IEA INTERNATIONAL ENERGY AGENCY

Policy Recommendations to Improve the Sustainability of Rural Water Supply Systems

Based on the Experience with Conventional and Photovoltaic Pumping Systems

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

PVPS

Report IEA-PVPS T9-11:2011

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Based on the Experience with Conventional and Photovoltaic Pumping Systems

IEA PVPS Task 9, Subtask 1
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Contents

Foreword

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

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

The 22 participating countries are Australia (AUS), Austria (AUT), Canada (CAN), China (CHN), Denmark (DNK), France (FRA), Germany (DEU), Israel (ISR), Italy (ITA), Japan (JPN), Korea (KOR), Malaysia (MYS), Mexico (MEX), the Netherlands (NLD), Norway (NOR), Portugal (PRT), Spain (ESP), Sweden (SWE), Switzerland (CHE), Turkey (TUR), the United Kingdom (GBR) and the United States of America (USA). The European Commission, the European Photovoltaic Industry Association, the US Solar Electric Power Association and the US Solar Energy Industries Association are also members. An Executive Committee composed of one representative from each participating country or organization heads the overall programme. The management of individual Tasks (research projects / activity areas) is the responsibility of Operating Agents. Information about the active and completed tasks can be found on the IEA-PVPS website www.iea-pvps.org

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

This paper, developed by Task 9, demonstrates that there are various common problems experienced in rural water supply projects implemented by experts form the water and sanitation sector and those implemented by experts from the field of photovoltaic energy. A closer collaboration with and information exchange between the water and renewable energy sectors are called for.

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Abstract

This paper outlines the various common problems experienced in rural water supply projects implemented by experts from the water and sanitation sector and projects implemented by experts from the field of photovoltaic energy. It is desirable to promote closer collaboration and enhanced information exchange between the water sector and the renewable energy sector to benefit from the solutions already developed for the identified problems. Recommendations have been developed to improve the sustainability of rural water supply system projects and to support the institutional and planning frameworks involved in rural water supply programmes.

Executive Summary

During the past thirty years, the international donor community has placed considerable emphasis on extending the access to safe water for the rural population in developing countries. Heavy subsidies for water infrastructure have allowed the quantitative targets to be achieved, but often at the expense of high operational costs and the early breakdown of systems. Investment decisions were frequently based on the initial investment costs rather than the life-cycle costs of systems and, as governments were often bypassed, there was little coordination for the establishment of adequate operating and maintenance frameworks.

"Heavy subsidies for water infrastructure have allowed the quantitative targets to be achieved, but often at the expense of high operational cost and the early breakdown of systems."

While hand-pumps are an efficient way to supply small communities, motorised pumps are needed to supply larger communities. Compared to conventional diesel motor-pumps, photovoltaic pumping systems (PVP) would in many instances provide the least life-cycle cost option. The application range of PVP is constantly increasing due to price decreases of PV technology and improvements in pumping technology. PVP is a mature and reliable technology; however, like any kind of rural infrastructure it also needs adequate maintenance frameworks for sustainable operation.

To improve the sustainability of rural water supplies it is recommended that international efforts focus on providing support to governments to shape policies that create enabling environments for rural water supply. Measures should be taken to attract private investors to leverage available funds. Larger-scale projects are required, with a critical mass of similar systems, to lower investment costs and to make rural maintenance services feasible. When PV systems are chosen, the whole water chain should be considered to guarantee system reliability. Where possible, the setting up of larger, integrated renewable electricity and water supply systems should be encouraged.

International efforts should focus on providing support to governments, to shape policies that create enabling environments for rural water supply.

1. Introduction

The United Nations announced in its 2010 Millennium Development Goals report that the target of halving the population without sustainable access to safe drinking water by 2015 will be achieved. While the drinking water coverage in urban areas of developing countries, which stood at 94% in 2008, has remained almost unchanged since 1990, considerable achievements were reported from rural areas. Rural drinking water coverage increased from 60% in 1990 to 76% in 2008, narrowing the gap between rural and urban areas. Despite these achievements, the report also mentions that large disparities remain, particularly in Oceania and sub-Saharan Africa (United Nations, 2010). In sub-Saharan Africa only 47% of the rural population have access to safe water, whilst the total number of un-served people has gone up by 37 million to 228 million (IRC, 2009).

While the numbers presented in the UN statistics are impressive, they do not consider the fact that many of those who were counted as having been 'served' actually have systems that are not working properly or have failed completely. Furthermore, those actually working might be at a high life-cycle cost. The issue of sustainable access, i.e. how to safeguard investments and make them permanent has, on the whole, not been adequately addressed. Thus, the access to a reliable source of clean water remains a dream for a billion of the world's poorest people despite decades of investment in new rural water supply infrastructure. To reduce the waste of funds in the future, it is therefore necessary to review the experiences with rural water supply systems over the past thirty years and to identify the shortcomings of current policies and approaches to rural water supply.

"…the access to a reliable source of clean water remains a dream for a billion of the world's poorest people despite decades of investment in new rural water supply infrastructure."

This paper focuses on community-operated rural water supply systems and compares the experiences with conventional approaches with those of photovoltaic pumping (PVP) systems. PV pumping is considered a mature and reliable technology. The paper outlines the power range for which PV pumping can be a technical option for rural water supply and how this range has developed amid price decreases for PV technology in recent years. The main objectives of the paper are to identify the reasons for the poor performance of many rural water supply systems and to analyse to what extent PV technology could be a more sustainable alternative.

The paper is based on a literature review and expert interviews. Based on common findings with experts from the water sector as well as the renewable energy sector, recommendations are formulated on how to shape policies for the future. The aim is to create an enabling environment for the development of a rural water supply sector in which the most economical technologies are selected and operated on a sustainable basis. The recommendations will not only be useful for community-operated water supplies but also for other rural infrastructure programmes which are not discussed in detail, such as water supply for irrigation and rural electrification in general.

2. Review of Experiences with Conventional Rural Water Supply Systems

The ongoing focus of the international donor community on rural water and safe water supply started with the International Drinking Water Supply and Sanitation Decade from 1981 to 1991. The main objective was to provide 'safe water for all'. Much was achieved during the decade but the target of safe water supply for all was not. The reason for the disappointing results was mainly considered a consequence of the ineffectiveness of water utilities in many developing countries. Rather than addressing the causes for these symptoms the international donor community sidestepped utilities and governments and began to place increased emphasis on the operation and maintenance of single water points or systems such as public taps and hand-pumps. Village Level Operation and Maintenance (VLOM) became the leading concept, based on the desire to ensure that each community was able to manage the operation, maintenance, repair, and eventual replacement of its own water supply independent from any government services.

