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# Renewable Energy Technologies for Rural Development

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# 1. Introduction

This paper provides an overview of some of the issues surrounding the use of renewable energy technologies (RETs) to increase access to modern energy services in rural areas. RETs include, inter alia, the provision of electricity generated from renewable sources such as wind, solar, water, tide/wave and geothermal, and the provision of other modern energy services that are powered by renewable sources for activities such as household heating, space conditioning and water pumping. These kinds of technologies have long been subject to international debate and action as a means of expanding access to electricity by means of off-grid or grid extension programmes. Similarly, the development of RETs such as improved cookstoves to increase efficiency and reduce health impacts of traditional fuel use has had a long history and has shown some success. However, growing concern over climate change and the increasing acceptance of a need for low-carbon development trajectories have provided renewed emphasis on improving access to modern energy services using RETs.

Chapter 2 of this paper reviews current international commitments to RET use and rural development and examine the literature connecting RETs with rural development. Chapter 3 looks at RET options and some potential benefits and challenges to deploying them. Chapter 4 investigates, using a number of case studies, how RETs have been used to promote rural development and how innovative project/programme design can help overcome some of the barriers inherent to RET deployment in the market. Chapter 5 provides a synthesis of our case study findings and Chapter 6 presents conclusions and recommendations.

# 2. Energy poverty and rural development

## 2.1.International commitments on reducing energy poverty

The potential of RETs to power rural development has been understood for many decades. However, it is only recently that significant effort has been made to mobilize the resources to realize this potential and there is still a long way to go (Kristoferson, 1997; Bhattacharyya, 2006; Boyle *et al.*, 2006). In September 2000, the connection between clean sources of energy and rural energy access was explicitly made in the form of the United Nations General Assembly's commitment to a global partnership to achieve a series of eight goals and targets known as the Millennium Development Goals (MDGs), by the year 2015. Reducing rural poverty through rural development is viewed as a key requirement to achieving these goals, and underpinning this is the need for expanding access to modern energy services. Modern energy services are benefits derived from modern energy sources, such as electricity, natural gas, clean cooking fuels and mechanical power, that contribute to human well-being (Modi *et al.*, 2005: 8–9). MDG 7 – ensuring environmental sustainability – promotes RETs as a way of expanding access to these services (World Bank, 2004b; United Nations Public–Private Alliance for Rural Development, 2009; United Nations, 2009).

This connection between clean energy and rural development has been further reinforced by international commitment to the Johannesburg Plan of Implementation (JPOI) adopted at the 2002 World Summit on Sustainable Development (WSSD) in Johannesburg. The JPOI reiterated support for Agenda 21, the outcome document of the 1992 United Nations Conference on Environment and Development (UNCED), also known as the Earth Summit, as well as the MDGs, specifically noting the importance of modern energy services for rural development.

## 2.2.Linking energy access and rural development

Access to modern energy services and rural development are inextricably linked (Barnes and Floor, 1996: 500; Chaurey *et al.*, 2004). Definitions of access vary (Brew-Hammond, 2007); we base ours on that of Ranjit and O'Sullivan (2002: 300-301):

> *Access to modern energy can be defined as a household's ability to obtain an energy service, should it decide to do so. Access is a function of availability and affordability. For energy to be considered available to a household, the household must be within the economic connection and supply range of the energy network or supplier. Affordability refers to the ability of the household to pay the up-front connection cost (or first cost) and energy usage costs. A high up-front cost may discourage poor households from making a switch to a modern energy form.*

We would broaden this definition beyond households to include any potential consumer, from individuals to large organizations. Most rural societies experience limited access to modern energy services, due to problems of availability and/or affordability. Instead, they rely on traditional fuels – predominately animal dung, crop residues, and wood – for the majority of their energy needs (World Bank, 1996: 5). Such "energy poverty" has a serious impact on living standards and productivity. When burned, traditional fuels often produce hazardous chemicals with negative health impacts, especially when used indoors. For example, Ezzati and Kammen (2002) provide strong evidence that exposure to indoor air pollution from the combustion of traditional fuels in Kenya enhances the risk of acute respiratory infection. They show that relatively affordable environmental interventions, such as use of an improved stove with traditional fuels can reduce acute respiratory infection by 25 per cent among infants and young children.

The fact that traditional fuels cannot produce a range of modern energy services such as mechanical power and electricity limits their ability to improve other aspects of life, including education and employment. As shown in table 1, traditional fuels also produce energy inefficiently. As a result, they require substantial time and effort to collect, and as local resource stocks decrease they increasingly have to be sourced from further afield. This significantly reduces the time available for productive activities. If managed ineffectively, such resources use can also degrade the environment and create negative spillover effects in other sectors. Given the cultural practices in many rural areas, these impacts are often most felt by women and children (World Bank, 1996; Barnes and Floor, 1996; Cecelski, 2000; Murphy, 2001; Barnes, 2005; Sagar, 2005: 1,367).

Although there are some methodological difficulties establishing a clear relationship between energy poverty and rural development (Cherni and Hill 2009: 645), a common concept used is that of the "energy ladder" (Barnes and Floor, 1996; Modi *et al.*, 2005: 22–23). Societies that depend on traditional energy activities are found at the bottom rung of the energy ladder. As they increasingly access modern energy services, they move up the energy ladder. At the top of the ladder are societies that have full access to modern energy services and experience greater levels of economic development and higher income levels (Barnes and Floor, 1996: 500; World Bank, 1996: 7; Modi *et al.*, 2005: 22-23). Figure 1 shows the correlation between a country's dependence on biomass and its per capita gross national product (GNP).

*Table 1. Energy efficiency of cooking fuels*[a]

| Fuel | Delivered energy (MJ/kg of fuel)[b] |
|---|---|
| Wood | 3 |
| Wood, with stove | 5 |
| Charcoal, with stove | 10 |
| Kerosene | 12 |
| Biogas | 15 |
| Liquid petroleum gas (LPG) | 25-30 |

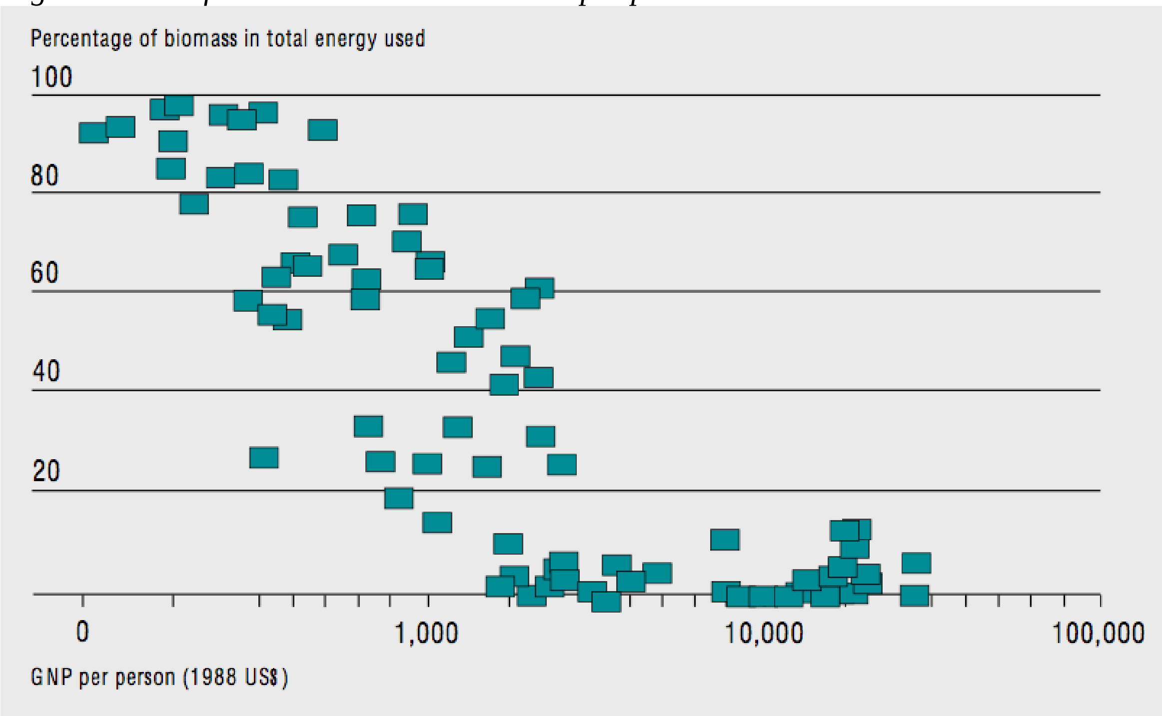
[a] The values in this table are derived from a combination of a fuel's energy content and the efficiency with which the fuels are typically burned for cooking in developing countries.
[b] Energy "delivered" to the cooking pot. Figures are approximate and rounded.

*Source:* Barnes and Floor, 1996: 506.

Movement up the energy ladder can occur within various aspects of rural life: agriculture, household cooking, household lighting, heating (Barnes and Floor, 1996: 500). However, it is important to appreciate that figure 1 shows only a *correlation* between a dependency on biomass and per capita GNP – it does not necessarily indicate *causality* (Barnes and Floor, 1996: 500).[1] It seems logical to assume that increased access to modern energy services (moving up the energy ladder) can catalyse rural development (measured in increased income). In fact, there is a co-dependent relationship: access to modern energy services can increase incomes (if used productively) and an increase in income can make modern energy services more affordable.

