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A comparative analysis of the Solar Energy Programme for Rural Electrification and lessons from South Asia

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Abstract

South Asia accounts for 42 percent of the world's population without access to electricity. Such a situation continues to exist despite several initiatives and policies to support rural electrification efforts by the respective country governments including use of renewable energy technologies. While conventional grid extension has been the predominant mode of electrification in the region, the countries have also extensively used solar photovoltaic (PV) technology for energy access. However, there have been implementation challenges including technical, financial, institutional and governance barriers. This paper, based on extensive literature review and survey of selected programmes, shares the experience and lessons of solar PV programmes for rural electrification in South Asia – both at the regional and country level - and also do a comparative analysis to exploit the cross learning potential. The paper also attempts to analyze the potential of the small scale solar interventions as an effective mode to meeting the goal of universal energy access as well as to mitigate the imminent climate change menaces in the region.

Keywords: Rural Electrification, Solar, South Asia

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1.0 Introduction

Home to one-fifth of the global population in just 4% of the world land mass, the South Asian region comprising of eight countries is densely populated. With large percentages of the population in almost all the countries of the region inhabiting rural areas, the current penetration of electricity in the rural areas of the region is 59.9 percent, leaving two out of every five people in the rural areas without access to electricity (IEA, 2011). While the figure serves as a common denominator to the problem, there exists wide disparity in rural electrification in South Asia. Sri Lanka has a rural electrification rate higher than the global average while only 15.5 percent of the rural population in Afghanistan has access to electricity.

While the centralized grid based electrification has been the most common approach, decentralized renewable energy options especially, solar PV(photovoltaic) systems has also been adopted, especially for areas where it is techno-economically not feasible to extend the electricity grid. These off-grid communities are generally small, consisting of low-income households – with characteristics that may have been economically unattractive to electricity distribution companies to extend the grid. However, a substantial section of such beneficiaries of solar PV systems are also found in mainstream rural and peri-urban areas, already connected to the grid, where the issue seems to be less of opportunity to get connected to grid, but more of inability of households to take grid electricity connection due to their financial constraints or the perception that electricity services (quantity and quality) will be inadequate. With large population in the region continuing to be without electricity access and the huge amount of funding support required for extension of grid-based electrification to cover such remote areas coupled with inadequate supply and reliability in existing grid connected areas provide a window of opportunity for off-grid solar solutions.

Table 1: Rural electricity access in South Asia (as of 2009)

Country	Population without electricity (millions)	Electrification rate (%)		Per capita consumption (kWh)*
		Total	Rural	
Afghanistan	23.8	15.5	12.0	35
Bangladesh	95.7	41.0	28	144
India	288.8	75.0	52.5	543
Nepal	16.5	43.6	52.5	81
Pakistan	63.8	62.4	46.0	475
Sri Lanka	4.8	76.6	75	418
South Asia	493.4	68.5	51.2	NA

Source:IEA(2011).http://www.worldenergyoutlook.org/database_electricity/electricity_access_database.htm>
*IEA (2009). <http://www.iea.org/stats/indicators.asp>

1.1 Solar PV for rural electrification

The importance and impact of enhancing energy access through solar PV based decentralised interventions in bringing about social and economic benefits for communities in South Asia, ranging from incremental livelihoods to better facility for health and education has been well documented in literature (Gunaratne, 1994; Chakrabarti and Chakrabarti, 2002; Wijayatunga and Attalage, 2005; Urmee and Harries, 2009; Palit and Singh, 2011; Laufer and Schafer, 2011; Mondal and Klein, 2011) . At the same time literature also shares that significant portion of solar PV projects and programs in the region have met with limited success (Martinot et al., 2001; Palit and Shukla, 2003; Kumar et al., 2009; Wong, 2010).

While there is available literature (Palit and Shukla, 2003; Wijayatunga and Attalage, 2005; Komatsu et al., 2011; Mainali and Silveira, 2011) analyzing the solar PV program for rural electrification at the individual country or program/project level, almost no recent literature exits on comparative analysis at the South Asian regional level for cross learning by the countries in the region and other developing countries facing similar rural electrification challenges.

This paper examines the current trends of solar PV for rural electrification at the regional level and at the same time attempts to comprehensively capture the development in India, Bangladesh, Nepal and Sri Lanka, where solar PV based rural electrification has been relatively significant. The analysis is based on an extensive review of peer-reviewed literature as well as reports from various projects implemented in the region complimented by visit to some of the projects for interaction with the implementing agency, the system operators and end users Based on the review, we attempt a comparative analysis to exploit the cross learning potential, both at the country and region level. Section 2 of this paper attempts to capture the current trends of solar PV based electrification in four countries, namely India, Bangladesh, Nepal and Sri Lanka, where solar PV based electrification has been significant as compared to other countries in the region. Section 3 analyzes the dissemination of solar PV in terms of technical design and sizing, service delivery models, system pricing, access to finance, policy & regulatory architecture, and monitoring & maintenance. As data availability on off-grid electrification is often limited, the review is selective. Finally, the conclusion section summarises the study for cross-learning possibility from the wide range of experience from the above mentioned countries and discusses the way forward for improving the rural electrification level through the use of solar PV based intervention.

2.0 Current trends in South Asia

Solar PV technology has been in the forefront for off-grid area electrification in India, Bangladesh, Nepal and Sri Lanka. However, the progress of such programs has shown a mixed trend. The most common solar PV applications implemented in the region include both decentralized - solar home systems[1] (SHS) and solar lanterns[2] (SL) and centralized solutions such as solar PV mini-grids[3] (SMG), solar DC micro-grids[4] (SDCMG) and solar

[1] A typical SHS consists of PV module(s) that charge a battery bank to supply DC electricity to run appliances such as CFL/LED lamps, DC fan, TV, etc. The charge controller which is an integral part of the SHS controls the energy inflow and outflow into and from the battery bank.

[2] A solar lantern is a portable lighting device using either CFL- or LED-based luminaire, housed in an enclosure made of plastic or metal that contains a rechargeable battery (either sealed maintenance free lead acid or NIMH or Li ion)and necessary electronics. The rechargeable battery is charged using a separate PV module by connecting it through an electric plug-and-socket arrangement or the PV module is sometimes integrated in the solar lamp itself.