Despite early critics of such VLOM (e.g. Carter 1993), and little evidence that village institutions could escape the problems of their more centralized counterparts in the long run, the concept is still being pursued by many organizations under the Millennium Development Goals. The MDG target is to halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation.[1] This chapter mainly focuses on the experiences with hand-pumps for the provision of domestic water.

2.1 Adverse Effects of High Subsidy Levels

The implication of the above-mentioned programmes and associated objectives has been that, for the past thirty years, governments, donors, and NGOs have tended to focus on numerical targets and put their efforts into building new water facilities. The focus on village institutions paired with 'basic needs'-oriented policies of 'free water' has led to a situation in which available funds are largely used to heavily subsidize hardware. The Rural Water Supply Network (RWSN 2010a) estimates that for government and NGO-supported rural water supply schemes across sub-Saharan Africa, between 90% and 100% of the hardware costs are subsidized (i.e. not paid for by the recipients or operators).

The very high subsidy levels for rural water supply infrastructure have prevented more economical decision-making when it comes to technology selection. Due to limited budgets, it is more the rule rather than the exception that investment decisions are based on initial investment costs rather than life-cycle costs. Furthermore, it has also created considerable market distortion and overpricing, limiting private sector investment in the construction and management of water supply systems in rural areas.

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1 "Access" is defined as at least 20 litres of water per person per day from a public tap or protected source within one kilometre of the user's home. The definition does not clearly define aspects of water quality, making it difficult to compare data from different countries.
"Basic sanitation" is defined as private or shared, but not public, disposal systems that separate waste from human contact.

2.2 Insufficient Focus on Operation and Maintenance Strongly Affects Systems' Sustainability

Heavy subsidies for most conventional technologies have allowed the achievement of numerical targets but often at the expense of high operational costs and early breakdowns of systems. The issue of sustainable access, i.e. how to safeguard investments and make them permanent has, on the whole, not been adequately addressed. Questions regarding how to support water users after construction of new infrastructure, and also who should pay for the long-term costs of operation and maintenance, were considered to be 'somebody else's problem'. From the field of hand-pumps it was reported that, despite widespread construction and rehabilitation of communal water points, between 10% and 50% of these facilities may be out of service at any given time, generally due to the problem of hand-pump breakdown (Sutton, 2004:2). Problems of affordability, availability of spare parts, and communal management were found to be the main culprits, especially among poorer and more remote communities.

Yet strategies to reach the MDG target tend to assume that all existing supplies are sustainable and continue to function. According to the Millennium Development Goals Report 2010, the world is on track to achieve the goal of halving the population without sustainable access to safe drinking water. The report claims that the access by people in developing regions has increased from 71% in 1990 to 84% in 2010. The fact that a large share of recently built water infrastructure is out of operation is not mentioned in the report. Even if the target were to be achieved, this would mean that 800 million people, mainly from rural areas of developing regions, would remain without access to safe drinking water. Further, taking into account the non-sustainable water infrastructure, this number is very likely to remain considerably above 1 billion people by 2015.

Many experts from the rural water supply sector have realized that the approach of massively subsidizing hardware will not contribute to sustainable attainment of the water access targets. While some are still attached to past doctrines that consider the community ownership and management of water infrastructure as the key to success, there is a general consensus that water users should pay for all O&M costs through user fees and possibly also contribute to at least some of the capital costs (Whittington et al., 2009). However, sensitization of beneficiaries is required because they are used to free-of-charge water access.

It has also been recognized that there is a need for improved coordination in the development of rural water supplies and in particular to (re-) involve governments, as well as local partners, in the process. In many countries it is currently possible that any organization can appear in a particular village and "improve the water supply" as they see fit. Support is often provided on a charitable basis. Organizations work according to their own standards and procedures, bypass national sector policies and completely ignore government agencies in the process. However, it is usually only the local government who could provide support to the community once the project developer has left. It is therefore required that institutions need to be strengthened and mechanisms improved to better hold NGOs and donors to account (RWSN, 2010a).

2.3 Trend for Increasing Involvement of Private Investors

The involvement of the private sector, and in particular small and medium-sized enterprises, to leverage existing financing and to operate and maintain water supply systems on a more sustainable basis, is increasingly being demanded (Salter, 2003; Mehta 2003; RWSN 2010a). In Vietnam and Cambodia, it has been demonstrated that between 60% and 100% of required funds can be raised for rural water supply infrastructure through investing enterprises, consumer fees, and consumers paying for water source development (see Box 1). The World Bank Social Investment Project in Bangladesh is attempting to get communities and local governments themselves to raise at least 50% of the financing for rural piped water schemes operated by private operators (Kleemeier & Narkevic, 2010).

There is also a growing understanding in the rural water supply sector of the need for a paradigm shift, from a project-based way of working in individual communities to planning and working at the scale of districts, municipalities, or other intermediate-level regions. The International Water and Sanitation Centre (IRC, 2009) is leading an initiative to shift from projects to a Service Delivery Approach. The approach emphasizes the need for increased coordination and harmonization, in addition to working at scale, as a precondition for sustainable operation of rural water supply infrastructure.

A similar approach has been formulated by the World Bank's WSP Programme called FRUGAL (Forming Rural Utility Groups and Leases). Under this approach a private firm or individual would work under a long-term government contract to design, build or rehabilitate, operate and/or maintain water supplies within a defined geographical area.

There is evidence that privately operated systems are not only operated more economically but also more sustainably. However, to attract the interest of private investors there is a need to develop and adapt regulations to provide the legal basis for private sector involvement in rural water supply, to reduce investment risks, to allow reasonable water pricing and to offer innovative financing mechanisms.

Box 1: Private Investments in Piped Water Supply Schemes in Tien Giang Province in Vietnam's Mekong Delta

In 1998, the Tien Giang Provincial Government issued a decree to govern the involvement of the private sector in the Rural Water Supply sector. The decree stipulates investment and operating mechanisms, regulates water pricing, drilling, and water quality. The decree created an enabling environment for piped water schemes which triggered a staggering growth in private, cooperative, and community user-group investments:

During five years after the decree was issued, the number of user-group invested schemes grew by 800%, cooperatives by 230%, and private investors 130%. Of the 415 schemes operating in 2003, 80 were investments by private enterprises, 28 by cooperatives, 258 by user groups, and 49 by state owned enterprises. Most of the non-state operated schemes were virtually fully financed by the private sector. In addition, the state budget supported the construction of piped schemes in poorer areas, where the government contributed 40% of the costs and the remaining 60% were raised by users. Most of these schemes supply untreated groundwater while a few supply treated surface water.