[1] Technology advances and reduced costs can allow movement up the ladder to happen earlier, or at lower income levels.

*Figure 1. Use of biomass in relation to GNP per person in 80 countries*




*Source:* World Bank, 1996: 7.

For the past 10 years, it has been frequently estimated that around 2 billion people have no access to modern energy services and about 1.5 billion people live without access to electricity (World Bank, 1996: 1; IMF and World Bank, 2006: vi). Access to modern energy services and electricity is low in many developing countries, particularly in sub-Saharan Africa and parts of Asia (see table 2 for figures on Africa). If the MDGs are to be achieved in these parts of the world, then significant efforts are needed to bring rural areas out of energy poverty (Modi *et al.*, 2005: 7-8). This can be done in two ways: increasing access to energy for domestic use – essentially increasing access to technologies which use modern fuels or make use of traditional fuels in cleaner, safer and more environmentally sound ways - and increasing access to electricity.

*Table 2. Levels of electricity access in selected sub-Saharan African countries*

| **Country** | **Population** | | **Access to electricity (% of population)** | | |
|---|---|---|---|---|---|
| | **Total (millions)** | **% living in rural areas** | **Total** | **Urban** | **Rural** |
| Benin | 9 | 59.2 | 22 | 51 | 5.5 |
| Cameroon | 18.5 | 44 | 46 | 77 | 16.5 |
| Ethiopia | 79.1 | 83.3 | 12 | 86 | 2 |
| Kenya | 38.5 | 78.7 | 13 | 51.5 | 3.5 |
| Malawi | 13.9 | 81.7 | 7.5 | 34 | 2.5 |
| Mali | 12.2 | 68.4 | 13 | 41 | 2.5 |
| Senegal | 12.4 | 57.9 | 46.5 | 82 | 19 |
| Uganda | 30.9 | 87.2 | 47.5 | 8.5 | 2.5 |
| Zambia | 11.9 | 64.7 | 20 | 50 | 3.5 |

*Source:* World Bank, 2006a.

# 3. Renewable energy technologies

## 3.1.Defining RETs

RETs are energy-providing technologies that utilize energy sources in ways that do not deplete the Earth's natural resources and are as environmentally benign as possible. These sources are sustainable in that they can be managed to ensure they can be used indefinitely without degrading the environment (Renewable Energy Association, 2009).[2] By exploiting these energy sources, RETs have great potential to meet the energy needs of rural societies in a sustainable way, albeit most likely in tandem with conventional systems. The decentralized nature of some RETs allows them to be matched with the specific needs of different rural areas.

For the purposes of this paper, it is useful to separate RETs into two categories: those used to provide *energy for domestic use* (predominantly cooking and heating) and those used to supply *electricity*. RETs used to produce energy for domestic use tend to do so by exploiting modern fuels or by utilizing traditional fuels in new and improved ways. RETs that generate electricity can do so either as part of a stand-alone (or off-grid) system or as a grid-based system, by way of connection to a mini-grid or the national grid. Table 3 lists renewable energy sources, as defined by the United Kingdom Renewable Energy Association, and corresponding RETs that provide modern energy services and electricity.

*Table 3. Renewable energy sources and corresponding RETs*

| | RETs | |
|---|---|---|
| **Energy source** | **Energy for domestic use** | **Electricity** |
| *Elemental renewables* | | |
| Solar | Solar pump, solar cooker | Solar PV |
| Water (including wave/tidal) | | Micro- and pico-hydroelectric generating plant |
| Wind | Wind-powered pump | Wind turbine generator |
| Geothermal | | Geothermal generating plant |
| *Biological renewables* | | |
| Energy crops | | Biomass generating plant |
| Standard crops (and by-products) | | Biomass generating plant |
| Forestry and forestry by-products | Improved cookstoves | Biomass generating plant |
| Animal by-products | Biogas digester, improved cookstoves | Biogas digester |

*Source:* Renewable Energy Association 2009.

Common RET options for providing energy in rural areas utilize wind, solar, small-scale hydropower and biomass resources. Wind energy is used for pumping water and generating electricity. Solar photovoltaic (PV) systems convert sunlight into electricity and solar heaters use sunlight to heat stored water. Small-scale hydropower plants are used to generate electricity and vary in size (mini, micro and pico, in descending size). Many small-scale hydro systems are "run-of-the-river" schemes, meaning that the main energy-carrying medium is the natural flow of water. In these cases, dams are small and there is very little storage of water. As a result, they are cheaper and less demanding on the environment, although they are less efficient and heavily dependent on local hydrological patterns. Technologies that utilize biomass include improved cookstoves for efficient burning of

[2] Although the supply of energy used in RETs may be indefinite, it is important to recognize that in some cases large amounts of energy and resources are used in the creation of RETs. The extent to which this is taken into account can significantly shape the debate over the "renewable" nature of different RETs.

traditional energy sources or biogas. Biogas can also be used in small power plants to generate electricity (Alazraque-Cherni, 2008: 107; World Bank, 2004b).

Decentralized RETs are particularly suitable for providing electricity services in rural areas. It has been argued that decentralized systems can provide local power and so can be locally designed (Havet *et al.*, 2009). Generally they also have low up-front costs (though often higher costs per kW installed than centralized technologies), and can help avoid the high costs associated with transmission and distribution grids (Alazraque-Cherni, 2008: 105; Steger, 2005: 212-213). They operate at smaller scales (kWh), appropriate to local needs and are accessible in remote locations as they are situated close to users (Kaundinya *et al.*, 2009: 2,042). Also, the possibility of adopting RETs is particularly important in the light of the limited success of conventional national grid-based rural electrification programmes to reach small, dispersed rural communities in developing countries (Goldemberg, 2000: 374-375; Alazraque-Cherni, 2008: 105).

## 3.2.Benefits/impacts of RETs

Greater access to energy for domestic use and electricity using RETs can have a significant impact on livelihoods in rural areas. Cleaner use of traditional fuels can significantly improve health by reducing acute respiratory infection and conjunctivitis, commonly caused by indoor pollution. Wider health benefits can occur too; cooking with more efficient technologies can make dietary choice and boiling of water more affordable or more likely. Women and children in particular will have more time for education, leisure and economic activity (Murphy, 2001: 177).

Access to electricity can significantly reduce the time required to devote to household activities. Electric water pumps, for example, can provide clean water, reducing the effort needed for collection. Electricity can make possible the refrigeration of vaccines and operation of medical equipment in rural health clinics. Access to radio and television can improve educational opportunities and provide entertainment. Electric lighting provides higher quality illumination than kerosene lanterns, improving opportunities for extended work and study time as well as better security, comfort and safety (World Bank, 2004b: 11; World Bank, 2001: 11-12).

Improved health and education, combined with more time to undertake non-energy related activities, are important goals in themselves. However, access to modern energy services also have the added value of helping local populations to engage in income-generating activities. Demand for services associated with RETs can help generate local economic activity based on these technologies, in addition to the means to power local industry. Applications of RETs for productive activities vary from mechanical wind-powered water pumping to motorized milling machines for grinding grain. Radio services can provide farmers and fishermen with weather forecasts and telecommunication services can provide growers with information on crop prices (World Bank, 2004b). As noted by Steger (2005: 213), these applications can lead to job creation and improved livelihoods, both of which can contribute to significant increases in productivity in rural areas.

## 3.3.The need for institutional support

Despite the potential of RETs to catalyse rural development, access to these technologies has not always translated into widespread adoption and effective performance (Alazraque-Cherni, 2008: 105). To be sustainable, efforts to strengthen access to RETs need to be accompanied by the right incentives, policy alignment, political and institutional support, and the development of local technological capabilities – the "know-how" and the "know-why" (Steger, 2005: 213; Alliance for Rural Electrification, 2009; Ockwell *et al.*, 2006).

Although the use of RETs as off-grid options for providing electricity services in rural areas is not new, the approach of developing countries and international financial institutions such as the World Bank to expanding electricity services has usually been expansion of the national grid (World Bank IEG, 2008). A stable national grid serving the entire population might be an attractive long-term vision. However, grid extension has not always proved to be the most cost-effective means of expanding access to rural areas, mainly due to low population density and greater technical losses as transmission networks increase (Goldemberg, 2000: 375; Alliance for Rural Electrification, 2009). By contrast, off-grid systems served by RETs can be the most appropriate option. ESMAP (2007) found that RETs can be more economical than conventional generation for off-grid (less than 5 kW) applications. For example, pico-hydro can deliver electricity for between $0.10 and $0.20 per kWh, less than one quarter the cost of similar sized gasoline and diesel engine generators.

