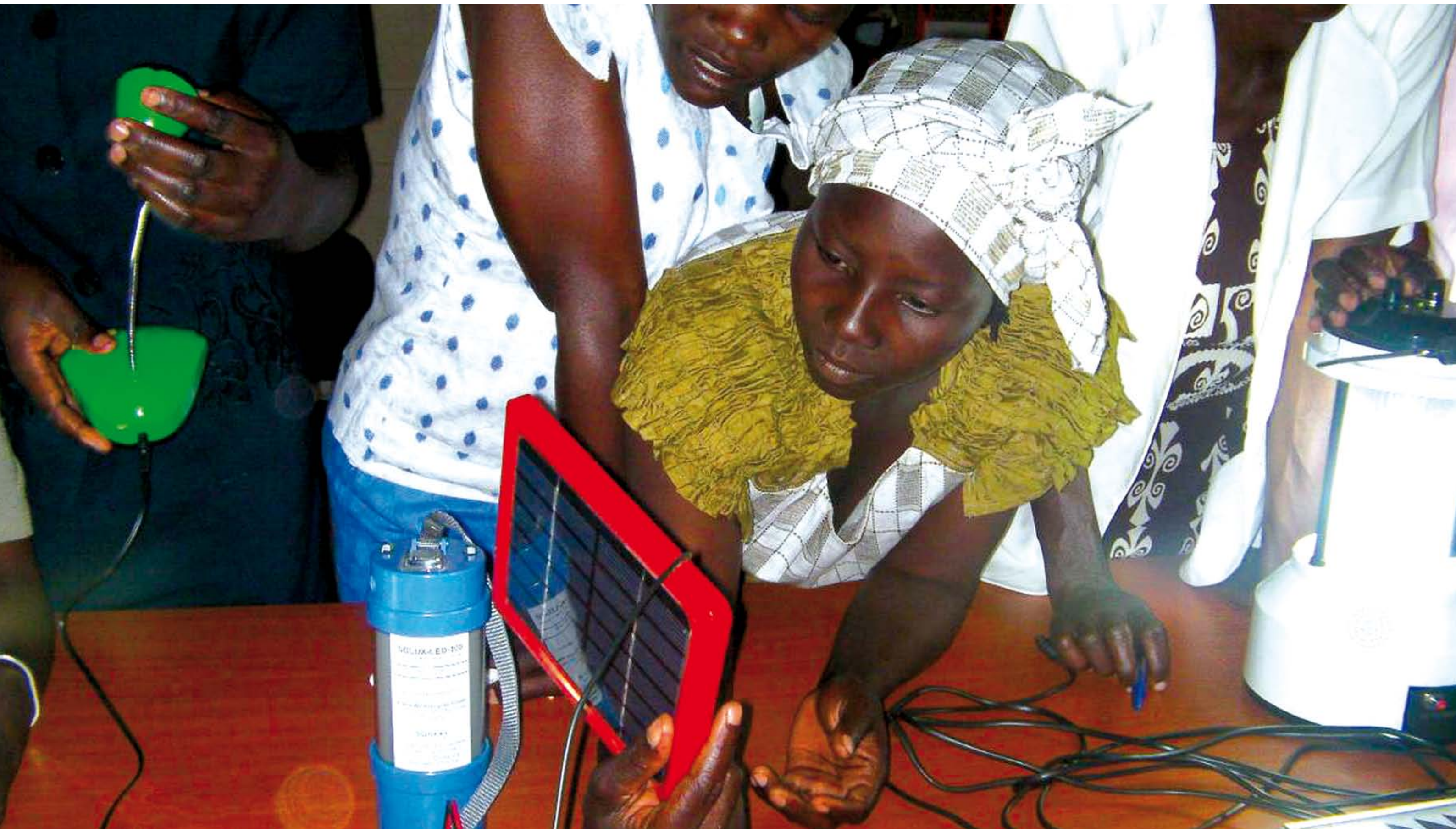

What difference can a PicoPV system make?

Early findings on small Photovoltaic systems – an emerging low-cost energy technology for developing countries

gtz

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The present publication is the short version of a comprehensive report on Pico PV, which will be published in the second half of 2010 on www.gtz.de.

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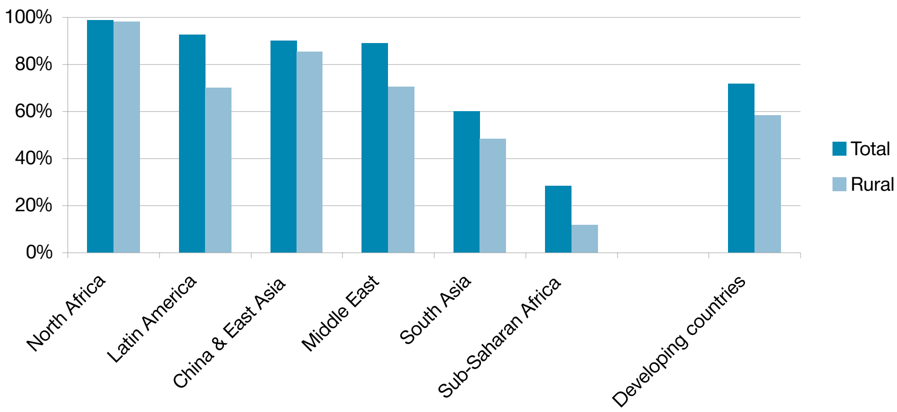
1. Introduction and Rationale

Every fourth human being is without access to electricity today.[1] Electrification rates are the lowest in Sub-Sahara Africa (SSA), but rural access rates remain surprisingly low even in countries with high GDP and impressive overall access rates. The fact that rural access rates are lagging behind across all countries and regions reflects the fact that costs of traditional grid electrification grow exponentially with falling population rates (and load) density.
At the same time, access to modern energy for cooking, lighting and ICT is a social, political and economic priority to households and policy makers because of its direct socio-economic and environmental benefits, as well as the indirect benefits of energy as an important input factor to growth and the Millennium Development Goals (MDGs). In spite of the growing recognition of this fact, progress remains slow as governments and the private sector lack funds for the substantial investments needed for electrification, and household budgets are often too small to pay full cost recovering connection fees and/or tariffs. Wherever clusters of users without service can be reached by grid extension or "densification"[2] it is clearly the most cost efficient - and usually the fastest - way to increase access rates, especially in countries with well functioning public or private utilities. Grid electrification is perceived by the vast majority of households as the "gold standard" of electrification, partly due to rational arguments (the price per kWh is low; typically users are allowed to draw unlimited amounts of energy;[3] alternatives may have shorter service guarantees) and partly to psychological effects (connotations of social status, inclusion and an urban, modern lifestyle).
Nevertheless, in reality rural grid users often continue to use surprisingly low electricity amounts on the long haul (average values below one kWh per day are frequent in rural areas in least developed countries (LDC)!), as they typically use it exclusively to power 2-5 lights, TV, radio and sometimes a cell phone.

Picture 1: Children reading with candle light.

For these "typical rural households", the electricity amounts generated by small, decentralized alternatives to grid power would therefore often suffice. In addition, off-grid electrification is the least cost option today for most unconnected LDC users who live more than 5 km away from a small town or an existing LV grid. The exact market size has not been quantified to date, though. Diesel generators are the most widely spread off-grid technology in use today, and will remain the source of choice for micro-enterprises that need AC power for their production processes (such as grinders or soldering machines). However, increasing fuel prices and environmental concerns make renewable energy powered alternatives increasingly attractive. Wherever sufficient hydro or wind potential with adequate load curves (or sustainable biomass stock) is available close enough to populated areas, much lower specific energy costs can be achieved than with solar systems under the current market prices, in spite of the considerable engineering and operations and maintenance (O&M) efforts involved with both.
Due to the highly site-specific nature of all other renewable power sources, solar powered off-grid options are the only economically viable option for all dispersed users in LCDs today.[4] Yet, currently available PV solutions for household level use in LDCs – the so called solar home systems (SHSs) – are not affordable for the vast majority of these users and this is not expected to change in the next decade (in spite of falling photovoltaic (PV) prices). This is because many developing country markets remain inefficient

Diagram 1-1: Electrification Rates in Selected Regions. Source: IEA Electricity Database 2009.



on the retail side and SHSs require expensive logistics. For example, the retail price of a typical 50Wp SHSs (enough to power the small rural household load defined above), including installation costs, varies from 400 US$ in some Asian countries to more than 1,000 US$ in SSA (Table 1-1).[5] It has to be noted that the low-end of this price range can be encountered in countries where SHSs can be sold in densely populated areas (e.g. Bangladesh). Here retailers can reach many customers per day, as opposed to more remote areas typical for Latin America and Africa, where it can take up to two days to reach one household! This SHS price range corresponds to levelled lifecycle costs of about 3-10 US$ per month (the NPV of SHS replacements is typically around 50% of the initial investment). This compares to typical monthly expenditures in the range of 3-15 US$ for lighting and ICT in rural areas in developing countries, depending on the country and income levels. While this seems high enough to pay today's prices of 50Wp SHSs at full cost recovery in countries at the low end of the global price range, it should be noted that (i) half of the rural income strata pays less than 5 US$/month and (ii) even less poor households often don't have enough savings to cover the very high upfront costs of SHSs (two thirds of the total NPV over twenty years). Therefore, many governments today revert to subsidies to close the gap between cost and current energy expenditures, on grounds of welfare gain and/or market inefficiencies. Such access subsidies – if designed properly[6] – can, on one the hand, have a surprisingly strong impact on poverty. On the other hand, they can lead to massive misallocations qua price distortions and have often wrecked havoc among existing local small and medium sized enterprises (SME) active in the off-grid market. Yet, even if funding for massive subsidies for grid and off-grid scale-up were available from taxes, sector levies or official development assistance (ODA), vast majorities of today's energy poor would still remain without access for the next two decades (IEA suggests 1.3 billion people without power by 2030), given that the bottom third income strata cannot afford SHSs even after a 50% subsidy buy-down.

Figure 1-1: SHS costs GNI for ten African Countries (Schweinfurth 2009).

Country	Estimated SHS cost (50 Wp; US$)	GNI / capita (US$ per year)	Cost / income ratio
Eritrea	650	160	4.06
Ethiopia	750	100	7.5
Kenya	550	350	1.57
Lesotho	1000	530	1.87
Somalia	> 800	296	> 2.7
Sudan	650	340	1.91
Tanzania	850	270	3.15
Uganda	500-700	260	2.8
Zambia	1200	320	3.75
Zimbabwe	800	387	2.07

What to do, then, with more than 1 billion poor people who will remain without electricity for another twenty years even under optimistic scenarios?!

