Book

Improving lives of rural communities through developing small hybrid renewable energy systems

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IMPROVING LIVES OF RURAL COMMUNITIES THROUGH DEVELOPING SMALL HYBRID RENEWABLE ENERGY SYSTEMS

ASIAN DEVELOPMENT BANK

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ASIAN DEVELOPMENT BANK

6 ADB Avenue, Mandaluyong City, 1550 Metro Manila, Philippines
Tel +63 2 632 4444; Fax +63 2 636 2444
www.adb.org

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Notes:
In this publication, "$" refers to US dollars, and "€" refers to euro.
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ADB recognizes "China" as the People's Republic of China and "Ceylon" as Sri Lanka.

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ABBREVIATIONS

ADB	Asian Development Bank
AEPC	Alternative Energy Promotion Centre (Nepal)
CEB	Ceylon Electricity Board (Sri Lanka)
O&M	operation and maintenance
PV	photovoltaic
STELCO	State Electric Company (Maldives)

Weights and Measures

kW	kilowatt, unit of power: used in the context of installed generation capacity/connected load(s)
kWh	kilowatt-hour, unit of energy: measures energy supplied and consumed and billed
kWp	kilowatt-peak, installed or nominal solar photovoltaic capacity
m/s	meter per second
MW	megawatt, unit of power: 1 MW =1,000kW

PREFACE

As part of the efforts of the Asian Development Bank (ADB) in implementing its Energy Policy (2009), which aims to help its developing member countries (DMCs) to provide reliable, adequate, and affordable energy for inclusive growth, ADB has implemented a regional technical assistance (TA 7485) for the development of small hybrid renewable energy power systems in Asian rural areas. The TA provided technical and financial support to implementing six pilot projects in five DMCs and capacity-building activities in a number of DMCs. Details are discussed as case studies in this publication.

Through these case studies, we hope the experiences from the pilot projects can be shared with government agencies, nongovernment organizations, private sector partners, and communities in Asian rural areas in developing similar systems to meet the increasing demand for electricity for improving rural life and development in DMCs.

The implementation of this TA has encountered many challenges, but the final results are encouraging and have achieved the objectives of the TA. We would like to thank all the parties who provided support to the implementation of this TA. In particular, we would like to give credit to the implementing agencies in Bangladesh, Maldives, Nepal, Pakistan, and Sri Lanka, including Electricity Generation Company of Bangladesh, State Electric Company of Maldives, Alternative Energy Promotion Centre of Nepal, Energy Department of the Government of the Punjab in Pakistan, and Ceylon Electricity Board of Sri Lanka. Without them, the TA would not have been successful.

The ADB project team—comprising Liping Zheng (advisor), Mukhtor Khamudkhanov (principal energy specialist), N. K. Ranishka Yasanga Wimalasena (Sri Lanka Resident Mission), Pushkar Manandhar (Nepal Resident Mission), Zhang Lei and Ehtesham Khattak (Pakistan Resident Mission), Antonio Lopez Martinez (former energy specialist), Paul Hattle (former senior climate specialist), and Maila Cinco (associate project analyst)—has provided strong leadership and management for the implementation of the TA and contributed to the preparation of this publication.

We would also like to acknowledge the contributions made by the following consultants to the success of this TA: Jose Antonio Aguado, Martin Stegmann, Yinguo Huang, Ram Poudel, Amrit Thapa, Avishek Malla, Charles Duo, Shahid Ahmed, Waqar Ahmad, Hussain Awan Mubasha, Srinivasan Sunderasan, and Marietta Marasigan.

The guidance provided by ADB's Energy Advisor Yongping Zhai on this publication is highly appreciated.

Priyantha Wijayatunga
Director, Energy Division
South Asia Department
Asian Development Bank

INTRODUCTION

The Energy Policy (2009) of the Asian Development Bank (ADB) emphasizes three priorities for achieving inclusive and sustainable growth in its developing member countries (DMCs): (i) promoting energy efficiency and renewable energy; (ii) maximizing access to energy for all; and (iii) promoting energy sector reform, capacity building, and governance.[1] ADB has also committed to reinforcing its efforts to facilitate the transfer of low-carbon technologies to DMCs and to increase financial support for clean energy projects to enhance regional energy diversity and security.

As a part of such efforts, in December 2009, ADB approved a regional technical assistance (TA) for Effective Deployment of Distributed Small Wind Power Systems in Asian Rural Areas.[2] During the implementation, the scope of the TA was expanded to cover development of hybrid renewable energy systems, including solar, wind, efficient diesel generator, and energy (battery) storage. The TA aims to enhance access to clean, reliable, and affordable electricity by poor communities in Asian rural areas and small isolated islands. It adopted an approach of implementing six pilot projects in selected DMCs and conducting dissemination and capacity-building activities using the experiences drawn from these pilot projects to engage rural communities, financial institutions, private sector partners, and nongovernment organizations for deployment of small hybrid renewable energy systems in rural areas.

Of the six pilot projects, three have been implemented in remote island communities in Maldives and Sri Lanka, one in a remote mountain village in Nepal, one in a local school in Bangladesh, and one in a small village in Pakistan. For these projects, ADB provided technical and financial support for the design, procurement, installation, and commissioning of the power plants as well as training of the local implementation agencies counterpart staff. The TA also assisted in the procurement of a roadside solar power system in Tajikistan and supported capacity-building activities for power sector utilities and renewable energy agencies in Maldives, Mongolia, and Thailand.

This publication presents brief descriptions of the six pilot projects; discusses the lessons learned from these projects; and highlights the factors for consideration in planning, designing, procurement, installation, and operation and maintenance of small hybrid renewable energy systems in Asian rural areas and small isolated islands.

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1 ADB. 2009. *Energy Policy*. Manila.

2 ADB. 2009. *Regional Technical Assistance for Effective Deployment of Distributed Small Wind Power Systems in Asian Rural Areas*. Manila (TA 7485).

PILOT PROJECTS

The six pilot projects developed under the TA brought substantial tangible benefits to local communities, improved their livelihood, and resulted in lessons learned from implementation of these projects. These benefits and lessons learned are briefly discussed in each relevant case study below.

Bangladesh Subproject: Compact Photovoltaic–Battery Storage Power Plant in Siddhirganj

Background

The 36-kilowatt-peak (kWp) Siddhirganj solar photovoltaic (PV) plant demonstrates two innovative approaches to project development: (i) a containerized plug-and-play installation that delivers power to a school during the day (the anchor consumer), and (ii) utilizing capacity more efficiently by distributing the surplus power to nearby settlements.

The school chosen to host the project is located 25 kilometers southeast of the capital Dhaka and experienced constant power outages. To address the situation, the Bangladesh Power Development Board designed the project to gain autonomy from the grid, subject to budgetary constraints and rooftop space limitations.[3]

In addition, the school was the location best suited to raise awareness among the students and visitors. The TA contributed the project hardware and technical expertise for design and implementation. The scope of the project was expanded to supply surplus power to the nearby residences.

While solar resource at the site was known to be stable and predictable for most months of the year, the average wind speeds in the area were found to be too low and generally inadequate for small wind turbines to generate power at the site.

Implementation

The project comprises 36kWp alternating current (AC)-coupled solar PV systems and 120 kilowatt-hours (kWh) of lead-acid battery storage units (providing consumers with 3-day "no-sun" autonomy). Although lithium-ion batteries have significant advantage of having nearly 10 times more recharge cycles than lead-acid batteries, the latter was nevertheless chosen in the design for its low maintenance cost. The system was designed to meet a projected average daily demand of 151kWh and a maximum demand of 192kWh per day. The

[3] ADB. 2015. *Compact PV-Battery Off Grid Power Plant for Power Development Board School, Siddhirganj, Bangladesh.* p. 10.

