



## Harnessing Energy From The Sun: Empowering Rooftop Owners

White Paper on Grid-Connected Rooftop  
Solar Photovoltaic Development Models  
2014

### **Cover Image**

Courtesy of Anjali Garg/IFC

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# Harnessing Energy From The Sun: Empowering Rooftop Owners



## FOREWORD

India is particularly vulnerable to climate change impacts. As the world grapples with the effects of climate change, manifested in the form of unprecedented heat waves, cyclones, floods, and impact on agriculture, solutions to India's urgent energy needs have to be more climate-friendly.

India's abundant natural and renewable resources can be used to generate clean energy. Vast untapped opportunities to capitalize solar need to be realized and scaled up. The National Solar Mission launched in 2010 has set an ambitious target of 20 GW of solar capacity by 2022.

We at the Solar Energy Corporation of India, are focused on building a greener India by harnessing the abundant solar radiation the country receives annually, thereby helping India become self-reliant in meeting the energy demands of its citizens. A vision that is shared and supported by the Honorable Prime Minister, Narendra Modi.

The pioneering Rooftop Solar Program in Gujarat, supported by IFC as lead adviser, is a stellar example of how the government can partner with the private sector to develop a sustainable, replicable model to implement rooftop solar PV systems and meet the energy needs of the state.

It is our hope that this project can be replicated across the country with appropriate adaptations.

This white paper prepared by IFC, *Harnessing Energy from the Sun*, is therefore a timely initiative. It addresses the growing interest of developing countries to use grid-connected rooftop solar PV initiatives to provide green power access to large numbers of people, and to review the use of private participation to support their dissemination. It draws lessons from selected global experiences in designing and implementing rooftop solar photovoltaic systems, identifying some success drivers and potential challenges in implementing these projects. Finally, it also looks at some of the fundamental steps to successful project preparation to enable private sector participation, based on the case study of the rooftop solar program piloted in Gujarat, India.

I believe that this white paper successfully showcases how the interaction between all stakeholders can lead to benefits for each one of them, and to society as a whole. It should serve as a valuable knowledge bank to help policy makers, developers and regulators hoping to roll out solar rooftop programs across India.

**Rajendra Nimje, ex-IAS**  
Managing Director  
Solar Energy Corporation of India



**L. Chuaungo, IAS**  
Principal Secretary

## PREFACE

India's electricity sector is estimated to be the world's fourth largest, in terms of installed capacity, yet there is a large, unmet demand for electricity across the country. People, especially in rural and semi-urban areas continue to rely on more traditional means of lighting their homes; children continue to study by the light of the kerosene lamp.

I firmly believe that if we are able to tap hydro-power from our rivers, wind-power at the sea-shore and develop solar-generated and other renewable energy, we can be entirely self-reliant in energy production in a sustainable and environment-friendly way.

It is this vision that led to the pioneering work currently underway in Gujarat under the vision of the Honorable Prime Minister Narendra Modi, who as chief minister of Gujarat envisaged a maximizing of the city's potential for solar power. Gujarat is indeed at the forefront of India's climate change agenda. It also gives me immense pride to note that Gujarat's capital Gandhinagar is the first city in India to have about 5 MW of solar power connected to the grid through rooftops. This project is now expected to be replicated across other cities in the country including Vadodara, Rajkot, Surat, Mehsana and Bhavnagar in Gujarat state.

Gujarat made this possible with the advisory assistance from IFC and the lessons learnt are captured in this white paper, titled, '*Harnessing Energy from the Sun: Empowering Rooftop Owners*'. The publication documents the global evolution of solar rooftop system, analyses various business models and their associated issues and challenges and suggests next steps for a large-scale roll out. It takes, as an example, the innovative Rooftop Solar Program in Gujarat, to showcase how states can meet the power needs of future generations, and do so in an environment-friendly manner.

This white paper developed by the IFC team, I believe, will serve as a valuable guide, chronicling how successful collaborations can develop the rooftop solar market. With India receiving some of the highest levels of solar irradiation in the world, energy generation can be increased using available natural resources.

I congratulate the IFC team for bringing out this well-analyzed and very pertinent document on the innovative concept of solar rooftop systems.