Pico PV systems may well be part of a solution, by allowing "pre-electrification". There are several good reasons to be bullish regarding the potential of this emerging off-grid market segment:

- Pico PV prices are coming down fast.
- Pico PV systems are over-the-counter consumer products and don't need specific know-how for installation or O&M. Therefore, distribution has lower transaction costs than for all other grid or off-grid alternatives.
- The welfare gain from electrification at household level is arguably largest after stepping from flame-based lighting to efficient electric lights.
- Consumers do not fear that PicoPV lamps will bar them from future grid roll-out, as they often do in the case of SHSs.

1 IEA 2008 estimates updated to 2010 with own estimates for population growth and electrification success from 2008 to 2010. The latter was hampered by the 2008 financial crisis and the fact that energy sector revenues had to be used for new generation in many countries.

2 The term grid "densification" (sometimes called "intensification") refers to the connection of additional LV users to an existing grid in order to increase demand density and thus – hopefully – decrease unit costs.

3 It should be noted, however, that the lack of load limitation causes exploding peak costs and brown-outs in practically all SSA grids, so that load limiters, smart meters and/or decentralized backup generators (for businesses) are increasingly introduced into DC power grids.

4 In other words, while energy sector policy makers around the World are currently discussing the exact time and impact of PV (Utility) Grid Parity between 2015 and 2030, "PV off-grid Parity" is already a reality today for a large share of rural markets.

5 In some countries SHS below 100Wp are no longer available, as international manufacturers (and thus price reductions) focus more and more on larger modules for grid connected solar plants in G20 countries with feed-in tariffs.

6 A new GTZ tool can help to design sound access subsidies in practice (GTZ 2009).

2. Social, economic and environmental benefits of PicoPV systems

Modern energy services, lighting included, are fundamental to all three pillars of sustainable development, i.e. economic, social and environmental development. Making energy services affordable and accessible for consumers at the bottom of the income pyramid, therefore, offers enormous potential to contributing to inclusive and sustainable development paths for developing countries, as will be illustrated in this section.

2.1 Economic benefits for end-users

PicoPV products have the potential to help reduce users' expenditures for lighting and information and communication technologies (cell phone charging and radio) and thus relieve tight household budgets which is particularly important for families in the lower income strata in the developing world. In most developing countries, kerosene lamps, candles and battery-run torches are the most common light sources used in non-electrified areas, even though they are relatively expensive and inefficient: The cost for running the typically used low-efficiency kerosene wick lamps and candles is up to 150 times higher than for premium-efficient fluorescent lamps (Mills 2005).
Thus, poor households currently pay relatively more per lumen and per month for qualitatively poor lighting services (as a fraction of their income).[7]
Beyond this savings potential, the energy services that PicoPV systems provide to households have other economic implications. Improved lighting conditions for studying and income generating activities after dark, , the use of cell phones and radios for market information (market prices), education, social coherence and emergency situations can all enhance economic growth and reduce economic and social risks to which poor households are particularly vulnerable.

2.2 Economic benefits for micro, small and medium-sized enterprises (MSME)

PicoPV products will have economic impacts for two categories of MSME: those that sell PicoPV systems and offer after-sales services and those that buy and use PicoPV to improve their business. Much attention has been paid to the latter type in the (sparse) available literature on PicoPV: Pictures of food stalls at night "with and without" PicoPV lighting are very illustrative for any reader; clearly, bright colors and sufficient brightness will attract more customers (assuming appealing produce).
However, these firm level examples neglect the fact that welfare gains have to be aggregated over all players – and in this respect there can be losers as well as winners from the dissemination of PicoPV. For example, one food stall having a lantern may increase his sales. His neighboring competitor without electric light may become less attractive and lose clients. However, as PicoPV products fall into lower price ranges than more complex off-grid energy solutions, there is a high potential to enable large-scale inclusion of MSME into supply chains in importing countries. MSME with limited cash flows and lack of access to financial services, including the informal sector, will find market entry barriers smaller than when dealing with more complex and costly products.

However, there is again a crowing-out dimension to be taken into account: MSME selling nifty PicoPV lamps are likely to affect the sales of existing businesses currently active along the supply chain for candles and kerosene – and many retailers on the last level are micro-enterprises.
Participation in PicoPV markets requires a minimum level of know-how with regard to solar technology, as well as marketing and business management capacities. Therefore it offers opportunities for "learning-by-importing" and "learning-by-doing" to dynamic actors along the supply chain, including MSME. In addition, sustainable PicoPV markets will also call for business models that integrate financial and after-sales services with distribution, which will allow local retailers to skim higher portions of value-added.
Larger numbers of domestic businesses acting as importers and distributors in emerging PicoPV markets are also desirable from a market efficiency perspective, as chances of monopoly pricing or price discrimination will be reduced.

2.3 Health and safety benefits for end-users

Lighting with kerosene causes heavy indoor air pollution, resulting in a severe risk increase of respiratory diseases. Those who are most exposed to the kerosene vapours are typically women and children, as they are the ones who spend most

Picture 2-1: Charging a radio during a focus group in Uganda, 2009.

Picture 2-2: Boy studying in the light of Superbongo, 2009.

time inside the house. Acute respiratory infections like influenza and pneumonia kill nearly two million children in developing nations each year. In addition, the use of kerosene lamps and candles inside houses involves high risks of fire accidents. Over 95% of fatal fire-related burns occur in low- and middle-income countries.[8] If PicoPV products are widely disseminated among low-income households in developing countries, they can make a valuable contribution to improved health and safety conditions amongst the most vulnerable groups within these countries.

2.4 Improved educational opportunities

Traditional lighting devices in non-electrified areas of developing countries, like kerosene lamps and candles, do not provide sufficient lighting conditions for studying and reading (see section 3.2.1.). Literacy and school performance are often limited due to poor lighting conditions. Household access to electricity as well as to modern fuels has been found to be positively correlated with educational enrolment ratios in a global study based on country-level data (WHO/UNDP 2009).

In a comprehensive effort to measure the social benefits of improving educational opportunities and conditions in monetary terms, it has been estimated that there is a potential return of US$80–US$150 per month from provision of access to modern energy to one rural household (ESMAP 2002). PicoPV are a low-cost option for improved lighting and thus offer opportunities to improve studying conditions to large numbers of households of the lower income strata. They can thereby help enhance the educational performance in developing countries.

2.5 Gender aspects

In many countries, the provision of residential lighting falls under the responsibility of women. They bear not only the financial costs of lighting, but also the burden of bringing in supplies for lighting like candles and kerosene, which can add substantially to the work load of women in rural areas, where these fuels are not directly available in the villages. By reducing or eliminating expenses and efforts for provisioning of conventional lighting sources, PicoPV lamps can improve the financial situation, particularly in low-income households.

2.6 Environmental impacts and greenhouse gas emission reductions

Fuel-based lighting is the primary source of greenhouse gas emissions related to lighting in developing countries. 244 million tons of carbon dioxide are emitted each year through the use of fuel-run lighting devices like kerosene lamps, oil lamps, gas lamps, and candles. Finding alternative clean lighting solutions that are affordable for low-income households in non-electrified areas (like PicoPV) is therefore an important entry point for reducing global GHG emission. Within the framework of the UNFCCC, efforts to replace carbon intensive lighting in off-grid areas with clean innovative technologies fall under options to off-set Annex I countries' GHG emissions via the Clean Development Mechanism under the Kyoto Protocol. They also offer relatively low-cost opportunities for emerging economies with large rural populations (like India, China etc.) to pursue low-carbon development paths without compromising the continuous improvement of living standards.
In addition to this global ecological impact, PicoPV can also help protect local environmental resources. Battery-run torches constitute an important element of the traditional lighting solutions in developing countries, particularly for uses outside the house. PicoPV lamps have a great potential to replace torches as they are light and portable while their use involves zero running costs. Dry-cell batteries used in conventional torches involve a high risk of contaminating local water and soil resources with toxic heavy metals, notably as there are no appropriate disposal structures in place in many developing countries. In contrast to dry cell batteries, which have a lifetime of only 2-20 hours, the batteries that are used in PicoPV products last much longer and result in fewer battery disposals. Therefore, the large-scale dissemination of the innovative devices can help preserve local environmental resources, which in turn present important livelihood bases for rural communities.

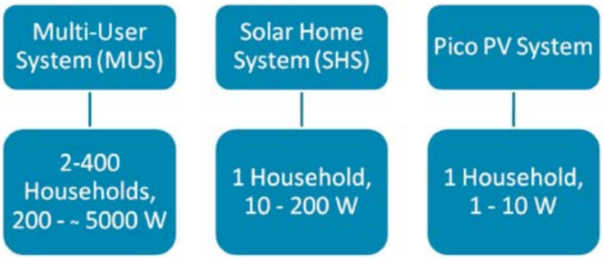
7 Furthermore, it has been discovered that within the target group of poorer households the expenditures for kerosene are as much as 10% of overall spending of the household. Therefore, the economic benefits for solar lighting systems in comparison to the traditional kerosene lantern should become favourable within a reasonable time frame. A comparison of the lifetime costs shows that a LED-solar lantern breaks even against kerosene lantern within a year assuming the monthly kerosene expenditure is US$ 2.4 (Stanford University 2003).

8 http://www.who.int/violence_injury_prevention/other_injury/burns/en/

3. Classification of off-grid PicoPV systems and lighting technologies

PV off-grid systems are mainly defined through power dimension and the number of users (Mitja et al., 2003). All systems include one or more solar modules of different sizes and various appliances. Frequently used categories are multi-user systems (MUSs), solar home systems (SHSs) and the very small PicoPV systems.

Fig 3-1: Off-grid PV technologies. Source: GTZ.



MUSs have, compared to SHSs, several advantages, e.g. lower system cost per household, the sharing of maintenance costs among several households and increased performance. Nevertheless, the operation is more complex as several consumers are involved (Vallve et al., 2001; Schweizer-Ries et al., 2000). Because of relatively high system costs, SHSs are used mainly by middle and and upper class households in developing countries (Jacobson, 2007). In contrast to relative expensive SHSs, the downsized PicoPV systems offer low-cost energy access for low income households.

PicoPV systems are small independent appliances providing light and/or additional small electrical services, such as radios, mobile phone charging, mp3 player, etc. They are powered by a solar panel and use a battery for electricity storage. Mainly, the use of PicoPV systems allows the substitution of traditional light sources like inefficient and relatively dark kerosene lamps. There is an intersection to small lighting or multi-functional electric devices without solar power supply. Some systems can be charged by standard plugs served by AC-power from electricity grid, too, or normal batteries can be used instead of rechargeable batteries.

