Partnerships IQ

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Rooftop Solar

Public-Private Partnerships: Lessons from Gujarat Solar

Rooftop solar PV provides access to green power for large numbers of people, using structures that already exist—a must for crowded urban sites where space is at a premium. Public-private partnerships have made these "rent-a-roofs" successful throughout India. The State of Gujarat's in-depth experience with rooftop solar PPPs, tailored specifically to overcome complex constraints, is a model that is being replicated widely throughout the country and has implications for other emerging economies.

INTELLIGENCE AND INSIGHTS ON PUBLIC-PRIVATE PARTNERSHIPS

WORLD BANK GROUP

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GLOSSARY

Balance of systems, or BoS, are all components of a photovoltaic system other than the photovoltaic panels. These include structures for mounting the PV arrays or modules, powerconditioning equipment that adjusts and converts direct current to alternating current of the proper form and magnitude, and storage devices such as batteries.

Feed-in tariff (FIT) is a policy mechanism designed to accelerate investments in renewable energy technologies, generally by offering long-term contracts to renewable energy producers. These are typically based on electricity-generating costs using a particular technology.

Grid feed refers to injecting or feeding the electricity generated into to the main electrical distribution system, commonly referred to as the grid.

Grid-tied inverter is a power inverter that converts direct current from photovoltaic modules into alternating current and feeds it directly into a power grid.

Jawaharlal Nehru National Solar Mission (JNNSM), also known as the National Solar Mission, is a major initiative by the government of India to promote ecologically sustainable growth while addressing India's energy security challenges. It was launched in January 2010 and has set itself the ambitious target to deploy 20,000 MW of grid-connected solar power by 2022. It aims to reduce the cost of solar power generation through (i) long-term policy; (ii) large-scale deployment goals; (iii) aggressive research and development; and (iv) domestic production of critical raw materials, components, and products, and achieve grid tariff parity by 2022.

Levelized cost is the constant unit cost (per kilowatt hour or MW hour) of a payment/revenue stream that has the same value as the total cost of building and operating a generating plant over its life. In other words, it is the constant price per unit of energy that causes the investment to just break even. It is useful in comparing costs of generation from different sources.

Low-voltage grid: In an electric power supply system, last mile connectivity to consumers (mainly domestic consumers) is provided through electrical distribution lines that transmit electricity to consumers. This is referred to as the low-voltage or low-tension grid. In this white paper, low tension refers to electrical distribution at 230 volts/240 volts (single-phase system, phase to neutral voltage) or 415 volts/440 volts (three-phase system, phase to phase voltage).

Off-taker procures the energy produced from energy generators, conventional or renewable. These are primarily distribution or transmission utilities.

Open access is the non-discriminatory use of transmission lines in the distribution system by any licensee or consumer or a person engaged in generation as per specified regulations.

Phase imbalance: A three-phase power system is called balanced or symmetrical if the three-phase voltages and currents have the same amplitude and are phase shifted by 120° with respect to each other. If either or both of these conditions are not met, the system is unbalanced or asymmetrical. This is a power quality issue. Multiple grid-connected small-scale (kilowatt-scale) inverter-based single-phase distributed generation systems at low voltage have the potential to cause unbalance of low-voltage distribution systems. To decrease effects of unbalance, various actions need to be performed (by the utility), each with different degrees of technical complexity and associated costs.

Photovoltaic (PV) is the process of generating electrical power by converting solar radiation into direct current electricity. It uses semiconductors that create electric current when exposed to sunlight. Solar panels containing a number of solar cells made of photovoltaic material are used for photovoltaic power generation.

Power purchase agreement (PPA) is a contract between two parties, one who generates electricity for the purpose of sale (the seller) and one who is looking to purchase it (the buyer). A PPA specifies commercial terms including when the project will begin commercial operation, schedule for delivery of electricity, penalties for under-delivery, payment terms, and termination. A PPA is the principal agreement that defines the revenue and credit quality of a generating project and is thus a key instrument for project finance.

Renewable energy certificate (REC) represents the green attributes of electricity generated from renewable energy sources. This attribute can be unbundled and the two products - the attribute embodied in an REC and the electricity - can be sold or traded separately.

A renewable portfolio standard (RPS) is a regulation that requires the increased production of energy from renewable sources, such as wind, solar, biomass, and geothermal. The Renewable Electricity Standard (RES) in the U.S. and Renewables Obligation in the United Kingdom are typical examples of renewable portfolio standards.

Time of day (ToD) tariff is an electricity tariff structure in which different rates are applied at different times of the day. For a consumer this means that the cost of using one unit of electricity is different at different times, say morning, noon, evenings, or night.

Wheeling charge is an amount charged by one electrical system to transmit the energy of, and for, another system. In case party A wants to use the transmission/distribution network of party B to transfer its power from place X to Y, then party A must pay the charges defined by the regulatory authority to party B for this. This transfer of power on the network for another party is called wheeling of power.

ACRONYMS & ABBREVIATIONS

AD	Accelerated depreciation
ASTM	American Society of Testing and Materials
BIS	Bureau of Indian Standards
BoS	Balance of systems
CDM	Clean development mechanism
COD	Commercial operation date
DDG	Decentralized distributed generation
FIT	Feed-in tariff
GHI	Global horizontal irradiation
GW	Gigawatt
HT	High tension
HVAC	Heating, ventilation, and air conditioning
IEC	International Electromechanical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEP	Integrated Energy Policy, India
JNNSM	Jawaharlal Nehru National Solar Mission, India
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt hour
LC	Letter of credit
LV	Low voltage
MNRE	Ministry of New and Renewable Energy, India
MW	Medium voltage
MW	Mega watt
MWp	Mega watt peak
NAPCC	National Action Plan for Climate Change, India
NREL	National Renewable Energy Laboratory
O&M	Operations and maintenance
PCU	Power control unit
PIA	Project implementation agreement
PPA	Power purchase agreement
PPP	Public-private partnership
PV	Photovoltaic
R&B	Road and buildings
R&D	Research and development
RE	Renewable energy
REC	Renewable energy certificate
RPO	Renewable purchase obligation
RPS	Renewable portfolio standard
RPSSGP	Rooftop PV and Small Solar Power Generation Program, India
SERC	State Electricity Regulatory Commission
T&D	Transmission and distribution
ToD	Time of day
V	Volt

All dollar amounts are U.S. dollars unless otherwise indicated.

INTRODUCTION

A visitor to Gandhinagar, capital of the Indian state of Gujarat, is likely to notice the glint of the sun reflecting off solar panels on the city's rooftops. Some of these solar panels sit atop schools, others on hospitals. Many are perched on residential buildings. Altogether, the panels generate about 5 megawatts (MW) of electricity, providing better access to power for an estimated 10,000 people.

The groundbreaking project to enhance access to energy for urban households, a pilot public-private partnership (PPP), attracted approximately $12 million in private financing and helped advance the Government of India's plan to make Gandhinagar a solar city.

But the greatest success of Gujarat's solar rooftop program, informally referred to as the "rent-a-roof project," lies in its replicability. Launched in 2010, the project paved the way for a wider rollout of solar rooftop initiatives by working through technical, legislative, and financial issues. Two private firms, Azure Power and SunEdison, each won 25-year concessions to install solar photovoltaic (PV) panels on the rooftops of public buildings and private residences and connect them to the grid.

"RENT-A-ROOF" IN GUJARAT

Gujarat, a state of 80 million in western India, enjoys about 300 sunny days a year. To harness this energy, private solar companies selected through a competitive bidding process lease rooftop space from government buildings and private residents, who receive Rs 3 ($0.05) per unit produced. The operators are responsible for installing the panels and connecting them to the grid. They in turn receive a feed-in-tariff of Rs 11.21 ($0.18) under a 25-year concession.

The concept sounds simple. But to make it work, numerous technical issues had to be addressed, including connectivity issues, selecting the solar panel system and other components, and resolving connectivity issues. The optimal terms of the lease and power purchase agreements also had to be determined in light of existing regulations and business conditions.

But most important was the unambiguous vision for solar power articulated by the state government of Gujarat. As early as 2009, it became the first state in India to announce a solar policy, which included ambitious solar power generation goals and plans to develop its capital as a "solar city." Gujarat has made significant progress toward its goals. In June 2014, *The Times of India* reported that Gujarat was already producing 891 MW of solar power and had plans to increase solar capacity by an additional 500 MW in the next three years.

REPLICATION THROUGHOUT INDIA

Vadodara, a city of 2 million people, became the second municipality in Gujarat to adopt the solar rooftop concept. In June 2014, Madhav Solar Private Limited won a 25-year concession for a 5 MW solar rooftop PPP based on a model similar to the one in Gandhinagar. It is expected to attract $8 million in private investment, provide 9,000 people with better access to power, and reduce greenhouse gas emissions by 6,000 metric tons.