However, a number of barriers work against utilizing off-grid RETs. Even when RETs are available, affordability can often undermine their deployment as they usually compete with traditional energy supplies and practices that involve no financial transaction (Bhattacharyya, 2006). It is claimed that the limited influence of rural populations in political decision-making has resulted in capital cities and economic centres remaining the focus of policy-makers (Alliance for Rural Electrification, 2009). Often the use of RETs is tied to reduction of carbon emissions at a national level, especially given internationally recognized targets and the availability of incentives such as the Clean Development Mechanism (CDM) within the framework of the United Nations Framework Convention on Climate Change (UNFCCC). Off-grid systems rarely enjoy CDM support because they are small and the transaction costs can outweigh any benefits from selling emissions reduction credits. As a result, they may look uncompetitive when compared to grid-based options (Kaundinya *et al.*, 2009), although there is now increased support for bundling small projects together to overcome transaction costs. The concentration of CDM projects around the world shows a disposition towards large emerging economies such as Brazil, India and China. However, many small-scale[3] projects have been approved, indicating that there is potential for small rural projects to take more advantage of this financial mechanism. (UNFCCC, 2009)

Some have argued that tackling the various barriers associated with deployment of RETs is made all the more difficult because of the disparity between the energy sector and rural development sector agendas (Goldemberg, 2000; Martinot, 2001; World Bank IEG, 2008). RETs have predominately been a result of an energy policy agenda, which was very much a market-push agenda: modern energy services and electrification are required for rural development; grid extension is too costly and time consuming; RETs represent a low-cost and environmentally-friendly alternative. But this fails to reflect market demand: what are the energy needs of that particular rural society that will enable it to develop? In order to take advantage of the opportunities afforded by increased access to modern energy services, parallel investments in other sectors are required (World Bank, 2004b). Energy investments should be integrated into rural development strategies so they can provide the modern energy services required by other sectors.

[3] The UNFCCC defines small-scale projects as projects with a power output of less than 15MW, efficiency gains through consumption reduction of less than 15GWh, or $CO_2$ emissions reductions of less that one kiloton (UNFCCC, 2001).

Finally, for RETs to be a sustainable part of rural development, technology choice must be supported at a policy level and be context-specific (Byrne *et al.*, 1998; Murphy, 2001; Chaurey, 2004). Added to this is the need for ensuring local capabilities exist to supply, install, maintain and repair these technologies. Therefore, the provision or sale of technology "hardware" must be complemented by development of local know-how related to that technology: the technology "software" (Ockwell *et al.*, 2009). In general, sustained rural development can only be possible if the existing political, economic and technical basis of rural society can adapt to new ways of living. If RETs are to be a feature of this new situation, then the capacity of local populations to manage them is imperative (Barnett, 1990). In order to facilitate this, institutional development must be a key feature of programmes to use RETs for rural development.

# 4. Case studies

## 4.1.Introduction

In this section, we look at a number of projects in which RETs have been employed to reduce energy poverty. These projects provide useful case studies of how RETs can meet the challenge of energy provision in rural areas and also what challenges they face from established energy systems.

Case studies of projects using RETs can be divided into two categories: projects that aim to increase access to energy for domestic use, and projects that aim to increase access to electricity. Within these two categories, the case studies cover a number of different RET technologies, contexts and issues. A list of initial candidate case studies was compiled from a variety of sources including the Ashden Awards for Sustainable Energy, the World Bank and affiliated programmes (such as the Global Village Energy Partnership) and the United Nations Development Programme and affiliated programmes (such as African Rural Energy Enterprise Development). The case studies chosen are listed in table 4.

*Table 4. List of case studies*

| Project name | Location | RET used | Funder/developer |
|---|---|---|---|
| *Access to energy for domestic use* | | | |
| Biogas Sector Partnership (BSP) | Nepal | Biogas plant | Netherlands/ Germany |
| Dissemination of Improved Stoves Program (DISP) | Eritrea | Mixed fuel stove | Government of Eritrea |
| Improved Stoves Program | Guatemala | Wood stove | Government of Guatemala/various donor funding |
| *Access to electricity* | | | |
| Renewable Energy Development Project (REDP) | China | Solar PV lighting | IBRD/GEF |
| Renewable Energy in Rural Markets Project (PERMER) | Argentina | Mixed technologies (PV, wind power, mini-hydro) | IBRD/GEF |
| Market-driven pico-hydro | Lao PDR | Pico-hydro | Consumers |
| Powering telecoms base stations | Namibia | Wind turbine | GSM Association/ Motorola |

## 4.2.Access to energy for domestic use

### 4.2.1. Introduction

In this section we look at three case studies promoting the use of RETs to achieve greater access to energy for domestic use: biogas in Nepal and improved cookstoves in Eritrea and Guatemala. The case studies reveal how these RETs overcome indoor air pollution problems, the implications of the technologies on individual households and communities, and where resistance and barriers to their introduction might be expected.

### 4.2.2. Nepal: biogas plants

Landlocked Nepal is located on the southern side of the Central Himalayas. The country has a population of 28.6 million, 82 per cent of whom live in rural areas, and its per capita gross domestic product (GDP) is approximately $441. Rural access to modern electricity is low (the rural electrification rate is only 5 per cent) and the vast majority of the rural population depends on traditional biomass for its energy needs (World Bank, 2009b; Mendis and van Nes, 1999: 16; Asian Development Bank, 2002).

**From biomass to biogas**

Traditional forms of energy used for cooking and lighting in rural Nepal come mainly from cattle dung cakes, fuelwood and agriculture residues. However, since the early 1990s there has been an increased effort to utilize biogas produced from cattle manure, human excreta and vegetable wastes in anaerobic bioreactors.[4] This has significant potential to generate income, improve livelihoods and save fuel costs. Today there are over 170,000 household biogas plants in Nepal, and the development of the sector owes a great deal to the Biogas Support Partnership (BSP), an independent non-profit organization financially supported by the Netherlands, Germany and Nepal (Gautam *et al.*, 2009: 249-252).

The first official biogas programme was initiated in 1974 by the Government of Nepal (HMGN) and consisted of construction loans from the Agricultural Development Bank of Nepal (ADBN). This was followed in 1977 by the establishment of the Gobar Gas Company, a State-owned enterprise responsible for advancing the development and promoting the large-scale dissemination of biogas technology (Mendis and van Nes, 1999:15-18). Yet it was not until the early 1990s that uptake was scaled up. In July 1992, BSP began operations with funding from the Directorate General for International Cooperation of the Netherlands (DGIS) through the Netherlands Development Organization (SNV). BSP is managed under the Ministry of Science and Technology's Alternative Energy Promotion Center and provides subsidy support to promote cooking and lighting using biogas. From 1992 to 2007, the BSP followed four implementation phases resulting in the installation of 172,505 biogas plants (Nepal, 2008: 7-9; World Bank, 2004a).

**Scale-up of biogas**

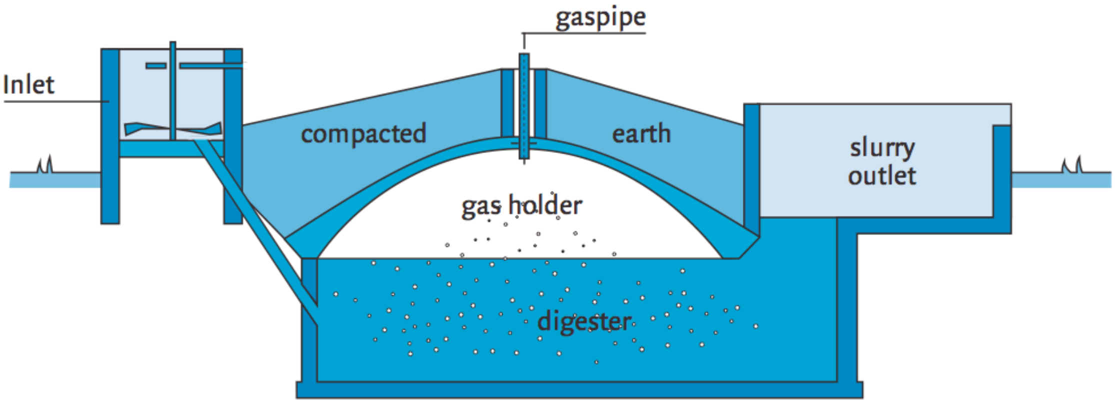
The main objectives of BSP are to provide training to biogas companies and plant users, ensure the quality and long-term reliability of plants, and manage the subsidization programme that makes biogas plants affordable. BSP accredits the work of private installation companies, an approach that has helped the private biogas sector to thrive (Ashden Awards, 2005).

The biogas plants promoted by BSP convert animal dung, human excrement and other biomass into biogas and slurry. Figure 3 illustrates the structure and process of a typical biogas plant in Nepal. The specific plant design was based on the Chinese fixed dome plant, and most of the materials used in plant construction (bricks and mortar, concrete and soil) could be sourced locally (Ashden Awards, 2005).

[4] Biogas is the mixture of gas produced by methane-based bacteria acting upon biodegradable materials in an anaerobic environment, and consists of methane, carbon dioxide and small amounts of other gases. Biogas is colourless and burns with a clean blue flame similar to that of liquid petroleum gas (LPG), allowing for practically smoke-free combustion. Biogas can be used for cooking and lighting, refrigeration, mechanical power and electricity generation (Acharya *et al.*, 2005: 2).

A $6m^3$ plant costs between $280 and $360, depending on location. About one third of the cost is paid in kind, through the family providing labour and materials for the installation of the plant. The remainder is still a significant amount of money in Nepal, but people are willing to pay because of awareness of the long-term benefits associated with biogas. The availability of financial support is an important additional factor: over 80 banks and microfinance organizations offer loans for biogas systems. This willingness to pay is largely due to experience of payback times of around 18 months. The BSP programme provides generous subsidies to families in more remote areas in order that all purchasers of $6m^3$ plants pay the equivalent of $200, regardless of price differentials in different locations. This cost includes a three-year guarantee period in which free maintenance is provided by the installation company (Ashden Awards, 2005; Acharya *et al.*, 2005).