PicoPV systems can be categorized according to their appliances and the respective energy services they provide. Accordingly, The classic solar lantern which provides mainly lighting service constitute one category and are to be distinguished from multifunctional systems which provide lighting as well as additional services. Bigger PicoPV systems allow for operation of external devices as well.

Alternatively PicoPV systems can also be categorized according to their main lighting use (task light; outdoor light; room light) or according to whether the PV module is integrated into the lamp, linked by a cable – or centralized in a nearby charging station for many lamps at a time ("Solar Battery Charging Stations" as piloted in Brazil and Nicaragua in the late 1990s and early 2000s, or energy kiosks / hubs as implemented recently in Asia and SSA).

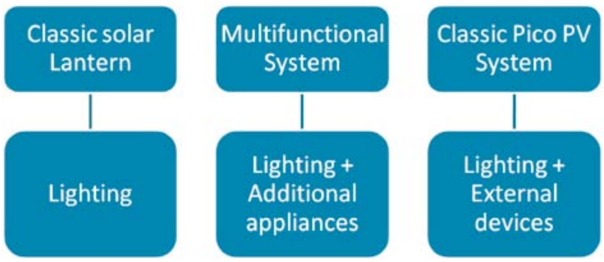
3.1 PicoPV Uses: Lighting and ICT

End-users of PicoPV systems are not primarily interested in electricity generation itself, but rather in the energy services they provide. Efforts to reduce costs and to improve quality should therefore not be limited to the generation of electricity but on the appliances that translate electricity into energy services (Adelman 2006). In fact, the most important component of a PV system is the appliance as it determines the end-user's utility and the overall quality of the system.

3.1.1 Lighting

The primary purpose of PicoPV systems is to provide lighting services which in turn can be used in diverse ways. For instance, a 360°- light source can provide indoor illumination for private houses for domestic work and socializing, while a smaller light cone or a concentrated ray may be better suited to support actions where high light intensity is needed in one spot, such as for reading or handicrafts, and a light of little power, but little energy consumption, may be sufficient as night light. A PicoPV system can be equipped with various lighting technologies. Compact fluorescent lamps (CFL) are based on the same functional principle as standard fluorescent lamps, but are more energy efficient than the latter as they work at a higher internal pressure, are smaller and have a higher illuminating power. At present the light emitting diode (LED) technology seems to be the most forward-looking option. A LED is an electronic semiconductor element which emits light. Although this light source still lacks behind the light output of energy-efficient CFL, LED lamps consume less energy, while their quality standards are improving at a fast pace. Both CFL and LED bulbs outperform by far the traditional lighting technologies based on kerosene, biomass, diesel, propane and wax (used by 14% of urban households and 49% of rural households in the developing world IEA 2002 cited in Mills 2005), in terms of output of lumen per watt.

Figure 3-2: PicoPV systems: Energy services. Source: GTZ.



3.1.2 Lighting Ergonomics

85% of the information an average human being takes in with his senses is absorbed by the eyesight. Good lighting supports the handling of activities which require high concentration. It also helps to prevent work-related accidents as potential dangers can be identified much better and earlier. Improved lighting increases the quality of work and of products and reduces mistakes. Furthermore, it contributes to humane and adequate working conditions by making difficult tasks more acceptable to the employees.

Bad lighting, in contrast, does not only reduce the potential output of labour in an enterprise, but can also lead to health hazards and affect the long-term productivity of staff. Tiredness and bad concentration are often named as a result of bad lighting (HMWVL, 2005). A bad level of lighting during work time can also lead to visual fatigue and a high level in general tension. Furthermore, different studies have found that light is not only important for human well-being through its visual function; optical radiation and the non-visual radiation (UV and IR radiation) also influence the release of hormones in our body, our psychology as well as the general health. In more general terms, good lighting is part of humane and adequate working conditions and an important factor for human well-being.

The optimal level of lighting depends on the visual activity which is required for doing a particular task. As a general rule, a horizontal illuminance of at least 300 lux is recommended for workplaces. Research has found that the danger of causing accidents increases rapidly if illumination levels fall below 300 lux. For certain activities where high concentration is required (in particular office or laboratory work) an illumination level of at least 500 lux is recommended.

The above mentioned regulations on illuminance levels for different tasks are set in the context of grid based lighting services in G8 countries. They do not offer appropriate standards in the context of basic lighting needs addressed through micro lighting systems which replace kerosene lamps or candles in developing countries. Nevertheless, minimum brightness levels for systems promoted by development cooperation programmes should be defined.

3.1.3 ICT appliances

An increasing number of mature PicoPV systems provide additional energy services through various appliances which can be integrated in a multipurpose system or connected as external devices through a plug. The presently most common and popular appliance is a mobile phone charger which is either connected to the main device (the lamp) through a cable for charging from the battery, or directly to the module. These systems usually come with a set of different phone charging pins intended to cover a range of the most widely spread mobile phone types.

Many models of PicoPV systems also allow for the operation of other small electric devices such as a small radio, small loudspeakers, or a MP3-player. In general, the size of the module and the storage capacity of the battery determine the range of electric appliances which can be connected to the system. If required even a small TV or a little fridge can be operated. One example is the seven inch solar LCD Colour TV of Free Energy Europe which consumes less than 10 W per hour. In addition, various standard plugs USB-ports are also on the rise. They facilitate the operation of a huge range of small USB-devices like for example small fans.

Our recommendation: We recommend a minimum illumination level of 20 lux (on a surface of at least two typical sheets of writing paper (0,125 m² = DIN A3) for task lights and portable lights in Developing Countries. By contrast, room lights should provide a minimum illumination of 50 lumen (comparable to the brightness of a petroleum wick lamp). To reach a satisfying level of light in one household, we recommend a minimum of 300 lumen (comparable to a 30 W incandescent bulb) which may require more than one lantern.

4. General market aspects

4.1 The market for off-grid PV

The off-grid PV market in developing countries is half commercial, half donor-driven. Interestingly, while commercial market development tends to target the low end of the market (poor HH, low cost), donor driven projects often contrary to overall objectives, seem to reach only richer households (van der Vleuten 2006). This fact may be related to the ambitious minimum requirements of most government electrification policies. In 2000, about 1.3 million households in developing countries used solar home systems (SHSs) or solar lanterns 0.4-0.5 million of which were procured through donor driven projects (Nieuwenhout, 2002).

The most mature off-grid PV markets exist in India (450,000 installed SHSs), China (150,000 SHSs), Kenya (120,000 SHSs), Morocco (80,000 SHSs), Mexico (80,000 SHSs), and South Africa (50,000 SHSs). Kenya and China are by far the fastest growing markets, with annual growth rates of 10% – 20% in recent years. Many of these countries also manufacture components for SHS, such as batteries, controllers, and lights. In 2002, PV module manufacturers existed in India (23 firms), China (7 firms), Thailand (3 firms), and Namibia (1 firm). PV cells are manufactured in India (9 firms) and China (7 firms). In recent years, the manufacturing base in China has grown exponentially. Gabler (2008) and Photon (2008) estimate for 2007 that newly installed off-grid PV capacity in Developing Countries lies at around 50 MWp per year (compared to 150 MWp global annual market volume for off-grid PV – including off-grid PV for recreational uses and industry, such as telecom repeaters, worldwide). At system prices of about 10 €/Watt, total turnover in Developing Countries can be estimated to account for 0.5 € billion.

4.2 The market for PicoPV

The current market size as well as the future market potential for PicoPV is difficult to predict at this point in time, as data on demand response does not exist. However, a simple "back of the envelope" calculation allows getting a first idea of the potential market size: one could take the roughly 1.5 billion people currently without modern energy and assume that this corresponds to about 300 million households which are currently using traditional low performance lighting at high costs. If we are right in our predictions for cost reduction, all of these would (theoretically!) profit from a fuel swap, and many would be able to afford the US$30 entry level products which will be available soon. Thus the potential theoretical market size is 300 M x 30 US$ or 9 billion US$. Once early findings on demand response and market penetration rates will become available, realistic market estimates and growth rates can be calculated, which would also factor in households buying more than one lamp and urban customers.

Picture 4-1: Auction of lamps in Nicaragua, 2009.

Box 4-1: Off-grid PV in India, China and Kenya

In India the PV market began to develop in the 1980s, supported by a governmental program composed of subsidies, tax, and financial incentives. The large part of the PV market is made up of subsidized SHS. However, with increasing market volumes, commercial, market-orientated approaches are also on the rise, as well as investments by manufactures in dealer and distributor networks. PV markets on commercial terms developed especially in China and Kenya. In China business markets for PV products concentrate mainly in the north-western provinces and autonomous regions of Qinghai, Xingjian, Tibet, Inner Mongolia, and Gansu. In these regions, a moderate developed solar industry and infrastructure exists for installation, distribution, and maintenance of solar systems. In Kenya most SHSs are sold for cash. Kenya's PV market is considered to be the prime example for donor initiated PV market development (Martinot et al., 2002).

5. SUPPLY: Assessment of Quality and Cost

5.1 Quality

5.1.1 Market survey

Currently, more than 50 PV lamp models are available on the market. The majority of them are manufactured in China, followed by India, the USA and Germany.
A majority of the lights are equipped with low power LEDs (< 100 mW/LED) instead of power LEDs (≥ 1 Watt/LED). The available data sheets of the products show a light output in a range from 13 to 350 lumen, with the majority of the systems delivering a luminous flux of only 15 to 50 lumen. According to manufacturers' product information, lighting durations with fully charged batteries range from 1 to 24 hours.

From the long experience of GTZ in testing lighting systems, the technical data given by the manufacturers tend to be very optimistic. Burn-time information often refers to extremely low illuminance levels, at which a lamp is practically unusable. Also the luminous flux as per manufacturers' specifications was often calculated from LED datasheets without considering light distribution losses (reflectors, diffuser foils) and temperature influence.
There are different types of batteries used in the systems, lead-acid and NiMH batteries being the most common types, while Li-Ion batteries are presently used only in few cases. Battery capacity ranges from 20 mAh in a crank-charged system to 7,200 mAh for a combined Solar lantern-Solar Home System. Many systems are not equipped with a charge controller.
The PV panels for the lights are mostly made of polycrystalline- or mono-crystalline silicon. The nameplate power ranges from 0.3 Wp for a solar lantern with an integrated panel up to 12 Wp for the combined system. The majority of the systems are equipped with panels from 1 to 3 Wp.