[3] SMGs are designed to generate electricity centrally and distribute the same for various applications to establishments spread within a designated geographical area. They usually supply 220 V 50 Hz three-phase or

charging stations[5] (SCS). While the advantages of SMGs over SHS in terms of enhanced electrical performance and reduction of storage needs are well documented (Aulich et al., 1998; Chaurey and Kandpal, 2010), in terms of numbers disseminated during the last five years, SHS is found to be the most favoured in all the countries studied (Figure 1). The lower growth of SHS dissemination in Sri Lanka can be attributed to higher growth in grid based electrification in the country, whereas Bangladesh records a high growth due to community's aspiration to shift to cleaner lighting in absence of grid electricity reaching them and aggressive marketing efforts by the project proponents. While most of these projects/programs have and continue to be via grants and donor driven in most countries, a combination of free market and grant based model have also been successfully tested and being scaled-up in Bangladesh, Sri Lanka and India, showcasing innovations in system design and financial and institutional mechanisms (Palit and Chaurey, 2011).

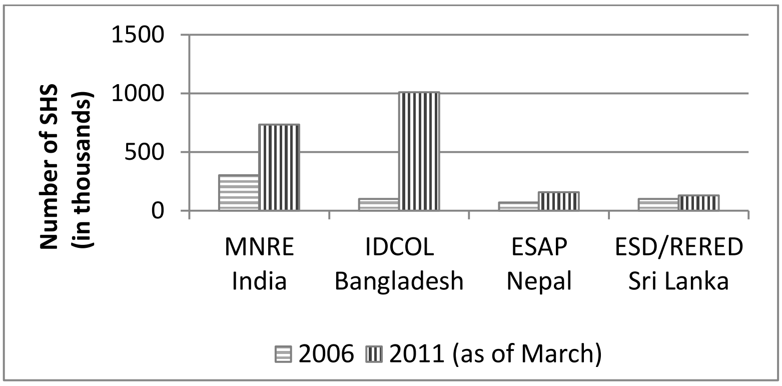

Figure 1: Growth in SHS dissemination in South Asia (Source: Author's compilation)

single phase AC electricity through low-tension distribution networks to households for domestic power, commercial and community requirements SMGs essentially consists of (a) Solar PV array for generating electricity, (b) a battery bank for storage of electricity, (c) power conditioning unit consisting of junction boxes, charge controllers, inverters, AC/DC distribution boards and necessary wiring/cabling, etc. and (d) power distribution network consisting of poles, conductors, insulators, wiring/cabling; service lines to individual households

[4] SDCMG are designed to generate DC electricity using one or more solar panels and is distributed over a short distance from the battery banks to the cluster of households or shops within the village. They usually supply at 24 V DC to households or shops for providing lighting services for 5-7 hours using LED lamps.

[5] The SCS requires installation of solar PV modules in a specific voltage and current configuration to charge a number of lanterns or batteries. The charge controller is designed to ensure that all the lanterns and or batteries are adequately charged. It is housed inside a junction box that has sockets to plug-in the leads for individual solar lanterns or batteries. This integrated charge controller-cum-junction box thus the heart of the SCS that controls and coordinates all inflow and outflow of energy and ensures its proper function.

2.1 India

Statistics from the Indian Ministry of New and Renewable Energy (MNRE) indicate deployment of about 733,245 SHS and 831,604 SL (as of March, 2011) for providing lighting to rural households. Apart from these, SMGs with capacity ranging from 1 - 500 kWp have also been installed in many remote villages with a cumulative capacity of 8.16 MWp. Majority of the 8846 villages and hamlets (as of June 2011), taken up for electrification under Remote Village Electrification program of MNRE were provided with SHS or solar power plants. The SMGs, on the other hand, have been implemented in few select states predominantly in Chhattisgarh, West Bengal and Lakshadweep Islands. CREDA (Chhattisgarh Renewable Energy Development Agency) have electrified around 35,000 households spread across 1000 villages and hamlets with mini-grids. WBREDA (West Bengal Renewable Energy Development Agency), on the other hand, has more than 15 functional solar power plants with aggregate capacity of more than 1 MWp capacity, supplying stable and reliable electricity to around 10,000 households. The non-governmental organizations and small solar companies have also been complimenting government efforts to augment energy access with solar PV. TERI, a non-governmental organization, has been implementing its "Lighting a Billion Lives" (LaBL) program[6] since 2008 and has so far covered more than 1600 villages in India, benefitting around 380,000 people, and has also taken its footprints to some countries in East and West Africa. LaBL operates on fee-for-service modelwhere SCS or SDCMG are set-up in villages to provide lighting services. SELCO India, a social enterprise operating since 1995, has installed more than 0.1 million SHS. In addition, rural banks have also been financing SHS especially in grid connected areas with poor electricity supply.

2.2 Bangladesh

Though the rural household electrification level is low, the country recorded an impressive SHS program for off-grid areas, implemented by IDCOL (Infrastructure Development

[6] TERI has undertaken the LaBL initiative to address the global challenge of providing clean lighting to populations without access to electricity. The initiative which started in the people's space of PPP now encompasses the strong role of the private sector, the government sector, the communities all working towards common pro-poor agenda. LaBL provides a flexible entrepreneurship based energy service model where local entrepreneurs are trained to operate and manage the SCS and or SDCMG and rent out certified, bright, and quality solar lanterns and or through fixed LED based lighting services respectively to the rural households every evening for 4-5 hours at a very affordable fee.

Company Limited), a state-owned financial institution. IDCOL implements the SHS program through its 29 partner organizations (POs) whose main role is to select the project areas and potential customers, offer micro-lending, install the systems, provide after sales maintenance support, and training to users and local technician in order to create local expertise and ownership on the system. Some of the leading POs with impressive achievements are Grameen Shakti, BRAC and Rural Services Foundation. IDCOL achieved its targets years before the proposed time more than once, with the financing of 50,000 SHSs by 2003 instead of the stipulated 2008 and financing of 200,000 SHSs which was also achieved, seven months ahead of schedule in May 2009. While the target was to finance 1 million SHSs by the end of year 2012, IDCOL achieved financing of 1,429,440 systems[7] as on April 30, 2012, with more than 50% of the total SHS installed by Grameen Shakti alone (IDCOL, 2011).