Of the total invested capital in piped rural water supply schemes in the province in 2003, USD 3,645,000 (61%) was invested by the private sector, USD 1,760,000 (29%) was invested by state enterprises, and USD 618,000 (10%) was provided as government subsidies. Of the capital invested by non-government funds, USD 998,000 was invested by private enterprises, USD 610,000 by cooperatives, and USD 2,037,000 by user groups.

In all cases, the government provided technical design support, offering a series of pre-designed systems that were tailored for varying populations and water source conditions. The drilling of wells remains tightly controlled by the government and there are no private sector well drillers in the province.

It should be noted that whilst this province has a particularly impressive record in the development of piped water schemes, it is perhaps one of the best examples in Vietnam but not the norm.

(Source: Salter, 2003)

The involvement of the private sector in rural water supply also has its limitations when it comes to achieving socio-economic objectives. For example, in an unregulated environment a profit oriented private company would offer its customers incentives to encourage greater water use. Unit prices would be lower for large users and higher for small users. A socially and environmentally designed pricing structure would be the opposite – the less water one uses, the less one has to pay. The mechanism to achieve socio-economic objectives is regulation, but it must be cautiously balanced so that the private entrepreneur can still make a decent profit and be encouraged to remain in business (Salter, 2003).

The involvement of private sector players is not restricted to system size. Examples range from village-sized owner-operator models in Vietnam (Box 1) to maintenance contracts for hand-pumps in Burkina Faso (Box 2).

Box 2: Licensed standpipe operators in Burkina Faso

Ouagadougou, Burkina Faso, has a network of close to 500 standpipes. Most of these are located in peri-urban areas and at the entry of unplanned settlements. They constitute an important source for the public, as there are few alternatives. In order to be selected to manage a standpipe, one must deposit CFAF 30,000 (USD 60)and sign a contract with the National Water and Sanitation Office (ONEA). Standpipe operators buy water for CFAF 187/m3 and sell it at CFAF 300/m3 (USD 0.60/m3). Average monthly sales are in the area of CFAF 360,000 (USD 720), or 30–50 m3/day. Operations are closely supervised by ONEA, and any deviation from contract conditions can lead to the reassignment of the standpipe to another manager. There is an association of standpipe managers that seeks to bring common concerns to the attention of ONEA. Such concerns include improved transparency in the selection of standpipe managers.

(Source: Kjellén & McGranahan, 2006)

3. Review of Experiences with PV Water Pumping Systems

Conventional methods for rural water supply, as described in the section above, have focused mainly on the installation of hand-pumps for the provision of domestic water. Hand-pumps can be considered the appropriate solution in rural areas beyond the reach of electricity grids to supply water for small village communities of up to 300 people. However, to supply larger communities with water above an equivalent hydraulic energy[2] of 25 m^4 per hour, the use of hand-pumps is no longer adequate and motorized pumps are required. Power sources include diesel/gasoline, wind power, grid-electricity or photovoltaic electricity.[3] PV pumping technology is competing mainly with diesel pumping. In the sections below, we initially discuss the economic viability of PV pumps as opposed to diesel pumps, and then consider both the lessons learned with PV pumping and market prospects.

3.1 Economic Viability of PV Pumping

Various analyses of the economic viability of PV pumping versus diesel pumping were done in the past. Analyses usually tried to determine the upper limits of the equivalent hydraulic energy in m^4 or the power range in kWp for which PV pumping is still cheaper than diesel pumping. However, the comparison of different analyses across different countries is difficult, due to significant differences in insolation levels, equipment prices, interest rates, labour costs and diesel prices. Still, the tendencies are clear as shown by the examples below.

Earlier analyses conduced in the 1980s and early 1990s typically identified PV pumping to be cheaper than diesel pumping up to equivalent hydraulic energies of 1000 m^4/day or pumping powers of up to 1 kWp (Barlow et al., 1993). Due to decreasing prices for PV modules the application range expanded. For seven countries (Argentina, Brazil, Indonesia, Jordan, the Philippines, Tunisia, and Zimbabwe) it was later shown that PV pumping systems had a cost advantage over diesel pumping systems in the power range up to 4 kWp (Posorski and Haars, 1994). An analysis of existing PV pumping stations conducted in Jordan came to the conclusion that PV pumping is economically more interesting than diesel pumping up to an equivalent hydraulic energy of 6000 m^4/day, at a time when heavily subsidized fuel was available for less than USD 0.10 (Mahmoud, 1990). In 2005, when Jordan diesel prices increased to USD 0.20, another analysis concluded that the competitiveness of PV pumping increased to 8000 m^4/day (Odeh et al, 2006).

Since 1984 Japan has done considerable pioneering work and implemented a large number of PV pumping schemes for drinking water and irrigation. Japanese comparisons of the life-cycle costs of different systems usually refer to the size of the villages to be supplied with water. In the mid-1990s PV pumping was found to be more economic than diesel pumping for villages with a population of up to 1100 people. A recent comparison conducted in Kenya in 2010 found that PV pumping has become considerably cheaper than diesel pumping for village sizes between 500 and 1500 people. Cost advantages of PV pumping ranged from 36% to 24% for these respective village

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[2] The equivalent hydraulic energy is defined as the product of pumping head (m) and volume (m^3) of water delivered per hour, or day, or year.

[3] For an overview about rural water supply options see Bauman & Erpf (2005).

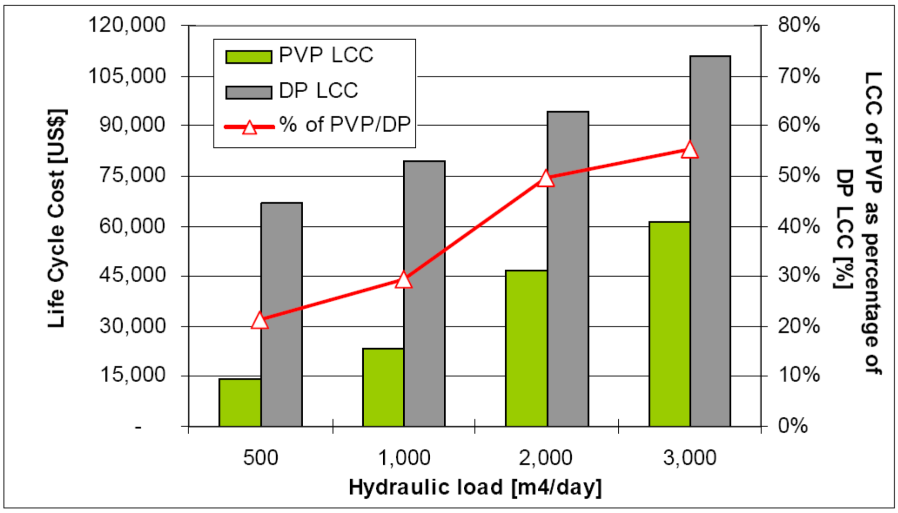
sizes (Watanabe, 2012). Larger villages were not analysed but it can be concluded from the figures that PV pumping would be more competitive for population sizes far beyond 1500.