Compact Hybrid Power Plant at Power Development Board High School, Siddhirganj, Narayanganj, Electricity Company Bangladesh Limited.

Source: Electricity Generation Company of Bangladesh.

projected annual power generation of 59,580kWh was intended to meet close to 80% of the annual demand at the school.

Experience

The electrical fans, lights, and computers were projected to consume about 25kWh during each school day. Over the 206 days between plant commissioning on 25 February and 18 September 2016, the school was operational for 120 days (approximately 60%), with the 86 days accounting for weekends and the Ramadan vacation. Over this period, the school consumed 5,035kWh of power, or about 42kWh each school day.

Early experience with implementing and operating the Siddhirganj PV project yielded a few valuable lessons:

(i) Mobilizing the community during the planning and implementation stages helps build goodwill for the project.

(ii) Involving local residents and technicians during project implementation (and having them collaborate with the equipment vendors) helps residents understand the design and also builds local operation and maintenance (O&M) capacity.

(iii) The power plant is designed to meet aggregate consumption demand but needs to be optimized to meet hourly and weekly demand through appropriate charge–discharge of the battery, supplying anchor loads over weekends.

(iv) Compatible and efficient appliances, such as lamps and fans, could be procured simultaneously to inculcate efficient utilization of power generated by the plant from the very beginning.

(v) Building local capacity and maintaining inventory of crucial spares on-site serve to ensure uninterrupted plant operations and service provision.

Maldives Subproject: Solar–Battery Storage and Diesel Hybrid Energy System on Rakeedhoo Island

Background

Rakeedhoo Island in the Vavoo Atoll of the North Central Province of Maldives is located 96 kilometers north of the capital, Malé. It faced a unique set of circumstances. The government census of 2006 counted a total population of 158 on the island including 69 men and 89 women, with near total literacy and with roughly half the total population within the 26–64 age group.[4] By mid-2014, when the project was designed, the island had over 370 registered inhabitants but only about 90 residents. Given the paucity of educational opportunity and economic activity on the island, people had left in search of opportunity elsewhere.

Previously, the island was supplied by three diesel generators of varying vintage: two 40 kilowatts (kW) and one 60kW. The project was therefore designed to optimize the generation

[4] Government of Maldives. 2016a. Isles. http://isles.egov.mv/Island/?id=609 (accessed October 2016).

mix to promote ecotourism on the island, as a means of expanding economic opportunity while mitigating emissions, lowering unit costs, and enhancing reliability.

Project design was compounded by the challenge of meeting mean power demand during most parts of the year, as well as of supplying power to meet peak demand when all the 370 inhabitants (and possibly more) arrived on the island.

Implementation

Wind resources on the island were assessed to examine the prospect of installing micro or small-wind turbines. The optimal microgrid was to incorporate solar PV arrays, and lithium-ion battery storage, with the existing diesel generators serving to meet peak loads.[5]

Power demand on the island was estimated at 173kWh, and the solar PV arrays were slated to provide 129kWh to meet demand simultaneous with generation during the sunshine hours. The battery storage units were sized to balance between surplus generation and peak demand.

The project is implemented jointly by ADB and the State Electricity Company (STELCO), the electricity utility in charge of generating and distributing electricity in Maldives. Project equipment was procured on the basis of a competitive bidding and included supply, installation, and commissioning.

The design included solar PV, lithium-ion battery bank, and diesel generators. The proposal to install a small wind energy generator was shelved because of inadequate wind resource availability on the island. In coordination with STELCO, ADB procured the equipment for the pilot project, and recruited consultants to help with the resource assessments, design, capacity building, and other aspects of implementation. The project is operated and maintained by STELCO with inputs from the equipment supplier. The consultants and equipment suppliers provided hands-on training to STELCO counterpart staff on installation, testing, and O&M of the hybrid renewable energy system.

The energy system comprises 29kWp AC-coupled solar PV arrays, operating in tandem with the existing two 40kW and one 60kW diesel generators, 2kW (3-phase) inverters, and 60kWh lithium-ion batteries for power storage.

Experience

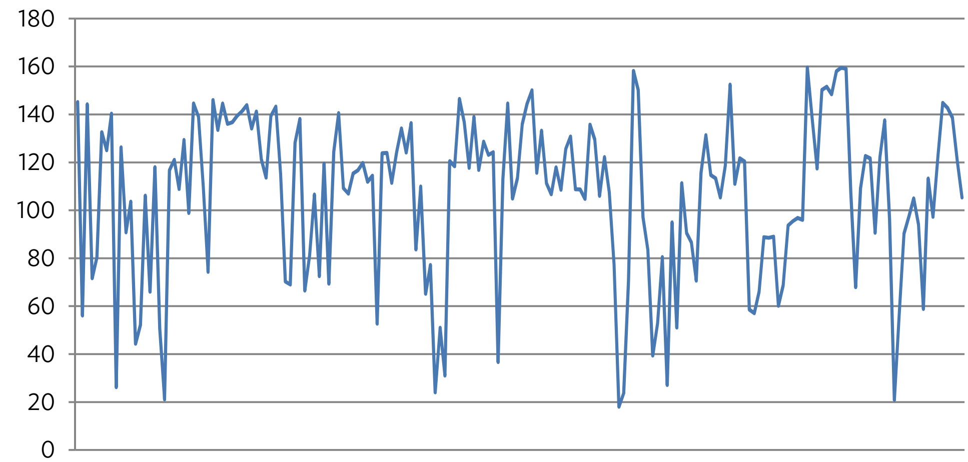
In mid-2014, when the system was designed, the aggregate load on the island was estimated to be 173kWh and design simulations showed that power from the solar PV arrays could meet about 82% of this demand while reducing dependence on the diesel generators. However, by the time the project was commissioned in mid-2016, the typical daily load had increased to 487kWh, while frequently exceeding 500kWh. This demand is met through continuously operating the existing diesel generators to supplement power from the PV system.

As depicted in Figures 1 and 2, during the early stages of project operation in 2016, the power produced from the 29kWp solar PV array fell within a wide range—between 18kWh and 163kWh—with a daily average of about 100kWh. This was lower compared with the

[5] Effergy Energia. 2014. *Hybrid Energy System: Feasibility Study for Rakeedhoo Island.* August. p. 14.

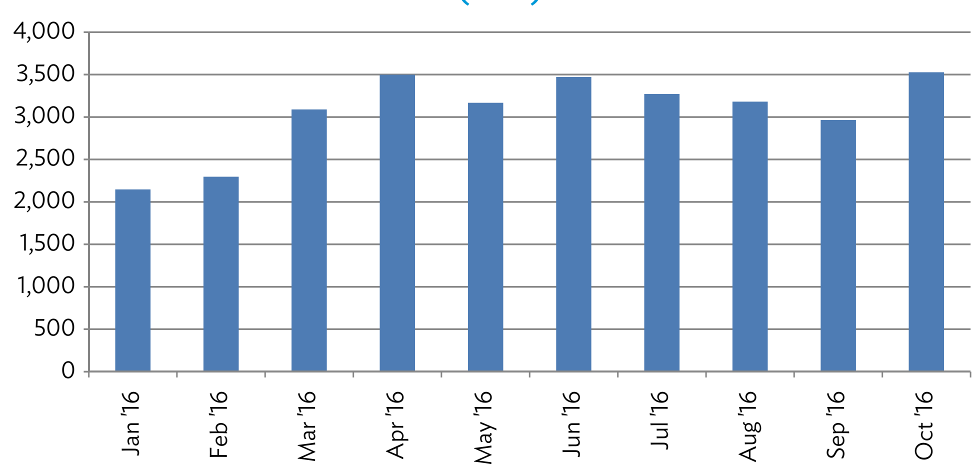
141 kWh output measured at the time of testing and commissioning the project. Optimizing the project to balance among various parameters is slated to align power supplied by the PV arrays with demand patterns on the island.