**L. Chuaungo, IAS**  
Principal Secretary  
Energy & Petrochemicals Department  
Government of Gujarat



## INTRODUCTION

Electricity is essential for development, which includes industrial growth, urbanization, and better living conditions. However, rapid economic growth and high population growth rates significantly impact the ability of economies to meet increasing energy demands, especially in developing countries. The problem is further accentuated by climate change and energy security considerations.

Policy makers worldwide look at the sun as a reliable, affordable, and environment-friendly source of power, easily accessible by the greatest number of citizens. Harnessing the sun's energy has several advantages over other forms of electricity generation: it reduces dependence on fossil fuel; has limited environmental impact; and can match peak supply with peak demand. Solar photovoltaic technology is also modular, scalable, and flexible, making it the most attractive renewable energy source. Finally, it enables production of electric power where it is needed the most: at consumer locations, which almost eliminates transmission losses.

If appropriately planned and properly implemented, and supported by enabling policies, rooftop solar PV systems can help solve power shortages at the household level.

This white paper aims to create awareness - among stakeholders including policy makers, utilities, and regulators - of the opportunities and challenges of the rooftop solar market. It focuses on implementation options, including public-private partnerships, and discusses practical issues related to planning and implementing rooftop solar initiatives. It provides information and discusses policy and technical issues that can help stakeholders make informed decisions and policies suited to local objectives. It also discusses how to successfully involve rooftop owners and the private sector in developing the rooftop solar market. This white paper draws on current international rooftop solar experience through case studies and interviews. It provides an overview of the nascent market in India, and specifically the Gujarat Rooftop Solar Program.

I am proud to support the development of this white paper through the Norwegian Trust Fund for Private Sector and Infrastructure. We hope this will be of value to government officials and policy makers who have chosen rooftop solar initiatives, with the help of the private sector, as an option for better access to power. This white paper is also designed to bring critical aspects of the sector to the attention of key market players, including regulators, distribution companies, private sector developers, and rooftop owners.



**His Excellency Eivind S. Homme**  
Ambassador  
Royal Norwegian Embassy in India

## ACKNOWLEDGEMENTS

This white paper covers a number of complex issues. It draws from the experience and advice of a wide range of professionals involved in rooftop solar and public-private partnership-related issues from around the world.

IFC would like to thank the Gujarat Power Corporation Limited and the Gujarat Energy Research and Management Institute for their leadership and guidance in preparing the Gujarat Rooftop Solar Program. This exercise contributed to the gathering of necessary insights, which are captured in this publication.

The team is grateful to Deloitte Touche Tohmatsu India Private Limited for their role in supporting this publication.

The team is also grateful to the peer reviewers, Alexios Pantelias and Pratibha Bajaj, for their insightful inputs. We especially thank Isabel Chatterton (Manager, South Asia, Public Private Partnerships, IFC) and Jeeva A. Perumalpillai - Essex (Manager, South Asia, Sustainable Business Advisory, IFC) for their constructive guidance and valuable support.

The team is grateful to the Norwegian Trust Fund for Private Sector and Infrastructure for its support.



**Photo:** Anjali Garg

## 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, power-conditioning 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 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 megawatts 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 megawatt 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  $120^\circ$  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.

## 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
MV	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

<b>PCU</b>	<b>Power control unit</b>
<b>PIA</b>	<b>Project implementation agreement</b>
<b>PPA</b>	<b>Power purchase agreement</b>
<b>PPP</b>	<b>Public-private partnership</b>
<b>PV</b>	<b>Photovoltaic</b>
<b>R&amp;B</b>	<b>Road and buildings</b>
<b>R&amp;D</b>	<b>Research and development</b>
<b>RE</b>	<b>Renewable energy</b>
<b>REC</b>	<b>Renewable energy certificate</b>
<b>RPO</b>	<b>Renewable purchase obligation</b>
<b>RPS</b>	<b>Renewable portfolio standard</b>
<b>RPSSGP</b>	<b>Rooftop PV and Small Solar Power Generation Program in India</b>
<b>SERC</b>	<b>State Electricity Regulatory Commission</b>
<b>T&amp;D</b>	<b>Transmission and distribution</b>
<b>ToD</b>	<b>Time of day</b>
<b>V</b>	<b>Volt</b>



**Photo:** Anjali Garg

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# SOLAR ROOFTOPS

## LEARNINGS FROM GLOBAL AND INDIAN EXPERIENCES

Countries all over the world are faced with climate change and energy security concerns. An estimated 700 million people in South Asia do not have access to electricity. About 90 percent of them live in rural areas. To help address these concerns, IFC is working to eradicate energy poverty by focusing on both grid connected and off-grid energy through innovative and market transforming initiatives.