*Figure 2. Typical biogas plant designed for Nepal*




The amount of dung to be fed into the digester depends on the size of the plant and the ambient temperature. Sizes are available in the range of 4, 6, 8, 10, 15 and 20 $m^3$. At moderate temperatures as found in the hills of Nepal, the corresponding daily input of dung amounts to 6 kg per $m^3$ of plant. Prior to feeding, the dung should be mixed in the inlet with an equal amount of water to make homogeneous slurry. Depending on the ambient temperature the slurry will retain in the digester for 50-70 days on an average. After leaving the outlet, it will flow to a compost pit. The produced gas is used for cooking and to a lesser extent (by half of the users) also for lighting.

*Source:* Mendis and van Nes, 1999: 18.

The involvement of BSP has amplified uptake of biogas plants by enabling the sector to function and grow successfully. Since BSP started, training in plant construction has been provided to over 6,000 people and 120,000 users have been trained in operating biogas plants and making minor repairs. Roughly 61 private installation companies exist and BSP monitors quality control by scrutinizing constructions and only subsidizing accredited companies. The mix of affordable finance, support, quality control and quality installations has led to a high success rate for biogas plants in Nepal: around 97 per cent of plants installed under BSP are still in operation (Ashden Awards, 2005).

**Key issues**

The success of BSP has been attributed to a number of factors. Biogas plants offered a way of meeting demand for increased access to energy in rural areas at the same time as reducing energy, health and environmental costs. The availability of biomass input required in biogas plants and availability of biogas technology and materials to build plants made them an attractive option (Gautam *et al.*, 2009: 249-250). However, local awareness of the benefits of biogas and willingness to adapt, combined with availability of subsidies to enable the purchase of biogas plants, stand out as the most important factors contributing to successful large-scale uptake. The development of standards for building materials helped to create competition amongst biogas plant construction companies, leading to a reduction of overall plant costs (Mendis and van Nes, 1999: 7).

With BSP support, the innovative subsidy programme adopted by Nepalese banks, which targeted small and medium-scale rural farmers, has been highly successful. However, there is much potential for expansion of domestic biogas. It is estimated that over 1.3 million biogas plants could be installed in the country (Gautam *et al.*, 2009: 252). Many potential users are poorer and more remote than those already using the technology. If the subsidy scheme is to be phased out at the same time as the poorest households are targeted, it will be vital to design the relevant lending mechanism to attract users and lending institutions (Mendis and van Nes, 1999; Ashden Awards, 2005; Acharya *et al.*, 2005).

**Benefits derived from BSP and use of biogas**

BSP supports affordable solutions that rely on local resources for their manufacturing and use (Paul, 2005: 4-5). The benefits of BSP have been substantial and wide-ranging. Reduced deforestation has always been touted as a major benefit of the BSP programme and, indeed, each biogas plant saves approximately two to three tons of firewood per year. There is visible evidence of forest re-growth in Nepal, brought about mainly by an active programme of tree planting, and also by the reduction of unsustainable firewood use through the biogas programme. Cattle dung, kerosene and chemical fertilizer are also saved; in fact, each biogas plant produces 1.75 tons of organic fertilizer each year, thereby reducing households' dependence on imported chemical fertilizers and saving a total of almost $300,000 nationally and providing an opportunity to use indigenous technology (Ashden Awards, 2005; Gautam *et al.,* 2009: 250-251). There are also substantial reductions in the emissions of greenhouse gases as less firewood and kerosene are being used. BSP estimates a net reduction of 4.7 tons/year of $CO_2$ equivalent per plant, or 660,000 tons/year for all the plants installed to date.

However, there are many other benefits. Health benefits include reduced smoke exposure and particle concentration indoors, resulting in reduced acute respiratory infections and eye ailments, as well as lower infant mortality rates (Gautam *et al.,* 2009: 250-251; Acharya *et al.,* 2005: 3). Also, the connection of roughly 77,000 household toilets to biogas plants has significantly improved hygiene through effective management of excreta and wastewater. Energy for lighting for more than 20,000 rural households has also extended study hours. Technical and management training programmes provided by BSP have led to the development of a private biogas business sector in Nepal. There are now over 55 construction companies, 15 biogas appliance manufacturers and 80 finance institutions involved in the biogas sector. This has generated 11,000 jobs in the biogas sector and an additional 65,000 jobs through spin-offs. Finally, gender-related benefits have been considerable. Women and female children - traditionally responsible for collecting firewood - have been able to save on average three hours per day, totalling 35,000 hours per annum (Ashden Awards, 2005; Gautam *et al.,* 2009: 250-251).

### 4.2.3. Eritrea: mixed fuel stoves

Eritrea is situated in the Horn of Africa and covers a land area of 124,320 square kilometres. It has a population of 48.4 million (of which 79.7 per cent lives in rural areas) and a per capita GDP of roughly $250. Rural access to modern energy services is weak, with over 80 per cent of the population using fuelwood for cooking; rural electricity access is only 2.1 per cent (World Bank, 2009a; World Bank, 2006a). Widespread deforestation has increased the time spent collecting fuelwood, the heat efficiency of which tends to average less than 10 per cent. Dung is often used as a substitute, reducing its supply for use as a fertilizer (Sitzmann, 2000; Ghebrehiwet, 2002).

**Targeting stove technology**

Eritrea's staple food, *injera*, is cooked on traditional *mogogo* clay stoves built over an open fire, usually indoors. The inefficiency of the *mogogo* stove exacerbates the problem of deforestation as it wastes fuelwood. The stove is also difficult to light, produces considerable smoke and because it stands at floor level it can endanger children. In response to the need for improved rural energy supply and preservation of Eritrea's remaining forests, the Energy Research and Training Centre (ERTC) coordinated the Eritrea Dissemination of Improved Stoves Program (DISP) to develop and disseminate an improved version of the *mogogo* stove.[5] DISP was initiated in 1996, with the first field-test taking place in 1999. Since the programme began, over 10,000 improved *mogogo* stoves have been disseminated, reaching about 1 per cent of traditional stove users (Climat Mundi, 2009; Ghebrehiwet, 2002; Ergeneman, 2003).

**Scale-up of improved stoves**

The ERTC was set up in 1995 to research and develop different renewable energy technologies, with stove improvement identified as a key project. The main objective of DISP was to disseminate the use of the new stove to rural communities. The programme has made dramatic improvements to the *mogogo* stove and has experimented with wind and solar power. ERTC is training women how to build the stoves themselves and also paying them to train other women, to become trainers (Ashden Awards, 2003).

The improved stove combines some of the advantages of the traditional *mogogo* design with efficiency and safety modifications (see figure 4). It has an enclosed ceramic fireholder with enhanced ventilation so that the fire burns more efficiently. It also includes a chimney to channel smoke outside. The improved stove can burn a wider variety of fuels such as twigs, leaves and animal dung, relieving pressure on fuelwood resources. As the fireholder is raised off the floor, it reduces risk to children (Ashden Awards, 2003; Climat Mundi, 2009; Ergeneman, 2003; Sitzmann, 2000).

Research, development and testing of stove design were undertaken by ERTC with assistance from the University of Asmara and the Ministry of Construction (Ghebrehiwet, 2002: 110-111). The materials required to construct the improved stoves are all produced in Eritrea. Apart from some curved ceramic bricks, the stove door, the cement chimney and its metal rain flap, all stove parts can be made in rural areas. In order to ensure uniformity and quality, DISP makes moulds for these parts in the capital, Asmara, and distributes them to installation sites (Ashden Awards, 2003). The total cost of a stove is roughly $20 and materials sourced from Asmara are subsidized through DISP, usually amounting to 85 per cent of total cost (Ergeneman, 2003). In order to encourage local communities to adapt to using the new stove, classes have been held to explain its use and to promote the technology (Sitzmann, 2000).

**Key issues**

The project evaluation report for the energy-efficient stoves programme states that acceptance of the new stoves is "widespread but not universal", and annual growth in the dissemination rate of stoves is around 17 per cent or 2,900 installations per year (Ergeneman, 2003).

[5] ERTC is housed under the auspices of the Eritrean Ministry of Energy and Mines (MEM).

*Figure 3. Improved Ertirean mogogo stove*

*Source:* Ergeneman, 2003: 17.

Stove improvements in developing countries are not a new phenomenon; efforts to reduce indoor pollution and improve cooking efficiency have been ongoing for over 40 years. The oil crises in the 1970s made moving up the energy ladder less affordable, and led to an increased reliance on biomass. Added to this was increasing awareness of the dangers of deforestation. The result was the growth of donor-assisted programmes in the 1980s to improve stove efficiency, with particularly large projects in India and China. However, these early programmes tended to overestimate how quickly a self-sustaining market could be formed. A key lesson from these early programmes was the importance of localizing the manufacture of stoves at affordable prices (Barnes *et al.*, 1994; Ergeneman, 2003). This lesson was clearly taken on board in the Eritrean case as ETRC designed the stove to be almost completely manufactured locally.

Interestingly, according to Ergeneman (2003), word of mouth was a major advertising tool. Demonstration stoves and media marketing were also used to inform the population about the programme. However, despite the relative success of DISP, there is concern that a lack of pro-rural energy policies and appropriate institutional frameworks is causing rural energy programmes to lose momentum during the implementation process. The tendency towards pursuing centralized, capital-intensive grid-based projects has left non-commercial rural electrification rather overlooked (Habtetsion and Tsighe, 2002).