The Vadodara project clearly benefited from the lessons of Gandhinagar's solar rooftop PPP experience. Many of the obstacles faced in the pilot project had already been addressed and resolved. The results were proven. Consequently, the Vadodara PPP took less time to implement.

Buoyed by two important successes, Gujarat is considering replicating this project in all of its cities. These projects aim to draw on recent experience to implement such projects, address challenges faced therein, and tweak existing business models to facilitate replication of the concept.

The solar rooftop concept has excellent prospects for becoming established throughout India. Cities outside of Gujarat have taken notice; even Delhi is eyeing the model. And Gujarat itself is providing a helping hand to other Indian states: the Gujarat Energy Research and Management Institute (GERMI) will support the Government of Odisha with its own rooftop solar initiatives.

Box 1

THE PUSH FOR PPPs

PPPs can jump-start solar rooftop projects. Here's how:

- PPPs give government and developers a bankable package/size by clustering together smaller rooftop owners. When government aggregates otherwise disaggregated components, it increases economies of scale.
- PPPs provide a professional implementation partner.
- PPPs make it possible for the local utility to deal with one or two developers rather than many individuals.
- PPPs allow new markets to be better equipped to create innovative policies.
- PPPs can inspire solar rooftop implementation for individuals on self-replication mode once a critical mass of projects is achieved.
- PPPs can be replicated in any market or country. Although technical considerations will be different everywhere, PPPs can work in a variety of appropriate conditions.

“RENT-A-ROOF” BECOMES REALITY

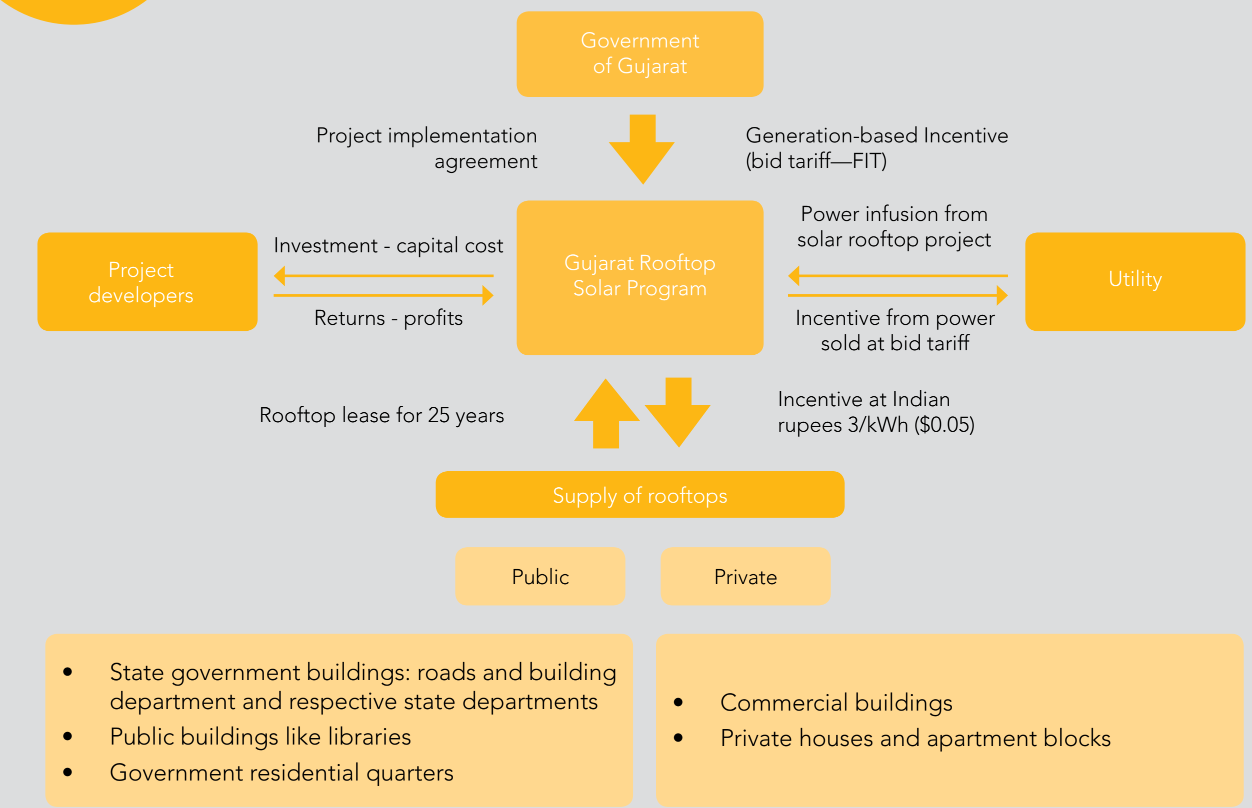
GUJARAT’S ROOFTOP SOLAR PPP SUCCEEDS

Gujarat’s rooftop solar program launched in 2010, when the state government embarked on an ambitious mission to structure and tender a first-of-its-kind grid-connected solar power public-private partnership to minimize the use of scarce and economically valuable land. Although the concept exists in developed markets (in the U.S. and Germany in particular), small-scale grid-connected rooftop solar projects, such as the pilot in Gandhinagar, are path-finding solutions in India, addressing the barriers preventing the solar rooftop market from developing. The project was financially and technically structured to specifically address the risks and challenges that currently constrain the market in India.

The Government of Gujarat launched a tender to select two private-sector developers to build, own, and operate solar PV installations on rooftops in Gandhinagar for an aggregated installed capacity of 2.5 MW each, or 5 MW in total. To mitigate the risk of rooftop availability, the government committed to lease public building rooftops to meet at least 80 percent of total capacity.

A project development and management unit was designated to undertake a detailed technical, commercial, and regulatory assessment for the project, to identify potential public rooftops, design transaction structures, draft tender documents, and bid out the project. The criterion for selection of the preferred bids was the tariffs quoted by developers for sale of power to the local distribution utility. Azure Power and SunEdison each won a 25-year concession for 2.5 MW of installed rooftop solar power in 2012. The projects in Gandhinagar were fully commissioned as of January 2014 and are operational with 4.68 MW of installed capacity. The structure for the Gandhinagar project is depicted in figure 1.

Figure 1: PPP Transaction of Gandhinagar rooftop solar PV pilot project



The solar rooftop business model, as structured in Gujarat, allows seamless collaboration among various stakeholders: policy makers, regulators, individual rooftop owners (lease rentals), solar module suppliers, project developers (returns on investment), and utilities (meeting renewable purchase obligations by procuring solar power). Value is created for all of them.

IFC provided advisory inputs on financial structuring and technical and legal/regulatory aspects of the project to the Gujarat Energy Research and Management Institute (GERMI) and the Gujarat Power Corporation Limited (GPCL), the bid process coordinator and the implementing agency for the project respectively. Aside from GERMI and GPCL, the pilot project had support from the Gujarat Energy Development Agency and the Energy and Petrochemicals Department, Government of Gujarat. Consultations were held with the Gujarat Electricity Regulatory Commission and formal approval was obtained from the commission on the framework and modalities of the program. The various risks, possible impact on the project, and the mitigation measures adopted are given in table 1.

Overall, the Government of Gujarat's initiative illustrates how the implementation of a pilot PPP model can transform a sector. In particular, it has achieved a number of milestones that will be the foundation for the future proliferation of rooftop solar systems in India:

- It brings together government agencies and think tanks to define appropriate technical specifications, interconnection mechanisms, and commercial frameworks to implement rooftop solar PV projects based on gross metering in a local context.
- It provides the opportunity for rooftop owners to participate in the program without bearing the investment costs because the PPP "packaged" the rooftops.
- It puts forward an implementation model that elicited substantial interest from a large cross section of investors.
- It provides a sound basis for a competitive tariff discovery process.
- The public-private partnership approach, when adopted early in the project development lifecycle, can bring policymakers, regulatory bodies, and utilities together to devise feasible frameworks for the future and benefit from a true market price discovery mechanism that is transparent and competitive. It helps establish permit provisions, regulations, and standards based on a consultative process.

Experience gained from varying implementation models also helps calibrate government policies and incentives in sync with preferred implementation model(s) envisaged in the replication phase.

Box 2

In a virgin market, a PPP can be a useful tool to jump-start solar, especially in the face of market constraints, because of these advantages:

- Governments can implement a few pilots, then make/refine a policy to be replicated it on a mass scale.
- Depending on the extant grid tariff and policy/regulatory framework on financial assistance and interconnection (with grid), both gross and net metering models can work.