A comprehensive study to examine the cost-effectiveness of solar water pumps compared to diesel water pumps was conducted in Namibia (NAMREP, 2006). Costs were compared for different solar and water pumps over a range of pumping heads (10m to 200m) and daily flow rates (3m^3/day to 50m^3/day).[4] The life-cycle costs were calculated over a 20 year period taking into account:

- the up-front investment costs,
- the operating costs (diesel fuel cost USD 0.90, inspections of pumping systems),
- maintenance costs,
- replacement costs.

Figure 1 shows the life-cycle costs for PVPs and diesel pumps that were averaged for different hydraulic loads. At low hydraulic loads, life-cycle costs of the PVPs were found to be as low as 20% of those of the diesel pumps. At higher hydraulic loads, the PVP option still provides a solution at half the life-cycle costs of the diesel pumping option.

Figure 1 Life-cycle costs of Photovoltaic and Diesel Pumps in Namibia



(Source: NAMREP (2006), recalculated in 2006 USD)

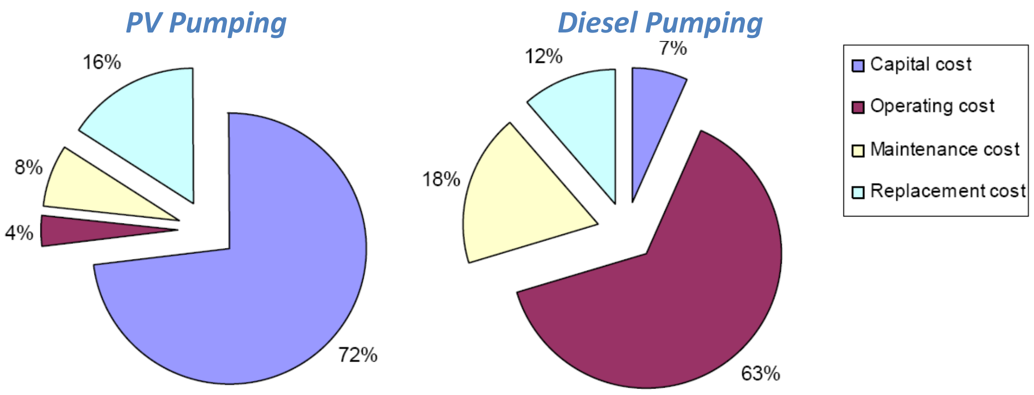
3.2 Life-cycle Cost Breakdown

Figure 2 shows the life-cycle cost breakdown of one PVP and one diesel pumping system. The first pie chart shows the cost distribution for a PVP at a hydraulic load of about 2500m^4/day (80m head, 32m^3/day, 3400Wpeak) and the second pie chart shows the life-cycle cost breakdown for a diesel pump delivering 32m^3/day at an 80m head (5m^3/h for six hours every day).

The breakdown for PVP is typical for a renewable energy system, showing that the main portion of the costs is the initial capital cost. The breakdown of the diesel pumping system shows that the bulk of the costs are the operating costs or the fuel costs.

[4] Solar pumps included: Grundfos SQ Flex, Lorenz PS, Total Energie TSP 10000 and TSP 2000+, Watermax (Diapragm pump). Diesel pumps considered: Kia and Kirloskar (India), and Lister (South Africa).

Figure 2 Cost breakdown of Photovoltaic and Diesel Pumps in Namibia



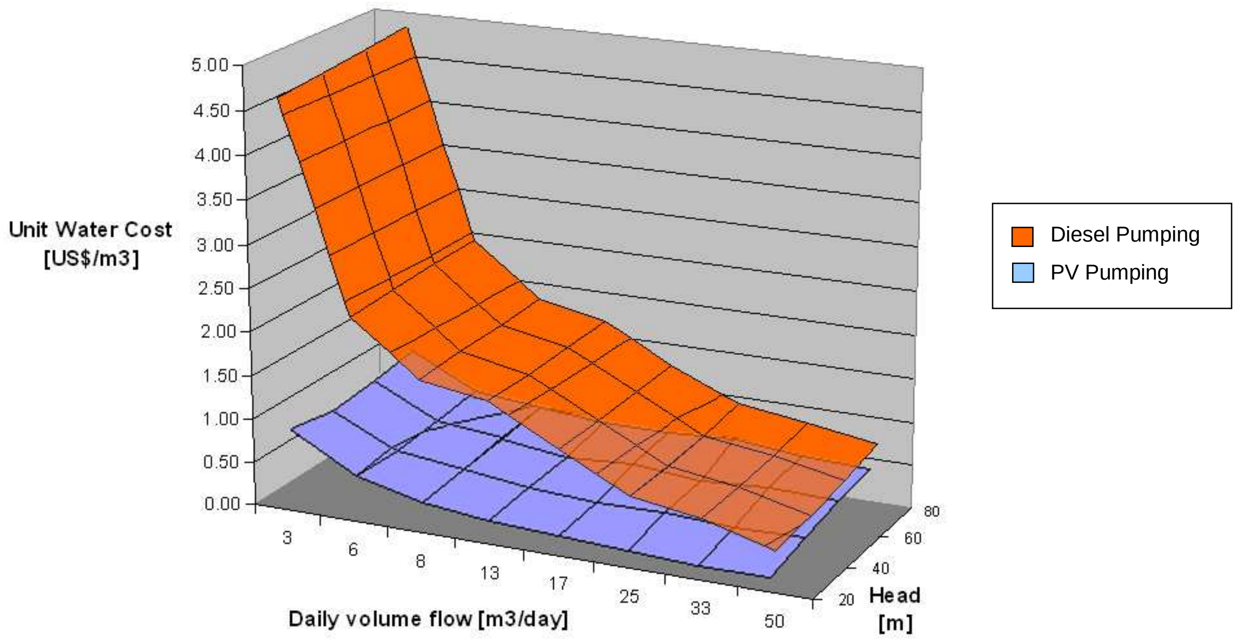
Source: NAMREP (2006)

3.3 Unit Water Cost

Based on the life-cycle costs of the above pumping options in Namibia, the unit water costs (UWCs) were calculated (NAMREP, 2006). The UWC was calculated by coupling the life-cycle costs with water delivery. Figure 3 compares the UWC for PVPs and diesel pumps for different daily flow rates and pumping heads ranging from 20m to 80m. The figure clearly shows that diesel pumps are particularly uneconomical at low flow rates (less than 8m^3/day). At higher flow rates the UWC of diesel pumps approaches PVPs but they still remain the more expensive option.