5.1.2 Standards and norms

The differences of the product quality found in the market survey underline the need to inform potential consumers about lantern quality and to define standards and norms to make the quality of consumer goods comparable. The only existing proposal for a quality standard regulation for solar lamps (PVGAP PVRS 11/11A) covers only CFL based lights; it is also relatively complex which constitutes a hurdle to its application through laboratories in developing countries. In the case of LED lighting systems, such standards are missing.
As a result, no established norms for PicoPV lamps and kits exist today. Therefore, GTZ and Fraunhofer institute started working on an extensive literature review on specifications for comparable products, early work on LED-based portable lamps, and assembled general quality criteria for such products as the basis for the detailed test method which was applied in Lab tests.[9] The table below illustrates recommended quality parameters for PV lanterns. They cover three main "groups" of requirements for customers with respect to the daily use of LED lighting systems (lighting service, usability and durability).
The lab tests carried out by Fraunhofer demonstrated that many solar lanterns did not fulfil these requirements. Main problems were:

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

Thus, the quality of most solar LED lamps available in the market today is still very low. Over the next 2-5 years many customers are likely to buy low quality products due to the absence of sufficient information. At the same time, the prices of current products are still too high to allow for massive market penetration.

5.2 Cost

To assess the price-worthiness of PicoPV products available in the market today, and to get an idea of the price range for which they will become a serious alternative for many end users, GTZ analyzed three dimensions of costs for a PicoPV lighting devices tested in the lab, namely:

i. the initial investment, i.e. the lamp price,
ii. monthly cost, i.e. initial investment divided by lifetime,
iii. lighting service cost, i.e. initial investment divided by lighting output measured in kilo-lumen-hour.

The initial investment ranged from (36 US$ to 120 US$). Such relatively high initial investment costs will prevent a large-scale diffusion of PicoPV lamps among low income strata for the time being, given their severely restricted household budgets (typically US$ 2-5 per month for lighting, with no buffer for savings) and lack of access to financial services.
In contrast, monthly costs are low (2 US$ to 9 US$, except for the poorest price performer) in comparison to running costs of kerosene wick lamps and candles (2-5 US$), not taking into account their inferior lighting output.

9 Grüner, Roman; Lux, Stephan; Reiche, Kilian; Schmitz-Günther, Thomas: Solar Lanterns Test. Shades of Light, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Eschborn Mai 2009.

In terms of lighting service costs (0.10 US$ to 0.60 US$ per kilolumenhour), good PicoPV lamps perform much better than all traditional lighting alternatives, except for the kerosene pressure lamp (which in turn is as expensive in monthly cost and initial investment cost similar to most PicoPV products).

Due to the fundamental advantage of low lighting service costs, and in consideration of falling LED prices and increasing - and volatile - fossil fuel costs (further enhanced through carbon emission reduction targets)[10], we expect this nascent market segment to take off massively over the next five years.

Table 5-1: Lamp features recommended by GTZ / Fraunhofer PicoPV lab test.

Criteria	Issue	Remarks
Basic components	• Plug • load controller	Plug for external devices, such as radio, mobile etc.
Performance	Daily burn time (Duty cycle)	3 hours of light per one day recharge
Performance	Maximum run time	6 hours of light with full battery
Brightness	Enough to read; to illuminate a room; clearly brighter than regular oil lamp	Illumination: min. 300 LUX (on a table e.g.) Lumen: min. 150 lumen! (oil lamp)
Manual	Manual must be provided in English language (Comics and language of user better)	• operation • maintenance • DOs and DON'Ts
Guarantee	Producer must issue a guarantee on performance and lifetime of lantern and its components	2 years
Ambient condition	Lamp must cope with typical ambient conditions and ensure required performance	• bright sun • dust • insects • water • humidity • Temperature: -5 °C – +45°C
Lifetime	Light	At least 1000 switches and operation of 2200 hours? no blackening of more than 10%[11]
Lifetime	Battery	Load cycles: 750 (= 2 years with 1 cycle per day) -> performance requirements must be fulfilled Battery must be stored fully charged free of damage: 20°C -> 6 months; 30°C -> 4 months; 40°C -> 2 months
Lifetime	Panel	PV Panel must be scratch resistant. PV panel must show certified performance of 90% after 5 years.
Durability	Switches, plugs and all other moving parts	Must withstand 1000 cycles and function
Energy efficiency	Luminous efficacy	The luminous efficacy of the lamp, inclusive of the power requirement of the inverter, must be either: (a) greater than 30 lumens/watt with any reflectors, lenses, covers or grids (if used) in place; or (b) greater than 35 lumens/watt without reflectors, lenses, etc in place.
Labelling	Every lamp must show basic information	- main tech. Details (for light, plug etc.) - manufacturer - serial no. - model no.
Energy efficiency	Energy losses with no operation	No electricity losses shown with light switched off.
System protection	Components need electrical protection resp. charge control	battery must be protected against deep discharge (Active charge controller for Lead Acid and Li-Ion Batteries) - battery must be protected against overcharge - PV panel must be protected against reverse polarity
Shipping	Suitable packing	Vibration resistant

6. DEMAND: Results of a Field Survey

Based on the results of the lab tests, GTZ/EnDev supported field studies with lantern of higher quality in Bolivia, Nicaragua, Mozambique, Senegal and Uganda between 2008 and 2010. The goal of the field studies was to gain insights on the following questions:

- Which lamp types / designs / sizes / colours / lighting modes are preferred by local customers?
- How do the lamps perform in everyday use by typical target groups in terms of our main lab-test criteria (durability, functionality, light output, etc) and other relevant criteria we may not have thought of?
- Which other lighting means are used before/in addition to after the introduced PicoPV and at which prices?
- Can evidence for socio economic impacts of the new lighting device on the user / household / area be found?

It has to be noted that sample sizes in the field tests were small and the applied methods of this early pilot have not been meant to produce academically valid results.

6.1 Field Survey Results

In the country surveys four main field survey instruments were employed which were developed specifically for the purpose of the PicoPV study:[12]

i. Focus Groups with users, local authorities and potential vendors in different geographical regions of each country to cover the full range of socio-cultural and economic diversity.
ii. Field tests: The most interesting lamp models are disseminated to a sample of test users, either through household rotation where families get to test and compare all lamp models in turn, through a locally appropriate sale model, or through a lending model;; ex-ante and ex-post user opinions and observations are collected with standardized questionnaires.
iii. PicoPV "Dutch Auctions", where target consumer groups were invited to purchase selected lamp models, indicating their willingness to pay (WTP) through a bidding process.
iv. Expert interviews with local authorities, business owners (to get insights into the views of potential vendors) technicians and religious and spiritual leaders.

6.1.1 QUESTION 1: Which lamp models do users prefer?

The GTZ PicoPV country survey results underpin that an 'all-size-fits-one' lamp model does not exist. The lamp models were rated differently by users across different continents, and they were liked and disliked for different reasons. However, there are some aspects that turned out to be important for consumers in all the test countries.

Above all, light quality, including the size of the light cone and light intensity, mattered most to the majority of respondents. Apart from that, in Latin America it was the radio function that made people like certain lanterns, whereas for African consumers the phone charging function was considered more important. Another selling point for lamps in Uganda was visual resemblance of the kerosene lanterns that are conventionally used there. For these reasons, people felt that the solar lamp could directly replace the traditional model and therefore perceived it as particularly useful and relevant.

Another result that emerged from the research was that consumers are highly suspicious of poor quality products that have only a short lifetime. Even among poor households there is a willingness to pay for quality, and there is evidence that the target consumer groups do think ahead and are not interested in products that may be relatively cheap but have to be replaced after a short time. There is also concern among all potential retailers that maintenance and repair services may be a major hurdle towards the development of PicoPV markets in rural areas, where there is no local expertise on these new kinds of products.

The field survey also revealed certain reservations by different consumer groups against some visual design features that will have to be taken into account for any successful PicoPV marketing strategy. For example, people had very particular positive or negative associations with certain colors or forms which might have an impact on their purchasing decision even though they said that these product features were not decisive factors. One lantern, for example, reminded Ugandan women of a camera, which limited its attractiveness, while in Nicaragua people particularly liked the handy format of the lamp.

Picture 6-1: Lamps tested in the field survey.

10 GTZ Furel Price Index 200-2009.

*11 2200 hours = 365 days * 3 hours (duty cycle) * 2 years (guarantee) may vary with different performance and warranty requirements!*

12 The World Bank Group's Lighting Africa Programme as well as ESMAP/SME-funded projects in Bolivia and Nicaragua provided inputs to some sections of the baseline questionnaire.

Table 6-1: Results of the solar lamps auction in Arua town/ Uganda (prices in US$)

	Initial auction price	Purchasing price
Aishwarya with radio radio	73	57
Aishwarya without radio	62.5	34
Solux LED 100	151	75.5
Freilassing +radio	177	88.5
Solux LED 50	52	not sold
Solata	23	not sold

In Mozambique, one of the lamp models was described as "masculine" so that women would hesitate to use it. In Uganda, white is associated with religious ceremonies like funerals and therefore not regarded an appropriate color for a lamp.

6.1.2 QUESTION 2: Did lamps perform in everyday field use?

In general, it can be noted that overall the tested PicoPV lamps proved robust and performed well during the field trial. Here again, an interesting observation is that the performance of the same lamp models was not the same across all countries due to the specific local conditions.

Picture 6-2: User charging a solar latern.

6.1.3 QUESTION 3: How much are users willing to pay?

The willingness to pay for PicoPV products in general, and for certain lamp models in particular, differed enormously between the countries. African users indicated a higher willingness to pay than users in Bolivia and Nicaragua (again, leaving much room for future validation of applied methods and ways to account for potential behavioural differences between survey countries). The figures obtained through Dutch auctions indicate a WTP of 50-90 USD for lamps of the highest value class from a consumers' perspective. Lanterns falling into a medium value category were bought at 25-50 USD. The remaining lanterns were sold for 5-25 USD.

In spite of these high willingness to pay indications, a central finding from all the country surveys was that many households at the bottom of the income pyramid, which are in fact the main target population for PicoPV lamps, often lack the required cash availability. Even though the purchase of a lamp would pay off within a few months due to savings on running costs of conventional lighting solutions, consumers, notably in rural areas, mostly do not have the cash available to pay the upfront investment and have no access to financial services which could support by-passing this problem. This is a major a hurdle for the large-scale distribution of PicoPV lamps in LDCs. This is particularly true for the more expensive PicoPV lamp models, which range between 80 and 150 US$ per piece.