2.3 Nepal

In Nepal, the ESAP (Energy Sector Assistance program) has been instrumental in promoting SHS in the country. The phase 1 of ESAP installed a total of 69,411 SHS, bettering the programme target of 40,000 (EASP, 2010). Bhandari and Stadler (2009) note that of the 115,000 SHSs installed under various government programs and private sales, almost 83 percent of the installed SHS are smaller than 40Wp capacity indicating that these are mainly used for lighting. The current phase (2007-2012) of ESAP has reportedly assisted in installation of around 184,000 SHS as of June 2011 against a target of 215,000 systems (AEPC, 2011). ESAP also put in place a proper system for administering the solar energy subsidies and a quality assurance and monitoring systems for solar PV projects, which also contributed to their achievements.

2.4 Sri Lanka

The country has one of the most impressive market-based solar PV program, promoted through innovative financing schemes under the ESD (Energy Services Delivery) and RERED

7 Infrastructure Development Company Limited, Bangladesh < http://www.idcol.org/prjshsm2004.php>

(Renewable Energy for Rural Economic Development) program. The ESD project catalyzed the solar market by installing 20,953 SHS with a total capacity of 985 kW, against a target of 15,000 systems, during the period 1997 to 2002 (RERED, 2011).

After the successful implementation of the ESD project, the Government of Sri Lanka established the RERED Project (in association with the World Bank and the Global Environment Facility), which have electrified more than 130,000 rural households through SHS and 1,000 off-grid electricity connections to small and medium enterprises and public institutions.

3.0 Analysis of the solar PV programme

3.1 Technical design and sizing

As discussed in Section 2, Solar PV applications in the region include SHS as well as SMGs and SDCMGs. While a typical SHS includes a 20 to 100 Wp (peak watt) PV array, a rechargeable battery for energy storage, one or more high efficiency lamps (either compact fluorescent or LED) and an port for a portable black and white television or other low power consuming appliances, the SMGs are typically of much larger capacity and provide AC electricity. On the other hand, SDCMG are modular with capacity ranging from 75 Wp for connecting 10 households, using a DC (direct current) distribution grid, to around 1 kWp for connecting say around 200 households and usually provide only lighting services through LEDs unlike the SMGs which distributes electricity.

Almost all the countries reviewed have used SHS as a means for extending lighting to areas that could not be reached with grid electricity. Most SHS disseminated in the region are in the capacity range of 37-75Wp (Urmee and Harries, 2009), the most common being 50kWp systems. Komatsu et al. (2011) observe that household income and kerosene consumption to be the essential factors behind the selection of particular SHS capacity by households in

Bangladesh. On the other hand, an interesting feature in Nepal is large scale use of smaller capacity SHS (locally called *solar tuki*) with capacity between 2.5Wp and 10Wp.

India, on the other hand, has implemented both SHS and SMGs to cover un-electrified areas. While the SHS implemented are mainly of 37Wp/40Wp capacity, SMGs implemented in Sunderban region by WBREDA are in the range of 25kWp and 150 kWp, and those in Chhattisgarh state are of much lower capacity (< 5 kWp). Both CREDA and WBREDA installed SMGs in villages with concentrated populations, whereas villages with scattered settlement have received SHS. These mini-grids use state-of-the-art inverters and storage systems of the time to ensure long life and reliable field performance. Depending on the capacity, they provide grid quality power for domestic applications, commercial activities (e.g. shops, video centers, communication kiosks, and small grinders) and community requirements such as drinking water supply, street lighting, vaccine refrigeration and schools. Pico PV has also emerged as a new key word in rural electrification with the introduction of highly efficient LED bulbs for solar lamps. These very small (<10 Wp) “Plug & Play” systems enable people to access modern energy services in cases where the cost of conventional SHS is not affordable or the energy demand is too low.

Further, innovations in SMG design were also brought in India depending on technological development and communities’ need with change of time. Till 2000, Solar PV mini-grids in the capacity range of 25kWp - 26kWp were implemented by WBREDA (Ulsrud et al., 2011). Though load assessment was done at the planning stage keeping future demand into consideration, larger capacity schemes were not commissioned as the acceptance of concept and technology was not yet proven. However, observing the strong growth in interest and demand, WBREDA started to build the power plants with larger capacity (>100 kWp) and in some places installed additional generation units such as small wind-generators and biomass gasifiers to provide the incremental power (Palit and Sarangi, 2011). Chaurey and Kandpal (2010) observe that centralized and professionalized maintenance in the SMG model frees the individual user from such responsibilities except for repair and replacement of appliances used within the house/premises, which may have also contributed for their successful dissemination.

In terms of system functionality, the solar PV program appears to have better success rate in Bangladesh and India, where quality standards have been ensured for PV panels, batteries and other components as approved by the technical standards committees. On the other hand, a study of batteries indicate that the SHS design adapted in Sri Lanka was based on a given price limit determined by the political and financial arrangements (Laufer and Schafer, 2011). This made the project proponents use automobile batteries and not deep-cycle batteries for the SHS. These batteries could store electricity for only around 4 hours a day and have an average lifespan of only 2.5 years. Laufer and Schäfer (2011) further observe that due to the poor battery performances which in many cases do not function until the end of the loan duration of 3 years, there has been default in loan repayment by the customers. On the other hand, SELCO India (through Energy Service Centres) and Grameen Shakti (through Grameen Technology Centres) and other POs in Bangladesh, disseminating SHS through micro-lending, have taken due care on the quality assurance and post installation maintenance service of the systems at the local level, ensuring technical sustainability thereby achieving very low default in loan repayment in their areas.

Off later, newer battery technology are also being put into use. For instance, Ni-MH and Li ion batteries have not only improved their volumetric energy densities and their useful life, the costs have also come down substantially over the past few years making them an attractive option for the portable solar lanterns and task lights in view of offering longer operating hours (Chaurey and Kandpal 2009). Since Li-ion and Ni-MH batteries are routinely used in products such as portable computers, cordless appliances, telecommunication and medical equipment, the outcomes of technological advancements and cost reductions will also benefit the solar lighting sector. Gram Power, a company based in Jaipur, India has developed smart stackable batteries called MPower, which is a modular power source comprising high-density lithium ion battery and intelligent power conditioning circuitry. The MPower is designed in a way that its charging is locked to the microgrid, i.e., no other power source but Gram Power's electricity supply is only able to charge the MPower. This avoids misuse of the device and ensures revenues for the local entrepreneur. Such advancements in battery technology will propel the economic competitiveness as well as the reliability of the systems even further.