NEXT STOP: VADODARA

Following up on the success of the Gandhinagar project, the Government of Gujarat is supporting the proliferation of the model to other cities in the state. In this replication program, greater flexibility is being made available for devel-

Table 1: Risks of the Gandhinagar rooftop solar PV pilot project

Risk	Risk Details	Impact on Project	Mitigation
Securing adequate rooftops	For a distributed and grid-connected solar rooftop project, securing an adequate number of suitable roofs (institutional, commercial, and residential) is a challenge. Lack of availability of an adequate number of suitable roofs would significantly reduce the total size of the project and could consequently affect the economies of scale.	Project may not materialize if there are not enough rooftops or would be skewed to include only large-capacity plants.	Assured roof availability for 80 percent of the project capacity for the developer; green incentive mechanism for institutional buildings and residential buildings to monetize an otherwise idle asset (rooftop). Handholding for securing 20 percent rooftops from residential buildings through initiatives like website and physical shop for prospective customers.
Identification of off-taker	Distributed generation rooftop PV projects based on gross metering are economically effective only when they feed power into the local grid. If the local distribution utility is not the off-taker, there could be additional commercial implications.	If the distribution utility is not the off-taker, then tariff to be paid for the power will be higher on account of losses and wheeling charges that may become applicable.	Off-taker identified and all technical, commercial, and legal aspects discussed and agreed on with off-taker; off-taker participated in site visits with potential bidders.
Technology and interconnection	Lack of clear guidelines for interconnection of sub-1 MW generation facilities in the state electricity distribution code or grid code.	Local distribution company may impose restrictive interconnection requirements post project award.	Developed guidelines and interconnection schemes working with the distribution company (also off-taker) and secured regulatory approval before bid process.
Grid availability	Localized grid failure at low tension level may adversely impact project viability.	Risk of (i) escalation of bids (in absence of any data on downtime) or (ii) adverse impact on financial sustainability in case downtime is higher than expected.	Availability details at high tension level mentioned for various geographic areas in the bid document. Deemed generation provisions included in the power-purchase agreement.
Leasing	Lack of established long-term leasing arrangements and precedence for private household rooftops.	Non-development of adequate quantum of private rooftops which was a key element for future replicability.	Allowed flexibility in leasing arrangements—flexible power-purchase agreement/lease arrangements, room for exit by developers, the state government facilitated solicitation of private rooftops.

Table 1: Risks of the Gandhinagar rooftop solar PV pilot project cont.

Risk	Risk details	Impact on project	Mitigation
Regulatory	Lack of approval of the process and documents by the regulator.	Process may not be considered valid.	Key approvals from regulator secured before bid process (power-purchase agreement, project implementation agreement, and project-lease agreement).
Tariff and incentive	Eventuality of bid tariff turning out to be substantially higher than the FIT proposed by the state electricity regulatory commission.	The reasonableness of the tariff could be an issue in case of very high tariff bids resulting in incentives exceeding subsidies provided by the state.	Project competitively structured and marketed to enable competitive market discovery of tariffs.
Project structure	Two projects of 2.5 MW each. May lead to the risk of two different tariffs being proposed for similar projects.	Questions on rationale for accepting two different tariffs for similar projects.	Approval formally obtained from the state government and regulator before the bid process was initiated.
Commission of the project in one go versus phased approach	Delay in procurement, construction, and commissioning of the project by the developer in prices of modules and inverters. Delay in interconnection of the built capacity would lead to revenue losses for the developer.	Overall delay in project commissioning.	Provisions for phased commissioning made in bid documents.
Long-term generation from the project	Use of poor quality panels, inverters, and balance of plant by the developer.	Overall delay in project commissioning.	Incentive to maximize generation (FIT); range of capacity utilization factors mentioned in the bid document. Penalty for non-achievement of minimum capacity utilization factor, shifting of rooftop solar PV system provisions.
Payment security risk	Risk of non-payment of tariff by the utility to the developer.	Adversely impacts the viability and thereby sustainability of the project.	Provision of letter of credit was given. In case of termination due to the payment default, developer is to get termination benefits. The utility has the regulatory requirement to continue procuring solar power to meet its solar purchase obligations.

opers and rooftop owners to transfer ownership of plants to rooftop owners, therefore moving toward the model used in developed markets. Government officials sought IFC's assistance in structuring a 5 MW rooftop solar project in the city of Vadodara. Here, the developer is responsible for identifying all the rooftops, the large majority of which are privately owned, and included homes, commercial buildings, and industrial facilities.

IFC recommended a 25-year concession on a build, own, operate (BOO) model. Under the agreement, the selected developer would install solar panels on hundreds of rooftops throughout the city of Vadodara, to be identified and accessed by the developer, with an aggregate capacity of 5 MW. As per the terms of the concession, the rooftop owners would receive rental income from the developer to lease their previously unused rooftop space. The developers would connect these individual systems to the local grid and sell the power generated to the local distribution utility at a pre-determined electricity tariff (gross metering model) determined through competitive bid process. Total project cost is estimated at $8 million, all of which would be financed by the winning bidder.

The contract was awarded to WAA Solar Private Limited. The 25-year Power Purchase Agreement (PPA) for the project was signed on June 19, 2014 between the distribution utility, Madhya Gujarat Vij Company Limited, and Madhav Solar (Vadodara Rooftop) Private Limited, an SPV set up by the winning bidder.

TRANSACTION CHALLENGES IN VADODARA

The Vadodara project attracted $8 million in private investment and is expected to result in 9,000 people receiving increased access to power and a reduction of 6,000 tons of GHG emissions annually. During the implementation of the Vadodara project, the project team faced several challenges, both technical and institutional in nature. The Vadodara project was more challenging than the Gandhinagar PPP for the following reasons:

ACCESS TO PRE-IDENTIFIED ROOFTOPS

A large majority of the rooftops in the Vadodara were "uncommitted"—unlike Gandhinagar, where the government committed to earmark government-owned rooftops with a rooftop solar PV installed capacity of 4 MW or 80 percent of the total project capacity. Rooftop availability and acquisition is the most critical risk in implementing a rooftop solar PV project. Given that a majority of the rooftops in the project were to be identified and leased by the developer, IFC provided several options to mitigate this risk.

- IFC was able to source satellite images of rooftops across the city from a state-owned agency. This data was made available to potential investors to assess the availability of suitable rooftop space across the city and help them identify the most attractive sites prior to the bid process.
- In order to provide more flexibility to investors, IFC recommended that rooftops outside city municipal limits also be included within the project scope to allow developers to choose from a larger set of potential rooftops and thus mitigate the risk of not securing suitable and adequate rooftop space within the city limits.
- There was also a considerable push from the client to specify that a large percentage of the rooftop space identified by the developer should be on residential rooftops. Given the difficult nature of entering into a long-term rooftop lease agreement with private individuals, this would have resulted in practical difficulties of implementing a 25-year project. IFC was able to convince the client of the increased implementation risk this requirement would impose on the project and recommended changing this minimum requirement of residential rooftops to an acceptable level of 10 percent of overall project capacity. This allowed private operators greater flexibility in choosing rooftops across other consumer categories such as universities, schools, commercial complexes, offices, and industries.
- The team also allowed the developer flexibility in the minimum required installed capacity by incorporating a buffer of +/- 20% on the nominal required capacity of 5 MW. The developer was free to install anything between a minimum of 4 and a maximum of 6 MW.
- To address the difficulty of entering into long-term rooftop lease agreements with private entities, an option was provided to the rooftop owner to buy out the operator's interest in the installation at a price to be determined on a negotiated basis.

POWER OFF-TAKER RISK

The power off-taker in Gandhinagar was a private distribution utility that had a reputation for excellent grid availability. Further, a "deemed generation" guarantee was included in the project agreements. This guaranteed minimum annual grid availability by the private utility for the life of the project, failing which penalties would have to be paid to the solar developer.

However, the distribution utility for the Vadodara project is a state-owned company that did not agree to provide any grid availability guarantee. IFC convinced the utility to share information regarding the uptime of the distribution grid. This was provided to developers to help them estimate loss in energy sale due to grid failure, and factor this risk into their bids.

COMMUNICATION CAMPAIGN

Given the large majority of privately owned rooftops in the project, rooftop availability was a key risk. GPCL, the client, had provided assurance in facilitating access to private rooftops through a project website, and it also conducted public outreach programs to ensure buy-in and participation of rooftop owners in the project. This was critical to ensure private sector participation in the project.

To partially mitigate this risk, IFC provided the agency with support in raising awareness of the program, building capacity among various stakeholders (government bodies, developers, rooftop owners, communities), and reaching out to rooftop owners who could participate. This dissemination exercise was conducted through several media platforms with the help of a communication consultant. The team helped the client in the design of a website where relevant project-related information, requisite documentation (such as application forms) and contact information was uploaded for public consumption. The team also provided assistance in the form of press releases in local newspapers to generate public interest in the project.

