for a given load.

The battery capacity (also in Wh) has to be at least higher than this output ratio, otherwise the PV system cannot deliver its optimum output to the load. But because it is better not to discharge a battery fully during every day/night cycle the battery capacity has to be much higher.
Lead-acid batteries for pico PV systems (quite different from starter batteries for cars) are designed for deep discharge. But the lifetime of the battery, measured in the number of charge-discharge cycles, strongly decreases with increasing depth of discharge (DoD). Rough indications are:

- 60 % DoD: a lifetime of about 500 cycles (1.5 years with daily cycles)
- 25% DoD: a lifetime of more than 1200 cycles (3 years)

Consequently, by not discharging more than 25% we need a minimum capacity ratio of 2.5/0.25 = 10 Wh per Wp of the PV panel.
Lithium-ion batteries do allow much higher DoD values, up to 75% or more (as we know from our mobile phones). In this case the required battery capacity ratio is at least 2.5/0.75 = 3 Wh/Wp.

These values are reflected in table 4.2 below. The larger PV systems recommend even higher battery capacity ratios, allowing a longer standby period in case of days with less sunshine.

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[4] Ironing six shirts consumed 0.57 kWh (Lysen)

[5] In Northern Europe the output is much lower: about 900 Wh/yr per Wp (about 2.5 Wh/d/Wp), and in desert areas the output can reach 2200 Wh/yr/Wp (or 6 Wh/d/Wp).

Source	Battery type	Battery	PV panel	Cap. Ratio
Pico PV systems		Wh	Wp	Wh/Wp
Fosera: Scandle 75	lithium-ion	2.6	0.5	5.2
WakaWaka	NiMH	2.9	0.75	3.8
Barefoot: Firefly Mobile Lamp	Lithium Iron Phosphate	2.8	1.5	1.9
Barefoot: Firefly Mobile Ultra Torch	Lithium Iron Phosphate	5.6	1.5	3.7
Fosera: PSHS 2800	lithium-ion	9.0	1.5	6.0
Barefoot: PowaPack Junior Matrix	Lithium Iron Phosphate	12.2	2.5	4.9
Sundaya: Ulitium 200	lithium-ion	16.7	3.0	5.6
Bettalights: BettaOne	Lead crystal (SLA)	24.0	3.0	8.0
Fosera: PSHS 7000	lithium-ion	22.4	5.0	4.5
Bettalights: BettaTwo	Lead crystal (SLA)	24.0	5.0	4.8
Barefoot: PowaPack 5W Bright	Lead Acid	60.0	5.0	12.0
Bettalights: BettaTwo Plus	Lead crystal (SLA)	72.0	10.0	7.2
Barefoot: PowaPack Village Kit 10W	Lead Acid	204.0	10.0	20.4
larger PV systems				
DEEP-EA: Solar Charging station	Lead Acid	312.0	14.0	22.3
Free Energy Europe: solar TV	Lead Acid	360.0	14.0	25.7
DEEP-EA: Solar Charging station	Lead Acid	1200.0	50.0	24.0
DEEP-EA: Solar Charging station	Lead Acid	1560.0	75.0	20.8
R&S: Sukatani Solar Home System (1988)	Lead Acid	1200.0	80.0	15.0
Free Energy Europe: solar fridge	Lead Acid	2640.0	112.0	23.6

Table 4.2 Battery capacity ratios for a sample of PV system examples

5. Suppliers, products, costs and quality

5.1 Introduction

There are a large number of manufacturers of pico solar PV systems. While solar lamps and solar lighting kits have been the dominant products for two decades, the last few years have seen a new generation of pico systems being introduced, supplying additional services. Sometimes they are modular so a growing load can be served by buying additional units.

Solar Lanterns

The systems tested and approved by the Lighting Africa programme are largely focused on the African markets, but these can also be sold in other regions of course. The overall test results are given as XX lumens for YY hours, after one day of solar charging.