3.2 Service delivery models

Different service delivery models have also been adopted in different countries for solar PV based rural electrification. In case of individual SHS, fee-for-service, leasing and consumer financing have been attempted. Sri Lanka and Bangladesh followed the consumer financing model involving banks and MFIs (micro-financing institutions) for large scale dissemination of SHS.

In Bangladesh, the SHS model is implemented by IDCOL through its POs. The PO act as the financial intermediaries in the model. IDCOL is responsible for providing grants and refinancing the systems, setting the technical specifications for the solar equipment, developing publicity materials, providing training for PO capacity building and monitoring PO performance. Two different type of grant support – institutional development grant and system buydown grant is provided by IDCOL to its POs. The institutional development grant has been instrumental in creating the necessary rural infrastructure for service delivery both in terms of dissemination as well as post installation maintenance of the systems by the POs. The institutional development grant also enabled the POs to build their capacity by hiring staff, and training employees in microfinance and credit monitoring. Both these grants are also intended to enable POs to purchase the technology below market rates and provide loans to customers, in essence lowering the price of SHS and increasing the institutional strength for last mile distribution and maintenance. However, to promote competition, such grants are reduced in amount over time as more SHS capacity is installed, an element called "a phased reduction of grants" (Sovacool and Drupady, 2011).

On the other hand, the Rural Electrification Board (REB) in Bangladesh have innovated a different model in disseminating SHS. REB installs the SHS in the customer's house and the household pays a monthly bill for electricity consumption but never own the actual solar panel. Grameen Shakti has also been using a solar DC micro-utility model on a small scale under the aegis of the IDCOL solar programme. In this case, a rural entrepreneur procures the panel system, say of 50 Wp capacity, along with LED lamps on installment basis (around 10% is paid as down payment) and connects 4-5 neighboring households to provide each household with one LED lamp. The entrepreneur makes a livelihood though the fee (around 6 US cents/night/light point) charged from each household. Solar based AC mini-grid model is also seen to be emerging in Bangladesh with their Ministry of Power planning to expand the model under the recently launched Remote Area Power Supply System (RAPSS) scheme. Thirty remote Upazillas (sub-districts) have been identified for implementation where the SMGs will be run by private RAPSS operators. It is reported that these operators will be selected through a competitive bidding process for a contract period of 15-20 years. The system cost will be met through 50% grant from Ministry of Power, 30% low interest loan from IDCOL and 20% equity from the operator (Anam, 2012). IDCOL will channelize the grant and credit support and REB will provide the required supervision and if required, viability gap financing, through a tariff subsidy.

Sri Lanka has witnessed a rapid growth in the SHS market which is mainly driven by the private sector, and is supported by the World Bank (International Development Association), Global Environment Facility (GEF) and local financial institutions. This private sector led initiative is part of RERED and its predecessor ESD project[8] whose aim was to complement grid-based extension by the Ceylon Electricity Board, the country's vertically-integrated national utility. The project's centre piece was a market-based credit program available to the Participating Credit Institutions (PCIs) – such as commercial banks, microfinance institutions, and leasing companies that meet the eligibility criteria of the programme (Govindarajulu et al, 2008). These PCIs refinance upto 80 percent of their loan disbursements. They access credit at the average weighted deposit rate[9], repayable in 15 years with a maximum 5-year grace period. PCIs used their standard procedures to appraise the projects, establish creditworthiness and negotiate lending terms with their customers. They also assumed full credit risk on sub-loans disbursed to subprojects and have to repay them according to an agreed-on amortization schedule, regardless of whether their borrowers repay.

[8] The duration of RERED project is from 2003-2010, while that of ESD was from 1997-2002.
[9] Defined as the weighted average of the interest rates paid to depositors by all commercial banks on interest-bearing term deposits, as issued weekly by the Central Bank of Sri Lanka

The financing model followed for SHS is consumer credit, through the MFIs who works closely with solar companies. Via their dealer networks, the solar companies sell SHSs and offer operation and maintenance services. Since poor service by the solar company can lead to dissatisfaction in customer and a breakdown in loan repayment, the PCIs who provide micro credit also enter into a memorandum of understanding with the solar companies, typically covering aspects such as minimum service levels, repossession of the solar panel on foreclosure and buyback in the event of a grid expansion. This leads to a tripartite arrangement involving the PCI, solar company and the end user. This led to the consumers avail the finance from the PCIs and procuring the systems from solar firms, thereby having to deal with two different agencies.

In India, private agencies like SELCO[10] and rural banks (such as Aryabrat Grameen Bank and Prathama Grameen Bank in Uttar Pradesh, Gurgaon Grameen Bank in Haryana, SEWA Bank in Gujarat and Syndicate Bank in Karnataka) have been using consumer financing model (around 10% interest rate for tenure of 3-5 years) to disseminate SHS (Palit and Chaurey, 2011). On the other hand, the SMGs in India are operated by local cooperative societies or VEC (Village Energy Committees) formed by the beneficiaries and are responsible for selection of consumers, planning for the distribution networks, tariff setting and revenue collection. While the community model for solar PV projects have been largely successful unlike other technologies such as biomass gasifiers mainly due to lesser technical intervention required for the solar technology (Palit and Chaurey, 2011), there has also been negative fallout making it more challenging for sustainability. Shrank (2008) observes, based on a case study of solar power plants in the Sunderbans, that the community management system did not create incentives for maximizing profit at each power plant, thus creating

[10] While SELCO does not provide credit or loans directly by itself, the company has built up working relationships with local banks and microfinance organizations, built over the years. This has given finance organizations the confidence to provide credit for PV systems, and an understanding of the payment terms which different owners may need. The average loan size is INR 13 000 (average system cost being INR 15000 for a 2-3 light system and the rest is margin money). For a tenure of 5 years and the interest rate of 12% (which keeps varying depending on base rate), the EMI is about INR 300. At the initial phase of the activity, along with the lucrative financing scheme, SELCO also had an additional one-year guarantee to the manufacturer's warranty, a 90-day money back guarantee along with a year's free service to build consumer's trust. Currently SELCO provides a free service for 1 year and after that consumer has the option of availing an annual maintenance contract or pay per service (www.ashdenawards.org/winners/selco07 accessed on 12th February 2011.).

problems for the coverage of costs of the power supply. CREDA, however, have been more successful in its approach. They evolved their own service delivery model and directly take care of the operation and maintenance through a three-tier system of maintenance[11] to ensure trouble free working of the mini-grid systems.