CLIENT COMMITMENT RISK

The implementation of a rooftop solar PV project requires addressing the concerns and objectives of several stakeholders, such as the power off-taker (distribution utility), potential investors, state government, regulator, and rooftop owners. Sometimes, it requires that the team go beyond the terms of its engagement in providing comfort to the client by addressing issues unrelated to the project.

For example, during implementation of the Vadodara project, the client stated that this project would be implemented only when the Gandhinagar rooftop solar PV project, on which IFC had earlier advised GPCL, showed significant progress. IFC went beyond its stated role and worked with the selected developers and relevant government agencies in ensuring rapid implementation of the pilot project in Gandhinagar.

Upon selection of the winning bidder, the team also had to liaise extensively with the off-taker to address its concerns on certain regulatory aspects of the project that were not raised previously. The team was able to convince them to comply with regulatory aspects of the bid process and eventually ensured signing of the Power Purchase Agreement.

It would be prudent for other teams working on similar projects in other regions to be aware of these challenges and prepare for them adequately during project implementation.

ALTERNATE MODELS

The recent boom in solar PV installation in India, combined with the state distribution utilities' increasing obligations to purchase expensive solar power, has resulted in certain state utilities lodging formal protests with their respective state regulators. Given the highly subsidized retail electricity tariffs in India, state utilities cite increasing losses as a reason to limit their purchase of solar power.

Further, grid availability in Indian cities and towns outside of large metropolitan areas is mostly poor. Grid availability during the afternoons, when solar power generation peaks, is critical to the viability of any rooftop solar PV. However, large losses faced by several state utilities result in low investment in their distribution infrastructure—leading to frequent power outages. Hence, scaling of the rooftop solar PV model on a gross metering model may achieve limited success in cities and towns where the distribution infrastructure is poor or non-existent.

Hence, net metering is a concept which is now being actively explored by several stakeholders, including regulators, central and state governments, developers, and development finance institutions. Under this model, the energy produced by a rooftop solar installation is consumed within the premises of the rooftop owner (i.e., consumer). Any surplus power generated is sold to the distribution grid and is credited toward the consumer's consumption from the grid.

Technically, inverter electronics and functionality are also improving. Inverters, which can function both in grid-tie mode (when grid is available) and in the off-grid mode (or intended island mode when the grid is unavailable but another source can be used), are now commercially available. These can be combined with local storage systems, whose prices are scaling down rapidly. These systems can also be made to function under the net metering regime.

The ultimate aim of rooftop solar PV-based market development is to reach a stage where projects replicate organically without depending on a limited set of large investors. A replication stage will see a wide variety of consumers coming forward and developing their own rooftop projects. Eventually, rooftop solar has the potential to involve each household as stakeholders in creating a secure and sustainable energy source. Net metering seems like the most likely model for replication of the rooftop solar concept. However, issues and concerns of all stakeholders need to be addressed satisfactorily. On the government and regulatory side, policy and regulatory frameworks, including incentives, need to be clear and stable to attract investors as well as consumers who wish to "rent" their roof.

Strengthening the electricity distribution infrastructure and clarifying permit norms are two essential steps toward maximizing utilization of rooftop solar systems. This can be facilitated through utilities with suitable regulatory support. On the market side, selecting well-analyzed and sustainable business models with greater access to financing from financial institutions like commercial banks and non-banking financial institutions will help increase participation of private sector suppliers and developers.

STRUCTURED APPROACHES TO PPP PROJECT DEVELOPMENT

IDENTIFY AND SECURE ELIGIBLE ROOFTOPS

Identifying suitable rooftops in an emerging market where urbanization is chaotic can prove challenging. It must take into account factors such as shade from trees, adjoining buildings, and water tanks, in addition to the varying sizes, heights, rooftop use and ownership (residential, commercial, or public buildings) patterns. For large-scale distributed rooftop solar projects covering hundreds of roofs, various technical and location-specific issues have to be resolved before shortlisting rooftops.

The identification of rooftops can be undertaken through a combination of site visits and secondary sources such as satellite imagery. Table 2 highlights the broad approach that was adopted for the Gandhinagar project, which can be adopted in other cities.

The rooftop area required to install solar systems typically varies from 10 to 18 square meters per kilowatt, depending on the shadow-free area available. The architecture of the building is also a key factor due to elements such as parapets or varying roof levels, at times making large parts of the rooftops unusable for solar installations. Most information such as building plans and existing rooftop installations is not available from urban bodies and town planning departments. This can make mapping and identification of appropriate rooftops very challenging. Individual rooftop assessment studies involving physical visits to each potential site is cost intensive and time consuming. However, this has to be undertaken, given that data from secondary sources is inaccurate and cannot be relied on.

Table 2: Possible approaches to overall eligibility assessment

Key tasks	Activity description and outputs
Identification of potential rooftops through various secondary sources: satellite data systems, online tools (Google maps), global information systems (from utilities).	Desk analysis. Activity to be conducted during pre-feasibility phase.
Identification of potential rooftops through consultations with various stakeholders as well as using citywide master plans, area-specific plans and maps from urban local bodies, town planning departments, residential and commercial layouts. Preparation of the first broad list of potential buildings.	Needs to be conducted partly by visiting the administrative location of the project-specific geographic area. Activity to be conducted during pre-feasibility and feasibility phase.
Preparation of questionnaire for data collection.	Technical content for analysis of parameters such as utility consumer numbers, utility interface, connected loads, and consumption patterns. Non-technical content for analysis of consumer interest and collecting feedback on commercial expectations, current uses of rooftops, possible alternate uses, future construction plans, and possible developments in neighborhoods.
Detailed physical survey of potential buildings and assessment of consumer interest.	Activity to be undertaken at the geographic area by physically visiting each potential building/rooftop after securing buy-in from stakeholders: government departments, utility, and residential associations. For each site building data should include building address, utility consumer numbers, ownership, building height, and vintage. Roof data/measurements should include type of roof, roof orientation, existing roof installations (tanks and telecom towers), measurement of total rooftop/terrace area using portable instruments (tape, hand-held lasers, ultrasonic instruments, global information system instruments), rooftop plans, and derivation of shadow-free areas. Other data should include utility consumer numbers, interconnection voltages, approximate connected loads, locations of utility meter, lists of possible interconnection points (with the utility) and approximate distances from the roofs (roof to utility meter, utility meter to interconnection point or points). Data should also list requirements regarding digging through roads.
Verification of positive consumer interest, cross verification of details with the utility/ other concerned departments, and preparation of final shortlist of buildings.	Activity can be undertaken at the geographic area or outside, depending on cross verification by utility. Short-listed buildings: address and assessed rooftop plant installed capacity. Interconnection voltage and distances. Additional information like roof drawings, single line diagrams could be included if available.

Detailed technical surveys are necessary as initial steps in the project preparation. However, in the long term, urban bodies and town planning departments can take rooftop solar installation across all ownership patterns. To do that, the following steps are necessary:

- Optimize rooftop area by concentrating structures on a particular side of the rooftop, and standardize profile elements like parapets and levels across rooftops.
- Establish clear long-term provisions for building heights and types of buildings (residential, commercial, or public) to be developed in a particular zone. This ensures shade-free rooftops over the life of the projects.
- Develop online databases of information related to buildings, including location, ownership types, zoning plans, rooftop areas, and building plans.

DEVELOP ROBUST TECHNICAL STANDARDS AND SPECIFICATIONS FOR ROOFTOP PV SYSTEMS

Defining proper technical standards for rooftop projects is important to ensure safe and reliable operations over the lives of plants. These standards have two broad functions: address the ground situation and adapt to local grid conditions, and at the same time conform to international standards and specifications.

Technical standards defined for system design may vary from one location to the other based on the quality of power supply and annual uptime based on the operational efficiency of utilities. Given geographical variations, a proper technical assessment undertaken before a project is actually implemented will go a long way toward understanding specific technical issues likely to impact rooftop installations. Appropriate strategies can then be developed to mitigate technical challenges.

Technical standards and specifications for various components will also ensure their safe integration with the grid. For example, safety specifications regarding operations of inverters during grid interaction need to be customized to local conditions. Inverters are the primary grid interconnecting components, and have to be robust enough to operate under grid conditions at the tail-end of distribution networks. Here, flickers and wide variations in voltages, frequency, and harmonics are common.[1]

In emerging markets, a much wider operating range for inverters is required than normally applicable for European solar applications. Therefore, it is important that local grid quality data be analyzed thoroughly on parameters such as availability, voltage and frequency, and duration of power outages, as well as adequacy of safety equipment based on detailed analysis of grid quality. This will help arrive at appropriate technical standards for inverters and safety equipment.