A consumer credit scheme piloted in Uganda suggests that offering the possibility of payment in rates enhances affordability of the lamps by rural households tremendously.

The willingness to pay (WTP) figures collected in the GTZ PicoPV field survey by far exceed the respective figures resulting from household surveys under the Lighting Africa Market Research programme. This high deviation may be partly due to the very different research approach used by Lighting Africa in this part of the survey, where households were asked to indicate their WTP statements for different lamp types without having had a chance to test-use them.

Table 6-3: Results from Lighting Africa Market Research – Monthly average running costs per household for different lighting devices (US$).

	kerosene	candles	batteries
Ethiopia	4.2	0.3	0.9
Ghana	5.6	1.4	2.3
Kenya	10.9	0.8	1.4
Tanzania	7.5	1.5	2.3
Zambia	8.2	4.7	2.3

Table 6-2: Household expenses on conventional lighting devices and degree of substitution through PicoPV lamps

	degree to which conventional lighting is substituted by solar lamps	monthly expenses (running cost) for conventional lighting devices	monthly duration of use of conventional lighting devices
Bolivia	66% of test users completely abandoned the use of candles; 59% reduced or completely abandoned the use of kerosene lamps; 90% reduced or completely abandoned the use of batteries.	candles – US$ 2.3 kerosene – US$ 3.2 batteries – US$ 5.9 total (hh average)[13] – US$ 9	hours of use of traditional lighting devices per month[14]: 110 -120
Nicaragua	93% of test users substituted traditional lighting devices (candles, kerosene lanterns) by 100%.	candles - US$ 3.7 US$ 4.8 batteries for torches (linternas) – US$ 3.2 batteries for lamps (lamperas) – US$ 1.6	duration of use / month candles – 61h kerosene lamps – 92h battery torches (linternas) – 61 h battery lamps (lámparas) – 70h
Uganda (NACWOLA test users)	90% of test users completely replaced their formerly used lamps.	candles – US$ 4.7 kerosene – US$ 8.2 batteries for lanterns – US$3.7	candles – 57h kerosene lamps with glass cover – 114h kerosene lamps with single wick – 214h light bulb in socket – 102h battery lanterns – 94h battery torch – 62h

6.1.4 QUESTION 4: What socio-economic benefits did users experience?

As part of the baseline analysis of the GTZ field surveys, households were asked to specify their monthly expenditures for conventional lighting devices, whereas the ex-pot survey assessed to which degree the PicoPV lamps had replaced the use of these traditional lighting devices. The finding across countries was that PicoPV lamps have a true potential to substitute conventional lighting sources to a large degree. The associated substantial savings (and poverty alleviation) potential through the use of PicoPV lamps is underpinned by both the GTZ field survey data on lighting costs and the respective Lighting Africa Market Research results from the large-scale household survey in part II of the research project (n=1000 for each country)

Kenya (ITC)

In a study conducted by ITC in Kenya in 1998 people in urban and rural areas were asked for what purpose they would use solar lanterns: The main priority was given to (1) ambient lighting in households. This was followed by the desire for (2) studying and reading, using the light to (3) conducting housework during the dark hours and improving the (4) perceived security by having bright light in or in front of their houses. The least importance was given to (5) business. If only rural areas had been taken into account security would have had the lowest ranking (ITC, 1998).

The ITC survey was the first step to discover what customers would expect from their solar lantern. Out of these findings the “Glowstar”-lantern was developed.

6.2 Field Evidence - Others

Besides the studies mentioned above, market research on Pico PV systems is limited and has so far focused on lighting appliances such as solar lanterns. As rural customers expect more than only light but also other energy services as mobile phone charging or radio, existing studies could be seen as somewhat one-sided.

13 The total average monthly expenditures on lighting per household does not correspond to the sum of the average monthly spending on particular lighting sources because not all households use all of them.

14 i.e. the number of hours for which households use at least one traditional lighting source.

Box 6-1: Ranking of preferred features of solar lanterns, Kenya (ITC, 1998):

Service characteristics:

- The maximum price of the lantern should be no more than $75.
- The lantern should provide light for up to 4 hours each evening.
- Customers should have access to affordable and readily available spares.
- Customers expect an overall lifetime of the lantern of 6 years.
- Customers expect a 12 months warranty for the product.

Design characteristics:

- The lantern should spread the light over 360°.
- The bulb enclosure should allow maximum transmission of light.
- The carry handle should be sturdy and comfortable.
- The preferred choice of bulb is a 5W CFL.
- The lamp should be portable and weigh no more than 2.5 kg.
- The lantern should be stable with a good base.

Some of the extra features that potential customers expressed a need for were:

- An indicator to show that lamp is charging,
- A warning light to show that the lamp is about to switch off when the battery is low,
- A power socket to allow a small radio to be connected to the unit.

India (Stanford University)

A survey (Stanford University 2003) which summarises experience from various states of India indicates that the rural population uses kerosene to a large extent for lighting of approximately 2-4 hours per day. Given that 60% of India's population live in rural areas, there is a vast market potential for PicoPV, which can cut household energy expenses by replacing fuel-based lighting. The survey also found indication of demand for PicoPV among those parts of the Indian population which have access to the grid, as power supply in most rural areas is highly unreliable. PicoPV may serve as a back-up during power outages for this consumer group which is marked by higher income levels and has a demand for higher quality energy services.

The survey also brought to light that most target customers would not be willing to pay 100% up front in cash for purchasing a system. However, these results vary extremely between various regions. Some of the interviewed groups would prefer some form of microfinance option through retailer financing, village co-operatives or saving groups.

Tanzania (GTZ)

From GTZ experiences in Tanzania, it has been observed that customers prefer to have a switch installed in the house rather than a portable system. Even if it provides only very basic services, there was a preference for small solar home systems at least if they are affordable. Furthermore, a disadvantage of portable systems has been that they can be stolen easily in comparison to a fixed system in the house. A crucial point has also been the recharging of solar lanterns. As they are usually placed outside and oriented to the sun in the morning and remain in the same position throughout the day, the full charging potential cannot be achieved.

Table 6-4: Willingness to pay for PicoPV systems in India (Stanford University 2003).

Istallment Size	% surveyed expressing preference
Rs. 100 or less	29-31%
Rs. 150	14-22%
Rs. 200	34-37%

7. POLICY AND MARKET

Arguably the most important result of the field studies is that PicoPV lamps will probably reduce a far larger fraction of traditional lighting expenditures than expected: Field test users in Uganda, Bolivia and Nicaragua have reported decreases of 60 to 90 percent of previous expenditures on traditional lighting sources.

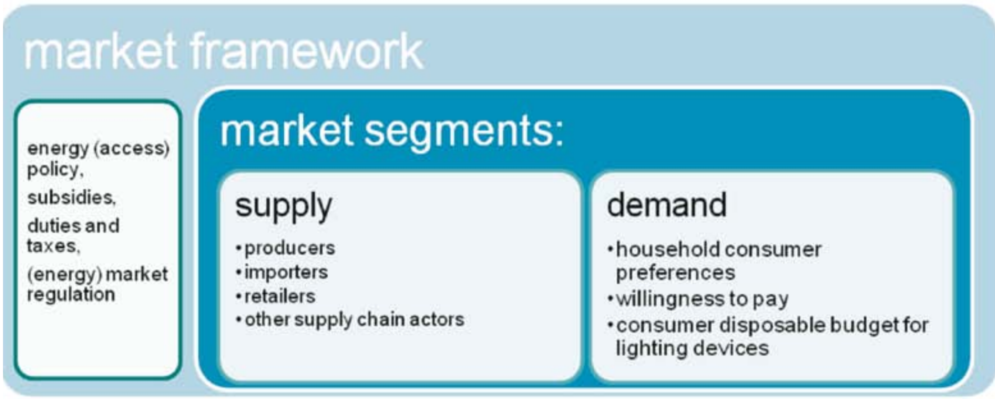
This finding (if confirmed by future research with larger sample sizes and more sophisticated quantitative methods) has several direct implications on pro poor energy policy:

1. If PicoPV lamps could reach a massive market penetration amongst un-electrified users, this would represent a change in lighting behaviour of historic dimensions.
2. In the current, nascent market stage consumers and local retailers lack information on PicoPV quality. This can lead to inefficiencies and delays in the development of a healthy market - and more importantly to dramatic malinvestments by poor households (who have no savings to recover from such bad investments). Therefore, governments should protect consumers early on by spreading information on quality at all stakeholder levels.
3. Donors and Governments concerned about universal electricity access will need to reconsider their (economically or politically motivated) implicit “minimum service levels” and start to discuss the frontier between “electrification” and “lighting.” What is the added benefit from “lighting” to electrification? What is it worth to the public?
4. In this context, it is enlightening to look at prevailing subsidy levels for lighting and electrification: Where governments decide to subsidize access to energy services, the currently prevailing subsidy levels per household or system for different technology options are as follows:

a.	PicoPV subsidies	0-20$
b.	SHS subsidies	0-200$
c.	rural grid extension subsides	0-2000$

5. The subsidy levels stepping up by a factor of ten from a. to b. and from b. to c. (meaning there is a factor 100 between maximum grid subsidies and PicoPV subsidies) clearly do not reflect welfare gains. This factor of 100 can be explained only partially with additional power uses (TV, productive uses) and may rather be related to the positive psychological (and political) effect of “electrification” as most rural grid users limit their electricity use to lighting and ICT. While SHSs have often been perceived by users (rightly or not) as a potential barrier to future grid electrification, PicoPV lamps and very small SHSs may not suffer this fate – governments could openly encourage the diffusion of PicoPV lamps as pre-electrification while maintaining (realistic!) roll-out plans for grid-based electrification and “large SHSs” from 100Wp (which enable TV and lighting of many rooms).
6. An important argument for policy makers to favour grid electrification over off-grid options – such as SHSs or PicoPV – has always been the price in $/kWh. However, this point is often mute in rural energy contexts, because: (i) cost covering grid extension would result in even higher costs in $/kWh as compared to off-grid PV for many of the remote and dispersed low-demand users and (ii) this argument entirely neglects an important assumption underlying typical demand curves: marginal utility (and consequently WTP) is highest for the first kWh (or lumenhours) and diminishes steeply with increasing amount of lighting consumed. In other words, the additional benefit the user gains with an additional “unit” of lighting is immense when he steps up from very poor lighting of kerosene lamps and candles to a small electric light, but much lower when he steps up (by the same increase in lumenhours) from low- to higher-power electric lighting. Rationale users pay a premium for the first, decisive step up the “lighting ladder”.