Figure 1: Daily Energy Yield from the Solar Photovoltaic System on Rakeedhoo Island, May–October 2016 (kWh)



Source: Developed from project data archived on Sunny Portal (https://www.sunnyportal.com) linked to inverter installed at site.

Figure 2: Monthly Energy Yield from the Solar Photovoltaic System on Rakeedhoo Island (kWh)



Source: Developed from project data archived on https://www.sunnyportal.com/, linked to inverter installed at site.

During the 2-year period between the design and commissioning of the project, retail power tariffs were lowered and the load had changed substantially; tourism on the island was more actively promoted and a hotel was opened to serve tourists. However, at the time of implementation, no changes were made to the proposed energy system design.

With a view to catering to the additional demand, and to lowering the run-time of the diesel generators, STELCO proposes to add solar PV arrays on Rakeedhoo Island and to connect such arrays to the existing microgrid.

Photovoltaic Solar Power Plant on Rakeedhoo Island.

Source: Photo by Martin Stegmann (Effergy Energia).

Maldives Subproject: Solar, Battery Storage, and Diesel Hybrid Renewable Energy System on Dhihdhoo Island

Background

Dhihdhoo Island in the Alifu Dhaalu Atoll of the North Central Province of Maldives is located at a distance of 212 kilometers southeast of the capital city of Malé. The enumeration records in 2006 counted a total of 116 inhabitants with a 93% literacy rate. Of the 55 men and 61 women residents, 50 were within the 26–64 age group.[6] In mid-2014, the population grew to about 140 inhabitants. In addition, a proposed hotel intended to cater to the tourist traffic on the island was likely to drive demand further.

The hybrid energy system demonstration project was designed to reduce dependence on existing three units of 32kW diesel generators by supplementing them with 45kWp of solar PV generation and 90kWh of battery storage.[7]

At the time of the feasibility study in 2014, the average load per day was estimated at 330kWh, of which 77% was intended for domestic consumption, 20% for government, and 3% for businesses.

Implementation

The compound project comprises 45kWp AC-coupled solar PV systems, three 32kW diesel generators, and 90kWh lithium-ion batteries for storage. The TA contributed project equipment and associated technical inputs for project implementation and supported capacity building of implementing agency personnel.

The introduction of the solar PV array was intended to displace power from the diesel generators, to reduce average costs of electricity generation, and to mitigate emissions.

Experience

The electricity utility STELCO has replicated the 45kWp solar PV-90kWh battery pack of the Dhidhoo project on the island of Gulhi Falhu. With a view to replicating the pilot efforts, the European Investment Bank (EIB) provided €45 million of the estimated €175 million required to enhance the use of renewable energy technologies and microgrids comprising solar PV combined with efficient diesel generators and lithium-ion battery banks along with required distribution grid upgrades, and thereby to support Maldives to integrate increasing volume of renewable energy and reducing diesel dependence in their electricity mix.

6 Government of Maldives. 2016b. Isles. http://isles.egov.mv//Island/?lid=2&id=567 (accessed October 2016).

7 Effergy Energia. 2015. *Hybrid Energy System Feasibility Study for Dhihdhoo Island.* p. 14.

Solar photovoltaic array (*upper photo*), and battery bank and inverters (*lower photo*) in Dhihdhoo Island.

Sources: Upper photo by Srinivasan Sunderasan (Verdurous Solutions) and lower photo by Stefan Oexle (Enerquinn).

Nepal Subproject: Hybrid Wind–Solar Photovoltaic Energy System in Dhaubadi Village

Background

Dhaubadi Village is located in the remote area of Nawalparasi District falling within the Lumbini zone in Nepal. It is home to 46 households with a combined total of 333 members, including 193 men and 140 women. Ginger and bean cultivation, and livestock farming constitute the primary economic activities in the village. A survey carried out in 2010 identified electricity provision as a means to enhancing the quality of life and to addressing shortcomings in education and health care provision.[8]

The pilot project was designed to supply electricity to this remote settlement and to deploy electric lamps to replace the kerosene lamps used for lighting.[9] In doing so, the project was also intended to mitigate emissions, improve indoor air quality, and contribute to better health of the residents. The project was also designed to demonstrate the technical viability of small wind energy systems in remote rural areas of Nepal.

Implementation

The TA procured the project hardware and support services to help build capacity, while the Alternative Energy Promotion Centre, the renewable energy agency in Nepal, coordinated logistics and project implementation. The project is operated and maintained by local residents.

The hybrid energy system comprises two 5kW rated small-wind turbines; 2kWp AC-coupled solar PV systems; 40kWh 36-battery string, 200 ampere-hour each, 12-volt battery storage systems; and associated power conditioning equipment. The project was completed, commissioned, and inaugurated in December 2011. The system was designed to generate a daily average of about 27kWh.

Experience

The base-case power demand from the 46 households was estimated to be 33.6kWh, and the actual load measured shortly after commissioning was 10kWh largely due to the widespread use of energy-efficient light-emitting diode (LED) bulbs and other efficient appliances. The demand was projected to rise progressively, as the residents procured more power-consuming gadgets and home appliances. In addition, a total of nine streetlights, one police post, and one school operating in the village were supplied with power from the plant.

Details of power generated by the hybrid energy system between December 2011 and July 2012, and comparisons with estimates are presented in Table 1.[10]

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8 N. B. Amatya, S. K. Gupta, P. B. Tamang, and Y. P. Shreshtha. 2010. *Baseline Survey in Renewable Energy Village.* Practical Action Nepal. February. p. 9.

9 B. P. Shrestha. *Performance Evaluation Report: Nepal–Hybrid Wind Solar Project.* Asian Development Bank. July 2012. p. 8.

10 R. C. Poudel, A. S. Thapa, A. Mall, and P. Manandhar. 2012. *Preparing and Implementing the Pilot Project in Nawalparasi: Technical Assistance Consultant's [Final] Report.* August. p. 33.

Table 1: Projected and Actual Power Generation from Hybrid System at Dhaubadi Village, Nepal (December 2011 to July 2012)

Year	Generator	WT1 (kWh)			WT2 (kWh)			PV (kWh)			Consumption	
	Month	Estimate	Actual	$∆	Estimate	Actual	$∆	Estimate	Actual	$∆	kWh	%
2011	December	96	138	31%	96	126	24%	167	241	31%	205	40%
2012	January	312	284	-10%	312	235	-33%	252	290	13%	306	38%
	February	742	212	-250%	742	134	-453%	270	219	-23%	187	33%
	March	1,113	325	-243%	1,113	168	-563%	335	283	-18%	306	39%
	April	1,106	332	-233%	1,106	177	-526%	342	245	-40%	296	39%
	May	861	316	-172%	861	180	-378%	350	290	-21%	325	41%
	June	399	365	-9%	399	227	-76%	315	223	-41%	420	51%
	July	479	301	-59%	479	278	-72%	272	197	-38%	389	50%

kWh = kilowatt-hour, PV = photovoltaic, WT = wind turbine.

Source: R. C. Poudel et al. Preparing and Implementing the Pilot Project in Nawalparasi, Technical Consultant's Report. August 2012. p. 27.