The cost of water increases more significantly with increasing head in the case of PVPs compared to diesel pumps, which are relatively insensitive to head. The UWCs of PVPs at flow rates above 8 m^3/day are similar at the same pumping head and range from around USD 0.13/m^3 for a 20m pumping head to USD 0.43/m^3 for an 80 m head.

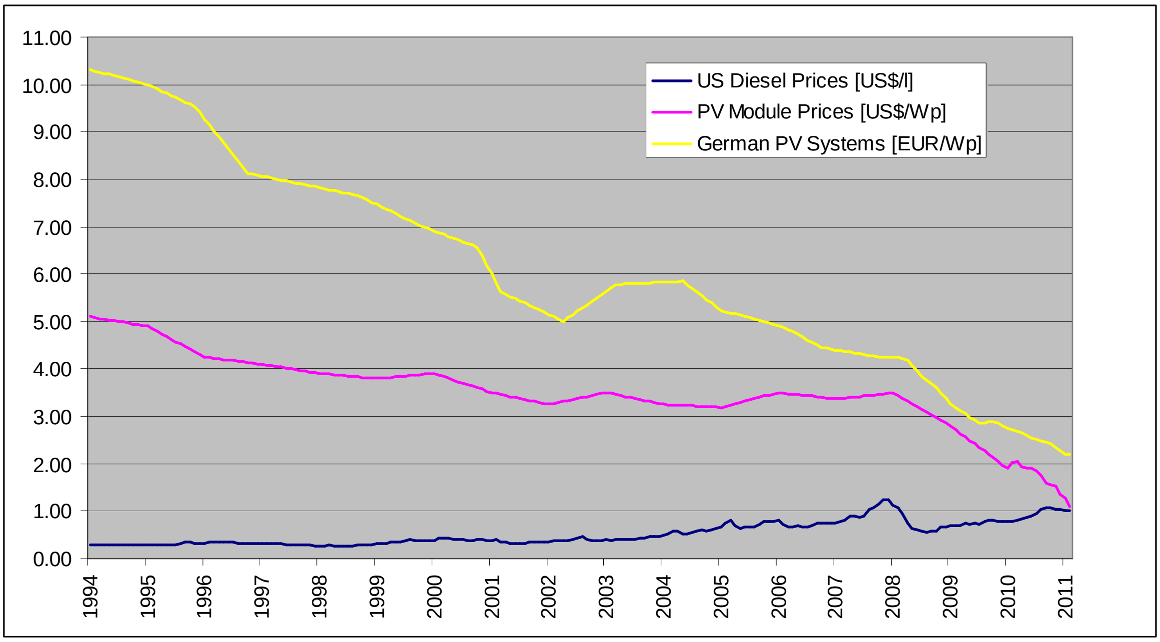
Figure 3 Unit Water Cost Comparison of Photovoltaic and Diesel Pumps in Namibia



(Source: own diagram, based on data from NAMREP (2006), recalculated in 2006 USD)

The capacity range within which PV pumping is economically more interesting than diesel pumping is largely determined by the price developments of diesel fuel and PV modules. Recent price increases for diesel fuel in most countries, along with uncertainties about future price developments, have also raised the awareness of PV pumping solutions in the private sector. For example, the mining industry in Chile has recognized PV pumping systems as an alternative to grid extension and diesel engines to provide process water for mineral extraction in remote areas of the Andes and the Atacama Desert. Comprehensive studies comparing life-cycle costs of the three technical options found PV pumping to be the least-cost option for small and medium-sized pumping stations of up to 20 kWp pumping power. In the case of grid extensions longer than 5 km or diesel prices above USD 0.85/l even larger PV pumping systems become competitive. It was shown that in case of a 20% fuel price increase and 20% cost reduction of PV modules, PV pumping stations will become competitive even in the range of 100 kWp to 200 kWp pumping power, which is far above standard village needs (Chueco-Fernandez & Bayod-Rújula, 2010). Figure 4 shows the evolution of prices for diesel, PV modules and grid-connected PV systems over the past 15 years. The dramatic drop of PV module prices since 2008 will significantly increase the competitiveness of PV technology in the future.

Figure 4 Development of Prices for PV Modules, Installed Systems[5] and Diesel Fuel



(Source: own diagram, based on data from EIA and IEA-PVPS reports 1995-2010)

3.4 Competitiveness of PV pumping systems

The above examples reinforce the notion that PV applications have become more competitive in recent years; supported by the evidence of larger systems also being evaluated by increasingly interested private sector investors. This tendency is the result of developments in the PV market over the past ten years. The PV market has grown between 33% and 77% annually between 1999 and 2009 with market support programmes as the main driving force. In 2010, growth was higher than 100%, with capacity additions close to 17 GW, up from the 7.2 GW installed in 2009. At the start of 2011 the total installed world PV capacity was close to 40 GW, producing some 50 terawatt hours (TWh) of electrical power every year (PVPS 2011). In Germany, total prices of

[5] The diagram shows average retail prices for installed roof-top PV systems in Germany in EUR. The prices were kept in EUR because, if converted into USD, the graph would reflect currency fluctuations more than price trends.

installed grid-connected systems have fallen to USD 3/Wp. PV module prices have dropped by almost 70% since 2008. In the third quarter of 2011, PV modules made in China were offered for USD 1.1/Wp (BSW 2011, www.europe-solar.de). Further price decreases can be expected, with module prices projected to drop by 20% for each doubling of production capacity, occurring approximately every two years (Hoffmann, 2005).