This white paper explores the growing interest in developing countries in using grid-connected rooftop solar PV to provide access to green power for large numbers of people. It also looks at how private participation can support dissemination of rooftop solar PV systems. This white paper draws lessons from global experiences in designing and implementing rooftop solar systems, identifying success drivers and potential challenges. It is based on industry consultation, and the development of case studies from recent rooftop solar initiatives, such as the Indian state of Gujarat's Gandhinagar experience with the public-private partnership approach.

In this publication, 'rooftop solar PV systems' refers to solar photovoltaic power systems installed on rooftops and elevated areas on consumer premises. A solar rooftop PV system can be either one or a combination of two arrangements, namely, (i) building-attached PV systems and (ii) building-integrated PV systems. Building-attached



**Photo:** Azure Power

PV systems are added on to the rooftops and elevated areas such as parking areas and canopies, but not directly related to functional aspects of the building or the premises. These generally include rack-mounted arrays and are used both to retrofit and for new buildings. Building-integrated PV systems are functional parts of the building structure, or architecturally integrated into the design of the building and elevated areas. This category includes designs where PV material replaces the normal roofing material, such as shingles, tiles, slates, roof, skylights, or facades.

This white paper explores how technological advances, production expansion, and the shifting of manufacturing bases to low-cost Asian regions have led to a rapid decline in the cost of PV, and looks at the two main approaches to develop rooftop solar: (i) the utility-driven route, and (ii) the consumer-driven route.

Globally, rooftop solar PV installations have led the development of the solar photovoltaic sector. Ground-based projects, on the other hand, have developed due to enabling policies and regulatory frameworks as defined by the laws of each country. This white paper identifies the phases of a maturing rooftop solar sector, based on the experiences of countries such as Germany, Japan, and the U.S., to highlight how the market grows from a concept stage where pilot models are tested, to become a mature market based on self-replication.

*Harnessing Energy from the Sun* looks at the opportunities provided by rooftop solar for developing countries like India and highlights the common barriers that prevent the development of the rooftop solar sector.

A key driver of rooftop solar PV development across the globe has been the design and implementation of models which combine policy and regulatory frameworks with market dynamics to deliver bankable and sustainable projects. Globally, implementation models vary in terms of ownership (self-owned versus third-party-owned) and metering (gross versus net metering). This document identifies six distinct models based on solar system ownership patterns and on the manner in which electricity generated is consumed and sold. It provides insight on how these models have evolved in response to specific policies and regulations suited to particular market conditions.

India and many other developing countries benefit from reliable solar radiation, and are keen to convert this into energy. But they are also challenged by the scarcity of land to develop large ground-mounted projects. This paper explores the regulatory path followed by India to create the enabling environment to support the growth of the rooftop solar market. It draws lessons from the preparation and implementation of the rooftop solar program piloted in Gujarat, India.

Incorporating private sector participation in the rooftop solar market can help its rapid development. However, forming a well-balanced complementary relationship between public and private sectors is challenging, and can have consequences on a wide range of stakeholders. The process needs to be carefully managed through adequate planning and implementation.

International experience indicates that several administrative and institutional challenges need to be addressed to allow each stakeholder to participate in the transition to a mature self-replication phase. This white paper explores these challenges and also the fundamental steps in successful project preparation, based on the rooftop solar program piloted in Gujarat.

Finally, this paper brings together the roles and responsibilities of each stakeholder: government, manufacturers and developers, rooftop owners, and utility companies in particular. It shows how interaction between these stakeholders can benefit each one of them, and society as a whole.