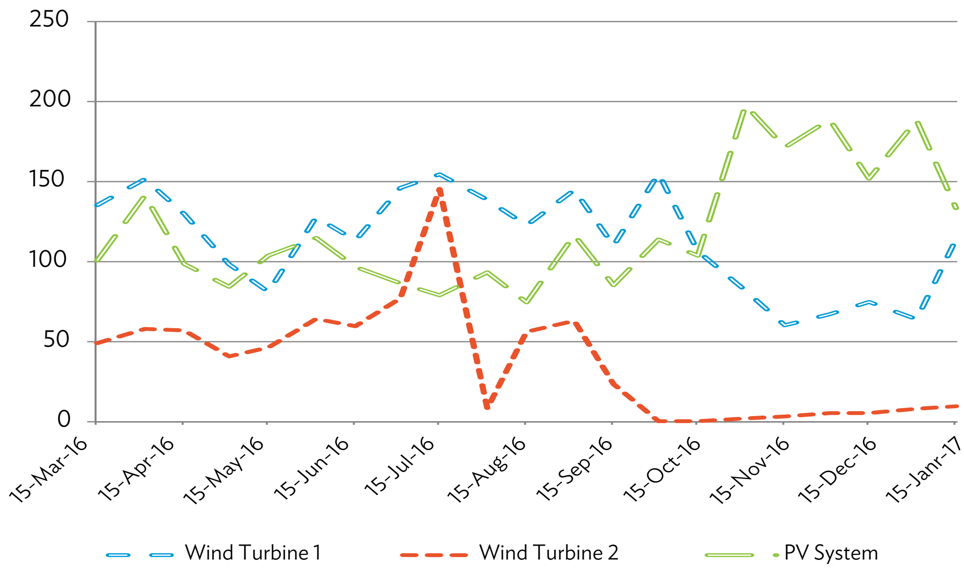
One of the two 5kW turbines had been performing below capacity since installation and had completely gone out of service by late 2015. More recent performance is illustrated in Figure 3. The community had not managed to repair the machine due to limited availability of technical skills and know-how in the local market. It was also not evident if the revenues from the sale of the generated power were adequate to cover routine O&M and to fund the replacement of the battery bank.

Due to these factors, the Alternative Energy Promotion Centre is investigating the possibility of a more substantial wind-farm deployment at the Dhaubadi site.

To provide further assistance in developing renewable energy sources, the South Asia Subregional Economic Cooperation Power System Expansion Project includes TA 8678–NEP, which supports rural electrification through renewable energy, more specifically, through building small hydroelectric power plants, minigrid-based solar PV, and solar PV and wind hybrid energy systems.[11]

[11] ADB. 2014. *Supporting Rural Electrification through Renewable Energy (formerly SASEC Power System Expansion Project)*. Manila.

Figure 3: Energy Output from the Wind–Photovoltaic Hybrid System at Dhaubadi Village at 15-Day Intervals (1 March 2016–15 January 2017)



PV = photovoltaic.

Source: Developed by Srinivasan Sunderasan (Verdurous Solutions) with data recorded at site by project operations personnel.

The two wind turbines installed at Dhaudabi, Nepal.

Source: ADB Nepal Resident Mission.

Pakistan Subproject: Solar Photovoltaic–Small-Wind Hybrid Power System in Khushab, Punjab

Background

The 50kWp solar PV and small-wind hybrid renewable energy power plant is designed to supply power to Dhok Wadgal and Dhok Pheera villages, which have a combined population of more than 500 members from 80 households in Khushab. The average base demand for energy was estimated at 172kWh per day, rising at 2% each year. On average, demand was projected to be 150kWh per day during June, July, and August (summer), and under 100 kWh per day between November and February (winter).

Monthly average wind speeds at the site were estimated at about 5 meters per second (m/s) during the months of April, May, and June, and under 4 m/s during August, September, October, and November. Consequently, the contractor was required to provide test certificates mentioning power generated by the turbines at 5 m/s. The turbine, which was to be mounted at hub height of 20 meters or higher, was designed to be strong enough to survive extreme wind speeds of up to 60 m/s.

System design therefore included a minimum of two turbines adding up to at least 20kW in generation capacity. The residual 30kW is to be provided by solar PV systems. The battery pack was designed to provide a minimum of 1.5 days of backup power supply.

Implementation

The two villages are about 500 meters apart, and the power project included distribution of power to individual power consumers and the supply of entry-level household appliances including fans for ventilation and lamps for illumination. The TA provided technical support and funding for capacity building at the implementing agency, equipment procurement, and project design and implementation.

The project also installed 20 waterproof outdoor lamps to provide lighting along streets. Since the villages did not have access to electricity before project implementation, the project design also included the provision of lights and fans to the village mosques, community centers, and schools.

With the project equipment shipped to site, construction work gained momentum during the latter half of 2016. As of April 2017, the wind turbine foundations had been built, the two lattice towers erected, and the two turbines commissioned. Likewise, the foundation and groundwork for the solar PV array had been completed, the mounting structures erected, and the solar PV system commissioned.

A total of 76 concrete poles were installed to carry the power to Dhok Pheera and Dhok Wadgal villages and electrify 80 houses, 2 mosques, and 1 school. Streetlights were installed and commissioned.

Residents of both villages were trained on operating the solar PV–small-wind–battery hybrid electric power system. The power plant and the grid network were expected to stimulate local economic activity and to help improve social outcomes within the zone of their influence.

Concrete transmission pole at the Khushab site (*left*) and the solar PV–wind hybrid installation (*right*) at Khushab, Pakistan.

Source: ADB Pakistan Resident Mission.

Experience

Prior to project implementation, residents of Dhok Pheera and Dhok Wadgal villages did not have access to electricity. They had relied on kerosene lamps and candles for lighting. Residents had no television sets and therefore had limited access to entertainment and news broadcasts. Mobile phone service was available at select locations, due to the remoteness of these two villages.

Each household had been provided with three compact fluorescent lamps, one fan, and one power socket to connect a television set and charge a mobile phone. Residents were happy to receive access to electricity and expected to benefit from the improvement in socioeconomic conditions that electricity services could bring about. The streetlights were expected to improve the conditions for movement in and around the villages after dark.

Clockwise from top left: Wind turbine tower foundation, installation of one of the small wind turbines, the fully built solar PV power plant at the Khushab pilot project site, and mounting structure for the solar PV array.

Source: ADB Pakistan Resident Mission.

Sri Lanka Subproject: Hybrid Renewable Energy System (Small-Wind, Solar Photovoltaic, Efficient Diesel Generator, and Battery Storage) on Eluvaithivu Island

Background

Eluvaithivu is a small island located in the sea of the Jaffna peninsula in the northwest part of Sri Lanka, 2.9 kilometers away from the nearest mainland point. The island is about 3 kilometers long, with an estimated surface of 1.4 square kilometers. It has a small population of around 800 inhabitants. This island was quite backward due to civil war that lasted nearly 3 decades and which ended in 2009. Since the end of the conflict, the government has been very keen to improve the living standards of the island inhabitants. The island residents were served by aging diesel generator sets of 100 kilowatts (kW) and 25kW that were unreliable,

Solar PV array mounted on the roof of the power house: small-wind turbines in the background.

Source: Photo by Srinivasan Sunderasan (Verdurous Solutions).

well past their economic life, and ran on fuel brought on to the island by boat. These diesel generators were fault prone. Average generation fuel efficiencies were very poor at 0.58 liter per kWh. Transportation costs, combined with the generator inefficiency, led to high power generation costs on the island. Retail tariffs however were subsidized by the electricity utility Ceylon Electricity Board (CEB), and tariffs were disconnected from the actual costs of power generation and supply.

The pilot demonstration project for installation of the hybrid renewable energy system, including small-wind, solar photovoltaic (PV), efficient diesel generator, and a lithium-ion battery storage, was designed with support of ADB in close cooperation with CEB to cut down on high-cost production and to replace the old, inefficient diesel-generated power with a reliable, clean, and cost-effective alternative.