Figure 7-1: The market framework is also a good starting point for policy measures aimed at supporting PicoPV market development.



7.1 PicoPV Policy: Issues and Options

Policy options to promote a dynamic development of the PicoPV market should entail the full range of typical instruments of ODA in the energy sector, all geared towards two objectives:

i. speed up the market penetration lest large (low income) market segments remain excluded for an undesirable interim period due to market inefficiencies or rationale private sector pricing strategies (cream skimming) and/or
ii. protect consumers from "lemons" so as to avoid welfare losses – i.e. prevent that markets are flooded with low quality short lifetime products due to information asymmetries to the disadvantage of consumers (which would be especially devastating to the poorest users targeted by some of the PicoPV lamps).

Once the need for such policy measures has been demonstrated in a given market at a given point in time, such interventions on micro, mezzo and macro level would target the three market pillars depicted in the figure below.

7.1.1 Regulatory measures

The main task of regulatory measures would be to protect customers (and markets) from the effects of market inefficiencies. This relates mainly to information asymmetries, but also to inefficient taxes and customs. Typical tasks would be to:

- Inform all national stakeholders about global product quality and key quality issues (including radio jingles etc, as successfully piloted in the GTZ stoves programmes)
- Define national specs
- Develop a quality Label (regulation by information)
- Develop local testing abilities.
- Delegate "PV regulation" to decentralized entities
- Align import duties on different solar equipment

7.1.2 Subsidies

Clearly, the most controversial discussion will be whether to subsidize PicoPV products or not. Historically, subsidies have oftentimes hampered a healthy growth of the local private sector. On the other hand, PicoPV lamps do not compete on a level playing field (in light of hefty fuel subsidies – see GTZ fuel price index 2009) and direct subsidies may be an efficient way to support the introduction of quality labels and products in national markets. It should also be noted that PicoPV subsidies and subsidies to small SHSs have a potential for stellar poverty targeting and are (in theory) matched by few other schemes for the transfer of funds to poor households, if designed the right. In this context, it will be key to decide if PicoPV products should be targeted only at rural poor, or also at better off and/or (peri-)urban users. Ultimately, the decision on subsidization needs to be taken by national governments after careful consideration of Pros and Cons. If subsidies (direct or indirect – such as TA to specific market players) are to be provided, it is important to design them intelligently, so as to minimize distortions and maximize the desired (poverty) impact.

Possible Indirect Subsidies to PicoPV would include (in addition to the measures above):

- Teaser & Road Shows: attract SME to the new market segment
- Demonstrate Lighting and ICT solutions for household-based "pico productivity"?
- Skills development for technicians
- Passing on University and High-School Know-How in North-South and South-South cooperations.
- Support local assembly through technology transfer measures

Direct Subsidies would include:

- Pump Priming subsidies of 10-20$ to lamps that meet minimum specs and or providers who guarantee local hubs for replacements and repair.
- Compensate quality investments with matching grant schemes (warranty, recycling)
- Tax reductions (NB: components versus kit)
- Support to MFI for consumer credits in the PicoPV range
- Import of Containers and commissioning to local retailers (thus implicitly subsidizing risk premium, import unit prices and pre-financing costs).
- Provide Coupons to qualified technicians against which they can buy qualified lamps.
- Buyers coops to import at lower cost

7.1.3 Pricing and (Subsidy) Policy

An important issue that is often neglected in the current discussion about lighting products for "the bottom of the (income) pyramid" is that the massive diffusion envisioned by policy makers will happen only at a later market stage, if manufacturers follow typical pricing strategies for market entry. While donor studies often ask for end user prices which allow for massive sales across all income strata (say, US$ 10-20 per PicoPV lamp), providers care for profit. Typically, profit can be maximized in the early market stage by selling the new product at a premium to early adopters (cream, skimming) and (sometimes much) later introducing better products for the early adopters while gradually easing the price of the bottom range products so that quantities increase. Cream skimming, combined with market segmenta-

Table 7-1: Illustrative profit estimates for a hypothetical dealer show that optimal pricing strategies will typically not start with sales at the lowest possible cost.

Scenario	Margin per system ($)	Sold systems (#)	Profit
Skimming	55	100	5500
Distribution	5	1000	5000

tion later on, allows producers to capture a larger part of the total consumer surplus. Wherever donors support producers with direct subsidies, they may consider subsidy schemes that are carefully targeted at the poorest users, to offset this effect. However, this may be difficult to do in practice, especially without compromising on quality.

Table 7-1 below presents a fictive example of a producer who can either opt for a cream skimming strategy, with a high price yielding a considerable profit margin per system, or go for a large-scale sales strategy, with low price and low margin accordingly. For optimal profits, the company will choose the skimming strategy even though only a tenth of systems, compared to the large-scale distribution scenario, is sold. Especially in developing countries with weak PV markets and unclear distribution channels for new products, it can be advantageous for PV companies to concentrate on a small section of the market in the first step. Unclear market situation, lacking knowledge of demand and willingness-to-pay of potential customers leads PV providers to concentrate on a limited market segment with solvent customers. Looking at the income pyramid in developing countries, providers of PV technologies often serve only the top of the pyramid, neglecting large parts of the population. Skimming the consumer surplus of the high-income strata, is a rational strategy from a company's point of view and is often observed in the market of high-end technologies like computers, stereo equipment and other entertainment technologies. Firms offering new products are aware of the rapid innovation process in this sector and set high prices in a first phase, reducing them once the customer group with low price elasticity gets satiated. Lowering the price taps demand among consumers with higher price elasticity and lower willingness to pay or – in the case of developing countries – ability to pay.

7.1.4 Quality Tests in Developing Country Labs

In the current market development stage, quality control is probably the most urgent task of all options listed in the previous section. This could be achieved via a simple, two-pronged approach: (i) cooperation between test labs, institutes and universities to apply the simple testing procedures developed by Fraunhofer institute with funding from GTZ and WBG,and (ii) national awareness campaigns for PicoPV among private and public sector, as well as future users.

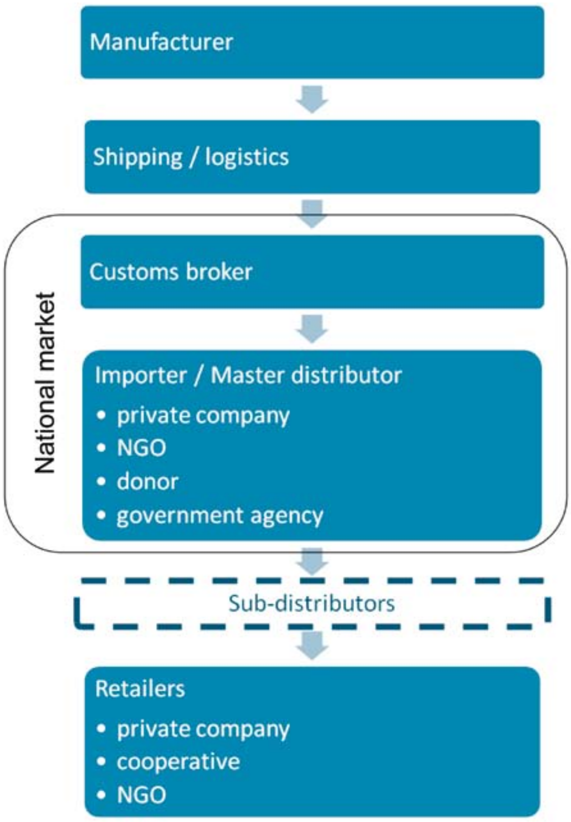
7.2 Developing the Local Market: GTZ PicoPV market development 2010

Within the framework of the PicoPV field studies the delivery of PicoPV lamps to (test-) end users was organized externally to a large degree. However, the ultimate objective of the project is to support the development of viable commercial local market structures resulting in a self-organized distribution of PicoPV products to consumers with a minimum distortion through subsidies and support measures. The following section will outline some basic options for PicoPV distribution models.

7.2.1 PicoPV Diffusion Channels and Value Chain Implications

There are different institutional models for the dissemination of PV products to end-users, like cash sales (at subsidized or market prices), including in combination with consumer credit schemes, donations through donor or government programmes, fee for service models, or concession

Figure 7-2: Typical supply chain of imported PicoPV products.



models. Preliminary findings of the PicoPV pilot tests suggest that there is not only a willingness to pay, but also, in contrast to larger PV energy solutions, sufficient purchasing power for PicoPV systems among the target group of poor households in developing countries. For this reason, the following section will focus on cash sales models, which have also proven to offer the most sustainable solutions in studies on SHS (see for example Niewenhout et al., 2000).

7.2.1.1 PicoPV supply chain structures

It should be highlighted up-front that for PicoPV products, in contrast to more complex higher-priced solar products, it will be relatively easy to find already existing distribution channels firmly rooted in the private sector, into which PicoPV products can be integrated in a competitive and efficient manner. Already established distribution and financing infrastructure for household electronics and ICT products, for example, can offer ready entry points for the inclusion of PicoPV products, which fall into similar consumer price ranges and require a similar maintenance and repair service structure.

Local distribution models for PicoPV lamps based on cash sales to end-users may have several possible structures, and how they emerge depends on numerous factors, like regulatory frameworks for energy markets and for imports, but also subsidies and donor support. A typical supply chain of an imported PicoPV product (which applies equally for larger PV products like SHSs) consists of the elements illustrated in Figure 72. It must be noted that agents along the supply chain can be private companies, but also non-governmental organizations and governmental agencies.
End-users buy the PicoPV products from a local retailer, e.g. in a local market or a shop, who may have obtained the product from a sub-distributor or directly from a "master distributor" or importer operating at national level.