On the website www.lightingafrica.org the following manufacturers are mentioned, in alphabetical order, with the number of qualified and approved products between brackets (August 2012):

- Barefoot Power (3)
- Betta Lights (2)
- D-light (3)
- Greenlight Planet (2)
- Lemnis Solar (1)
- NIMH Technologies Foce (1)
- Nokero (1)
- Nuru (1)
- Philips (1)
- Prakruthi Power (1)
- Schneider Electric (3)
- Solux (1)
- Sunnight (2)
- Suntransfer (1)
- SunSumSolar (1)
- Sunlite Solar (1)
- Toughstuff (2)
- Trony Solar (2)
- Uniglobe (1)

Apart from these tested systems there are many other solar lamps and solar lighting kits on the market. Some manufacturers have not (yet) submitted their product for a test, such as the WakaWaka lamp, or they focus on markets in specific countries or regions.

Multi-service systems

A typical example of a multi-service PV system is the “Pico Solar Home System” produced by the Thai-German company Fosera. Also Sundaya, primarily active in Indonesia, and Free Energy Europe for the African market, produce systems that serve not only lighting but also other services, such as playing a radio, charging a mobile phone, or even running a TV. As examples a few products will be described in more detail in the following paragraphs.

NOTE: Mentioning these products does not in any way imply an approval by IEA-PVPS. Their technical data are used to illustrate the earlier analysis.

5.2 Examples of multi-service systems

Barefoot Power

The Australian company Barefoot Power, founded in 2005, produces various lighting products such as the Firefly series, solar phone chargers and larger so-called PowaPacks.

Fig 5.1 Examples of Barefoot Power systems

Barefoot Generation 2.5	Specs	Specs	Specs	Calculated
Product	Battery type	Battery cap.	PV panel	Cap. Ratio
		Wh	Wp	Wh/Wp
Firefly Light	Lithium Iron Phosphate	1.9	1.0	1.9
Firefly Mobile Lamp	Lithium Iron Phosphate	2.8	1.5	1.9
Firefly Mobile Ultra Torch	Lithium Iron Phosphate	5.6	1.5	3.7
PowaPack Junior Matrix	Lithium Iron Phosphate	12.2	2.5	4.9
PowaPack 5W Bright	Sealed Lead Acid	60.0	5.0	12.0
PowaPack Village Kit 10W	Sealed Lead Acid	204.0	10.0	20.4

Table 5.1 Technical details of Barefoot Power systems

Bettalights

Betta Lights was founded in South Africa to develop niche solar solutions. Apart from the lighting kits below, they also produce dedicated solar street lights and security lights.

Fig 5.2 Examples of Bettalights systems

BettaLights	Specs	Specs	Specs	Calculated
Product	Battery type	Battery cap.	PV panel	Cap. Ratio
		Wh	Wp	Wh/Wp
BettaOne	Lead crystal (SLA)	24.0	3.0	8.0
BettaTwo	Lead crystal (SLA)	24.0	5.0	4.8
BettaTwo Plus	Lead crystal (SLA)	72.0	10.0	7.2

Table 5.2 Technical details of Bettalights systems

Fosera
The Thai-German company Fosera has launched an expandable solar PV system, with the brand name “Pico Solar Home System” (PSHS). The smaller version of the system is a portable lamp, called the Scandle.

Fig 5.3 Fosera PSHS and Scandle

The PSHS of Fosera is available in three versions, with solar panels of 1.5, 2.5 and 5 Wp respectively. The Scandle has also three versions, for panels of 0.3, 0.5 and 1.5 Wp.

Type	Battery	PV panel	Output	Cap. Ratio	Output ratio
	Wh	Wp	Wh/day	Wh/Wp	Wh/d / Wp
PSHS 2800	9	1.5	3.8	6.0	2.6
PSHS 4200	13.4	2.5	5.8	5.4	2.3
PSHS 7000	22.4	5	11.5	4.5	2.3
Scandle 25	1.3	0.3	1.0	4.3	3.3
Scandle 75	2.6	0.5	1.9	5.2	3.8
Scandle 200	4.6	1.5	5.2	3.1	3.5

Table 5.3 Technical details of Fosera systems

Sundaya
The Sundaya company (1994) is an offspring of Sudimara, the successor of R&S which started with the first Solar Home Systems in Indonesia in 1988. Sundaya provides a broad range of equipment for large and small solar PV systems, with a focus on electronic charge regulators that are not only used in Indonesia but are also exported.