Implementation

The project was implemented jointly by ADB and CEB, the electricity utility in charge of generating, transmitting, and supplying electric power in Sri Lanka. ADB provided the technical conceptual design prepared by consultants recruited under the TA and supported procurement of the project equipment. CEB was responsible for the structural and civil works, local logistics, and connection of the new hybrid system to a small electricity distribution network in the island. The consultants and equipment providers carried out capacity-building activities and training of CEB personnel involved in the project on how to operate and maintain the installed hybrid system. CEB counterpart staff also gained knowledge and experience in installation of relevant equipment, testing, and commissioning.

The pilot project comprises six units of 3.5kW small-wind generators rated at 12 m/s wind speeds, 46 kilowatt-peak (kWp) alternating current (AC)-coupled solar PV systems, 90kWh lithium-ion battery storage units, and three units of 60kW (3-phase) inverters and related power-conditioning equipment. This combination of wind, solar PV, and storage systems is backed up by a 25kW efficient diesel generator unit. The small-wind turbines proposed in the design were of a tilted type which tilts the turbine down to the ground to allow easy maintenance.

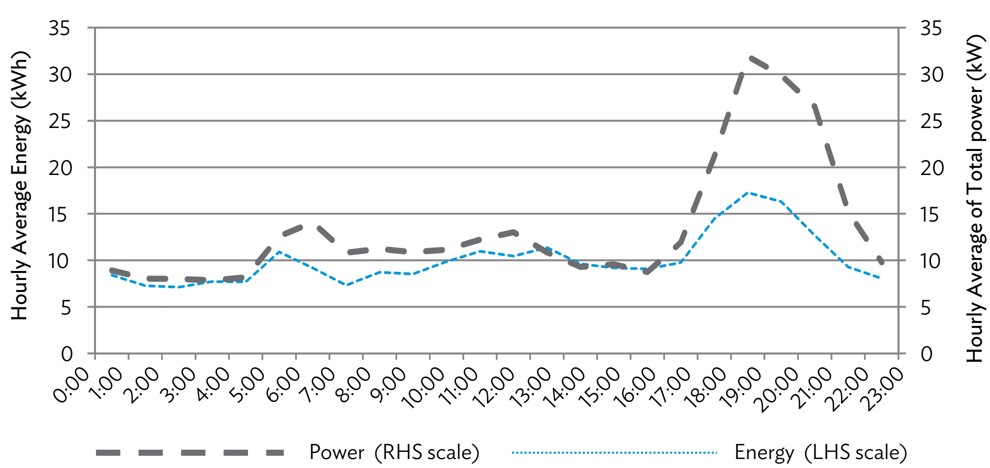
The typical daily demand (load) prior to installation was estimated at 283kWh, and the actual load at the time of commissioning was found to be 210kWh (or a total of 76,650 kWh per year). The system is sized to meet total annual demand with about 31,000kWh (approximately 40%) being supplied by the solar PV system and 45,000kWh (approximately 60%) cumulatively contributed by the six small-wind turbines.

Experience

Surplus power generated during hours of weak demand was originally intended to provide additional services to the residents: ice-making to preserve fish, desalination of seawater for consumption, or relevant amenities for small-scale tourism. Although these were not implemented in Eluvaithivu Island, such proposed approach is being used on one of the isolated islands in Sri Lanka under separate ADB financing.

Early experience with the system suggests that power from wind–solar PV hybrid system would be sufficient to meet the routine demand on the island with minimal usage of diesel generators, thereby achieving the project objectives of reducing generating costs, lowering fuel consumption, and abating carbon emissions. Figure 4 represents the actual electricity generation from the wind–solar PV–battery storage hybrid project.

Figure 4: Average Power and Energy Supply from the Eluvaithivu Wind–Photovoltaic Hybrid System



kWh = kilowatt-hour, LHS=Left Hand Side; RHS=Right Hand Side.

Source: Developed from project data archived on AllSolus (http://www.allsolusaccess.com) linked to inverter installed at site.

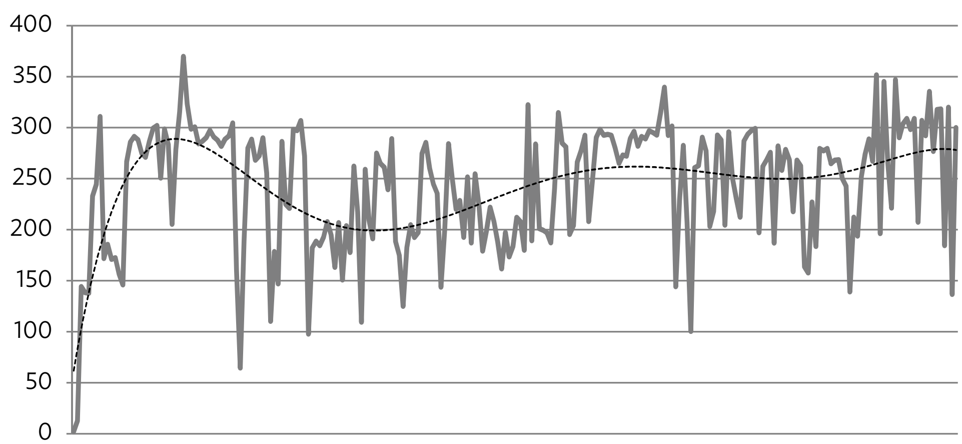
CEB has been working on optimizing the performance of the hybrid renewable energy system on Eluvaithivu. A few of the palmyra trees obstructing the flow of wind around two of the wind turbines are being removed by CEB to enhance performance of the turbines.

Encouraged by the performance of the pilot project in Eluvaithivu Island, CEB decided to replicate the pilot on three other small isolated islands close to Eluvaithivu Island to cater to the estimated power demand on those islands with clean, reliable, and more affordable power generation.

Fishing is the principal economic activity on Eluvaithivu Island. Residents struggled to access their fishing boats on their way out to sea and to then unload their catch on their return. CEB built a jetty to help with berthing of the boats. This helped the utility to establish rapport with residents and mobilized residents' support in favor of the proposed hybrid renewable energy generation project. This was crucial for the eventual success of project implementation. Later when a few palmyra trees had to be removed to allow for the wind to flow past the wind turbines, the villagers wholeheartedly contributed to the project.

Actual average daily energy consumption on the island since commissioning on 27 April 2016 through the end of December 2016 was estimated at 243kWh with peak demand approaching 370kWh on 8 June 2016 (Figure 5). On the average day, the microgrid network catered to increased consumption demand between 6 p.m. and 10 p.m. Power demand on the grid network peaked at 32kW at about 7 p.m. on the average day.

Figure 5: Power Demand on Eluvaithivu Island (26 April–31 December 2016)



kWh = kilowatt-hour.

Source: Developed from project data archived on http://www.allsolusaccess.com/ linked to inverter installed at site.

Solar Array on Eluvaithivu Island.

Source: Photo by Martin Stegmann (Effergy Energia).

The Small-Wind, Solar PV, Efficient Diesel Generator, and Battery Storage Hybrid System merges seamlessly into the landscape defined by palmyra trees on Eluvaithivu Island in the northern province of Sri Lanka.

Source: Photo by Srinivasan Sunderasan (Verdurous Solutions).

FACTORS TO CONSIDER REGARDING NEW WIND, SOLAR, OR WIND–SOLAR HYBRID POWER SYSTEM INSTALLATIONS

Planning

One of the most crucial considerations for the planning of a new wind, solar, or wind–solar hybrid power system in rural areas is the financing for installing the system and financial sustainability for operation and maintenance (O&M) of the system.