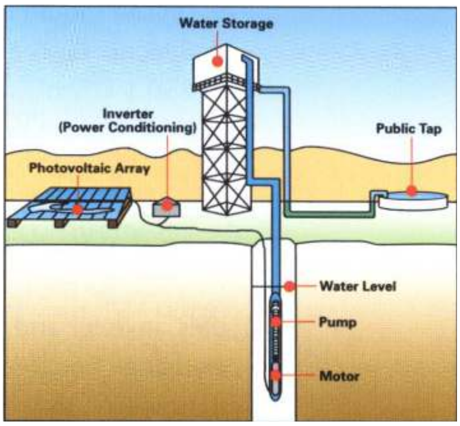
Amid such developments, grid-parity of PV electricity supply has become close to a reality. The situation is different for the largely unsubsidized off-grid systems, including PV pumping, which have to compete with diesel systems. As illustrated in Figure 2, the most sensitive factor in the case of a diesel system is the fuel price. Thus, the degree of competitiveness of an off-grid PV system is a function of the development of fuel prices (diesel and gas). As fuel prices are heavily subsidized in many developing countries, this means that the competitiveness of PV systems very much depends on the development of national policies regarding fuel subsidies. For example, when Mauritania introduced subsidies for natural gas the rural population quickly adapted their motopumps to gas operation, making it difficult for PVP to compete. However, in the case of favourable conditions of insolation and local system prices, PV systems can even compete with subsidized fuels. This was shown in a case in southern Egypt where the energy costs of a 2 MW multi-purpose off-grid PV system was EUR 0.13/kWh as compared to EUR 0.12/kWh in the case of subsidized fuel (one litre of diesel cost EUR 0.2 in Egypt in 2008). In the case of non-subsidized fuel (EUR 0.85/l) the diesel would clearly be much less competitive, with a resulting unit cost of energy of EUR 0.39/kWh (Qoaider & Steinbrecht, 2010).

Small and medium-scale off-grid PV technology has become cost-competitive, as long as investment decisions are being based on comprehensive life-cycle cost analyses. Such decision-making is usually carried out by medium and large companies, and industries for whom access to finance is not a major constraint. In the case of small enterprises that do not have ready access to credit, a decision in favour of low initial investment costs is more likely for reasons of opportunity cost of capital. However, the markets for rural water supplies in developing countries are not only distorted by fuel subsidies but also are even more heavily distorted by donor interventions and by import taxes. As has been shown above, in a donor-dominated market investment decisions are based on initial investment costs rather than life-cycle costs for reasons of both limited available budgets and the requirement to achieve numerical targets. There is a need to modify existing policies and regulations to create an enabling environment with low market distortions and appropriate incentives that allow investors to make adequate investment decisions.

3.5 Lessons learned from PV pumping programmes

A photovoltaic pumping system in rural areas generally consists of the following components:

1. Water source, often from a borehole
2. Submersible pump with AC or DC motor
3. Water storage facility
4. Water distribution network
5. Public water taps
6. PV array including DC/AC inverter or DC/DC controller



Worldwide experiences have shown that PV pumping can be a mature and reliable technology. System availability is particularly high in rural areas of Australia and the USA because systems are sold commercially and farm owners are prepared to invest in maintenance when required. In contrast, maintenance services are not readily available in developing countries, or there may be a lack of funds for maintenance. Still, PV pumping is not maintenance intensive - the maintenance of the photovoltaic part of a PVP system is restricted to regular cleaning of the PV modules. The electronics are usually located above ground in a controller box leaving just the motor and pump head in the well. This makes system troubleshooting easier and minimizes the need to pull the pump out of the well. Depending on the water quality, the only moving part of the system - the submersible motor pump - has to be checked every three to five years. Some suppliers of solar pumps offer extended warranties of up to five years.

The following points are generally seen as the main advantages of PVP systems:

- PVP systems do not require fuel, thus their operation is independent of fuel availability and price development issues. They may be the only practical option in many non-electrified areas where the logistics make it too expensive or even impossible to supply diesel generators with the required fuel.
- PVP systems can be located close to the demand centres, thus distribution and transmission losses can be minimized.
- PVP systems can run automatically and require little maintenance and few repairs.
- PVP systems do not require batteries, which are expensive and need a lot of maintenance. In PVP systems, the energy is usually stored in a high-level storage tank, which feeds the water by gravity to public water taps. The optimal storage capacity is roughly twice the daily water discharge rate.
- The use of solar energy eliminates air pollution and noise disturbance as well as soil pollution through motor oil and fuel spills.

3.6 Recent PVP Technology Developments

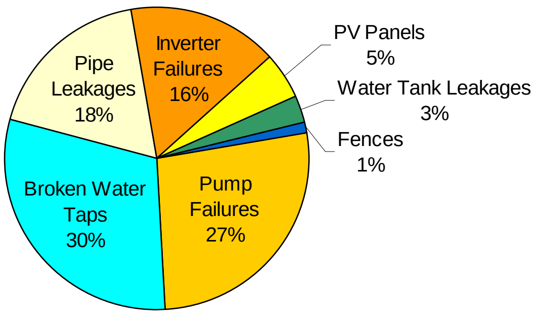
While PV pumping systems were initially mainly equipped with AC pump motors, all major equipment producers show a trend to increasingly use DC motors instead. DC motors reach efficiencies of up to 80% and are therefore significantly more efficient than sub-kW three phase motors that have efficiencies in the region of 60% to 65%. The use of brushless DC motors combines the high efficiency of DC motors with low maintenance, as opposed to brushed DC motors that require regular brush replacement.

Positive displacement pumps (e.g. helical rotor pumps) have gradually gained market share in PVP applications against centrifugal pumps, in particular for applications where the lift is more than 20m to 30m. Positive displacement pumps have a better daily delivery than centrifugal pumps when driven by a PV system with its characteristic variable power supply. This is due to the considerable drop in efficiency of the centrifugal pump when operating away from its design speed (the case in the morning and the afternoon for a centrifugal pump driven by a PV array, unless that array tracks the sun). The efficiency curve of a positive displacement pump is flatter over a range of speeds (NAMREP, 2006).

3.7 Known Problems of PV Pumping

Although PV pumping is a mature technology, past PVP programmes have also shown reliability deficiencies. A survey covering nearly 500 PVP units in Thailand found very positive impacts on the living conditions of villagers but also a considerable number of systems out of operation. Similar to the sustainability problems mentioned from conventional water supply systems, the main reasons for failure were identified within public agencies focusing on numerical targets: PV units were publicly funded, poor consideration was given to preparation and participation of villagers, and agencies had inadequate follow-up action. Six years after installation, up to 40% of systems were out of operation (Kirtikara, 2004). The main reasons for system failure are shown in Figure 5. Only a small fraction of the breakdowns were related to PV modules (damaged or stolen). Major technical damage of the PV part was due to motors/pumps and inverters. Motor and pump failures resulted from inappropriate technology transfer - Thai agencies adopted overseas deep-well pumping technology, whereas water pumping in Thailand is primarily from surface water that encounters more problems with sediment and soil run-off. More appropriate pumps would have been available for such circumstances. Despite inverter reliability appreciably increasing over the last ten years, some still failed because of moisture penetration, nesting of insects and lightning. However, half of the reasons for failure were found to be leakages or broken taps, and not components of the photovoltaic system. Thus, minor cost components could cause failures of whole systems due to the absence of after-sales service and spare parts.