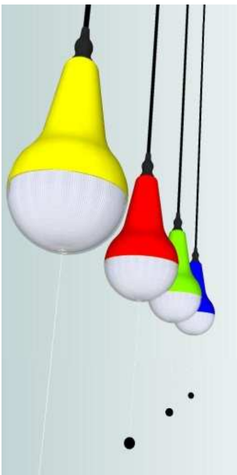

Fig 5.4 Sundaya Ulitium lamp

Recently Sundaya has added a pico PV system to their product line, the Ulitium solar lamp. This 240 lumen (2.2 Watt) LED lamp has an inbuilt 17 Wh lithium battery and the necessary electronics. By means of a pull switch (see fig 5.4) the lamp can be dimmed to 120 lumen or 25 lumen respectively. A 3 Wp solar panel can be directly connected to the lamp. The system is expandable from 1 lamp to 10 or 100 lamps, simply by adding and connecting more panels and lamps. Also a Sundaya LCD Color TV with similar built-in storage technology can be added, with automatic regulation of energy between devices. Devices that are used most will receive the largest recharge the next day.

5.3 Costs of PV systems

It is always difficult to collect reliable cost data, as they tend to vary in time and depend on the point of sale. Transport adds to the costs and dealers add their margin. The following graphs represent, where possible, the final costs for the consumer, i.e. at the end of the product chain.

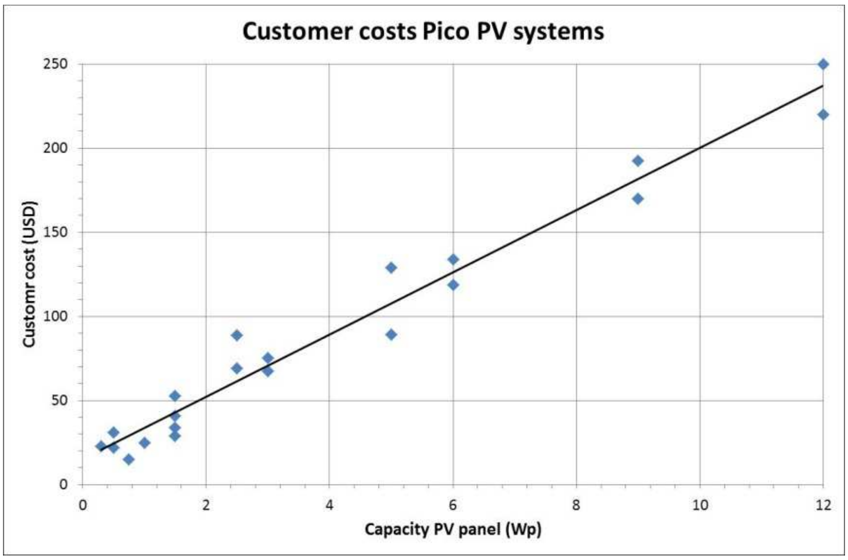

Fig 5.5 Costs of Pico PV systems (in USD 2011)