A wind, solar, or wind–solar hybrid power system requires relatively high capital cost for acquiring the system, but relatively low cost for O&M. As the technology has advanced significantly in recent years, a wind, solar, or wind–solar hybrid power system can have very long service life if the system is properly maintained. The authors[12] of "Net-Metering Reference Guide" published by GIZ of Germany suggest two options for easing the financial burden on the initial cost of procuring the system by spreading the cost over the long term while the beneficiaries using the system are already benefiting from using the system. The two options are Term Loan and Equipment Lease.

An alternative approach to procuring or leasing the system is contracting for power supply by equipment vendors. This approach, however, could be difficult to apply by small remote rural communities as the economic benefit for the vendors might be insufficient for such business mode.

For poor rural areas where the local communities cannot afford the financing of a new wind, solar, or wind–solar hybrid power system, the government may consider integrating rural electrification with renewable energy into other national programs, such as environmental and poverty reduction programs, which can help ease the financial burden of such poor communities. In the People's Republic of China, for example, the central and local governments have been providing financing for building solar energy systems in rural areas as a part of the national solar energy for poverty alleviation program, and the program has been generally successful in raising living standards as well as revenues of the farmers who

[12] Silver Navarro, Jr., renewable energy and financing consultant; Noel Verdote, operations officer, IFC - Sustainable Energy Finance; Rustico Noli De La Cruz, assistant vice president, Development Bank of the Philippines.

use the systems.[13] As the investment for the equipment in such programs is usually heavily subsidized by the government, how to make the program sustainable should be worked out at the planning stage of the program.

A key to making an off-grid wind, solar, or wind–solar hybrid power system in the rural areas affordable and sustainable is to minimize the unit cost (cost per kWh) to the extent possible. One way to achieve this is to increase the total demand for electricity by (i) connecting the system to nearby commercial or production establishment(s) or (ii) setting up new establishments of this nature within the beneficiaries' community. The second option is more desirable as it provides a threefold benefit to the local community: it creates employment, it generates revenue, and it lowers the electricity unit cost. Here are some good examples: in the northern region of the People's Republic of China, farmers are using solar-generated electricity to control the temperature in greenhouses for growing vegetables that are otherwise not produced during winter in that area. In tropical Sri Lanka, island communities are building ice-making plants using wind- and solar-generated electricity to produce ice for preserving fish, to power desalination plants that provide potable water in coastal areas, and to provide electricity for tourist amenities.

The flow of private and institutional investments that are necessary to sustainably scale up the microgrid segment of the power sector is impeded by the site-specific nature of microgrids, uncertainty with load characteristics, evolving regulatory environment in most developing countries, and the risks associated with individual microgrid projects. Public funding could defray some of the project-specific, technology-specific, or market-specific risks, and catalyze the microgrid segment by structuring public–private partnerships to develop bundled microgrid project portfolios. Such bundling could also reduce the transactional costs associated with mobilizing structured debt financing from mainstream institutions.

Whether a new system will be a wind, or solar, or wind–solar and battery storage hybrid, and whether it should be off-grid or grid-connected, are all essential factors in planning a new system. The decisions on this must be based on a feasibility study that takes into consideration solar and wind resources, demand for energy as well as geographic conditions and distance to the nearest utility grid. For areas where solar resource is not sufficient all year but can be supplemented by wind resources or vice versa, a hybrid system would be desirable for providing reliable supply of electricity if it is off-grid. Connecting to the utility grid provides the benefits of having reliable electricity supply, and offset the cost for electricity supplied from the grid or sell surplus electricity generated by the system to the grid. However, on the other side of the balance is the cost of building and running a power line from the system to the grid. All these factors must be carefully assessed at the planning stage of a new wind, solar, or wind–solar hybrid system.

When estimating electricity demand for a new system, project planners should not only consider the current demand from the local community the new system is to serve, but also the potential increase of such demand over the life span of the system. Experiences tell that

[13] E. Nilsson. 2017. Solar Power Lights up the Path to Prosperity. *China Daily*. 12 June.

in Asian rural areas, the increase in power demand can be rapid and significant due to rising living standards and increase in revenue-generating productivity brought about by access to electricity supply through the new system. In relatively large clusters, the demand for power could be projected using mathematical models that take into account economic activity, population size, migration patterns, power prices, ownership of household appliances, and other relevant socioeconomic–cultural parameters. With large populations, near-term changes in demand for power could even out, with average demand remaining within a narrow range of baseline projections. In smaller settlements, however, as with off-grid markets where such hybrid systems are likely to find application, a detailed household level and institutional level survey of the catchment area might be necessary, even mandatory. In addition to ascertaining the propensity for appliance ownership and use, such a survey should also help project demand across hours of the day, and across seasons of the year, with greater precision. Custom-designed stand-alone systems are frequently left with little flexibility to accommodate rapid changes in demand. In smaller settlements, the mere addition of a few air conditioners or refrigerators could represent a substantial increase in demand for power. Likewise, inward or outward migration of a few families might represent a sizable change in load.[14] The acquisition of household appliances, when combined with subsidized power tariffs, could lead to higher loads on the generation system (in kW terms), while the longer hours of operation could increase the demand for electricity (in kWh terms), and vice versa. The large-scale deployment of air conditioners and other household appliances as witnessed on Rakeedhoo Island in Maldives, simultaneous with the government's decision to reduce retail electricity tariffs, meant that the utility was required to continue operating the diesel generators in addition to the solar PV systems installed under the TA. On the other hand, power from the solar PV system installed in Siddhirganj near Dhaka in Bangladesh was available for distribution outside of the school, especially over weekends and during vacations, partly because more efficient lamps were used. More generally, such surplus power could serve to energize "anchor loads" such as agricultural pump sets or to be distributed for household consumption among the residences located in close proximity to the installed power plant. A detailed survey of the neighborhood could help incorporate such data into the project at the planning stage and to design the project to cater to the seasonal needs of the present and of the foreseeable future.

Design

Solar photovoltaic systems. Given the rapid decline in solar PV module prices and the respectable advances in battery technology, even when combined with the relatively modest declines in prices of power-conditioning equipment (power electronics such as inverters, charge controllers, switchgear, "balance-of-systems" including cables), a solar PV system has emerged as an attractive option for rural, isolated island and remote-area electrification. Maintenance needs of solar PV might be minimal compared with that of equipment with "moving" sub-assemblies as with wind turbines or biomass gasifiers.

[14] The 70kW small-hydro power plant / minigrid project in Chendebji village in central Bhutan, commissioned in 2005, attracted a sizable inward migration from neighboring villages in short order.

CDM. 2005. e7 Bhutan Micro Hydro Power CDM Project. http://cdm.unfccc.int/Projects/DB/JACO1113389887.76/view (accessed 5 June 2017).

Global horizontal irradiance data can be obtained with adequate functional precision from global datasets, for purposes of planning a stand-alone or hybrid system. This data could be used for assessing diurnal and seasonal patterns. Software packages, such as the US National Aeronautics and Space Administration (NASA) or Atmospheric Science Data Center's Hybrid Optimization Model for Electric Renewables (HOMER), provide hourly-average solar resource data, which help optimize system design to better match the demand for, and supply of, power. Location-specific yields could also be estimated with an experimental solar PV module coupled with a data recording device. More site-specific solar resource data is now available on mainstream "smartphones" working on Google Android platforms, as with the data provided by the Indian Space Research Organisation[15] and other such organizations.

Wind energy generators. Finalizing the design for a wind energy generator package might be marginally more complicated. A NASA global dataset containing information on wind speeds at a height of 50 meters above ground could provide preliminary indication of resource availability and its seasonality.[16] Installing wind masts and anemometers to gather location-specific data may be necessary. Data could be recorded locally, transmitted to remote locations, or both.[17] Such site-specific wind resource data viewed in the context of the demand for power at the site helps optimize the sizes, numbers, and locations of the wind energy generators.