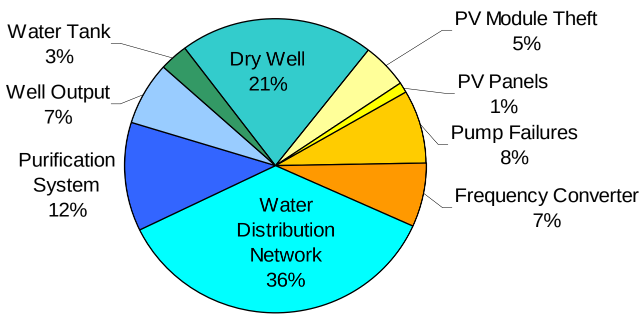
Figure 5 Nature of Damages to PVP Installations in Thailand



(Source: own diagram based on Kitikara, 2004)

Narvarte et al. (2006) reported similar findings from a PVP project in Morocco. It was shown that the most important failure rate is not in the 'photovoltaic part' (i.e. PV generator, frequency converter and motor pump) but in the 'rest of the system' (well, water tank, distribution network).
Figure 6 shows the different damages that occurred during an average operation time of ten years.

Figure 6 Nature of Damages to PVP Installations in Morocco



(Source: own diagram based on Narvarte and Lorenzo, 2010)

In contrast to the case in Thailand, less than 25% of the failures were related to the PV part of the system. The capacity of some wells was obviously smaller than planned, addressed by deepening the wells and building galleries. The systems in Morocco also included water-piping networks to each household and a purification system (chlorine injection) that contributed almost half of all system failures. Not conveyed in Figure 6 is the fact that 34% of all systems did not experience any damage during ten years of operation. The mean time to failure (MTTF) value was 8.81 years for the PV part and 2.34 years for the non-PV part of the systems.

The Morocco case also experienced system failure due to theft of PV modules as PVP systems were usually installed in remote places. Similar problems were also reported from PV experts responsible for the implementation of the RSP programme in Sahelian countries.[6] Once PV modules had been stolen (fully or partly), there were usually no spare modules available for replacement and no budget available to buy new ones. Solutions to the theft problem include the use of security guards, special system design, anti-theft accessories such as barriers, alarms, etc.

Another problem reported from the RSP programme was frequent customer complaints related to the lack of flexibility and limitations of water supply. In all villages, occasional demand situations occur (e.g. during ceremonies or when having visitors) when the design capacity of the PV system is too small to satisfy demand. Similarly, the systems cannot easily be adapted to a growing demand due to demographic changes or changes in water consumption patterns. Over-sized PV systems are not a solution as they are not cost-effective. Therefore, the second phase of the RSP programme has opened the market to "hybrid systems" offering the possibility to increase pumping capacity with back-up diesel gensets. Other means to address capacity bottlenecks such as water rationalization, automatic switch-off, or larger storages were found to be inappropriate and led to dissatisfaction among the beneficiaries.

[6] Regional Solar Programme (RSP or PRS) in CILSS countries (Sahel) : PRS 1 = 1990-98 ; PRS 2 = 2001-2010 (www.prs-burkinafaso.com)

4. Conclusions and Recommendations – Improving the Sustainability of Rural Water Supply Systems

"…lack of an enabling environment is often hampering the development dynamics in the water sector."

The review of experiences with conventional and PV powered rural water supply systems has shown some considerable differences in the approaches pursued but also some similarities in implementation problems faced. Noticeably, whether we are talking about hand-pumps or motorized pumps, the main issues which need to be tackled to allow a sustainable operation of systems are: a) the need to obtain a steady stream of revenues to pay for operation and maintenance, b) to be able access spare parts and repair services, and c) to have an organization capable of managing a) and b). The lack of an enabling environment is often hampering the development dynamics in the water sector.

Based on the findings of the previous chapters the following recommendations are made, focusing on the key causes of unreliable and non-sustainable rural water supply systems.

4.1 Increase Support to Governments in Creating Enabling Environments for Rural Water Supply Development

In most countries, the provision of water supply services is considered a basic service to be provided by the government. The provision of basic services, both for electricity and water supplies in rural areas, is by nature an expensive and often loss-bearing enterprise. If possible, rural losses are financed through cross-subsidizing from profits achieved in urban areas. Where cross-subsidizing is not feasible, public utilities have little incentive to expand services to rural areas and will only do so if they are forced to by clear national rural development policies. Such policies are required to adapt laws and to formulate measures creating an enabling environment for rural water supply development (licensing, concessions, permits, pricing mechanisms, capacity building, incentives, financing schemes, quality assurance, technology advice and so on).

With the 'water for all' and MDG initiatives promoted by the international development community, policy making and target setting was made on an international level over the past 30 years. Through the avoidance of involving governments in water project implementation and turning directly to communities, governments were relieved of their responsibilities. This has led to a situation in which foreign organizations are chasing targets instead of national governments. The success of a project is often measured in terms of funds spent but not in terms of sustainable water access.

Implementing rural water supply infrastructure needs a long-term perspective in order to result in sustainable solutions. The direct implementation of water projects by donor agencies is not part of such a long-term perspective if it is not embedded in government policies. Donor agencies should increase their support to governments to create enabling environments for rural water supply development. The success of implementing organizations should not be measured in terms of funds spent and number of people served, but to what extent their activities have contributed to the creation of an enabling environment for rural water supply, including the development of successful and sustainable Service Delivery Models.

"Donor agencies should increase their support to governments to create enabling environments for rural water supply development."

4.2 Attract Private Investors to Leverage Available Funds

Financing of rural water infrastructure is often mentioned as a problem. However, providing infrastructure for free, as is often the case in the rural water sector, does not only lead to non-sustainable solutions but also results in market distortions and over-pricing. Better solutions are possible: it was shown that where an enabling environment exists and where the needs and preferences of users are addressed, it is possible to raise significant funds from the private sector and communities that would otherwise have to be sourced from public funds.