On the other hand, TERI has been extending clean lighting under its LaBL initiative using the flexible[12] fee-for-service model, through adopting both the SCS as well as SDCMG model. Mera Gao Micro Grid Power (MGP) and Naturetech Infra are small start-ups in India, who are also building several pilot SDCMGs in small villages in Uttar Pradesh and Bihar following the fee-for- service model. Their model focuses on implementing the full energy system – generation, storage, DC distribution lines and LED lamps – with users paying service charges for availing the lighting. Their core innovation is profiting from the low cost power delivery of LED lights and charging of mobiles (both DC applications) without provision for powering any other appliances.

[11] CREDA selects an operator from each solar powered village to clean the modules every day and report any faults to a cluster technician. For this service the operator charges a monthly fee of INR 5 per house (10 US cents). For regular maintenance of batteries and inverters and for fixing minor technical problems, the operator directly receives a payment of INR 30 (60 US cents) per household per month from the state government. CREDA also employs an operation and maintenance contractor, who appoints a cluster technician for every 10 to 15 villages. Each technician earns INR 4,000 (US$ 80) and if desired a motorbike is provided, which is redeemed in instalments of INR 1,000 (US$ 20) per month. The technician is also paid a fixed monthly fee. A third tier is managed by CREDA, which monitors all of its installations through monthly reports and replaces damaged equipment. For this an adequate supply of replacement lamps is kept in stock with each technician in case a light burns out.

[12] The fee-for-service model of the initiative has ensured that the Base of Pyramid gets access to clean energy at an affordable price. While the capital cost of setting up the SCS/SDCMG in the village borne through equity contribution by the entrepreneurs and users, depending on their affordability to pay and in some cases through financing from local banks, the viability is ensured through fund raised by TERI through government agencies, corporate donors, bilateral/multilateral agencies. The operation and maintenance cost is borne from the rent/tariff that users pay to the operator. This has ensured that the communities afford clean technologies like solar and shift from polluting kerosene lamps to clean and bright solar lamps. For a project of this nature that supports the BoP, social inclusion becomes an essential component. The flexibility in the delivery model has made it possible to take the initiative to remotest and most inaccessible areas as well, covering tribal belts and difficult terrains in India, offering a range of options suitable for different socio-economic groups.

3.3 Pricing of systems

The unit cost of the solar PV systems offered in different countries varies significantly, with programs in India and Bangladesh offering the lowest average installed system cost (US$ 6.5-7.5/Wp). A typical 40 Wp SHS in India costs US$ 300, but the cost to users is lower due to subsidy provided by MNRE for rural areas. The average reported cost of 50 Wp system in Sri Lanka is US $480 (Urmee and Harries, 2009), whereas the average electrification cost in Nepal is US$ 432 per household using solar PV (Mainali and Silveira, 2011). The national subsidy per sold SHS in Sri Lanka and Bangladesh is paid directly to the solar firm, and the contract of sale is combined with a warranty offer. The cost varies between various programs/projects in these countries and is determined by factors such as remoteness, number of system program users and most important reliance on imported equipment (Table 2). The lower system cost in India and Bangladesh is mainly because of indigenous manufacturing of some component or the complete SHS. A scoping survey of the Bangladeshi solar market reveals that the local assembly of charge controllers has reduced their costs from around US $18 to US$10 for some distributors. In case of SMG, the cost per kWp is around US$7-10 in India. A study of the SMG systems implemented by CREDA indicates that the cost of setting up SMG (power system plus transmission cables) is US$500 per household whereas the same for SHS is US$ 280 (Malviya, 2011). Though the cost per household in case of SMG is higher, CREDA observes that SMGs are seldom prone to theft and require minimal maintenance. Hence, the capital funds invested are protected. TERI's experience in implementing SDCMGs indicate their typical cost around US$ 55-60 per household for providing only lighting services (2-3 LED points/household) to the customers.

Table 2: Solar technologies, business models and pricing in four South Asian countries

Country	Technologies implemented	Business models	SHS pricing $/Wp
India	SHS, SMG SL	Consumer financing, leasing, VEC, fee-for- service	7.5
Bangladesh	SHS	Consumer financing	6.5
Nepal	SHS, SSHS	Consumer financing/ credit sales	11.6

Sri Lanka	SHS	Consumer financing	9.6

Source: Author's compilation

3.4 Access to Finance

The types of financing mechanisms used in the various programs include micro-credits schemes, interest rate buy-downs and fee-for service mechanism, all with or without any subsidies. A survey of solar PV programs in South Asia (Urmee and Harries, 2009) show that majority of the customers have availed micro-credit or consumer credit financial mechanism, a quarter used state or donor funded subsidies and fee-for-service and only 5% used cash purchase for procuring solar PV systems. Among the successful SHS programs, IDCOL and ESD/REREDP offer refinancing through loans (6% interest[13] with 10 years maturity and 2 years grace period) to their intermediaries (such as POs and PCIs) and also channel grants (for example around US$25 per 50Wp system is provided as system buydown grant to POs by IDCOL) to reduce the cost of SHS. The intermediary provides credit to customers, who pay 10-20% of the total cost as down payment and the outstanding in monthly installments, which also covers the interest[14] and the maintenance cost. Mainali and Silveira (2011) share that in Nepal loans covered 55% of the capital cost of SHS, followed by subsidy (27%) and owner's equity (18%). The centre piece of these schemes were long term loan packages from donors to the national government which made it possible for government to 'on lend' funds to local banks for proving credit to customers.

In India, JNNSM (Jawaharlal Nehru National Solar Mission) provides capital subsidy on off-grid solar products (INR 90/Wp) and soft loan at 5% per annum. Further, to meet unmet community demand for electricity or in un-electrified rural areas, standalone solar power plants with mini-grid, capital subsidy is provided at INR150/Wp and soft loan at 5%. However, inspite of having the available financing window, the amount of disbursement is

[13] IDCOL offers refinancing through soft loans (6% interest with 2 years grace period and 10 years maturity to the smaller POs and channels grants to reduce the SHSs costs as well as support the institutional development of the POs. For the larger POs, the interest charged for refinance is 8% with other above mentioned terms and conditions remaining same.