Various standards, established by the International Electro-technical Commission, Institute of Electrical and Electronics Engineers, Bureau of Indian Stan-

[1] The Central Electricity Authority (CEA) is the designated agency in India under the Jawaharlal Nehru National Solar Mission to outline applicable standards for various solar systems. A task force chaired by CEA was constituted by the Ministry of New and Renewable Energy to devise guidelines for solar rooftop systems to interconnect with the grid. Its brief is to lay out the scheme to be followed, specifications, metering, and safety aspects, along with recommendations on standards to be adopted.

dards, or the American Society for Testing and Materials and Underwriters Laboratories, for instance, specify norms for panels, balance of system, cables, and interconnections. If the right normalization is in place, then investors and developers must comply with those standards, thus ensuring a certain degree of reliability and safety of operation. In addition, it will ensure that panels are exploited for their useful life, which makes the project more profitable for investors. As an example, the technical standards, specifications, and interconnection schemes used for the rooftop solar project in Gujarat are outlined in Appendix 1.

ENSURE STRUCTURAL SOUNDNESS OF ROOFTOPS

An important consideration in determining viability of rooftops is structural soundness. The roof should support the weight of the system, including racks and supports (referred to as "dead load"). In addition, the roof should withstand the added load resulting from wind blowing under the modules.

The support system of the PV array should be designed and certified by professional structural engineers to ensure that racks, anchors, and structures are appropriate for the rated wind loads and safety factors, and also pass appropriate pull tests. This requires drilling an anchor into the deck and applying tensile force to the rated load capacity.

Structural requirements will depend on the age of the building and building standards of the area. The module mounting structure should be designed to last a minimum of 25 years without much maintenance and replacement. At the same time, structures with significant water leaks on slabs or rooftops should be avoided; construction should not introduce water leaks into the structure.

Here is a list of key structural aspects to be considered for Gandhinagar:

- Occupy minimum space for the given output. Allow easy replacement/maintenance of modules.
- Withstand wind speeds of up to 200 kmph and comply with relevant Indian wind load codes.
- Roof should withstand the total weight of the module and module mounting structure (30 kg per square meter).
- Array structure must be grounded with a maintenance free earthing kit.
- Position of solar module should be a minimum of 500 millimeters above the terrace level with proper drainage.
- Any puncturing/drilling of RCC roof must be avoided.

ADDRESS GRID INTEGRATION CHALLENGES

Grid interconnection norms and grid codes lay down detailed standards and specifications for components like unidirectional inverters, power control units, cables, lightening arrestors, energy meters, and data loggers. Rooftop projects are spread across several distributed rooftops with system sizes varying from 1 kilowatt to 1 MW. These are connected at the supply point of 230 volts single-phase or 415 volts 3-phase or 11 kilovolts 3-phase or higher.

A key challenge is the distributed nature of the system, which comprises a large number of dispersed and small capacity rooftop systems, each connecting to the grid. The main issues are as follows:

GRID INTERCONNECTION AND INTERACTION

Points of interconnections should be defined on a case-by-case basis, or based on some uniform principle. For example, in a gross metering system, this should be at the existing common coupling or the point at which the service line is drawn from the grid. Distribution codes do not directly specify interconnection points with respect to system capacity (kilowatt to MW scale). For each rooftop system, the utility gets involved in specifying the interconnection point. Pre-commissioning testing and periodic testing of rooftop systems (especially grid-tie aspects of the inverter) by developers as well as by independent third parties is recommended for safe parallel operation.

PHASE IMBALANCE WHILE CONNECTING LOW CAPACITY

A large number of residential connections in India are single phase. The rooftop systems on these buildings would also be small capacity single-phase systems. As these connect to one of the phases of low-voltage networks, phase imbalances (due to varied power getting injected into different phases of the grid) need to be analyzed. This can be resolved simply by injecting power equitably to different phases in the same grid.

For example, if there are 60 plants of up to 5 kilowatt each, these should channel power to the grid in three clusters of 20 plants to each of the three phases, minimizing imbalances. Every country has limits on imbalances. The grid operator decides the permissible imbalance ratio.

GRID ABILITY TO EVACUATE POWER FROM DISPERSED SMALL-CAPACITY ROOFTOP SOLAR PV SYSTEMS ON ALL DAYS

A specific issue arising due to the increase in rooftop installations is the flow of current from low voltage to the 11 kilovolt side of the transformer. Normally, all transformers enable power flow in both directions; a step-up transformer can also be used as a step-down transformer and vice-versa. Despite that, transformers are manufactured with either step-up or step-down as its primary function, and the process is distinct for both. As a result, the efficiency of a transformer is likely to be affected when power flows in the reverse direction. The incidence of current flows from low-voltage to kilovolt is likely to be high at some rooftop clusters—for example, a group of institutional buildings, with common holidays, connected to a transformer that does not have residential loads drawing power on holidays.

GRID AVAILABILITY

Uptime of the grid and variation of voltage or frequency in the grid will crucially impact power evacuation. Non-availability of the grid will result in loss of electricity generated. This is especially important in India, where grid availability at the low tension levels is generally not monitored on a real-time basis.

The commercial implications need to be ascertained and inclusion of clauses like "deemed generation" in case of unavailability of the grid beyond a certain threshold may have to be incorporated.

These grid integration issues may vary from region to region depending on grid infrastructure and availability. Standards and specifications for interconnection should be designed after analyzing all local issues. Rooftop project developers can be mandated to undertake the following steps from the perspective of grid interconnection at project construction and commissioning stages:

- Test running of grid-connected rooftop systems, including load trials at site, prior to handing over and commencing energy export for metering.
- Interconnection points to be checked and certified by the utility as well as other concerned authorities (like electrical inspectorates) for accuracy and safety.
- Meter installation and testing to be the responsibility of the utility, and project developers be required to submit drawings of grid interfaces for each individual rooftop and get these approved before on-site work commences.
- Commissioning certificate from relevant authorities.
- Project developers to place danger plates and warning signs at all relevant places and educate occupants on safety.

INCENTIVIZE FINANCING

Financing is a major factor restricting development of the rooftop solar sector. The problem is twofold: the financial viability of the system is uncertain, and/or financing options are not available.

The first issue can be tackled through financial incentives targeted at the various segments of stakeholders, established to kick-start development of the sector, with a phasing out over time. These incentives need to be backed by appropriate policy and regulatory mechanisms to provide mid- to long-term certainty to developers, lenders, and third-party service providers.

The second problem, which is now prevalent in emerging markets, can be handled by establishing innovative financing products, and attracting the commercial lending sector by implementing pilot projects with large third-party developers. The penetration of solar rooftop projects can be expedited by establishing an enabling financial environment that addresses the requirements of financiers, developers, third-party service providers, and consumers.

REGULATE, REGULATE, REGULATE

Regulation is also a critical element of sustainability. Regulators can encourage proliferation of renewable energy sources with several non-financial incentives, which will socialize specific costs of rooftop solar projects on the distribution grid. These could be in the form of mandatory purchase by utilities and waiver of wheeling and banking charges. In India, the Electricity Act of 2003 requires state regulators to specify a percentage of power to be procured by utilities from renewable energy sources.

Following the launch of the Jawaharlal Nehru National Solar Mission (see Appendix 3), central and state regulators have carved out a sub-category for solar energy with a target of 3 percent by 2020. This includes the solar renewable purchase obligation (Solar RPO). Given that rooftop solar generation is generally more expensive than generation from ground-mounted solar projects, even with the provision of solar RPO, utilities may prefer ground-mounted projects. Distribution utilities will therefore follow permit regulations and connect solar systems to the grid, but will not exercise discretion outside parameters specified by regulations.

PARAMETER TYPE CAPACITY TARGET INCENTIVES FOR ROOFTOP OWNER METERING

Andhra Pradesh, Tamil Nadu, Karnataka, and Uttarakhand have also drafted state-specific regulations and guidelines including enabling provisions that encourage the private sector to become further involved. Recently, the Forum of Regulators proposed a draft model regulation on net metering. It provides for a consumer or a third-party player to develop a rooftop solar project and sell the power generated to the rooftop owner without open access or wheeling charges.

With this, a conducive policy and regulatory framework is emerging and attracting more private players to the market. Many private developers, recognizing the opportunity to diversify into a profitable business, have increased their participation in rooftop solar projects. The Solar Energy Corporation of India has invited bids in three phases to develop rooftop solar projects across the country under gross metering or captive schemes. This is attracting new private sector players.

Other regulations for the development of rooftop solar projects in India have also launched recently, triggered by central and state government policies identifying specific targets for solar rooftop projects and provisioning incentives. These considerations are applicable to most developing countries.