Wind and solar power generation are not perfectly correlated. Solar PV systems and wind energy generators could attain peak generation at different times during the day. Likewise, the two sources could complement each other across seasons. Storage capacity for wind and solar combined could be less than the aggregate capacity required for storing surplus generation from solar PV and wind separately. When finely optimized, the storage capacity required for a wind and solar PV hybrid energy system could be lower compared even to the smaller of the stand-alone capacities necessary to buffer generation from wind and solar PV systems.[18]

The progressive decline in battery technology costs has contributed significantly to the mainstream adoption of battery storage within project designs. This is especially true of small and isolated grids. In addition to time-shifting of renewable generation, battery storage ensures stable microgrid operation by providing frequency response and voltage regulation.[19] On the other hand, when microgrids are connected to utility-wide grid networks, distributed generation, when combined with storage capacity, reduces the need for centralized base-load fossil fuel plants that are currently required to bridge intermittency in supply from the renewable energy sources.

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15 Indian Space Research Organisation. 2017. http://www.isro.gov.in/isro-develops-solar-calculator-android-app; the application can be downloaded from *Visualization of Earth Observation: Data and Archival System* (at https://vedas.sac.gov.in/vedas/).

16 Wind Speed At 50 m Above The Surface Of The Earth (m/s). https://eosweb.larc.nasa.gov/sse/global/text/10yr_wspd50m (accessed 7 May 2017).

17 The 3 x 800kW wind turbines on San Cristobal Island (part of the Galapagos Islands in Ecuador) are remotely monitored.

18 H.-W. Sinn. 2016. Buffering Volatility: A Study on the Limits of Germany's Energy Revolution. *NBER Working Paper.* No. 22467. National Bureau of Economic Research.

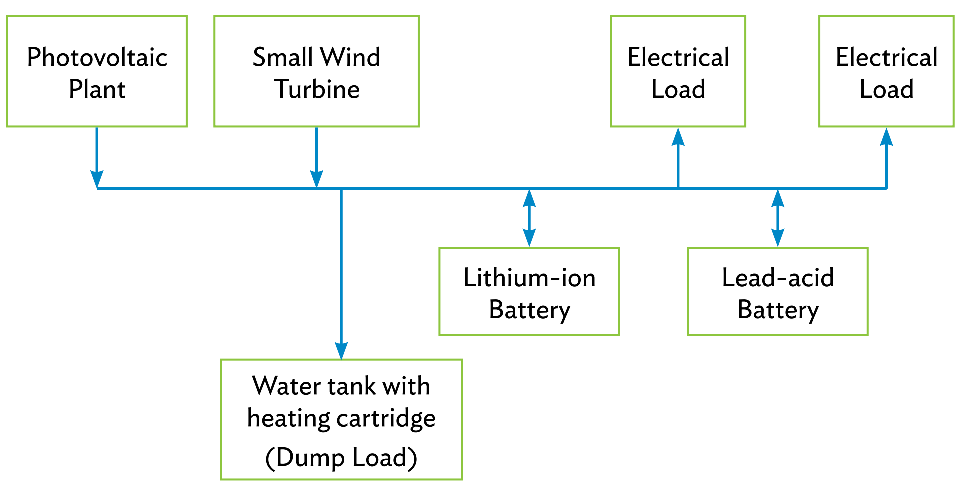
19 T. Houlding. 2016. Battery Storage Overview and How It Will Unlock the Full Potential of Renewables. *Renewable Energy World.* September / October. pp. 25–28.

Further, the inclusion of an energy storage system helps exploit renewable energy generation to the fullest and achieve significant fuel savings. The availability of energy storage to help time-shift renewable energy generation provides better balance between supply and demand, and significantly reduces the need for diesel generator operation. Peak energy generated by solar PV arrays and wind turbines could be used during hours of peak demand in the morning and in the evening.

For application in isolated islands, remote rural, and inaccessible locations, lithium-ion battery systems offer high energy density and low "round-trip" losses from each charge–discharge cycle. For reasonably well-connected sites, the relatively heavier lead-acid battery banks continue to offer acceptable price–performance ratios. Evidently, the sizing and technology selection of the energy storage system is customized to suit the site in question. The storage system forms part of a wider system and is tailored to match renewable energy resource availability, demand patterns, and other microgrid-network parameters.[20]

Further, a hybrid storage unit designed with a lead-acid battery (employed as medium-term storage) and a lithium-ion battery (as more short-term dynamic buffer storage) covers fast load transients and helps meet peak power. This arrangement is known to prolong the life of lead-acid batteries by minimizing microcharging cycles and delaying the aging of the battery.[21] A schematic representation of a decentralized/grid-connected solar PV–small wind turbine hybrid system with lead-acid–lithium-ion hybrid battery storage is presented in Figure 6. Where applicable, a storage water heater could be inducted to absorb peak power

Figure 6: Schematic Representation of a Solar Photovoltaic–Small Wind Hybrid Generation System with Lithium–Ion and Lead–Acid Battery Storage Components, and a Water Heater Serving as a Dump Load



Source: Developed based on a concept outlined by Thilo Bocklisch and Johannes Lindner (2016): http://www.sciencedirect.com/science/article/pii/S1876610216310864

20 M. Lippert. 2016b. Li-ion Energy Storage Takes Microgrids to the Next Level. *Renewable Energy Focus.* 17:4 July / August. pp. 159–161.

21 T. Bocklisch and J. Lindner. 2016. Technical and Economic Investigation and Comparison of Photovoltaic-Wind Energy-Hybrid Systems with Battery and Heat-Storage Path. *Energy Procedia.* 99. pp. 350–359.

output (dump load). The more expensive lithium-ion battery pack could be small relative to the traditional lead-acid accumulator capacity, but it could provide a more rapid response to sudden ramp-up in demand and shield the lead-acid battery pack from meeting peak power demand. The heated water could be provided to hotels, hospitals and clinics, or residences.

Environmental Considerations

Small wind, solar, or wind–solar hybrid power systems have significant environmental benefits compared with fossil fuel power plants. Small wind, solar, or wind–solar hybrid power systems do not produce or produce very minimal (when a diesel generator is used in a hybrid system) atmospheric emissions, or create acid rain or greenhouse gases. However, concerns have been raised over the noise generated by the wind turbine blades and land use for building wind and solar farms. Proper measures should be taken at the planning and design stage to address these concerns. Such measures may include locating the wind generator site in sufficient distance from residential areas, schools, and hospitals, and using existing rooftops or low-quality locations which are otherwise not used for other purposes.

Another safety and environmental concern is the transportation and disposal of batteries. Batteries used in small wind, solar, or wind–solar hybrid power systems, whether they are conventional lead-acid batteries or more advanced lithium-ion batteries, have the potential to impose safety and environmental hazard if handled improperly. Therefore, strict rules must be established and followed in their transportation, O&M, and disposal.

Procurement

Turnkey contract for the delivery, installation, and commissioning of small wind, solar, or wind–solar hybrid power systems is the preferred type of contract for procurement of such power systems in rural communities. This is because in most cases, rural communities do not have the technical capacity for installation of such systems. To save cost, the rural communities may contribute to preparing project sites and building foundations for wind turbine towers and/or providing spaces, such as rooftops, for solar panels. In doing so, the local communities must make sure their work and materials meet the requirements of the system design and the requirements of the supplier of the equipment; such requirements must be clearly stated in the contract. In certain cases, if the local community and/or government/utility agency sponsoring the project has the relevant technical capacity, they may assign engineers/technicians to assist the supplier in installation. This can provide a good learning opportunity for them about the system which would be useful for their work in the future for system O&M. However, in such cases, each party's responsibility must be clearly stated in the contract to avoid dispute over the system defect liability and warranty.