[14] A customer has to pay 10% - 20% (depending on the Wp capacity of the SHS) of the total cost of the system as down payment and the outstanding amount is paid in monthly installment. Since the POs are not registered as banks or financial intermediaries, they don't charge any interest charges. Instead, the POs charge 8%-12% as service charge, which also covers the maintenance cost of the system

reported to be poor under JNNSM. Based on interaction with rural banks and consumers, it is observed that accessing the finance from rural banks is tiresome with long approval process introduced by the implementing organizations in line with government requirements thereby creating a roadblock to the entire process. Further, it is also observed that commercial finance for solar PV off-grid electrification projects has been very minimal. Jaisinghani (2011) observes that most companies active in off-grid distribution are not able to access sufficient capital to expand. He further argues that off-grid electrification is also hindered by non-uniform technical approaches, undeveloped non-technical processes (such as tariff collection, and response to system abuse) which are also hindering access to finance at the early project stage.

Study also observes that the choice of financing mechanism used was also related to the organization type. Most government organizations used the fee-for-service mechanism and these programs provided all equipment and maintenance costs, and the users pay a service fee only. Private organizations or NGOs tended to use consumer credit, micro-credit or cash sale mechanism. An issue worth highlighting is that lack of suitable financing mechanism was regarded in a survey (Urmee and Harries, 2009) as most significant barrier to the uptake of SHS, and was considered to be of more importance than the technical and policy issues. For example, in case of Bangladesh, a TERI survey observes that in spite of an impressive dissemination figure of SHS, it is believed that benefits of solar technology have not fully penetrated into the lowest strata of the society, which find it difficult to procure the SHS on the currently available financing options. Another important finding was that while low incomes were regarded as barriers, it was not perceived to be the primary, or even a major barrier to the uptake of SHS.

3.5 Monitoring and maintenance

While most implementing agencies valued the importance of maintenance and monitoring and put into a regular maintenance system in place, this also seems to be one of the most critical determinants for limited success of many programs in the region. Urmee and Harries (2009) argue that where this responsibility had been outsourced to technicians or equipment suppliers, as found primarily in government funded programs, dissatisfaction with the timeliness of the maintenance was frequently reported by program implementing agencies. Wijayatunga & Attalage (2005) and Laufer & Schäfer (2011) reports, in case of Sri Lanka, that households surveyed were not satisfied with the service quality offered by the solar firms and the majority felt that the service personnel needed to visit the households more frequently. As mentioned in the earlier section, in Sri Lanka, consumers avail the finance from the PCIs and procure the systems from solar firms, thereby having to deal with two different agencies. As the solar firms were not responsible to get the repayment of the loans availed, they seems to be providing less importance to the after-sales services as payment default is directly not impacting them. PCIs bear the brunt of the poor service as delay or failure in providing the service directly impacts the loan repayment (Laufer and Schäfer, 2011).

The “single window” model is more appropriate to address users' needs and to assure functionality of the technical system during the period of loan repayment as observed from Bangladesh. The POs provides the micro-finance to the consumers, facilitates sale and installation of the SHS and also takes care of the after-sales service. TERI’s experience in implementing LaBL also corroborates the need for single window service for technical sustainability of systems. During the initial phase, the partner NGOs of the LaBL program were not getting the required post installation services from the suppliers of the lanterns, as TERI was procuring the lanterns (following a standard quality assurance) and sending them to various villages. With the SCS operators or users having not purchased the solar lanterns directly from the suppliers, the system suppliers were not addressing the defects occurred after installation on call by the operators or users. The issue is now addressed through setting up of Energy Enterprises, manned by local youths trained by TERI, covering cluster of SCS. The suppliers of the systems now involves the energy enterprise during installation of the systems and allow them to repair the systems during the warranty period as well as beyond, thereby ensuring a responsive post installation maintenance services created and managed at the local level.

It is also observed that appropriate training and capacity building has also played a key role for ensuring effective maintenance and monitoring of systems and thereby their sustainability. One of the key enabling factors for wide coverage of households by CREDA using the SMG and SHS systems is due to the provisioning of appropriate funding for regular maintenance training for technicians. It is reported that more than 1,400 trained operators maintain PV systems at different locations and a further 75 technicians and some 60 supervisors, trained by CREDA, repair inverters and other electronics in the state. The intensive training created a pool of technical manpower, who are providing services not only to the SMGs implemented by CREDA, but are also engaged in promotion of decentralised solar applications in the state. The LaBL initiative is also giving lot of importance to sensitization and training of every stakeholder at different stages of project implementation for ensuring sustainability (Chaurey et. al 2012). This includes community sensitization and engagement prior to the inception of the project at any site to assess the need and ensure acceptability of the project by the community. It is followed by training of the entrepreneur before and after installations, focusing on the technical and entrepreneurial aspects, apart from upkeep and maintenance of the charging station. Second level user training is conducted immediately after installation to ensure that the users are not only made aware about proper usage but are also trained on the institutional pattern to enable them to seek proper after-sales, as and when required. Every partner, particularly those involved in direct implementation is given exhaustive and advanced training on the vision of the programme, technology, implementation model and their role in sustaining the initiative.

In Bangladesh, while there has been no direct budget for training, institutional development grant and long-term refinancing are channeled to the executing agencies for capacity building. In addition monthly meetings of POs and IDCOL operational and technical committees are convened at IDCOL to discuss any field related technical and operational problems to find its solution. Apart from these, joint training, marketing and promotional activities are also continually undertaken by the POs to increase awareness among potential customers. IDCOL also provides a technical assistance grant once a certain amount of capacity has been reached, which can be utilized by POs for advanced training and promotional campaigns (Sovacool and Drupady, 2011).

3.6 Policy and regulatory architecture

The countries reviewed here have developed their own policy frameworks and envisage bringing more areas under solar PV based rural electrification. In India, the JNNSM, launched in 2009 as part of the Indian National Action Plan on Climate Change (NAPCC), though has not been established to foster rural electrification *per se*, it does mention the use of solar energy as a means for electrification and envisages that by the end of 2013, the mission should have led to the setting up of cumulative capacity of 200 MW of off-grid power (MNRE 2010). The Mission also envisages that by the end of the 13th Five-Year Plan, in 2022, around 20 million decentralized solar lighting systems will get installed in the rural areas.

Nepal and Bangladesh witnessed a significant growth in SHS installation since 1998 and 2002 respectively. The growth in Nepal can be correlated with the implementation of a number of policies (subsidy policy 2000 with its delivery mechanism, VAT exemption and import tax exemption) and support programmes i.e. Rural Energy Development Program (1996) and ESAP (1998). In Bangladesh IDCOL formulated the solar energy program in 2002, supported by the Government, and commenced its operation in January 2003 with an appropriately designed financial model of grant and micro-lending involving the POs.