TARIFF METHODOLOGY

Determining a separate tariff specific to small-scale rooftop projects remains the main consideration for regulators to address in gross metering-based projects that supply power directly to the grid. Many Indian states did not have separate tariffs for kilowatt-scale rooftop solar projects but have realized the need for tariffs that are different from large ground-mounted projects.

In the case of net metering-based projects, rooftop systems supply power primarily to the owner of the premises. Excess generation fed into the grid is credited to the consumer's account, to be adjusted against consumption from the grid over a defined settlement period (usually a full year to account for seasonality in irradiance and generation). Most state electricity regulators in India have capped generation over a settlement period to the rooftop owner's actual consumption or a percentage of it. This means that generation in excess of the rooftop owner's requirements is treated as free power for the utility.

For example, in Tamil Nadu, residential rooftop users are capped at injecting no more than 90 percent of their yearly power consumption in solar electricity into the grid, with excess energy treated as "lapsed." Similarly, in Andhra Pradesh, if there is a net export in a billing month, no payment is made.

For PPP projects, clarity on tariff frameworks is an essential first step for investors to evaluate project feasibility. The Gujarat project was conceived on a gross metering basis. It prompted the regulator to address the specificities of rooftop solar projects by designing a separate tariff for kilowatt-scale rooftop projects.

GRID CONNECTIVITY

Interconnection requirements and guidelines can be classified into three main categories:

- Voltage levels for interconnection/evacuation,
- Standards for interconnecting equipment such as inverters, and
- Economic criteria to permit interconnection by utilities.

Until recently, no specific interconnection guidelines had been issued by either central or state regulators for rooftop solar systems connecting to low voltage or 11 kilovolt. Draft tariff guidelines issued by the Central Electricity Regulatory Commission for rooftop systems and the report of subgroup-I on grid-interactive rooftop solar systems have largely guided interconnection until now. Detailed guidelines, standards, and processes are still to be framed for interconnecting equipment, voltage levels, and phase connection requirements for varying capacities of rooftop systems. The Gujarat Electricity Regulatory Commission, through its solar tariff order of 2012, provided clarity for the level of connection for kW-scale rooftop projects, as shown in table 5.

Availability and uptime of grid at LT (low tension or low voltage) and HT (high tension or high voltage) levels have to be analyzed on a project-by-project basis to build in necessary safeguards. Frequent grid outages beyond a level can lead to significant revenue losses to project developers and hence should be addressed in the regulatory framework with utilities faced with scarce financial and technical resources, there has to be sound economic rationale to permit interconnections.

A utility should consider if interconnections are duly compensated (economic returns should be more than or equal to the average economic and financial internal rate of return of utilities across the country). Utilities should also consider if the interconnection does not damage any other economic resource like public buildings and infrastructure, is technically viable, and utilizes capacity well, going forward.

In the Gandhinagar pilot project, several of these aspects were formulated as project specifications in the request for proposal document in the absence of regulations. Most countries have detailed regulations and standards to guide interconnectivity of large-capacity (mostly above 1 MW) systems with the grid.

However, initiatives must be taken to address distribution and regulation issues of grid connectivity, specifically for rooftop solar projects. This will also bring clarity on interconnection infrastructure cost-sharing between utilities and project developers.

Table 3: Level of connection of rooftop systems

Rooftop system capacity	Evacuation specification
1kW–6kW	230V, 1 ö, 50HZ
6kW–100kW	415 V, 3 ö, 50Hz
100kW–1MW	11kV, 3 ö, 50Hz

Source: Gujarat Electricity Regulatory Commission, Order No 1 of 2012

METERING ARRANGEMENTS

Globally, rooftop systems use two broad types of metering arrangements: gross and net metering. The type of metering arrangement depends on requirements and incentive structures. Net metering systems can have different configurations of meters with the main meter capable of reading both export and import of power from the grid (net meter). It could also have a meter to measure electricity generated by the rooftop system (solar meter) and a meter to measure the consumer's total consumption.

In India, for instance, the Electricity Act mandates that the Central Electricity Authority (CEA) specify metering standards. Accordingly, the Authority has issued CEA Regulations (Installation and Operation of Meters) to guide metering arrangements for rooftop solar systems. While this specifies type, class, and accuracy of meters to be deployed, it is silent about the numbers and configuration of meters for net metering systems in particular. This is left for state regulators to specify, or through specific project contracts.

MODEL POWER-PURCHASE AGREEMENT

A commercial agreement between solar producer and distribution utility is critical, as continued operation of a grid-connected solar system depends on fulfillment of certain obligations by each party. A model power-purchase agreement is required for gross meter-based systems to define the responsibilities of each party during development, commissioning, and operation phases of the project, with clear sharing of risks and course of action in event of default.

In the Gujarat solar rooftop project, the Gujarat Electricity Regulatory Commission approved the power-purchase agreement, which formed a sound basis when moving into the replication phase. In case of net meter-based systems, a connection agreement between the utility and the consumer is the norm and is often prescribed as a model agreement by the regulator. A model agreement, developed after considering the needs of a particular market that has been validated by a few pilot PPP transactions, can greatly help in faster replication.

CONCLUSIONS

As the experiences in Gujarat demonstrate, PPPs can be an effective means of market transformation in rooftop solar PV, particularly in emerging markets where developers and intermediaries are not fully active across the value chain of rooftop solar development. Effectively designed PPP projects—those that are bankable and sustainable, with adequate preparatory activities and technical due diligence, provision of scale, and equitable risk-sharing arrangements—can generate developer interest in the segment. PPPs can also help design and streamline policy, regulations, and technical standards that can make investments feasible and sustainable.

In India and around the world, PPPs can play the following roles in policy initiatives and institutional processes:

CLARIFY INSTITUTIONAL ROLES AND RESPONSIBILITIES

Given the state of the market and the limited experience in executing rooftop solar projects, appropriate policy actions can catalyze the market and move it to a mature replication phase. One area of focus is project facilitation. Projects should be promoted by clearly specifying roles and responsibilities of various stakeholders. This will facilitate monitoring and evaluation, and help make the segment efficient, competitive, and sustainable over the long term.

PROVIDE FOR CLEAR AND PREDICTABLE FISCAL SUPPORT

Three major solar rooftop markets (Germany, Japan, and the U.S.) have developed because of fiscal support from the government. This support is varied and includes regulatory incentives through preferential tariffs, subsidies for research and development, investment subsidies, and loans. Among the three countries, Germany has spent the most public money to develop the rooftop market. In Germany, public spending has helped the market grow substantially.

Emerging markets need to plan financial commitments well in advance. Fiscal incentives go hand in hand with the choice of an implementation model. Incentive structures will vary depending on the model adopted. While Germany continues to have a feed-in tariff mechanism to incentivize the solar rooftop market, it introduced a new subsidy scheme in 2012 in which the feed-in tariff for small rooftop systems up to 10 kilowatt was higher (approximately €0.20 per kilowatt hour) than the feed-in tariff for those up to 40 kilowatt (approximately €0.19 per kilowatt hour).

PPP transactions help determining the price and the level of incentives that the private sector is considering. The outcome of such transactions should help policymakers and regulators frame the fiscal incentives. Policy, legal, and market conditions are generally responsible for determining which incentives are good for which economy. In the U.S., for example, the legal framework has largely influenced incentive structures in solar. The country followed the Public Utility Regulatory Policies (PURPA) Act to initially implement net metering mechanisms. Subsequently, the Energy Policy Act 2005 created an environment to provide tax incentives to private owners of distributed renewable resources. Japan's movement from a system of capital subsidies to a feed-in tariff mechanism reflects the Japanese government's desire to rapidly expand the renewable energy sector, especially in light of current uncertainty over the future of nuclear power in the country.

Emerging economies need to formulate an incentive structure that takes market conditions into account, is consistent with the legal framework, and addresses the desired maturity that must be achieved. Moreover, economies that are moving from demonstration or early development stage to a replication stage, will have to adapt to market conditions and be open to making changes in incentives and/or legal and regulatory structures.

ENCOURAGE PARTICIPATION FROM ROOFTOP OWNERS

A critical issue for third-party developers is siting and access rights to public and private rooftops. Developers must negotiate and enter into separate lease agreements with public and private building owners. The role of building owners is restricted to leasing out rooftops; the owners may or may not take part in development or operations of the projects.

Rooftop rents are therefore prime drivers for successful rooftop projects over their 25-year life. Policies should provide for sustainable rentals in the overall revenue structure to promote rooftop projects. This can be in the form of fixed or variable incentives linked to electricity generated so that rooftop owners ensure maximum generation from the panels through regular cleaning and avoiding unnecessary shadows.