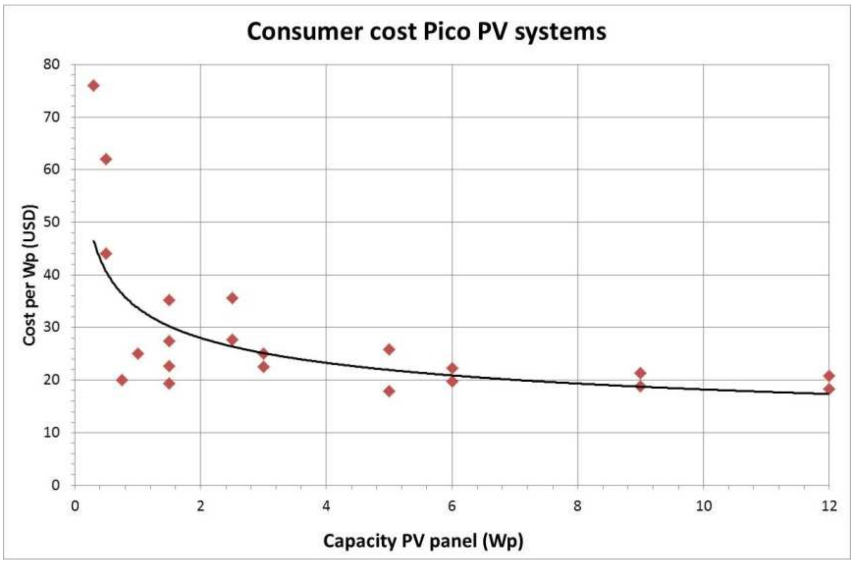

Fig 5.6 Costs of Pico PV systems (in USD 2011 per Wp)

The cost data indicate that the price per Wp for the consumer of these pico PV systems is of the order of about USD 20 per Wp, about double the price per Wp of a SHS system. But they include high quality appliances and LEDs with higher service levels and longer lifetimes, hence are much cheaper than SHS in absolute terms, trading off the size of the panel with high quality appliances and with the advantage of modularity. The very small systems, with PV panels below one watt, are of course relatively more expensive per Wp, but for these small systems the absolute price is much more relevant than the price per Wp.

5.4 Quality

To prove the quality of products, reference is being made to standards and norms. In the case of LED lighting systems in the past such standards were missing – except for PVGAP PVRS 11/11A. However, that standard is currently only covering CFL-based lights.

In view of the broad variety of specifications of LED-based solar lights, detailed testing is time-consuming and costly. Different testing procedures are possible with respect to the costs. Therefore two different test procedures were developed by Fraunhofer ISE:

1. the performance test procedure described below, which was developed with GTZ funding and uses pass/fail criteria to eliminate lights of inferior quality on each test level and thus save costs;
2. a new, complementary “non-evaluative” test procedure developed in a follow-up study with funding by the World Bank Group; this approach doesn’t apply fail/pass criteria but describes the characteristics of all tested lights within the scope of testing.

The test procedures were developed for use in and by developing countries. The options available to laboratories in developing countries are normally financially limited by small budgets and it must be feasible for the test procedures to be performed by general technicians who are not LED specialists. The test procedures were created with these guidelines in mind. Hence some tests cannot be carried out in accordance with international or national standards.

To limit overall lab test costs, a three level test procedure was developed [Avato, 2009]. If a lamp does not pass the low-level test (mainly simple function tests and visual inspection) it is not worth proceeding to the higher test levels. The second test level includes detailed light measurements and electrical measurements; mechanical characteristics are also assessed. The third test level includes a long-term test of the luminous flux maintenance.

Test Level 1 (Rapid Test)

The first test level enables a quick screening of the LED lights with regard to their overall quality and to "separate the wheat from the chaff". It comprises the following tests:

- Visual screening
- Rapid test light performance: ambient lights
- Rapid test light performance: task / portable lights
- Rapid test charge controller

Test Level 2 (Main Test)

The second test level involves a thorough examination of the light's component characteristics. LED lighting systems that have passed the first level are subjected to more than ten different, detailed tests. These tests comprise:

- Measurement of the PV module characteristic curve under outdoor conditions
- Battery capacity
- Passive charge controllers, in case of NiMH
- "Run time" (autonomous time)
- Main test for lighting service (ambient and task lights)
- Charging behaviour (solar, mechanical, grid)
- Mechanical durability
- Switches and connectors.

Test Level 3 (Long-Term Lumen Degradation Test)

An important performance metric for LED lights is consistent luminous flux during long periods of operation, called luminous flux maintenance. The lifetime of LEDs is mainly influenced by electrical operating conditions and thermal management. Further criteria that accelerate degradation include the quality of the phosphorus used in white LEDs and the UV resistance of the LED housing. Examination of the lumen maintenance is performed in a long-term test at the third test level. Due to time constraints, degradation is only examined over a period of 6 weeks, corresponding to approximately 1,000 hours. During operation, the light output must not be reduced by more than 5%.