The method for procurement should be as simple as possible provided the process is competitive and transparent, and all technical and quality assurance requirements are clearly defined in the procurement document. The main challenge for procurement of small wind, solar, and wind–solar hybrid power systems for rural areas is to attract highly qualified suppliers to participate in the bidding. A cumbersome bidding process with complicated bidding documents may discourage potential bidders to bid for the relatively small contracts with delivery requirement for remote locations.

The local presence of the supplier, either through a local branch or partner, for supplying spare parts and repair services is essential.

For rural communities or government sponsoring without capacity for system maintenance, the contract should include a clause for 1- or 2-year O&M and a clause for O&M training.

Operation and Maintenance

Appropriately trained personnel should be responsible for managing routine operation and periodic maintenance of the plant. Adequate training and periodic refresher courses combined with hands-on experience ensure that technicians do not overlook imbalances and incremental failures with the potential to disrupt the entire microgrid system. Such training should include commissioning the plant, system operation, record keeping, and periodic maintenance.

Proper maintenance of diesel generators and other backup sources is critical to ensure that the backup power system operates when most needed. Planned maintenance programs performed according to industry codes and standards ensure consistent system performance, especially when generators are frequently exposed to hot, humid, and salt-laden gusts of wind. Such foresight and abundant caution should extend to fuel acquisition and storage, starting batteries, dynamos, engine coolants and heaters, and ventilation of the generator building.

The hybrid power system should periodically be tested under design load, peak load, and under full-emergency conditions to verify uninterrupted operations. Periodic testing of the backup diesel generators eliminates accumulated condensation in the fuel tank, reduces fuel-filter clogging and fuel contamination, and enhances system reliability. Likewise, the use of additives, fuel filtering, regular sampling, and diesel fuel supplements help remove contaminants and prevent significant engine damage.[22]

The cost of transporting and replacing system components, under certain circumstances, could be larger than the cost of the components themselves, even by a large multiple, on occasion. It might be prudent to maintain a stock of critical spares such as bearings and other components needing upkeep and replacement at the project site, and to train the local technicians to replace such components in time.

Community and Utility Operation and Maintenance

Over the years, several O&M, service provision, or payment collection models have been deployed in various settings with different degrees of success. It is now recognized that moral ownership of the project by the community ensures project sustainability. However, high up-front costs, cost of spares, battery replacement, and other maintenance costs are known to be prohibitive for rural or island communities to bear on their own. Sharing of responsibilities between the distribution utility and the community might help optimize costs and ensure uninterrupted service provision. The two approaches are compared in Table 2.

[22] T. Robinett. 2015. The Dos and Don'ts of Genset Maintenance. *Cogeneration & On-Site Power Production.* November–December. pp. 29–31.

Table 2: Comparison of Community-Managed and Utility-Managed Projects

Community-Managed System
Advantages Community commitment, participation, and support are frequently identified as the most important factors for the success of remote hybrid renewable energy projects.[a] Moral ownership by the community promotes ethical, reciprocal, and cooperative production, consumption, awareness creation, financing, and maintenance. [b] Community management of the renewable energy-hybrid system and the operation and maintenance payments made to local residents ensures that the money invested stays within the community while ensuring the production of clean, reliable, and accessible energy for all. Capacity building for local technicians to operate and maintain the hybrid power system facilitates uninterrupted operations. The skills transferred also cascade to junior members within the community, which helps lay foundations for skill development and remunerative employment in the future.
Disadvantages Identifying local persons with requisite basic understanding of electrical and mechanical technology and training them to maintain the solar photovoltaic, wind, diesel hybrid systems could be challenging. Disturbance in society or disruption of peace and harmony could adversely impact energy service provision and system maintenance and repair.
Utility-Managed System
Advantages Skilled and experienced workforce at the utility could operate and maintain systems more professionally. The utility might enjoy greater legitimacy on matters relating to issuing bills and collecting periodic payments from consumers. Systematic data collection, maintenance of records, and analysis by utilities can help in identifying the inefficiencies in the system and therefore result in optimization and cost saving.[c] Utility-managed systems help in saving costs through better utilization of equipment and by avoiding duplication of asset purchase (scale economies). Periodic assessments of the performance of generation and distribution systems under peak load conditions undertaken by the utility's expert personnel confirm system reliability.[d] The presence of qualified and specialized personnel enables faster restoration of services after natural calamities such as earthquakes and cyclones.
Disadvantages Response times could be longer if utility personnel were required to access remote locations, especially if communication networks and/or access roads are cut off. Appointing utility staff to serve in remote locations and keeping such staff motivated could prove challenging.

[a] G. Fay and N. Udovyk. 2013. Factors Influencing Success of Wind-Diesel Hybrid Systems in Remote Alaska Communities: Results of an Informal Survey. *Renewable Energy*. September. 57. pp. 554–557.

[b] J. Shepard and L. Barrera. 2013. Community Power: What's In A Name. *Cleantechnica.com* https://cleantechnica.com/2013/07/01/community-power-whats-in-a-name/ (accessed 1 March 2017).

[c] EPM. 2011. Energy & Operating Cost Savings. *Ethanol Producer Magazine*. http://www.interstates.com/resources/resources-detail/22/Benefits_of_a_Utility_Management_System (accessed 25 April 2017).

[d] T. Robinett. 2015. The Dos and Don'ts of Genset Maintenance. *Cogeneration & On-Site Power Production.* November–December. pp. 29–31.

Source: Srinivasan Sunderasan (Verdurous Solutions).

Recommendation: Community–Utility Joint Management

Subject to the specific circumstances, it should be made possible to identify and train local residents or residents from nearby settlements possessing the aptitude and basic skills in managing routine operations and data collection. Utility personnel could be deployed to visit the site periodically and to undertake preventive and corrective maintenance, including, if necessary, to issue bills and collect payments for the electricity supplied.

CONCLUSION

Overall, the six pilot projects in five countries have been generally successful. Based on the experiences from these pilots, similar projects are being implemented or prepared for other locations in Asian rural areas or isolated islands. In particular, similar projects are being implemented under the Preparing the Outer Islands for Sustainable Energy Development Project in Maldives[23] and the Supporting Electricity Supply Reliability Improvement Project in Sri Lanka.[24] Also, South Asia Subregional Economic Cooperation Power System Expansion Project[25] and Additional Financing that is being processed for Bangladesh Power System Efficiency Improvement Project[26] include components similar to the pilot projects.

In Sri Lanka, the Supporting Electricity Supply Reliability Improvement Project includes a component that involves (i) establishing hybrid renewable energy systems, consisting of wind, solar, efficient diesel generators, and battery storage; (ii) support for productive energy use for small isolated island and rural communities on three islands in the Jaffna area of the northern province (Analativu, Delft, and Nainativu); and (iii) establishing a renewable energy microgrid system in the western province. The project in Nepal contains a component to establish minigrid systems consisting of small hydropower, solar power and wind power systems in rural areas. The project in Bangladesh is expected to expand the solar power based irrigation systems in the rural areas replacing existing diesel and electric water pumps.

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Improving Lives of Rural Communities Through Developing Small Hybrid Renewable Energy Systems

Despite significant economic growth in Asia in recent decades, millions of people in rural Asia still lack access to electricity. A project has been implemented to develop small hybrid renewable energy systems in these areas. This publication highlights the experiences of these pilot projects in five developing member countries. It provides technical guidance and recommendations for the deployment of similar systems in minigrids in remote rural locations and small isolated islands to achieve access to electricity and energy efficiency.

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ASIAN DEVELOPMENT BANK
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org