ESTABLISH A CONDUCIVE REGULATORY REGIME

Establishing appropriate regulatory frameworks is critical and is often greatly facilitated by pilot PPP projects, which benefit from the active participation of informed large investors. Regulations could cover feed-in-tariffs (for gross metered systems), non-financial incentives such as mandatory purchase obligations, appropriate standards for metering and energy accounting, grid connectivity guidelines, and model commercial agreements for exchange of power with the distribution grid.

The right regulatory regime is critical to the sustainability of the PPP, and sustainability is a primary goal. The success of PPP projects can open the door for replication with innovative business models and increased participation of third parties and intermediaries. Lessons gained from the Gadhinagar rooftop program, as well as Vadodara's, have universal application across most emerging markets.

APPENDIX 1: KEY TECHNICAL STANDARDS

Standards referring to solar cells and modules	
EN 50380	Datasheet and nameplate information of photovoltaic module.

Measurements—Reference Cells PV	
IEC 61215	Crystalline silicon terrestrial photovoltaic (PV) modules—Design qualification and type approval
IEC 61646	Thin-film terrestrial photovoltaic (PV) modules—Design qualification and type approval
IEC 61730-1	Photovoltaic (PV) module safety qualification—Part 1: Requirements for construction—for personnel safety
IEC 61730-2	Photovoltaic (PV) module safety qualification—Part 2: Requirements for testing—for personnel safety

Standards for photovoltaic systems	
IEC 60364-7-712	Electrical installations of buildings—Part 7-712: Requirements for special installations or locations—Solar photovoltaic (PV) power supply systems
IEC 61727	Photovoltaic (PV) systems—Characteristics of the utility interface
IEC 61683	Photovoltaic systems—Power conditioners—Procedure for measuring efficiency
IEEE 928	Recommended criteria for terrestrial PV power
IEEE 929	Recommended practice for utility interface of residential and intermediate PV systems

Standards for other parts/components of photovoltaic systems	
IEC 60947	Connectors for photovoltaic systems—Safety
EN 50521	Connectors for photovoltaic systems—Safety
IEC 60189-1	Low frequency cables and wires with PVC insulation and PVC[3] sheath—General test and measuring methods
IEC 60189-2	Low frequency cables and wires with PVC insulation and PVC sheath—Cables in pairs, triples, quads and quintuples for inside installations
IEC 60068-2	Environmental testing of specimen to withstand specific severities of repetitive and non-repetitive nature
IEC 61683	Photovoltaic systems—Power conditioners—Procedure for measuring efficiency
IEC 62208	General requirements for empty enclosures for low voltage switchgear and control gear assemblies
IEC 69947	Standard test and measuring methods for PVC insulated cables for working voltages up to and including 1,100V, UV resistant for outdoor applications
IEEE 519-1992	Recommended practices and requirements for harmonic control in electric power systems

[3] 28Poly (vinyl chloride)

SPECIFICATIONS OF INVERTER/POWER CONDITIONING UNIT

Detailed specifications	
Output voltage	230V / 415V +10 percent/-15 percent VAC (/ +15 percent/ -10 percent)
Output frequency	50 Hz +1.5Hz / -3.5Hz (/ +/- 0.5 percent) (/+/-5 percent)
Power factor	0.95 inductive to 0.95 capacitive
Waveform	Sine Wave
Harmonics	AC side total harmonic current distortion < 5 percent AC side single frequency current distortion < 3 percent
Ripple	DC voltage ripple content shall be not more than 3 percent
Efficiency	Efficiency of PCU shall minimum 90 percent at 20 percent load
Losses	Maximum losses in sleep mode: 2W per 5kW Maximum losses in stand-by mode: 10W
Casing protection levels	Degree of protection: Minimum IP-20 for internal units and IP 65 for outdoor units Should withstand temperatures from -10 to +60 degrees Celsius Should withstand humidity up to 95 percent Completely automatic including wake up, synchronization (phase-locking) and shut down
MPPT	MPPT range must be suitable to individual array voltages in power packs
Internal wiring	Copper wires shall be insulated with flame resistant material
Protections	Over voltage; both input & output Over current; both input & output Over/Under grid frequency Over temperature Short circuit Lightening Surge voltage induced at output due to external source Islanding Manual intervention must be possible through an accessible emergency switch-off button

INTERCONNECTION SCHEMES: GANDHINAGAR ROOFTOP SOLAR PV PILOT PROJECT

All work must be carried out as per the following:

- Indian Electricity Act and rules therein
- Indian Electricity Grid Code
- Regulations of Chief Electrical Inspector

The successful bidder must place danger plates and warning signs at all relevant places as the plants would be on the roofs of occupied buildings of offices or residences.

Following are the major components of the proposed interconnection arrangements. Detailed specifications are given on following pages for each of these components. Bidder should note that these are minimum requirements and bidder must provide more than these laid out requirements so as to achieve maximum energy output from various power packs.

- Unidirectional inverter/power conditioning unit
- Cables
- Earthing kits
- Lightening arrestors
- Energy meter
- Data logger

The bidder must follow at the least all the minimum specifications and requirements as stated in the JNNSM document, in addition to the ones mentioned in this bid document.

POWER CONDITIONING UNIT/INVERTER

- Power Conditioning Unit (PCU) shall include a facility to convert the DC energy produced by solar array to AC voltage, through DC bus, using its Maximum Power Point Tracking (MPPT) control to extract maximum energy from solar array and produce AC power at 415V AC, 3 phase, 50 Hz.
- MPPT controller, Insulated Gate Bipolar Transistor (IGBT) based inverter and associated control and protection devices shall be integrated into PCU. DC bus can be either integrated or can be provided separately.
- The continuous power rating of this individual uni-directional inverter shall be equivalent to minimum 80 percent of peak power rating of each power pack array.
- Each individual inverter will have all necessary protections against disturbances in frequency, voltage, and current of the grid due to internal or external faults, abnormal temperatures, and islanding. Its prime function will be to protect itself and solar array from any factors as well as avoid unintentional islanding.
- Once the PCU has been shut off as a protective measure it must automatically re-connect once the normal conditions are restored for minimum of two minutes.
- There will be three modes of functioning, namely, sleep, stand-by and operational mode. It will have optimum efficiencies for each mode as given in the specification sheets.

Indications through LED/LCD display	Inverter ON Grid ON Inverter Under/Over Voltage Inverter Overload Inverter Over Temperature
Display on front panel	Accurate displays on the front panel DC input voltage DC current and AC voltage (all three phases and line) AC current (all three phases and line) Power factor Ambient temperature Solar radiation Instantaneous and cumulative array power Instantaneous and cumulative output power Daily energy produced
Certifications and compliances	The PCU/inverter shall be designed to meet the following standards in addition to the codes listed in IS and other relevant standards.
IEC 61683	Photovoltaic systems—power conditioners—procedure for measuring efficiency
IEEE 519-1992	Recommended practices and requirements for harmonic control in electric power systems
IEEE 928	Recommended criteria for terrestrial PV power
IEEE 929	Recommended practice for utility interface of residential and intermediate PV systems
IEC 61727	Photovoltaic systems—characteristics of the utility interface
IEC 61683	Photovoltaic systems—power conditioners—procedure for measuring efficiency
IEC 62103	Electronic equipment for use in power installations

- Typical failure analysis report of PCUs and recommended list of critical components shall be provided by the vendor while submitting their offer.
- Provision shall be available in the PCU to display of following parameters on front panel display.

ANTI-ISLANDING PROTECTIONS

The bidder shall conform to and undertake all precautions and requirements as have been laid down by the following standards:

- IEC 61727—PV systems—characteristics of utility interface
- IEC 62446—Grid connected photovoltaic systems - minimum requirements for system documentation, commissioning tests and inspection
- IEC 62116—Test procedure of islanding prevention measures for utility-interconnected photovoltaic inverters

Besides the above measures, certain precautions prescribed by the CEA shall also be incorporated into the solar PV system design:

- PV systems shall be provided with adequate rating fuses, fuses on inverter input side (DC: direct current) as well as output side (AC: alternating current) side for overload and short circuit protection as well as disconnecting switches to isolate the DC and AC system for maintenances.
- Fuses of adequate rating shall also be provided in each solar array module to protect them against short circuit.