The alternative test procedure, developed with World Bank Group funding, is now ready and available[6]. It contains a visual screening procedure which is very similar to test level 1 and allows a pre-selection of very bad products. The other test steps work without any pre-defined pass/fail criteria. As all lights run through the full test cycle this alternative procedure can be more expensive, but has the advantage that it allows well-informed users to decide for themselves about minimum quality levels and about their priority of lighting performance indicators. The results of these new, on-going tests within the Lighting Africa framework are published on www.lightingafrica.org.

Presently this voluminous testing procedure is being transferred into a new standard "IEC 62257-9-5 TS Ed.2: *Recommendations for small renewable energy and hybrid systems for rural electrification - Part 9-5: Integrated system - Selection of stand-alone lighting kits for rural electrification*" and will be published in 2013. This standard will include a new battery testing procedure by Fraunhofer ISE, financed by GIZ, which will allow "separation of the wheat from the chaff" within one month.

[6] http://www.lightingafrica.org/resources/technical-research.html

6. Business models

6.1 Delivery and financing models

Four different **delivery models** (otherwise referred to as "business models") can be distinguished, each having their specific **financing models** [Krause, 2004], [IEA PVPS, 2002, 2003]:

1. Commercially led approaches, in which suppliers and dealers develop the market (typically relying on cash sales)
2. Programmes managed by a variety of stakeholders (typically relying on consumer credit)
3. Utility models (often, but not exclusively, with fee-for-service payment)
4. Grant-based models (typically used for institutions, highly managed and structured)

The first two models are highly relevant for pico PV systems, justifying the reproduction of the illustrations in the above UNDP-GEF reference showing the flows of materials and finance in the respective models:

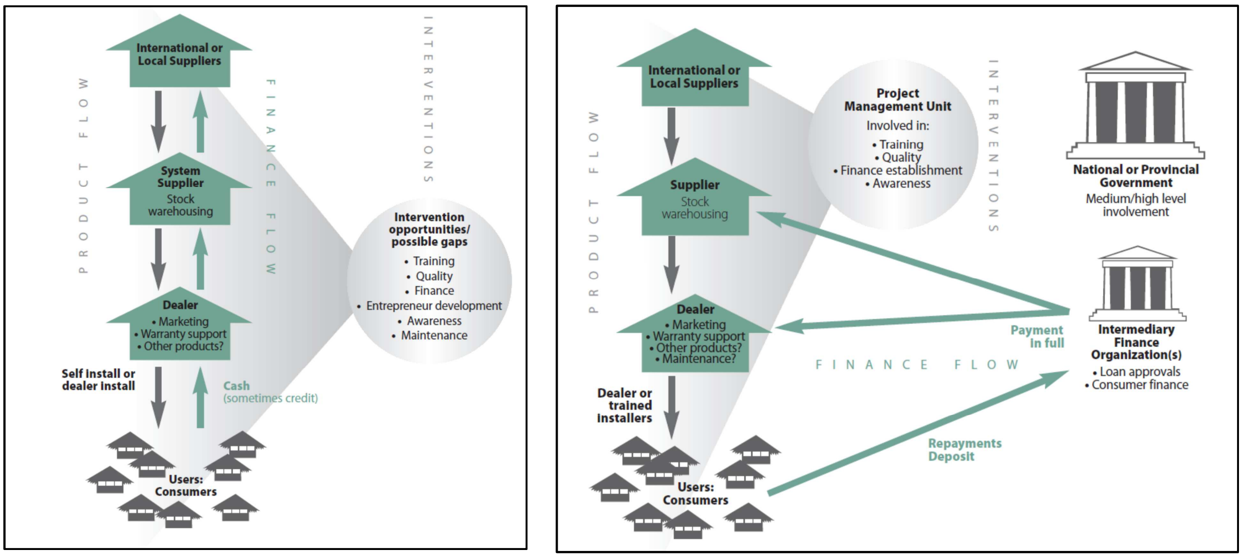

Fig 6.1: Commercially led delivery model (left) and Multi-stakeholder programmatic delivery model (right) [Krause, 2004]

In the first model the PV system is sold for cash to the end-user, who then directly becomes the owner of the system. Sometimes the dealers or vendors also operate a simple consumer finance scheme, called **layaway**. The consumer makes an informal price agreement with the supplier, pays monthly instalments (usually without interest) and receives the system after the instalments have reached the required level.