**Benefits of improved cookstoves**
There have been many benefits of DISP. It is estimated that the improved stoves reduce household consumption of biomass by more than 50 per cent, due to their improved efficiency and their ability to work with other fuels such as fallen branches, twigs and leaves. This reduces the need to fell standing trees for fuelwood, and this impact has made the project eligible for funding through CDM, which could have a significant impact on further implementation of the scheme (Climat Mundi, 2009). However, the project is small and is not being bundled with any other projects, so high transaction costs involved may limit its impact.

*Injera* is usually cooked in large batches a few times per week. Because the improved stove stays hot for longer than the traditional stove and does not require relighting, the process of cooking *injera* is much more efficient. Furthermore, the almost smoke-free nature of the improved stove has important ramifications for the health of women and female children, who are usually responsible for cooking (Ashden Awards, 2003; Ergeneman, 2003).

### 4.2.4. Guatemala: wood stoves

Located in Central America, Guatemala covers an area of 108,889 square kilometres. It has a population of over 13 million, 51 per cent of whom live in rural areas, and a per capita GDP of around $1,907 (World Bank 2009b). It is currently estimated that 67 per cent of Guatemalans relies on wood energy for cooking and that the country loses around 2,460 hectares of forest every year as a result (Alvarez *et al.,* 2004: 1).

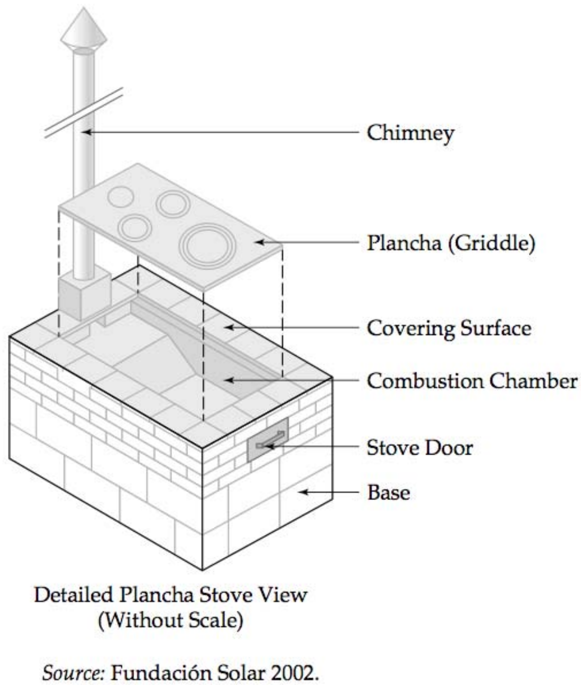
**Targeting stove technology**
Improvements in stove technology have been the target of Government and international efforts to reduce the consumption of fuelwood and improve energy services for domestic use. The first improved stove was the *Lorena* stove and its variants designed in the late 1970s. In order to coordinate and promote the improved stove technology, the National Group for Improved Stoves, a network of public and private institutions managed by the Ministry of Energy and Mines (MEM), was set up. The decline of this group in the late 1980s was followed in the early 1990s by failure of customers to buy new stoves when old ones wore out, instead reverting to old ways of cooking (Ahmed *et al.,* 2005: 53). The response was a number of projects that attempted to promote a new prototype stove, the *plancha armada* stove. One project in particular was especially successful in this endeavour: the Improved Stove Project (PEMF) run by the Government of Guatemala’s Social Investment Fund (FIS). Between 1996 and 2004, PEMF funded the installation of over 90,000 *plancha armada* stoves (Alvarez *et al.,* 2004).

**Scale-up of improved stoves**
FIS is a decentralized Government entity created in the late 1990s to provide grants to, and make investments in, activities to improve the quality of life for the rural poor. It provides technical assistance, finances development projects and strengthens community self-management. PEMF fell under the auspices of FIS’ Environment Unit and, due to widespread demand for improved stoves, it is the unit’s largest programme. PEMF involves promoting and subsidizing the installation of the *plancha armada* stove in rural areas as a replacement for worn-out stoves or an alternative to the open fire.

The design of *plancha armada* stoves was the product of many years of trial and error. In particular, the use of metal parts was based upon stoves used by commercial tortilla producers. In 1994/1995 the Ministry of Energy developed a training programme for artisans on how to make *plancha armadas*. This design was promoted during PEMF. The *plancha* *armada* stove includes a metal plate through which four holes are cut to fit a range of cooking pots. When the pot holes are covered, the stove top becomes a flat plate (the *plancha*), which is used for cooking tortillas. The main changes to the prototype since the beginning of the project have centred on the metal *plancha;* over time, projects have evolved to use 5mm reinforced iron *planchas* rather than the earlier 8mm cast iron *plancha*. The *plancha* fits on a base made of layered cinderblocks. There is also a chimney of galvanized sheet metal used to remove smoke from the house and improve the fire, and accessories to make wood-burning more efficient, including a regulator to control airflow and a door for inserting firewood (Alvarez *et al.*, 2004: 48-50; Boy *et al.*, 2000: 24). Figure 5 shows a typical *plancha armada* stove as promoted by FIS.

The *plancha* must be manufactured industrially in Guatemala City from imported metal. However, the cutting of pot holes and the construction of the base and chimney are done locally. Materials and installation cost between $100 and $150, depending on design, location and contribution of labour by the household. In order to make these stoves affordable to the rural poor, FIS subsidizes about 90 per cent of the cost (Boy *et al.*, 2000: 24; Alvarez, 2004: xv). As part of FIS, community groups are organized and given responsibility to select the list of projects they favour. FIS then provides financing for the highest priority project on the community's list. If a stove project is chosen, a stove construction company is contracted to build the complete stove, including purchase of materials, paying the cost of transporting materials to the site and paying for skilled labour. A one-year guarantee is also required. Demand for stove projects continues to be robust, and it is estimated that approximately 15,000 stoves are built each year (Ahmed *et al.*, 2005).

*Figure 4. Typical plancha stove promoted by the Social Fund (FIS) in Guatemala*




*Source:* Ahmed *et al.*, 2005: 54.

**Key issues**

Excellent participation of stakeholders involved in the implementation of PEMF has allowed it to achieve a higher level of success than other projects that promoted the *plancha armada*. The selection of decentralized FIS staff native to the area in which they are working has been instrumental in ensuring the needs of communities, their customs, language and geographic specificity have been incorporated into all FIS project designs. However, a key issue has been the limited flexibility of stove design. For instance, women users cannot choose the height of the stove base to suit their personal requirements (Alvarez *et al.,* 2004: 66).

Despite the success of PEMF, efforts to promote improved stoves have focused on heavily subsidized provision to the rural poor without much consideration of marketing and commercial sustainability. PEMF depends heavily on financing from donor funding to FIS. Potential stove users are therefore highly dependent on continuing subsidization (Alvarez *et al.,* 2004: xvii and 67; Boy *et al.,* 2000: 24). It is possible that a single fixed subsidy would allow users to choose between fully-subsidized, shorter-life stoves and partly-subsidized, longer-life versions (Ahmed *et al.,* 2005: 102).

**Benefits**

The benefits of improved stoves in Guatemala have been difficult to measure. Indoor pollution only seemed to be reduced when stoves were well maintained although, in an evaluation study reported by Ahmed *et al.* (2005), most users – predominately women - claimed that improved family health had resulted from less smoke inhalation. Users also said that lower consumption of fuelwood had saved them money and significantly increased the time available for other activities. Users also reported that the improved stoves were useful for cooking tortillas, an important part of the local diet (Ahmed *et al.,* 2005; Alvarez *et al.,* 2004).

## 4.3. Access to electricity

### 4.3.1. Introduction

In this section we look at four case studies that employ RETs as a means to increase access to electricity. These cases include the use of solar PV and wind in China, mixed technologies in Argentina, pico-hydro in the Lao People's Democratic Republic and solar PV and wind in Namibia. The case studies highlight the importance of Government policy frameworks, incentives for private sector participation, good relations with incumbent suppliers, and the engagement of local communities.

### 4.3.2. China: solar PV and wind for off-grid electrification

China has a per capita GDP of nearly $2,912 and some 56.9 per cent of its 1.325 billion population lives in rural areas (World Bank, 2009b). Although an intensive electrification programme has allowed China to achieve high levels of electrification (98.4 per cent), the country's huge population means that 20 million people still remain without access to electricity. Most of these people live in poor, remote rural areas in the western and central parts of the country. In these areas, electrification rates can be as low as 85.1 per cent amongst the critical poor (ZhongYing *et al.,* 2006). For those without access to electricity, lighting is usually provided by kerosene, butter lamps and candles (Ashden Awards, 2008).

**Targeting solar PV and wind technology**

The possibilities of further grid electrification in China are relatively limited. Those still without access to electricity tend to be found in rural, remote and often mountainous areas of western China. Because of limited infrastructure in these areas, grid extension and the provision of diesel supplies is difficult. However, this region of the country also enjoys the most renewable sources: solar energy in Qinghai, and Xinjiang, hydropower in Sichuan and Qinghai, and wind resources in Inner Mongolia and Xinjiang (ZhongYing *et al.,* 2006: 9).