7.2.1.2 Importers and master distributers

For importers or master distributers, one of the main challenges for entering the market may be the need for high up-front cash payments to buy larger numbers of lamps, combined with high costs for import duties, as well as a lack of knowledge about international supply options, in a situation of high uncertainty about the sales potential for the innovative products. At the same time, it is at this stage of the domestic part of the supply chain where the potential for profit margins is highest due to the large scale of operations.
Lack of cash availability on the side of potential importers / master distributers as a market entry barrier is of course less eminent in the PicoPV market than it may be in markets for

other more expensive PV products. Compared to markets for higher-priced PV technologies, there will be a larger number of domestic businesses who are able to enter the market as importers of PicoPV products, which is desirable from a market efficiency perspective as there is less leeway for monopoly pricing or price discrimination. The successful GTZ stoves market development programmes under HERA and EnDev are a promising example in this context. However, PV diffusion chains will probably require more technical expertise than low-cost stoves and may therefore benefit from combinations of centralized business planning with a vast number of decentralized extension agents or outlets (franchise might be an option but had limited success in SSA to date for similar products): the SHSs' success stories in Kenya and Bangladesh are based in large part on the previously existing, vast distribution networks of Exide (a global battery manufacturer) and Grameen (a leading MFI).
It may be easiest for established businesses who (i) have access to credit from commercial banks and (ii) have experience and expertise in imports and are familiar with regulations and procedures to enter the market at this stage. The challenge may be for businesses operating at national level and typically being based in capitals or other urban contexts to establish viable distribution channels to rural markets.
The organization of trade fairs for PicoPV products, possibly in combination with other innovative energy solutions, can be a way of raising awareness among domestic business owners about the new class of products, while at the same time opening up domestic markets for international suppliers.
Trade fairs can indicate new opportunities for the supply of solar products with higher market potentials to local enterprises and offer possibilities for exchanging business model ideas among enterprises active in this field.

7.2.1.3 Retailers at the local level

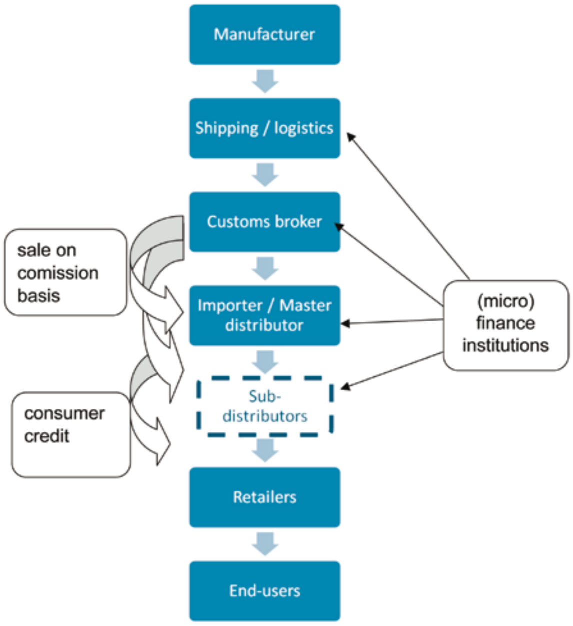
Further down the supply chain, the following hurdles to enter into PicoPV markets for business owners at local level have emerged from the preliminary findings of the qualitative PicoPV surveys (see chapter 4):

- lack of knowledge about PicoPV products;
- lack of certainty about the willingness and ability to pay for PicoPV products among local customers;
- lack of confidence in the quality of the products;
- high risk aversion due to small financial buffer;
- lack of expertise and lack of availability of well-trained staff to provide after-sales service to customers.

As the prices for PicoPV products fall into much lower ranges than those for SHSs and other more complex innovative energy solutions, PicoPV products offer realistic opportunities for MSME to enter this retail market and tap the high volume purchasing power of consumers at the bottom of the income pyramid. Lack of access to credit may still be a market entry barrier to some MSME if the products are available from wholesale retailers only against up-front payments. In that case, the risk born by the local retailer is high, given the huge uncertainty about consumer responses to the innovative lighting products, and the period before the investment starts to pay off may be too long.

Government or donor programmes aiming at sustainable market development and economic diversification in rural or semi-urban areas may therefore look into options for targeted PicoPV capacity development and financing support for MSME. Support for a commission-based sales model would be one possibility.

Figure 7-3: Financing models along PicoPV supply chains.



7.2.1.4 Models for after-sales service

Market structures for the supply of PicoPV lighting to end-users in developing countries must entail not only channels for system procurement, but also for after-sales maintenance and repair services. Several earlier studies on PV product dissemination have pointed out that the provision of service structures is often a bottleneck in the development of sustainable PV product markets and needs special attention in support programmes. The importance of maintenance and after-sales service structures has also been highlighted by several respondents across countries in the GTZ PicoPV field survey (see chapter 4).

In a market-based dissemination model, chances for sustainability are higher if sellers also play a key role in after-sales service (van Vleuten 2007). In rural areas, PicoPV vendors will have an intrinsic interest in putting into place service structures to ensure customer satisfaction, which is crucial as their business success will depend to a large degree on word-of-mouth recommendations. In addition, service delivery will be easier to organize by those supply side actors who already have gained a minimum of the required technical expertise to make informed decisions for the choice of the right lamp model etc.

However, PicoPV systems, in contrast to SHSs or other complex innovative energy solutions, are portable and not fixed to the house, which enables users to bring back the entire product to the shop or market where they have bought in case of technical problems. It is therefore relatively easy for retailers to offer after-sales services, as they do not have to visit customers in their homes, if they make the investment to gain the technical know-how for repair and maintenance of lamps.

7.2.1.5 Access to finance

Another crucial complementary service that needs attention when supporting the development of sustainable PicoPV markets is financing, both for local retailers and for end-users Consumers at the bottom of the income pyramid, particularly in rural areas, have limited access to financing services to bridge the gap between one-time up-front costs for the new lighting products and their monthly disposable budget for lighting. Financial services can either be provided directly from (micro) finance institutions to supply chain actors at national or local level or to consumers, or through consumer credits from retailers to end-users. Sale on comission basis will be a viable alternative to direct financing services for local retailers if the master distributor has the sufficient financial buffer.

7.2.2 Issues to be considered with regard to market restructuring

The survey results presented in this publication, in line with results from earlier studies (e.g. the Lighting Africa Market Research), indicate that kerosene lamps and battery-run torches account for the largest share of lighting expenses of PicoPV target customers, both in terms of running costs and for buying the lighting device. If PicoPV lamps replace the use of kerosene lamps, candles and torches in a large share of households in a certain area, vendors of these traditional lighting devices and the fuels on which they run will inevitably lose business.

It may in many cases be unlikely that it is the vendors of traditional lighting devices who will act as pioneers in the supply of PicoPV products at the local level. This would require a minimum level of technical capacity and innovative energy that may be found rather among established vendors of technically complex products with a higher occurrence of product innovations, like household electronics or ICT products. In other words, chances are high that PicoPV products will offer new business opportunities to one group of retailers, but another group is likely to lose business through the innovation. Losses for marginal and small enterprises in favor of new opportunities for more dynamic and successful small and medium sized enterprises may occur, and careful monitoring of such developments will be needed.

Against this background, it may be recommendable for government agencies and donors who design market development support programmes to undertake an initial stocktaking of supply chain actors, in which not only potential PicoPV retailers are covered, but also potential losers of large-scale PicoPV distribution at the local level. Programmes may then address also retailers of traditional lighting devices and identify suitable adaptation options for them.

A value chain analysis should explore possible labor market and human resources implications of a market transformation through replacement of traditional lighting solutions through PicoPV. PicoPV products may be more capital intensive as their production takes place in capital-based economies in industrialized countries, and they are also by nature more technology intensive products than conventional lighting devices. Concerns from the perspective of developing or least-developed importing countries may be that chances for "rising" on the value chain ladder (that is taking over assembly, manufacturing or even product development elements of the value chain) may be particularly difficult for domestic enterprises. Losses of labor opportunities along with limited opportunities for technological up-grading from the perspective of the importing country would be a pessimistic scenario of large-scale PicoPV market penetration. A more optimistic scenario would be that PicoPV products offer realistic opportunities for "learning-by-importing" and "learning-by doing" for actors along the domestic supply chain who face capacity gaps that they need to fill with regard to solar technology, but also regarding marketing of innovative products. Local entrepreneurs may also benefit as they need to develop more complex business models, which include financial and after-sales services. If MSME are able to successfully master this challenge, they would find themselves with a higher value-added stakes than obtainable through the provision of conventional lighting sources.

7.2.3 Options for PicoPV marketing strategies

Marketing of new and innovative lighting products will be a challenge, particularly in rural areas, and requires well-planned promotion efforts and innovative marketing strategies. Sustained consumer demand for PicoPV products can only be achieved through an expanding base of people that are aware of the products and confident that they offer value for money. Experience from the PicoPV field research has shown that successful marketing strategies, particularly in rural markets, will have to employ well-designed and innovative initial grassroots promotion instruments.

For example, village-level sales agents, like school teachers, technicians etc. who run a PicoPV sales part-time business can act as catalysts and help expand sales volumes until a critical mass of users is established. Social networks of sales agents can be harnessed to facilitate door-to-door marketing and product demonstration.

As mentioned above, it can be effective to use existing distribution structures to help the sale of PicoPV products in remote and low-income areas. This approach will minimize

Picture 7-1: Existing Lamp Vendor in El Alto, Bolivia, Source: ESMAP 2009

the costs of distribution and take the system to the widest possible audience. However, a requirement will be that dealers have a minimum of technical qualification to be able to explain technical features of the products to customers. Sales of Pico PV systems cannot only be affiliated to sales of SHSs, but also to other household electronics and ICT products in specialized shops. If such infrastructure does not exist in a rural area or is limited to towns, affiliation to less related businesses at village level may also be promising. Options include battery charging stations or kiosks which relate to energy services.

7.2.4 Options for supply side support activities for PicoPV market development

Support from donors and/or government agencies to (potential) PicoPV supply chain agents operating at national or local levels can be effective and crucial in the initial phases of PicoPV market development. Appropriate and well-designed measures will be needed to trigger the entry of supply chain actors, notably MSME retailers, into PicoPV markets or scaling up of their business. Such support programmes should aim at enabling a multitude of (potential) actors, including MSME, to come up with viable concepts for marketing strategies, distribution and (simple) business models for PicoPV products.
Five basic steps are suggested to develop appropriate support measures on a national level and prioritize concrete activities to help supply chain actors enter and prosper in emerging PicoPV markets.

STEP 1:
In order to understand the possible structures of a domestic PicoPV supply chain, a mapping exercise should be undertaken that takes stock of domestic businesses and existing distribution chains in the (rural) lighting sector: importers, wholesalers, traders, and retailers.

STEP 2:
As a next step, the existing state of knowledge and awareness of PicoPV products among business owners identified as potential PicoPV supply chain agents has to be analyzed. In addition marketing strategies for comparable products in the given country or region (e.g. ICT products, PV products, household electronics) should be analyzed in order to identify country specific success factors for market entry and marketing strategies for new technologies. This analysis should help to expand knowledge about ethnic and cultural particularities and demand patterns, especially in the lower income strata, as well as differences between rural, peri-urban and urban settings.