This begins to approach the operation of the second model, that of credit sales. In the IEA-PVPS publication on this subject three types of credit sales are distinguished [IEA PVPS, 2003]:

(a) Dealer Credit, the PV supplier/dealer sells the PV system to the end-user, who enters into a credit arrangement with the PV dealer. Depending on the arrangements, the end-user immediately becomes the owner of the system, or becomes the owner when all payments are made.

(b) End-user Credit, the PV supplier/dealer sells the PV system to the end-user, who obtains consumer credit from a third party credit institution. Usually the end-user becomes the owner of the system immediately, but this can be delayed until all payments are made. The PV system can be used as collateral against the loan.

(c) Lease / Hire purchase, the PV supplier/dealer or a financial intermediary leases the PV system to the end-user. At the end of the lease period, ownership may or may not be transferred to the end-user, depending on the arrangements. During the lease period, the lessor remains owner of the system and is responsible for its maintenance and repair.

An example of a traditional credit sales model in West Africa is the **participatory SUSU** model [Azimoh, 2012]. A local cooperation, headed by the village chief, collects daily fees from, for example, ten participating families. The fees of the ten families together are sufficient to buy the first PV system after one month, which is installed in the home of the first family, very visible for everyone. And so every month a new system can be installed, and after ten months every family has a system. Defaulters are sanctioned by the village chief.

Some difficulties faced by these financing models, as illustrated by the highlighted solutions, are the fact that financing and bank branches may not be available in the targeted rural areas. Unless the bank (be it for end user credit or dealer financing) agrees to take the system / panel as collateral, insufficient guarantees will be an issue. Finally, the cost of processing such small transactions is high for a bank, hence generally high interest rates apply (15% being far from uncommon). This in turn substantially weighs on the price the end user has to pay. In some countries this is overcome when energy or solar services are made eligible through publically supported rural infrastructure financing schemes. Cost of collection is critical as it can approach 60% of payments: the further and the more scattered the households are, the higher the collection costs. Involving local intermediaries and other innovative phone-based payments can offer interesting solutions.

6.2 Ability to pay

The choice between cash or credit sales depends on the ability to pay of the customer. As described in section 3.3 one can distinguish roughly four income classes, based on information for the Sub-Saharan countries from the Lighting Africa market analysis study [Alstone, 2011]:

- Poorest 25%: USD 0.12 to USD 1.30 per day
- Lower Middle 25%: USD 1.30 to USD 3.10 per day
- Upper Middle 25%: USD 3.10 to USD 4.10 per day
- Richest 25%: USD 4.10 to USD 50 per day

In the table below four typical representatives of each group have been chosen, with rounded-off daily incomes, starting with the proverbial “one dollar a day” person. It has also been assumed that a certain percentage of that income can be spent on lighting (20% for the lowest incomes, decreasing to 10% for the higher incomes), and that a week’s spending on light could be a reasonable estimate for a cash investment.

			Weeks to buy a product of USD xx			
Daily Income	Perc. Lighting	Avail. /week	USD 10	USD 25	USD 50	USD 100
USD 1.00	20%	USD 1.40	7	18	36	71
USD 2.00	20%	USD 2.80	4	9	18	36
USD 3.50	15%	USD 3.68	3	7	14	27
USD 20.00	10%	USD 14.00	1	2	4	7

Table 6.1: estimate of the number of weeks it takes to buy a PV product with cash - from the percentage of income spent on lighting

It is clear from the above table that only the richest part of the population is able to buy the smallest pico PV system, costing between USD 10 to USD 25, with cash from 1 to 2 weeks of spending on lighting. The lower income groups will have to go for upfront savings or credit sales, with increased costs, because interest has to be paid.

The great advantage of modular pico PV systems is that rather having to resort to credit, the customer can buy the components of the system step-by-step.

6.3 Link with mobile phone market

A link with the market for mobile phones is interesting, for a number of reasons.

Cost comparable
The cost of simple mobile phones in rural areas is of the order of USD 30 to 50 with USD 10 for the entry price of the simplest phone, hence about the same order of magnitude as the costs of simple pico PV systems. This means that similar financing mechanisms could be used.