Since the turn of the century, the Chinese Government has embarked on a number of projects in order to harness the potential of these renewable resources. One such project was the Renewable Energy Development Project (REDP), launched by China's National Development and Reform Commission (NDRC) in 2001 with assistance from the World Bank and the Global Environment Facility (GEF). REDP used solar PV and wind technologies to supply electricity to rural households and institutions in nine provinces. Between 2003 and 2008, the project subsidized the installation of 402,000 solar home systems and supported the rapid growth of the solar PV industry in China, improving production quality whilst maintaining low costs (National Renewable Energy Laboratory, 2004; Wohlgemuth and Painuly, 2006; Ashden Awards, 2008).

**Scale-up of solar PV and wind technology**

REDP consisted of a $13 million International Bank for Reconstruction and Development (IBRD) loan, a $27 million GEF grant and $102 million of Chinese co-financing. Its goals included the improvement of solar PV product quality, warranties and after-sales services, increased business capabilities and greater marketing efforts. It promoted installation of solar PV home systems (SHSs) and wind systems in remote off-grid households and some demonstration wind systems.

SHSs comprise a PV module, rechargeable battery, charge controller and, if necessary, an inverter. When exposed to light, the PV module generates direct current (DC) electricity and charges the battery via the charge controller. DC lights and appliances can be powered directly from the battery via the charge controller, while alternating current (AC) loads must be connected to an inverter. The power of the systems installed as part of REDP ranged from between 10Wp and 500Wp.[6] Smaller SHSs powered two lights and were portable, whereas larger systems could power radio cassettes, televisions and DVD players. The REDP has also supported some solar PV village systems (and a few with combined wind and solar PV) to provide electricity for public facilities such as schools, health centres and Buddhist temples (Ashden Awards, 2008).

REDP funds were channeled through NDRC to roughly 80 approved suppliers and 32 wholesale companies in various regions, including Quinghai, Gansu, Inner Mongolia, Xingjiang and western Sichuan and nearby areas in order to subsidize the cost of marketing, selling and maintaining solar PV systems. These companies included private enterprises, joint ventures, companies wholly or partially owned by research institutes and State-owned enterprises. They all had to meet strict standards of product quality, service and management in order to be approved and remain part of the programme. Participating companies were categorized into three groups, relating to the standards which they aimed to meet. The first group consisted of provincial market-driven companies aiming to meet provincial demand. This group used REDP grants to help them improve product design and quality for the rural market. The second group used REDP grants to bring their products up to national standards in order to participate in donor-supported programmes and meet urban demand. The third group was made up of export-oriented companies who used the grant to help them meet international standards so they could export to PV markets in Europe, Japan and the Unite States (World Bank 2009c). Providing they passed regular standards tests, companies were paid a subsidy of $1.50/Wp for each SHS they sold. As quality standards rose, so did the subsidy.

[6] Wp stands for Watt-peak. This is the maximum power output under standard test conditions.

Customers usually paid the retailer the full price of an SHS in one payment. No credit system was initiated as part of the project, although separate local arrangements did exist. Because of competition, sales prices tended to vary by only 15 per cent between retailers. A typical 20-Wp system sold for between $105 and $120 – about the price of a yak. These are low retail prices by international standards and were possible in part because of the low cost of solar PV modules in China, which accounts for about half of the total cost of a system (Ashden Awards, 2008).

The wind energy component provided a total capacity of 20MW at Chongmingdao and Nanhui to increase the public visibility of wind technology and to strengthen the capacity of wind farm companies to help them overcome barriers to developing wind resources in those areas (National Renewable Energy Laboratory 2004; Ashden Awards 2008).

Training, support and quality improvement were key aims of REDP, the latter accounting for 40 per cent of the total expenditure. In particular, REDP established technical standards for all components, based on national and international criteria. Technical workshops and training sessions were held to raise component quality, and suppliers who failed to meet the standards were offered support to achieve them. Importantly, the solar PV modules are guaranteed for 10 years but are expected to last for at least twice as long. REDP also requires retailers to give warranties for other components. These are two years for charge controllers, one year for batteries, inverters and lights, and six months for radio cassette players (Ashden Awards, 2008).

**Key issues**

By 2007, the annual number of SHS installations had decreased because the subsidy had been reduced. However, by the end of 2006 about 50 per cent of the sales of the participating companies were outside the subsidy programme, suggesting that SHS installation will continue to thrive even after subsidies have finished. Research undertaken by REDP suggests that the market for SHS systems will continue to increase by 10 to 20 per cent per year (Ashden Awards, 2008).

It is important to appreciate the context within which domestic solar PV projects are situated. Solar PV technology is not new to China. Government-funded research and development into solar PV began in China in the late 1970s and has since developed into a considerable industry. This has been driven by export demand from the United States and Europe, which has led to high manufacturing standards, high efficiency and low costs. It is only recently that Government policy incentives have been put in place to take advantage of this industrial expertise for the domestic market (Marigo *et al.*, 2008).

**Benefits of REDP and solar PV**

The benefits of REDP have been great and the impressive installation of 402,000 SHSs between 2003 and 2008 means a total of 1.6 million people have been able to enjoy them. For users, the main benefit has been better lighting for study, work and recreation. Use of entertainment and communications equipment such as radio-cassettes and mobile phones has also been important (Ashden Awards, 2008).

The risk of fire (from the use of kerosene lamps, butter lamps and candles) has also been significantly reduced. Where mobile networks are available, the ability to charge a mobile phone has not only facilitated communication but has also opened up a commercial avenue. Those households that previously relied on purchased kerosene or candles have saved significant amounts of money from installing a SHS. Environmental benefits have accrued from reduced greenhouse gas emissions. In addition, it is estimated that around 1,500 permanent jobs and 3,000 temporary jobs have been created in companies participating in REDP (Ashden Awards, 2008).

### 4.3.3. Argentina: mixed technologies for on- and off-grid electrification

Argentina has a population of 39.876 million, 8 per cent of whom live in rural areas. The country's per capita GDP is about $8,235 (World Bank, 2009b). Reform measures to improve the provision of modern energy services, in particular electricity, have tended to benefit urban populations already connected to the national grid; by 2005, an estimated 30 per cent of the rural population still lacked access to electricity (World Bank, 2008; Fuentes, 2005).

**Targeting mixed technologies**

As part of its ongoing efforts to reform the electricity sector during the 1990s, the Government of Argentina classified provincial electricity service into two markets: concentrated (primarily urban), grid-connected customers and dispersed (primarily rural), off-grid customers. A key barrier to increasing electricity access in dispersed markets was the inability of provincial governments (which were responsible for expanding access) to finance the investments required. Therefore, in 1995 the Government of Argentina sought to replicate within dispersed markets the ongoing efforts to attract private sector participation in concentrated markets. The Government of Argentina embarked on the Programme to Supply Electricity to the Rural Population of Argentina (PAEPRA), aimed at supplying electricity to around 1.4 million people and 6,000 public facilities in rural areas through private rural energy-service concessions (World Bank, 1999; Martinot and Reiche, 2000; Alazraki and Haselip, 2007).

In 1997, the Government of Argentina requested financial assistance from the World Bank and GEF to support the implementation of PAEPRA. This led to the approval in 1999 of the World Bank's Renewable Energy for Rural Energy Markets Project (PERMER), a $30 million IBRD loan and $10 million GEF grant to subsidize installation of a mix of RETs by private concessionaires (World Bank, 2008).[7]

**Scale-up of mixed technologies**

PERMER was designed to increase access to electricity in rural areas at a tariff level appropriate and affordable to poor consumers and the provincial governments responsible for subsidizing them. The project aimed to reduce high up-front costs associated with increasing access and also to strengthen the institutional and regulatory framework associated with the dispersed market. Private concessions for off-grid services in low-income rural areas had not been attempted by the Government of Argentina or the World Bank before, but the potential advantages were considered great enough to pursue this innovative approach (World Bank 1999).

Project objectives included installation of SHSs in 65,000 rural households, small off-grid generation units such as solar PV, wind-turbines, mini-hydro plants and diesel units to supply 3,500 households, and 1,100 renewable energy systems for public institutions such as schools,

[7] Concessionaires tended to be a mix of financial institutions, construction companies and foreign operators. Provinces eligible to benefit from this World Bank project must have privatized their concentrated market. Project funding would then be allocated to existing concessionaires responsible for servicing the concentrated market or new concessionaires.

medical centres and police stations. Alongside these installations was a programme of capacity-building and training to improve technical, institutional and regulatory capabilities (World Bank, 1999).

Each private concessionaire was free to choose the technology to apply. The concessionaires were required to provide and maintain household systems and public facilities in return for monthly fees. Each concessionaire was contracted to provide electricity to rural off-grid customers anywhere in the province for at least 15 years. This included the maintenance, repair and replacement if necessary of systems in order to ensure continuity of service. Regular reports were filed with the provincial utility regulatory agency in order to ensure service standards were met. Initially, 8 provincial Governments out of 22 were eligible for the project, given their attempts at reform of their concentrated electricity sectors (Reiche *et al.*, 2000).

Project documentation implies that the technologies used in PERMER were imported and the fact that most concessionaires involved foreign operators makes this even more likely. Technology quality standards were nationally designed, based on global criteria, but the development of knowledge and skills associated with operation and maintenance of the hardware was limited (World Bank, 2008; Alazraki and Haselip, 2007: 141).