It is also observed from the solar PV programs in the region that there is a component of subsidy in all the countries. The IDCOL model in Bangladesh and ESD model in Sri Lanka, however, is also based on market based delivery, apart from the small subsidy component, with a suitably designed financing model. However, the dissemination in many countries suffers from uncertainty in the political framework conditions with governments and politicians often deciding spontaneously to connect rural regions to the national grid. For example, interaction with key solar experts in Sri Lanka and survey by the author in un-electrified villages in India show many solar PV system users in Sri Lanka discontinue the repayment against the SHS procured once grid reaches such areas or many villages in India show their reluctance to have solar projects anticipating extension of grid in near future. Another fact worth highlighting is that while SHS are not taken into account in the national rural electrification figures in India and Bangladesh as they cater only to lighting needs, Nepal and Sri Lanka considers SHS also as a means of electrification (Palit and Chaurey, 2011).

It is also observed that programs such as IDCOL or mini-grids in Sunderban region and Chhattisgarh in India have been more successful as compared to other programs in these countries mainly due to their implementation through a proper institutional arrangement following a standard set of guidelines (Palit and Chaurey, 2011; Ulsrud et al., 2011). This clearly corroborates the need for a robust institutional structure along with appropriate policy enablers for success of any solar programs.

4.0 Conclusions and Recommendations

The success stories in the dissemination of solar PV technologies in Bangladesh, Sri Lanka, Nepal and India demonstrate that improved access to capital, development of effective after-sales service, customer centric[15] market development and regular stakeholder involvement assisted in scale-up. Further, output focused approach in Bangladesh and Sri Lanka offered the private companies and MFIs/NGOs incentives to enter new markets and deliver pre-defined products, while grants increased product affordability and covered a portion of the incremental costs of introducing clean energy products. Whereas the subsidy mechanism in case of India & Nepal did helped to increase the penetration of decentralized solar applications, the institutional grant mechanism in case of Bangladesh (instead of a direct subsidy) helped in sales promotion as well as effective after sales service. A case in point here is from Chhattisgarh state, where INR 25 per household per month, provided by the government, was pooled by CREDA to create proper infrastructure facilities for proving the required maintenance of the SHS and SMGs. It is also observed that the delivery networks as well as the technological performance are comparatively better placed for solar PV than for

[15] Many government programs sometimes are not in line with what consumers wants. For example, consumer surveys are not undertaken to ascertain the type of luminaire or appliances s/he plans to use after getting electricity connection and design the system capacity accordingly, or whether the consumers will prefer SHS or mini-grids in off-grid areas etc.

other off-grid technologies such as micro hydro or biomass gasifiers in the region (Palit and Chaurey 2011).

The analysis also highlights financial innovation and private sector involvement are the two main factors that assisted in higher penetration of solar PV technology to enhance rural electricity access. However, micro-credit being provided independent of income level, financial assistance from the government programs seems to have either not penetrated into the lower income households or the current financial mechanisms are not in line with their income level. Further, financial services have yet to reach everywhere in the region, and even though they exist in many areas, the relatively high interest rates still prevent economically challenged households to procure solar lighting solutions on the available financing options. The key issue which calls for immediate attention is rationalizing of the interest rate for micro-lending to cover poor households. Instead of direct subsidy by the government, flexible financial instruments, such as interest rate buy down, viability gap funding, output based aid, for both the end-users and/or energy entrepreneurs and appropriate risk mitigation measures for the rural banking sector will be more effective in ensuring not only dissemination of solar products but also their sustainability. There is also need for creating mechanism for easy access to credit and financing through simpler processes and better accountability mechanisms.

As the off-grid projects are invariably smaller in capacity, concentrating energy loads in a given area or bundling projects can assist in increasing the market size. Off-grid solar projects could be identified in clusters, to ensure economies of scale and scope, which would help to manage them sustainably. For example, CREDA has been successfully running the projects in remote and densely forested areas, mainly because of the cluster approach followed for operation and maintenance. Financial institutions/banks would also be interested as project implementation and credit risks would be less. Bundling also can be helpful in minimising the transaction costs associated to get carbon benefits.

Also with more and more areas being connected through grid electrification, the market for solar PV systems in case of un-electrified areas is being pushed to more and more remote areas. The traditional market approach being followed in most cases or the available financing options may not be suitable to cover such areas with low disposable income. Such areas could be covered through the pro-poor public-private partnership (5P) model. The 5P approach can explicitly target the provision of services to poor communities, which are often ignored by traditional PPPs since supplying the poor can involve substantial business risk. Each of the stakeholders in the 5P model can play a different role with the common goal of promoting access: private sector participants can meet their corporate social responsibility obligations, utilities and energy companies can fulfil their obligation to deliver basic services, communities and members of civil society can expand access to basic services.

Also, the fee-for-service model for renting of lantern from a SCS or providing only lighting service from SDCMG may be closer to the need of poor sections of population. Wong's (2010) research also corroborates the fact that without the support of any micro-credit systems and where poor people are expected to pay for the service by their own means, they prefer to pay for the 'service', rather than own the solar lighting systems since this exerts less financial pressure on the poor households. Simultaneously, it also fosters a sense of ownership that is essential for co-financing the technology. However, the amount required in setting up SCS or SDCMG grid is high as compared to equivalent number of individual lanterns/lamps with small panels. This is because of poor reach of existing solar installers to remote rural areas and un-availability of adequate technical capacity to install such systems in such areas, thereby increasing their cost. These calls for improved design efficiency, use of mobile telephony for fund transfer to reduce transaction cost, economy of scale and development of local operations to foster a large pool of talent in remote areas for overall cost reduction.

A hybrid model of SCS with SDCMG can be an ideal enterprise based model for providing lighting and value added energy services. The SCS will provide lamp/lantern recharge to villagers who live away from the micro-grid station and cannot be connected by the SDCMG due to high costs of extension lines. On the other hand, the SDCMG will provide access to lighting to households who do not wish to travel for collecting the lanterns. The cost structure of the micro-grid can be kept slightly higher in comparison and this customized model will benefit two levels of income within the BoP populations. The modular design of the SCS and SDCMG also offers the advantage of demand based capacity expansion. The capacity can be enhanced with additional PV module(s) and/or also in hybrid mode with any other renewable energy technology such as wind-electric generator, biomass gasifier based power-generating unit, etc. to provide power for productive applications in addition to lighting needs. They can thus function like a micro-utility in the village that can offer battery charging facilities as well as other applications such as mobile telephone charging, water purification, powering computers and television sets, etc. The enterprises can also have option to sell solar lamps and energy efficient cook stoves to meet any demand in the villages, thereby acting as rural clean energy hub.