Regular charging needed
Secondly, a mobile phone has to be charged regularly and they are now becoming very widespread indeed. Consequently, in rural areas the combination with a solar charger is logical and many suppliers offer these options all over the world. In Kenya, mobile phones with PV panels at the back have even been introduced to the market in 2009[7]. It could therefore be of interest to a vendor to sell not only mobile phones but also solar powered phone chargers. As these usually are equipped with lights, he will soon be selling pico PV systems. As a matter of fact, now nearly all lanterns are sold either as a basic lantern or with the option of a phone-charging outlet with adaptors for all phone brands…and a number of mobile phones, especially around the entry price, have built-in flashlights!

Payment via the phone itself
Thirdly, the mobile phone could be used to make regular payments for the pico solar system itself. Particularly in Kenya, the so-called M-PESA system ("Mobile Money") has grown very rapidly after its introduction in March 2007. In April 2012 there were 39,400 Agent Outlets available for 14.9 million customers (www.safaricom.co.ke). Every day millions of Kenyan shillings exchange hands through simple mobile phone transactions.

An example of the mobile phone and solar PV technology being combined has already been realized by a Cambridge spin-off company, Eight19, that developed the so-called IndiGo technology [Block, 2011]. The solar system, which also powers a LED light, has been rolled out to a number of customers in Kenya, Malawi and Zambia, with the support of SolarAid. Users activate their solar system by loading credit using a scratch card, validated through SMS using their mobile phone. In other words: if no credit is put on the system, it switches itself off. The system implies an additional electronic gadget on the PV system and so will probably not be applicable to the smaller systems. It will work so long as local technicians do not find clever ways to bypass the electronic switch-off system. An interesting side benefit is that local people could earn some money by selling the scratch cards.

[7] The surface area at the back of a mobile phone cannot be sufficient to fully charge the phone, but helps keeping it charged. Nokia has carried out real life performance tests (http://www.energymatters.com.au/index.php?main_page=news_article&article_id=1970)

Actually, the features of mobile banking – where your bank account is linked to your phone - offer great opportunities for dealer financing, as the dealers can thus operate remotely and to some extent do away with having to have a branch immediately at hand.

6.4 First lessons and perspectives for exploration.

Prepayment meters on SHS

The first approaches to integrating this technology consisted of adding pre-payment meters to the Solar Home Systems, with the customer required to buy a recharge, be it a scratch card or something else, and then entering the code on the meter.

Advantages of this approach are that customers have to pay in advance for the service, otherwise cannot avail themselves of it; both the options of a flat monthly rate as well as buying credit for kWh consumption exist (so the technology also applies to grid services); the agent, who should preferably also have technical know-how, need not go all the way to each house or village, but can be periodically at the local market days; some of the more sophisticated platforms today offer the possibility of the customer buying the credit through his mobile phone and then entering the code; and additionally, regarding load management, some of these meters also have the possibility of transmitting information to a central monitoring station.

There are additional costs and issues involved – the meter itself, which has the feature of blocking the system, adds cost to the investment; customers also try to bypass the system; and, not having a regular physical check by a technician can lead to deterioration. Given the additional cost, the feature only makes economic sense with the larger SHS, starting from 50 Wp.

Payment through mobile phones

Phone subscriptions are recharged even in remote rural areas, either through scratch cards or by a vendor making a call to a central station after taking the money from the customer and the phone then being electronically recharged. The end user gets a receipt similar to that of credit card payment. These terminals can be used for telephone and other payments.

The concept here would be: the vendor who offers these recharging services (and hence already has a contract with a central electronic service) becomes the collection point for the monthly payments of the buyers of the pico PV system. Customers would come every fortnight or month and provide the cash to the terminal holder, who will then electronically transfer the funds to the central account of the seller of the PV systems. This vendor would provide an electronic receipt to the customer and possibly sign off on the prepared payment card. The vendor would retain a fee for this and one could also discuss the possibility of becoming a “collection agent” – with the vendor going to collect funds if people do not come plus reporting any complaints. Hence, cost of fund collection would be limited to the commission given to the vendor (generally 2% to 5% of the transaction) and the supplier team of the PV systems would only have to travel to the sites in the case of technical problems and, for example, every six months for preventive maintenance.