STEP 3:
An appropriate national strategy for supply side support for the development of PicoPV markets can be designed on the basis of step 1 and 2 findings. To this end, national, regional and local government and donor structures for business development support should be mapped out, and links to key actors should be established in order to identify possible synergies and alignment to existing structures.

STEP 4:
The implementation of this support strategy will be the next step. The following activities may be part of the strategy (but locally appropriate activities may go beyond the initial ideas listed here):

a. Information on consumer preferences and market potential for PicoPV products
b. Capacity development support for developing business models and concrete concepts for market entry and marketing strategies.
c. South-south knowledge exchange

STEP 5:
Last but not least, for monitoring and evaluation of the measures taken and in order to identify good practice for PicoPV market development support, follow-up workshops with (emerging) supply chain agents should be organized for sharing of lessons learned, and for identification of remaining hurdles and needs for further support.

BIBLIOGRAPHY

ESMAP (UNDP/World Bank Energy Sector Management Assistance Pro¬gram). 2002. Rural Electrification and Development in the Philippines: Measuring the Social and Economic Benefits. Report 255/02. World Bank: Washington, DC, USA.

Fisch, J. (2000): Licht und Gesundheit: Das Leben mit optischer Strahlung.

Gabler, H. (2008) Photovoltaik zur netzfernen Elektrifizierung, 23. Symposium Photovoltaische Solarenergie, Kloster Banz, Bad Staffelstein, 5. - 7. März 2008.

Grüner, Roman; Lux, Stephan; Reiche, Kilian; Schmitz-Günther, Thomas: Solar Lanterns Test. Shades of Light, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Eschborn Mai 2009.

IEA: Electrification Rates in Selected Regions, IEA Electricity Database 2009 http://www.iea.org/weo/database_electricity/electricity_access_database.htm.

Jacobson, A. (2007): Connective Power: Solar Electrification and Social Change in Kenya, World Development, Vol. 35, No. 1, p. 144 - 162.

Martinot, E., Chaurey, A., Lew, D., Moreira, J.R., Wamukonya, N. (2002): Renewable Energy Markets in Developing Countries, Annu. Rev. Energy Environ. 2002. 27: 309 - 348

Mitja, A., Torra, C., Satue, D., Peters, C., Vallve, X., Vosseler, I. (2003): MSG - The sustainable alternative for rural electrification, Institute Catala d'Energia ICAEN, Barcelona, Internal Report.

Nieuwenhout, F.D.J., van Dijk, A., van Dijk, V.A.P., Hirsch, D., Lasschuit, P.E., van Roekel, G., Arriaza, H., Hankins, M., Sharma, B.D., Wade, H. (2002): Monitoring and evaluation of solar home systems: experiences with applications of solar PV for households in developing countries, Energy Policy 30, p. 477 – 499.

Schweizer-Ries, P., Schulz, M., Vallve, X., Vosseler, I., Ramirez, E., Serrano, J. (2000): Successful user schemes for photovoltaic stand alone systems: solar energy for rural electrification—lessons learned. Frauenhofer-Institut für Solare Energiesysteme ISE, Freiburg i.Br., Internal Report.

Vallve, X., Vosseler, I., Cisneros, E.J., Gafas, G., Serrassolses, J., Vasquez, M. (2001): First experiences from the electrification of rural villages in Spain with multi-user solar hybrid grids (MSG). Proceedings of the European Photovoltaic Solar Energy Conference, Munich, Germany.

Further Reading

Adelmann, Peter (2006): Strategie zur Elektrifizierung Afrikas und anderer nicht-elektrifizierter Reginen, internal draft.

Claus Dauselt (2001) Involving the user: Community based management of solar home systems in Indonesia, Refocus, Volume 2, Issue 9, November-December 2001, Pages 18-21.

Crawley, K., Holland R. and Gitonga, S. (2000): Improved Design for Solar Rechargable Lanterns and their Development and Marketing in Developing Countries.

Dipal C. Barua (2001) Strategy for promotions and development of renewable technologies in Bangladesh: experience from Grameen Shakti, Renewable Energy, Volume 22, Issues 1-3, January-March 2001, Pages 205-210.

Ellegård, Anders, Anders Arvidson, Mattias Nordström, Oscar S. Kalumiana, Clotilda Mwanza (2004) Rural people pay for solar: experiences from Zambia PV-ESCO project.

ESMAP (2005): Portable Solar Photovoltaik Lanterns: Performance and Certification Specification, and Type Approval, ESMAP Technical Paper 078.

Gölz, S., Preissler, E. (2004): Prepayment Solar Home Systems in the Field – An Analysis of their Performance Capability, ISE – Fraunhofer Institut Solare Energiesysteme.

Gustavsson Mathias (2007) With time comes increased loads—An analysis of solar home system use in Lundazi, Zambia, Renewable Energy, Volume 32, Issue 5, April 2007, Pages 796-813.

Gustavsson, Mathias (2007) Educational benefits from solar technology—Access to solar electric services and changes in children's study routines, experiences from eastern province Zambia, Energy Policy, Volume 35, Issue 2, February 2007, Pages 1292-1299.

Gustavsson, Mathias and Anders Ellegård (2004) The impact of solar home systems on rural livelihoods. Experiences from the Nyimba Energy Service Company in Zambia, Renewable Energy, Volume 29, Issue 7, June 2004, Pages 1059-1072.

Haak, H. (2007) Facilitating access to improved cooking stoves through Micro Credit in Bolivia, GTZ Proagro "Acceso a Servicios Energéticos", La Paz.

Hauptverband der gewerblichen Berufsgenossenschaften/ HVGB (2006): Natürliche und künstliche Beleuchtung von Arbeitsstätten.

Hessisches Ministerium für Wirtschaft, Verkehr und Landesentwicklung/HMWVL (2005): Gutes Lichtklima: Ratgeber zur energieffizienten Beleuchtungsmodernisierung

IFC (International Finance Corporation) (2005) The ELI Story: Transforming Markets for Efficient Lighting, IFC/ GEF Efficient Lighting Initiative (ELI).

IFC (2007) Selling Solar. Lessons from More Than a Decade of IFC's Experience, IFC: Washington DC.

LRC – Lighting Research Center (2005): Assist, Vol. 1, No. 1, URL: http://www.atgelectronics.com/education/ PDF/2007101703.pdf.

McMonagle, R. (2006): The Potential of solar PV in Ontario, The Canadian Solar Industries Assocoation.

Mills, E. (2005): The Specter of Fuel-Based Lighting, Policy Forum, Science, Vol. 308, pp. 1263 - 1264.

Mills, E. 2002. "The $230-billion Global Lighting Energy Bill." Proceedings of the Fifth European Conference on Energy-Efficient Lighting, International Association for Energy-Efficient Lighting, Stockholm, pp. 368-385.

Moner-Girona, M., R. Ghanadan, A. Jacobson and D. M. Kammen (2006) Decreasing PV costs in Africa. Opportunities for Rural Electrification using Solar PV in Sub-Saharan Africa, Refocus, Volume 7, Issue 1, January-February 2006, Pages 40-45.

Ochieng, F.O., Osawa, B. and Hankins, M./ITC (1998): Solar Lanterns in Kenya: What customers want

Raach, J. (2007) The role of Senegal in the African PV market, Presentation, Solar 23.

Rea, M.S./Lighting Research Center (2002): Light – Much more than a vision.

REF – Renewable Energy Focus (2007): Global solar PV market estimated at 2.3 GWp in 2007, URL: http://www.renewableenergyfocus.com/articles/general/news/071218EPIA07release.html.

Reiche, K., Tenenbaum, B., Torres de Mästle, C. (2006): Electrification and Regulation: Principles and a Model Law, Energy and Mining Sector Board Discussion Paper No. 18, URL: http://siteresources.worldbank.org/EXTENERGY/Resources/336805-1156971270190/EnergyElecRegulationFinal.pdf.

REN21 (2006) Renewables Global Status Report 2006 Update, REN21 Secretariat: Paris and World Watch Institute: Washington DC).

Renewable Energy, Volume 29, Issue 8, July 2004, Pages 1251-1263.

S. K. Velayudhan (2003) Dissemination of solar photovoltaics: a study on the government programme to promote solar lantern in India. Energy Policy 31(14): 1509-1518.

Schmitz, T. (2007): Decision criteria for evaluating suitability of solar lanterns for promotion within projects in developing countries-GTZ, unpublished draft.

Tomowski, A., Ziegler, F. (2007): Concept Note – Market Development Support for Renewable Energy Technologies, GTZ – German Technical Cooperation/ Deutsche Gesellschaft für Technische Zusammenarbeit, unpublished.

Uh, D. (2007) Energizing Africa – The Role of Photovoltaics. GTZ's Partnerships and Networks for Renewable Energies in Africa, Presentation, 22. European Photovoltaic Solar Energy Conference (EU PVSEC) in Milano.

van der Plas, R. (1998): Rural PV Lighting: Opportunity lost?

van der Plas, R. J. and M. Hankins (1998) Solar electricity in Africa: a reality, Energy Policy, Volume 26, Issue 4, March 1998, Pages 295-305.

van der Vleuten, F., N. Stam, R. van der Plas (2007) Putting solar home system programmes into perspective: What lessons are relevant?, Energy Policy 35, 1439–1451.

van der Vleuten-Balkema, F., Stam, N. van der Linden, J. (2003) Lessons Learned from Solar Sector Infrastructure Development in Africa and Asia, Proceedings of 3rd World Conference on Photovoltaic Energy Conversion.

van der Vleuten-Balkema, F., L. Brouwers, J. van der Linden, K. Peters, K. Arkesteijn (2002) Systematic approaches to sector infrastructure development for PV in developing countries. Proceedings of Int. Conference PV in Europe, From PV technology to Energy Solutions, 7-11 Oct. 2002, Rome.

Van Westendorp P.H. (1976) NSS-Price Sensitivity Meter: A New Approach to Study Consumer Perception of Prices // Venice ESOMAR Congress, Amsterdam: European Marketing Research Society, pp. 139-167.

Van Westendorp P.H. NSS-Price Sensitivity Meter: A New Approach to Study Consumer Perception of Prices // Venice ESOMAR Congress, Amsterdam: European Marketing Research Society, 1976. – pp. 139-167.

World Health Organization, United Nations Development Programme (eds.) (2009): The Energy Access Situation in Developing Countries. A Review Focussing on the Least Deveeloped Countries and Sub-Shara Africa. World Health Organization und United Nations Development Programme.

Zentralverband der Elektrotechnik –und Elektroindustrie e.V./ZVEI (2005) ZVEI-Leitfaden zur DIN EN 12464-1.

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