Added to this, developing necessary infrastructure and technical capacity at the local level for developing the last mile distribution channel and providing after- sales services is also critical. In many cases villagers have had an experience with poor-quality products, or inadequate after-sales which is bringing bad reputation to the solar solutions. There is thus need for strict adherence to quality assurance and quality control of systems. This can be best achieved by the solar industry itself who need to pool their collective expertise in and develop the code of practice/standard operating practises for installation of off- grid systems as well as standards and quality parameters for the products. Added to this, technical feedback on product performance has to be regularly collected and effort should be made to develop customized suite of products best suited for rural areas.

Further, the capital cost of solar PV systems also need to be brought down through use of upcoming technology such as LED lamps instead of the CFLs that are currently being used in most solar PV projects. The advantages of LEDs that make them suitable for solar lighting solutions are reduced maintenance; ability to be dimmed, cold start capacity and operability at low voltages thereby reducing the size of battery and of PV module (Babu, 2008).The capital cost can be brought down by 25-30% because of reduced panel size, freight and storage cost. TERI shifted to LEDs lanterns from CFL lanterns under LaBL, without compromising on the illumination level, and has achieved almost 30% cost reduction in terms of lumen-hour for solar lanterns (Palit and Sarangi, 2011). The shifting to high efficiency LEDs with subsequent cost reduction will also ensure economically challenged population taking advantage of the lower system cost, thereby improving the access to these deprived sections of society. The operating solar PV programs in the region should target to introduce

LED lamps, without compromising on the quality and level of illumination, to its existing technical model to cover the poorer households.

Another way to reduce the price of solar PV systems or meeting a part of the maintenance cost could be through the use of carbon funds. The solar PV systems directly replaces the kerosene or other fossil fuel used by the households and thus offer an opportunity to the project proponents, system dealers and customers to accrue carbon benefits by reducing the CO_2 emissions. However, as the decentralized solar PV systems replaces very small amount of kerosene or diesel, the challenge is to meaningfully bundle the number of systems operating in a country to make it a viable candidate for carbon financing. The magnitude of GHG emissions reduced depends on the capacity of the systems being used in a country. Studies differ in their estimation on the quantum of carbon abated from a system such as SHS. For example, while Chaurey and Kandpal (2009) show that a 50Wp SHS have the potential to mitigate of about 67.3 to 298.4 kgCO_2/year (depending on baselines used) another study (Wang et al., 2011) suggests that a standard SHS with 40-50Wp capacity could reduce 76 kg CO2/year. Chaurey and Kandpal (2009) further estimate that carbon finance mechanism could reduce about 15% of the capital cost of 37Wp system considering transaction cost of around 20% of the revenue are involved in getting the carbon revenues. The author's estimates indicate that at the current CER price (around US$12/t$CO_2$), around 1% of the cost of typical SHS can be recovered annually from CERs, which can probably be utilized for post-installation maintenance of the system to ensure technical sustainability. Although there is huge potential, current statistics reveal very limited number of projects in South Asian region have received carbon benefits. Existing transaction cost barriers and current ways to bundle up small sized projects may be acting as key roadblocks to accrue the carbon benefits. A way to address the high transaction cost could be through Program of Activities[16] (PoA) route of availing carbon financing. The PoA offers the flexibility of one time registration with its duration extending up to 28 years and addition of any number of CPAs during this duration, which have been developed using the same approved baseline and

[16] A PoA is a voluntary coordinated action by a private or public entity which coordinates and implements any policy/measure or stated goal (i.e. incentive schemes and voluntary programmes), which leads to anthropogenic GHG emission reductions or net anthropogenic greenhouse gas removals by sinks that are additional to any that would occur in the absence of the PoA, via an unlimited number of CPAs (CDM programme activity).

monitoring methodology for a particular technology. Further, the physical boundary of a PoA may extend to more than one country indicating that the PoA can be developed at the regional level thereby also getting benefits of economy of scale.

Lastly, for the solar sector to reach a significant scale, companies need to remove barriers to supply, demand and scalability and at the same time adopt standard process and metrics, which will also help them to attract the necessary level of investment from financial institutions and venture capitalists supporting 'green' programs. The strengthening of the financing, distribution and after-sales service chain by facilitating the development of local capabilities to micro-finance, assemble, supply and service the systems will not only facilitate enterprise development on the supply side, it could potentially enhance livelihood activities that can be linked to the provision of electricity services. The opportunities have to be seen not only from the rural electrification opportunities but in the larger context of enhancing energy security of the nation.

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Disclaimer

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OASYS South Asia project

The Off-grid Access Systems for South Asia (or OASYS South Asia) is a research project funded by the Engineering and Physical Sciences Research Council of UK and the Department for International Development, UK. This research is investigating off-grid electrification in South Asia from a multi-dimensional perspective, considering techno-economic, governance, socio-political and environmental dimensions. A consortium of universities and research institutes led by De Montfort University (originally by University of Dundee until end of August 2012) is carrying out this research. The partner teams include Edinburgh Napier University, University of Manchester, the Energy and Resources Institute (TERI) and TERI University (India).

The project has carried out a detailed review of status of off-grid electrification in the region and around the world. It has also considered the financial challenges, participatory models and governance issues. Based on these, an edited book titled "Rural Electrification through Decentralised Off-grid Systems in Developing Countries" was published in 2013 (Springer-Verlag, UK). As opposed to individual systems for off-grid electrification, such as solar home systems, the research under this project is focusing on enabling income generating activities through electrification and accordingly, investing decentralised mini-grids as a solution. Various local level solutions for the region have been looked into, including husk-based power, micro-hydro, solar PV-based mini-grids and hybrid systems. The project is also carrying out demonstration projects using alternative business models (community-based, private led and local government led) and technologies to develop a better understanding of the challenges. It is also looking at replication and scale-up challenges and options and will provide policy recommendations based on the research.

More details about the project and its outputs can be obtained from www.oasyssouthasia.dmu.ac.uk or by contacting the principal investigator Prof. Subhes Bhattacharyya (subhesb@dmu.ac.uk).

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