Human contacts

Nonetheless, human contact remains absolutely fundamental for the success of programmes in rural areas and, although such electronic features can contribute to cost reduction and improved management, they should by no means be considered as a substitute for all human contact.

7. Policies

7.1 Role of governments and donors

Pico solar PV systems represent a new dimension, largely underestimated by decision makers, in the landscape of fighting the energy poverty that can be a genuine source of social unrest. Due to their much lower initial investment costs they are also becoming affordable in the absence of government-subsidized programmes. And, because they are in fact consumer products, other policies are required compared to those for introducing Solar Home Systems.

Governments should take a facilitating role but should not directly interfere with the market as such. This facilitating role could have the following elements:

- Quality assurance scheme for the products in the market
- Providing and disseminating reliable information about the products
- Education of consumers about costs and quality
- No subsidies to products
- Gradual reduction of kerosene subsidies
- Guarantees for micro credit schemes

Donors can play an indirect role - by funding programmes to educate target groups, helping to guarantee a minimum quality level of the systems and supporting micro-credits. But they should also avoid subsidizing equipment.

It must be repeated: neither donors nor governments should consider pico solar PV systems as a substitute for full rural electrification, nor should the population benefitting from the growing availability of these consumer products be necessarily considered electrified.

6.5. Key market actors: what to do and what not to do.

Recommendations for the key market actors are provided below:

Market actor:	What to do	What not to do	Comments
Governments	• Provide and disseminate reliable information: pros & cons • Establish and support a fully transparent QA scheme • Link QA products to soft loans	• Do not interfere with market by direct subsidies • Reduce subsidies for kerosene etc. • Consider an area / HH covered by pico PV systems as electrified	Establish an enabling framework but stay out of the market. Only nominal payment for a test-label for a product. Micro-credit schemes can be backed by government guarantees.
Finance sector	• Provide micro-credit to QA products • Accept pico PV as collateral via retailers	• Leave administration of micro-credit to retailers/NGO's – otherwise transaction cost will be too high	Micro-credit to be administered by retailers or NGO's. Minimum down payment of 25%-30 % to back collateral.
Certification institutes	• Simple test-labeling QA scheme including follow up testing	• Do not introduce non tariff trading barriers by certification procedures	Any measure increasing transaction cost must be justified by economic gains, such as improved life cycle costs.
Commercial/retailers	• Try to establish industry	• Do not push people	Most pico PV dealers would

	associations with code of conduct	working in the informal sector out of business without giving them a genuine chance to become formal members of the sector	prefer to have a proper, registered business but they would need an affordable shop and, for example, two years VAT exemption.
Customers	• Ask the dealer for a guarantee period of the product	• Do not take a micro-credit where the payback period is longer than the lifespan of the product	Poor people risk entering a poverty trap if they spend money servicing an uneconomic loan.
Donors	• Support all the above measures via capacity building and funding	• Do not subsidize hardware • Do not consider this the means to achieve electrification goals	Subsidizing hardware is distorting markets and does not benefit poor people

Women could be a powerful driver in promoting the use of solar pico PV systems. They are the main users of dirty and dangerous kerosene lights and hence can more easily be convinced to change to a cleaner lighting system.

7.2 SWOT analysis

As with any new product or product range, pico solar PV systems have their strengths and weaknesses and also provide new opportunities and experience barriers. A preliminary SWOT analysis has been performed that may be helpful to guide the policies required to support their introduction.

SWOT analysis of Pico PV systems

STRENGTHS • Portable PV system • Expandable, so extra services can be supplied • Much lower costs than SHS, so larger target group • No risk of "solar trap"	**OPPORTUNITIES** • Millions of households will not be connected to grids in years to come • Combining mobile phone payments with phone charging
WEAKNESSES • Output relatively modest • For majority of potential users credit sales still required • System has to be put in the sun manually	**THREATS** • Devices can easily be stolen • Quality assurance must be provided

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