**Key issues**

Initially "satisfactory" implementation performance was downgraded to "unsatisfactory" by the World Bank in early 2002 after the onset of the economic crisis in Argentina. Project implementation was hindered as austerity measures put in place by the Government of Argentina led to reduced federal and provincial budget allocation to the project and delays from the reduced functioning of key employees in the energy ministry. A number of modifications to legal agreements led to the World Bank increasing its financing of SHSs to 100 per cent and allowed public utilities to take up concessions. In November 2006, project implementation improved to "moderately satisfactory" and in December 2007 it finally returned to "satisfactory" (World Bank, 2008).

Flexibility was vital to preventing project failure during the economic crisis and additional financing was requested towards the end of 2008 to assist plans for expansion of the project.

**Benefits of PERMER and mixed technologies**

It would appear that the project has brought considerable benefits to those rural communities involved. A preliminary impact evaluation confirmed that better lighting has significantly increased the time available for social and productive activities. Comfort and safety levels have improved, as have household savings. Higher income levels suggest the project has had a positive impact on productive activity. Improved education through increased use of various technologies and extended study hours has also been noted (Alazraki and Haselip, 2007: 141; World Bank, 2008).

Although the environmental impact of the project has not been evaluated post-implementation, estimates during project appraisal put the potential $CO_2$ abatement (as a result of the creation of a SHS market) at 0.8-1.1million $tCO_2$. This estimate was the rationale for the $10m GEF component (World Bank, 1999).

### 4.3.4. Lao People's Democratic Republic: market-driven pico-hydro

The Lao People's Democratic Republic is situated in South-east Asia. It has a population of just over 6.2 million, of whom 69.1 per cent live in rural areas. The country has a per capita GDP of about $837 (World Bank, 2009b). Whilst the Government of the Lao People's Democratic Republic successfully managed to increase household grid electrification from 19 per cent in 1996 to 60 per cent in 2008, the lower population densities and difficult terrain in rural areas make expansion of the grid to these areas very costly and therefore unlikely in the near future (Smits and Bush, 2009).

**Targeting pico-hydro technology**

There is considerable potential for using RETs to provide decentralized electricity supply in rural parts of the Lao People's Democratic Republic. However, despite the country's hydro potential and the fact that most of its on-grid electricity generation comes from large-scale hydro, pico-hydro has been given little attention in policy, data collection and donor assistance. This may be due to, among other things, a preference for SHSs, Government desire to maintain a centralized electricity system, and/or Government and donor hesitation over pico-hydro technologies. Nevertheless, a market for pico-hydro has developed "under the radar" in the Lao People's Democratic Republic. Data on the number of pico-hydro systems are limited but conservative estimates suggest there may be as many as 60,000 in the country. Its position as an established form of electricity generation in rural areas with a market-based network of technical support and spare parts warrants acknowledgement and its neglect in policy dialogues warrants attention (Smits and Bush, 2009).

**Scale-up of pico-hydro technology**

The most common pico-hydro system in the Lao People's Democratic Republic is the low-head type, requiring a small head (around 1.5m) and flow rate (around 35litres/s). Water falls into the propeller at the bottom of the unit, making the shaft turn. As the shaft rotates, it turns an alternator in the upper part of the unit to create an AC-electricity supply. The most popular units in the Lao People's Democratic Republic generate 1kW or less (Smits, 2008a; Smits, 2008b).

Most of the pico-hydro units and spare parts used in the Lao People's Democratic Republic are produced in neighbouring countries (including China) and then sold through trade networks in various countries in the region before arriving in the Lao People's Democratic Republic. Shops stocking these units and spare parts are supplied by traders of pico-hydro products who pass by at regular intervals, ranging from weekly to monthly. Support services for pico-hydro systems, such as welding shops, can be found in markets. The products themselves are low-cost and low-quality. Given the unregulated nature of the service provided by pico-hydro, there are no standards or regulations. Technical information about products and how to use them is also limited and when it does exist, it is often in a foreign language. As a result, systems are chosen on the basis of word-of-mouth. Most households undertake daily maintenance of their pico-hydro system. Leaves and branches often need to be removed and cables require checking (Smits, 2008b). There is very little information on whether pico-hydro technology has been developed or produced locally.

**Key issues**

Whilst the development of a pico-hydro market in the absence of Government, domestic bank or donor assistance is impressive, there are some concerns that result from this lack of attention to the technology. Unregulated installation and maintenance of these systems is dangerous and can result in fatalities. Paradoxically, this has often been used by Government and donors as a reason not to support pico-hydro development.

Load management of pico-hydro systems has to be done manually and regularly results in broken appliances, thereby increasing associated costs. The level of power generated also fluctuates with the river flow and this inconsistency damages equipment. Poor cable quality can considerably endanger populations using pico-hydro systems, and high-quality cabling can be unaffordable (Smits, 2008b)

**Benefits of pico-hydro in the Lao People's Democratic Republic**
The main benefit of pico-hydro systems in the Lao People's Democratic Republic is the provision of electric lighting. Most systems are connected to one or more light bulbs, used for lighting during evening meals, lighting paths to the toilet, reading, housework or homework. Income-generating activities such as weaving and making bamboo mats could also be undertaken in the evening and battery charging could take place. Some pico-hydro systems are large enough to power entertainment systems such as televisions, CD players and video CD players.

### 4.3.5. Namibia: wind turbines and solar PV for powering telecoms base stations

Namibia has a per capita GDP of $4,050 and a population of over 2.1 million people, 63.2 per cent of whom live in rural areas (World Bank, 2009b). Provision of mobile telecommunication services in rural areas has been steadily increasing, but the high costs associated with powering telecoms base stations in poor and isolated rural areas prohibits extension of services to these areas. However, RETs can prove an economical way to solve this problem.

**Targeting wind turbine technology**
Improvements in solar PV and wind turbine technology coupled with falling capital costs have made these technologies increasingly competitive alternatives, especially where off-grid capability is desirable. Solar PV and wind turbine technologies are now at the point where they can power telecoms base stations, and Motorola has been undertaking pilot studies to assess their viability. A four-month wind and solar trial conducted by Motorola in collaboration with the Groupe Speciale Mobile Association (GSMA) and Mobile Telecommunications Limited (MTC) Namibia has recently been completed at a mobile phone base station site in Dordabis village, 100km east of the capital, Windhoek. Results have been positive and suggest that there is good potential for replication (Motorola Inc., 2007; Hello Namibia, 2008; TMCNet/Azuri, 2007).

The trial in Namibia consisted of a commercial base station powered by a 5kW solar PV array and a 6kW wind turbine mounted on a 15m mast with a 5.5m rotor diameter. It took four to five days to set up and be able operate traffic continuously. The solar PV system would charge two batteries to power the station at night and the wind turbine would be used to top up the battery as required (Green Telecom/Chan, 2008; GSMA Development Fund 2007). As this is just a pilot study, no assessment of the opportunities for building technical capabilities was made. Motorola plans to offer the service globally, but there was no mention of training schemes to support local installation and maintenance.

**Key issues**
The trial project for powering telecoms base stations with solar PV and wind turbines appears to have been a market-driven example of RET use. The extent to which it will be "rolled out" in the absence of specific policy/incentive support from governments remains to be seen.

**Benefits of wind turbine and PV technology for telecommunications**

Cost-effective expansion of telecoms infrastructure has always been an issue for telecom companies. Alternative energy solutions for powering base stations can provide a feasible way to expand mobile services to rural populations. This can have considerable impacts on people's lives, from communicating with family members to keeping track of weather and commodity prices. In addition, the transfer of money using mobile phones has become an increasingly important banking tool in many developing countries. Using RETs to power base stations also has the environmental benefit of reducing $CO_2$ emissions (GSMA Development Fund, 2007; LetsGoMobile, 2007).

# 5. Synthesis

The case studies presented in this paper provide examples of a range of RETs employed in various parts of the world to achieve a number of different objectives. Because of this variation, it is not possible to directly compare these projects or to generalize to any significant degree. However, each case study provides insights relating to how RETs can be successfully utilized to reduce energy poverty in rural areas, including how financial, political and social barriers can be overcome.

**Barriers to deployment of RETs in rural areas**

The applicability of RETs to rural settings has long been appreciated. However, various barriers continue to hinder widespread promotion of RETs as viable alternatives to extension of national grid networks. Despite some RETs having been around for a number of years, knowledge about their existence and how to use them has not extended to many rural populations. Traditional living patterns and cooking practices continue to dominate. A transition to RETs requires more than simply making the technology available; it must be actively advertised and also be affordable. In some cases, the design of these technologies has an impact on adoption, and a lack of consultation of potential users within the design and development process can inhibit diffusion. In most cases, the installation cost of RETs is too expensive for poor rural inhabitants. Only in some places do microcredit schemes exist that allow people to take out a loan to pay for the installation of a RET such as a solar PV system.

The lack of an adequate Government policy promoting RETs can be a significant barrier to their uptake. The lack of Government support for pico-hydro in the Lao People’s Democratic Republic, for example, has been a barrier to effective regulation of the market. Inadequate equipment standards or training are likely to increase the risks associated with faulty or poorly installed or maintained systems.