PHASE IMBALANCE

- Phase imbalance can occur due to varied power injected into different phases of the grid. Whenever solar power plants of lower capacities with single phase inverters are used to feed power into the grid using a single phase injection point, they tend to induce imbalance. This imbalance can be resolved simply by connecting/injecting power to different phases in the same grid.
- Different countries have different permissible limits for imbalance. For example, Germany has a 4.6 kilowatt limit and Australia has a 10 kilowatt limit. These limits are decided by the utility/grid operator from time to time based on its analysis of permissible imbalances.
- The developer shall have to follow the phase imbalance limits imposed by the grid operator and shall also have to follow the guidelines before connecting such limits to the grid.
- The injection points for each system to be injected into a single phase

CABLE SPECIFICATIONS

Sr. No.	Specifications of cables in the power pack and till grid connection
1	All module interconnection cables and those between solar module and array junction boxes shall be of flexible type, UV protected cables. These shall be laid along the module mounting structures.
2	Sizes of interconnection for modules and from modules to inverter shall be so selected that loss would not be more than 3 percent.
3	Rest all cables shall be armored type, of suitable size, and can be laid inside the PVC pipes of suitable diameter.
4	The cable shall be terminated using only the copper lug terminals.
5	All cables shall be copper and the voltage drop calculation shall be submitted y the successful vendor.
6	The cables shall design in such a way that voltage drop shall not be more than 1 percent in any cable size and length used in solar farm.
7	All cables shall be from a reputed manufacturer and shall meet minimum of IEC 60189/IS 1554 IS 694. The shall also meet following standards.
IEC 62208	General requirements for empty enclosures for low voltage switchgear and control gear assemblies.
IEC 69947	Standard test and measuring methods for PVC insulated cables for working voltages up to and including 1,100V, UV resistant for outdoor applications.
IEC 60947	Connectors for photovoltaic systems—safety.
EN 50521	Connectors for photovoltaic systems—safety.
IEC 60189-1	Low frequency cables and wires with PVC insulation and PVC sheath—general test and measuring methods.
IEC 60189-2	Low frequency cables and wires with PVC insulation and PVC sheath—cables in pairs, triples, quads, and quintuples for inside installations.,

EARTHING AND LIGHTNING ARRESTERS

All the solar PV power packs, including modules and mounting structures and inverters, shall have proper arrangement for earthing. DC part of the plant shall be singly grounded. Module array shall also have lightning arresters as necessary.

ENERGY METER

Each power plant will be provided with an energy meter for accurate periodic readings of AC energy generated and fed to the grid. This time of day type meter shall be of approved make of the off-taker and shall conform to the requirements laid down by the CEA's (Installation and Operation of Meters) Regulation, 2006. This shall be inspected, tested, and calibrated at the time of installation and also during operation lifetime of power plant.

STATUTORY CLEARANCES TO BE ARRANGED BY THE SUCCESSFUL BIDDER

- Building and architectural drawings approval.
- Factory inspector approval on drawings, wherever necessary.
- Electrical system approval (Electrical inspector).
- Fire system approval.
- All statutory requirements for working at the site like labor registration, workman compensation policy and employee state insurance corporation.

APPENDIX 2: INDIA'S REGULATORY STRUCTURE

In India, the Jawaharlal Nehru National Solar Mission (JNNSM) has identified rooftop solar PV as one of the three broad categories of solar projects to be encouraged. Official policy states:

> *"The Mission will encourage rooftop solar PV and other small solar power plants, connected to LV/11 KV grid, to replace conventional power and diesel-based generators. Operators of solar PV rooftop devices will also be eligible to receive the feed-in tariff fixed by the central level regulator, Central Electricity Regulatory Commission (CERC), both on the solar power consumed by the operator and the solar power fed into the grid. Utilities will debit or credit the operator for the net saving on conventional power consumed and the solar power fed into the grid, as applicable. A generation-based incentive will be payable to the utility to cover the difference between the solar tariff determined by CERC, less the base price of Indian rupees 5.50 per kWh with 3 percent p.a. escalation [$0.09]."*

In June 2010, India's Ministry of New and Renewable Energy launched the "Rooftop PV and Small Solar Power Generation Program" (RPSSGP) to provide incentives for both ground-mounted and rooftop-based solar projects. To date, all installed capacity under this program has been developed through ground-mounted projects, and unlike grid-connected large utility-scale projects and small-scale decentralized distributed generation projects for rural electrification, rooftop solar PV installations have seen only limited development.

With JNNSM identifying rooftop as a separate segment, several states have integrated rooftop solar PV into their state policy frameworks. This is summarized in table 4.

Table 4: Rooftop solar policies/targets for power generation

Parameter	Type	Capacity Target	Incentives for Rooftop Owner	Metering
Gujarat	Grid-connected	5 MW in Gandhinagar[2]	Incentive linked to rooftop solar power generation	Gross
Karnataka	Grid-connected	250 MW	Tariff of Indian rupees 3.40 ($0.06) per kilowatt hour	Net
Tamil Nadu	Grid-connected	350 MW	Generation-based incentive of Indian rupees 2 ($0.03) per kWh for the first two years; Indian rupees 1 ($0.02) per kWh for the next two years and Indian rupees 0.50 ($0.01) per kWh for subsequent two years	Net
Andhra Pradesh	Grid-connected			Net
Uttarakhand	Grid-connected	5 MW	Fee-in tariff of Indian rupees 9.20 ($0.15) per kWh	Net
Kerala	Grid-connected	10 MW	Indian rupees 93,000 ($1,541.52) per 1 kW system	Net

Source: Respective state government solar policy documents

[2] Additional 25 MW is proposed to be developed under the ongoing replication project covering five cities in Gujarat (Bhavnagar, Mehsana, Rajkot, Surat, and Vadodara).

In support of the Government of India's challenging target of 40,000 MWp of grid-interactive rooftop solar PV plants during the next five years, it has created a loan program for installation. The targets specify that these rooftop solar PV plants will be set up in residential, commercial, industrial, and institutional sectors in the country ranging from 1 kWp to 500 kWp capacity. The Government of India is proving a subsidy of 15 percent on these plants to the beneficiaries, which makes it even more attractive and increases its viability.

This massive target can be achieved with support from banks to provide loans for installation of Grid-Interactive Rooftop Solar PV Plants to the loan seekers as a part of a home loan or home improvement loan. To this end, India's Department of Financial Services, Ministry of Finance issued the following advisory to all public sector banks:

"All banks are advised to encourage the home loan/home improvement loan seekers to install rooftop solar PVs and include the cost of such equipment in their home loan proposals just like non solar lighting, wiring and other such fittings."

APPENDIX 3: JAWAHARLAL NEHRU NATIONAL SOLAR MISSION

India's concerted efforts to develop solar power began in January 2010, when the country launched the Jawaharlal Nehru National Solar Mission (JNNSM) as one of the eight missions under the country's National Action Plan for Climate Change. The Mission's aim was to deploy solar power on a large scale and position India as a major world power in solar manufacturing as well as research and development.

The first phase of JNNSM (2010-13) witnessed enthusiastic participation from Indian and international investors in the grid-connected segment. The strategy adopted the innovative mechanism of bundling relatively expensive solar power with power from the unallocated quota of the government's thermal power stations, which is relatively cheaper. It also followed a reverse bidding mechanism that enabled qualified bidders to benefit from declining global prices for solar components, thereby reducing the purchase price of both solar PV and CSP for the utilities.

Recognizing that future planning benefits from sound analysis of lessons learned, India's Ministry of New and Renewable Energy commissioned a study in 2012 to identify the key challenges that could impede the expansion of the program. The report, "Paving the Way for a Transformational Future: Lessons from JNNSM Phase 1: Lessons from Jawaharlal Nehru National Solar Mission Phase I," supported by the World Bank's Energy Sector Management Assistance Program (ESMAP), is based on consultations with key stakeholders. It identified the following issues as requiring closer attention:

1. **Increase access to funds from commercial banks and attract private financing.**

   Under Phase I of the program, scheduled commercial banks mostly shied away from lending for solar projects. Instead, export credit agencies, multilateral financial institutions, and some nonbanking financial institutions took up most of the financing. However, given that most infrastructure lending in India has been led by commercial banks, the solar program too will need their active participation to scale up to the levels envisaged.

2. **Develop shared infrastructure facilities, such as solar parks.**

   The provision of publicly developed infrastructure frees private providers to focus on solar power development, increases efficiency, and lowers costs. Gujarat was the first state to declare a solar policy (2009), and today is at the forefront of solar power generation in India. Its first solar park, developed in Charanka (Patan district), has the largest solar capacity in Asia. The park provides developers with already developed land along with critical infrastructure, including facilities for power evacuation and transmission, along with roads and water, thereby ensuring the rapid development of solar projects.

3. **Use India's comparative advantage to develop a niche in the manufacturing value chain.**

   India's solar PV manufacturing capacity is limited because India's manufacturers lack the raw materials, do not have access to low-cost financing, and face underdeveloped supply chains. Large imports from Chinese module suppliers meet the market demand for solar PV modules by solar power developers implementing projects under central and state solar PV schemes and auctions. Competitive pricing by Chinese suppliers allows local solar developers to compete in central and state level solar bids.

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