Private investments in the water supply sector remain at low levels. This reflects the nature of difficulties associated with low tariffs as a result of a politicized debate about basic needs and the lack of an enabling environment. A clear and independent regulatory framework offering adequate economic returns is a precondition to attract the interest of private investors. The often-felt reservations by NGOs and charitable organizations with regard to private companies need to be addressed in the regulations. Transparent pricing mechanisms are required, in return for performance guarantees by investors as well as performance supervision and the possibility to impose sanctions in cases of underperforming or misbehaving operators.

"A clear and independent regulatory framework offering adequate economic returns is a precondition to attract the interest of private investors."

4.3 Develop Rural Water Supply Projects at Scale

Many rural water supply reliability problems are caused by the lack of maintenance. This is not only the case for hand-pumps but also PV operated pumps, where unreliability is usually not associated with the PV technology but with the water distribution system. The roots of the problem are community-based management with inadequate systems for cost recovery, repairs and maintenance, difficulties in obtaining spare parts and, in some countries, the small number of systems installed in a specific region. There is little incentive for a potential provider of repair services to keep a stock of spare parts for only a few pumping systems.

"Maintenance and sustainable operation is less of a problem where market-based approaches to rural waters supplies have been introduced and private companies are responsible for operating the water supply schemes."

Maintenance and sustainable operation is less a problem where market-based approaches to rural waters supplies have been introduced and private companies are responsible for operating the water supply schemes. However, community-based management is still the reality in many countries. To assure a sustainable operation of community-managed rural water infrastructure, the existence of a maintenance service provider needs to be guaranteed. This can only be realized if a critical number of similar pumping systems are established in a region, making it feasible for a maintenance service provider to stock spare parts. Even if a critical number of systems are available, it cannot be expected that such a maintenance service provider could earn enough money only through maintaining PV pumping systems. The company should be able to maintain all components of a rural water supply system and possibly also other kinds of rural infrastructure. To operate on a financially sustainable basis, a maintenance service provider should be able to achieve an annual turnover of the order of USD 50,000 to USD 60,000.

The definition of regions for larger-scale projects and the harmonization of technology require the coordination by regional and national governments and need to be considered in national development strategies.

4.4 Base Investment Decisions on Life-Cycle Costs of Rural Water Supply Infrastructure

"To avoid such waste of funds, governments and donor agencies are advised to select rural water supply technologies based on proper life-cycle cost analysis."

While hand-pumps can be considered the least-cost solution to supply water for small off-grid communities of up to 300 people, the supply of larger communities requires motorized pumping systems. PV pumping systems and diesel powered pumping systems are the main competing technologies in this field. It was shown that PV pumping is more economical than diesel pumping in a growing power range due to the decreasing cost of PV technology. However, the initial investment costs of diesel systems are much lower than those of PV systems, which is why governments and large donor agencies are tempted to favour diesel technology for the sake of achieving numerical targets. This results in high operational costs, for diesel fuel and maintenance, which are often an overpowering burden for the low-income communities operating the diesel systems. This usually results in an early breakdown of systems.

To avoid such waste of funds, governments and donor agencies are advised to select rural water supply technologies based on proper life-cycle cost analysis. Consequently, investment decisions would more often be made in favour of PV technology. Many would complain that this results in a higher initial investment costs that limits the numbers of people that can be served. However, paired with new approaches to develop rural water supply, including the involvement of private sector investors, it will be possible to achieve leverage of available funds. This leverage will allow the achievement of numerical targets and, if implemented wisely, such projects would also lead to more sustainable water access for the rural population. In addition, the initial investment cost barrier could also be addressed through the development of innovative financing schemes.

4.5 Consider the Whole Water Chain to Guarantee System Reliability

"…PV pumping programmes very often divide implementation responsibilities by creating an artificial boundary at the outlet of the well or at the entry to the storage tank."

PV pumping technology, if properly designed, is a mature technology with low failure rates. It takes, on average, almost nine years until a component of the PV system needs to be repaired or replaced. However, the rest of the system, from the entry into the storage tank to the water taps, is much more prone to failure and often the reason for a failed PV pumping project. A key problem affecting system reliability is seen in the fact that PV pumping programmes very often divide implementation responsibilities by creating an artificial boundary at the outlet of the well or at the entry to the storage tank. The responsibility from this boundary to the tap lies with the users, sometimes supported by local authorities or NGOs. This boundary represents a threat to the water service as a whole, due to users' limited technical skills (Narvarte et al. 2006:734).

PV engineering, at least where isolated rural electrification systems are concerned, must deal with the final service as a whole. Otherwise service reliability becomes negatively affected. Although the main problems are not related to PV technology, all problems occurring in the water chain (pumping, storage, distribution) will be perceived as being related to PV pumping technology and will thus have a negative impact on the reputation of the PV pumping concept (Bonneviot et al. 2005, Narvarte and Lorenzo 2010).

4.6 Envisage Larger Integrated Electricity and Water Supply Systems in Off-grid Areas

"…grid-parity of PV electricity supply has become close to a reality."

Due to steadily decreasing prices for PV modules, grid-parity of PV electricity supply has become close to a reality. In combination with rising prices for fossil fuels, the application range within which PV technology can compete on economic terms has broadened, particularly in off-grid areas. Integrated PV systems in the power range of several hundred kWp and higher have become an option for governments to provide basic services in areas where larger settlements exist and where grid extension is not economical. An integrated system can be thought of as a system that supplies households and enterprises with electricity via a local or regional mini-grid, and which is also used to power water services, both for domestic use and irrigation. Consequently, water pumping can be operated during off-peak hours (allowing demand peak shaving). This would preferably be a hybrid system in which the PV design capacity would suit an average load scenario with additional diesel back-up capacity to cover occasional peak load situations.

An integrated electricity and water supply system could be built, operated and maintained like any other infrastructure project, and allow rural households to be treated in a similar fashion to urban customers.

An integrated system could be built, operated and maintained like any other infrastructure project through competitive bidding with different degrees of participation by the private sector. The complexity of an integrated system would by definition require a professional organization responsible for operation and maintenance. This could be a public company or a private sector company working under a regulated energy and water service concession. Again, an enabling environment is required for such systems to be realized and operated on a sustainable basis.

One good thing about an integrated system is that rural households can be treated in a similar way to urban dwellers. For an electricity connection they would have to pay a connection fee and a usage-bound fee-for-service. Similarly for a water connection: people who would like to have a tap in their house would have to pay a connection fee and a fee-for-service, others who prefer carrying the water from a public tap may be offered a life-line tariff. Larger integrated systems would also carry the possibility of providing cross-subsidies to support very low-income families.

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