In most cases, rather than seeing RETs as complementary to a national grid system, governments often continue to prioritize grid expansion. This means that remote and sparsely populated rural areas are pushed to the end of the queue, as grid expansion in these areas is highly unprofitable. Furthermore, the lack of political and economic influence of these populations reduces their ability to change this state of affairs.

**Policy options to overcome barriers**

*National*

National policies can play a major role in overcoming some of the barriers that hinder the successful deployment of RETs. These policies might support the development and implementation of subsidies, research projects, public awareness campaigns, pilot programmes, regulations, or waivers on import duties. In the case studies of Nepal, Eritrea, Guatemala, China and Argentina (all of which involved a Government programme), subsidies were employed as a key policy instrument to reduce the cost of installation. The improved stove programmes in Eritrea and Guatemala also benefited greatly from Government-funded research into possible technological improvements and the use of local materials to increase availability and affordability. Also, a public awareness campaign in Eritrea, including stove demonstration in neighbouring villages, was particularly important in facilitating stove dissemination and generating public support.

National regulation, such as requiring installation companies in Nepal and Guatemala to provide product guarantees, was an added incentive to customers as they could be assured of free maintenance, reducing the risk of their investment. Conversely, the lack of national regulation of the pico-hydro market in the Lao People's Democratic Republic has left the sector vulnerable to the dangers of poor equipment and improper installations, both of which customers without technical expertise will not be able to recognize. It is important to acknowledge that lack of information on the status of pico-hydro installations means that concerns about risks cannot be verified.

Waiving duties on RET imports in Argentina helped to lower the costs associated with installing solar PV systems. The Government of Argentina's understandably constrained macroeconomic policy during an economic crisis resulted in poor project performance, although flexibility helped it to regain momentum post-crisis. In China, increased policy focus on domestic use of PV as part of the REDP programme significantly motivated domestic private PV manufacturers to consider domestic markets. Their existing expertise substantially amplified programme success and sustainability. The roll-out of Motorola's wind and PV-powered base stations in Namibia and other countries may require some policy and financial support, but this is not yet clear.

*International*
Donor funding was a key component in nearly all case studies. It was most commonly used to support a subsidy programme to reduce the up-front installation costs associated with RETs. However, as shown by the case of improved stoves in Guatemala, donor funding fails to be effective without the development of alternative sources of finance to replace the subsidy as it is phased out. The Biogas Sector Partnership in Nepal has shown some success in developing a local private biogas market that does not require donor funding, but its sustainability has yet to be tested.

Donor flexibility and consistency with national policies are also important. In Argentina, donor flexibility allowed subsidy levels to increase to cover reduced Government input during the economic crisis and to ensure project implementation could resume.

**Role of stakeholders in improving chances of deployment**

*Local communities*
Where local input was incorporated into programme design, stronger local support and understanding was achieved. However, the input from local communities was not always consistent. In Guatemala, project managers indigenous to the region in which stove projects were being implemented helped design programmes in line with local needs. However, the limited inclusion of women in the design process meant some aspects of the stoves could not be adapted as much as they would have liked. The use of local materials in Nepal and Eritrea greatly increased the involvement of local manufacturers. This led to job creation and also to cost reductions as households were often given the opportunity to contribute labour in place of money.

*Private sector*
Private sector participation in developing standards and accreditation schemes can both raise quality and promote competition. These are important aspects of developing an RET market that can survive after subsidies have been phased out. The development of equipment standards and a system of accreditation of biogas plants in Nepal led to a reduction in overall plant cost as construction companies competed against each other. In China, private solar PV manufacturing companies participating in the REDP programme were expected to meet one of three sets of standards. Their market focus (rural, national or export markets) guided which

set of standards they aimed to meet and subsidy levels increased as higher standards were met.

An important service offered by private installation companies, often required as part of an accreditation scheme, was product guarantees. Biogas plants in Nepal came with a three-year guarantee period during which the installation company would provide maintenance free of charge. Construction companies in Guatemala were required to provide a one-year guarantee on the plancha armada stoves they installed as part of the PEMF programme. Solar PV modules installed as part of solar home systems in China under the REDP scheme were guaranteed for 10 years. Other components within the solar home systems had warranties ranging from one year for batteries, inverters and lights, to two years for charge controllers. On top of the subsidy programmes, these guarantee/warranty offers helped to further reduce the financial risk associated with relatively large up-front costs that poor rural households were required to pay for installation.

Private participation in the deployment of RETs in rural areas can be attracted if the demand is considered high enough. A private pico-hydro market has developed in the Lao People's Democratic Republic in the absence of any Government intervention. Market developments in neighbouring countries, coupled with local demand for pico-hydro systems, have allowed trade for this RET to develop organically. Using RETs to power mobile telecommunications base stations, such as the case in Namibia, is an attractive option for private firms given the large-scale demand for telecommunication services in rural areas in many developing countries. However, as this was only a trial project, it is not yet clear how interested private developers will be in further initiatives of this kind – and what Government policies (if any) might be required to promote the diffusion of this technology. In some cases, the existence of public subsidies for RETs in rural areas has not been sufficient for the private sector to participate. For example, lack of private sector interest in rural concessions in Argentina led to public utilities being given the opportunity to engage in the PERMER programme. In many cases, existing concessionaires saw rural electricity provision as a distraction from more profitable centralized electricity provision.

**Financial incentives for users and developers of RETs**

As noted above, financial incentives are necessary to achieve deployment of RETs. In nearly all the cases financial assistance was provided to reduce the costs and risks associated with the specific RET being used. These financial incentives were targeted at both users and developers. Access to bank loans made biogas plants in Nepal affordable to rural customers. High stove cost in Eritrea and Guatemala meant stoves had to be subsidized at 85-90 per cent to make them affordable to rural households. However, the example of the Lao People's Democratic Republic pico-hydro market development in the absence of financial assistance brings into question the need for subsidies in all cases. It is highly likely that if equipment and installation standards were in place in this case, costs would increase and subsidies would be required to make the technology as accessible as it is today.

A further financial incentive can be funding from the Clean Development Mechanism (CDM). As this paper has noted, one problem for RETs is that the CDM has tended to fund larger projects in middle-income countries. There is now an increasing emphasis on "bundling" smaller projects to overcome some of the transaction cost barriers that have reinforced this tendency. The eligibility of Eritrea's improved stove programme for CDM funding could have a significant impact on the continued roll-out of improved stoves by way of further subsidization and funding of training, product development and other activities.

However, in the long run, CDM funding – like all donor funding – must include an element which aims to foster a sustainable private market for RETs, otherwise the market will collapse once the funding runs out.

# 6. Conclusions

The aim of this paper is to highlight ways in which renewable energy technologies (RETs) can be used to support rural development. Reduced energy poverty can be a cause and result of rural development. Movement up the energy ladder from dependence on traditional to modern sources of energy can take place in many different ways. Given the expectation that biomass will continue to be used as the basis for cooking in most rural areas for some time to come, reducing energy poverty in this aspect of life depends on using technologies which reduce the negative effects of using traditional biomass. In other areas such as lighting, the installation of solar PV systems can enable rural populations to leap up the energy ladder, as they switch from using candles or kerosene to electricity.

The case studies reviewed in this paper have shown that RETs can play an important role in reducing energy poverty and increasing access to modern energy services in rural areas in appropriate and environmentally sound ways. The use of biogas and improved biomass stoves has led to increased cooking efficiency, less smoke inhalation, greater safety and reduced fuelwood consumption. The use of solar PV systems, wind turbines and pico-hydropower has increased living standards, powered entertainment systems and provided opportunities to undertake productive activities as artificial light extended work and study hours and electricity was used to charge batteries and power mobile telecommunications base stations.

The insights provided by the case studies and synthesized in the previous section lead to a number of tentative policy recommendations. It is important to note that all the case studies reviewed in this paper were off-grid applications of RETs in rural areas. Grid extension clearly has a role to play in improving access to modern energy services in developing countries, and where appropriate should be supported in tandem with off-grid RET deployment. The recommendations provided below are compatible with this principle, but are designed to focus in particular on off-grid applications of RETs.

- Programmes aimed at the deployment of RETs in rural areas should be integrated into wider rural development programmes to ensure suitability and harmonization.
- An enabling government policy is essential to stimulate uptake of RETs in rural areas, both on the supply and demand sides. Government support may take many forms: regulation, subsidization, import duties, public awareness campaigns, or more likely a combination of these.
- Given limited national budgets in most developing countries and competing sector demands, donor support is likely to be necessary to deploy RETs and to bring down costs. In order to mitigate against a dependency on donor funds, donor support must be closely in line with government policy and phase-out plans need to be clearly articulated. Mechanisms such as the CDM have potential to promote RETs in rural areas, especially if numerous small projects are bundled together.
- In order to leave a sustainable local market for RETs after subsidies and donor support is phased out, it is imperative that local supply and demand are developed and fully connected with each other. While regulation can play a role here, especially in maintaining quality control and managing competition, it should be carefully targeted so that it does not prevent sustainable markets for RETs from being established. Opportunities for knowledge sharing, innovation and learning by suppliers and users can also help to improve products and reduce costs.
- Deployment of RETs requires hardware and “software” elements. Adequate training in areas such as installation, operation and maintenance – as well as learning and awareness-

raising activities - are key to developing the local knowledge required for effective and sustainable RET use. If rural development through the use of RETs is to be sustainable and low-carbon, it is essential to build local capacity among both technology suppliers and users.

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