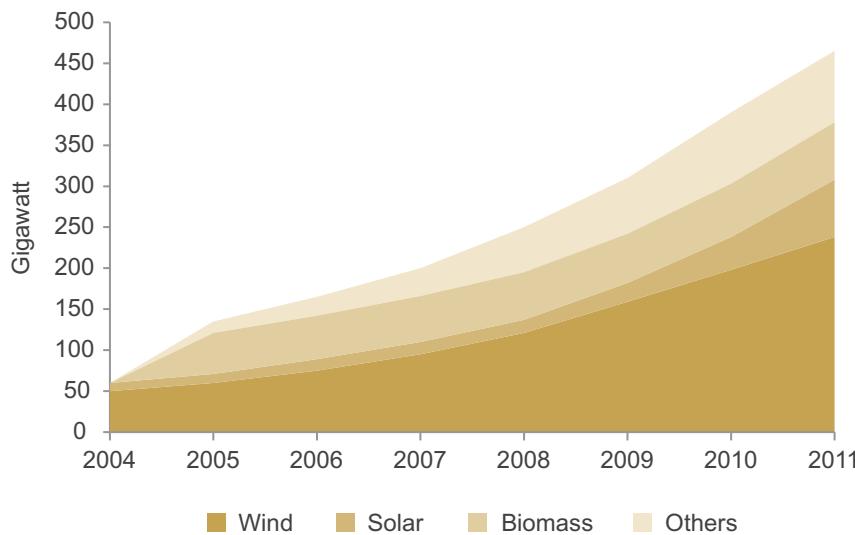
## HARNESSING POWER FROM THE SUN

Countries all over the world are faced with climate change and energy security concerns. Declining costs, and improved efficiency and reliability, are making the renewable energy sector attractive. This is leading to increased investment in renewable energy resources. Among renewable energy resources, solar photovoltaics are the third most important renewable energy source in terms of installed capacity, after hydro and wind power. As per the REN21's Renewables Global Status Report 2013, total renewable power capacity (not including hydro) reached 480 gigawatt in 2012, up about 21.5 percent in 2011. 2012 saw further movement in activity from developed to developing economies, although the former group still accounted for more than half of global investment. In 2007, developed economies invested two-and-a-half times more in renewables (excluding large hydro) than developing countries; in 2012, the difference was only 15 percent (figure 1 shows the growth of renewable energy installed capacity from 2004 to 2012).





**Figure 1: Global penetration of renewable energy (installed capacity)**

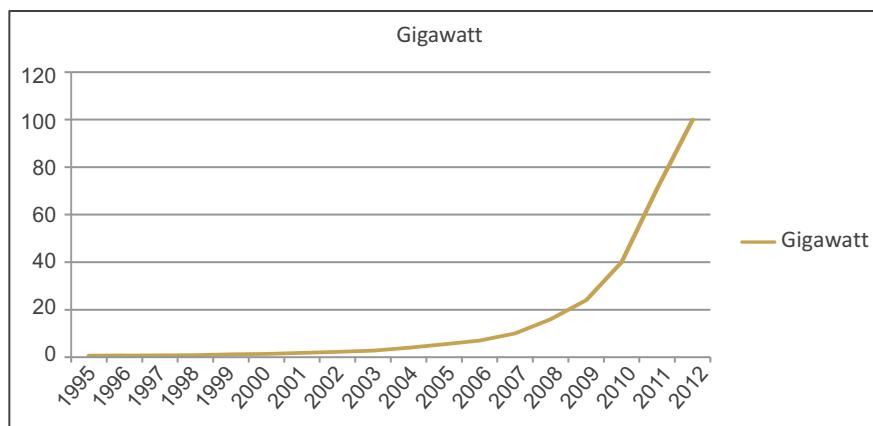


**Source:** REN21's Renewables Global Status Report 2013

## Overview of the Global Solar PV Market

Globally, solar energy is becoming the fastest-growing power generation technology. Figure 2 shows that the growth in global operating capacity of solar photovoltaics (PV) reached the 100 gigawatt milestone in 2012, from 20 gigawatt in 2007. From 2008 to 2012, the installed capacity of solar PV grew at the average annual rate of 56 percent (figure 2). These capacity additions are driven by rapid technological advances such as increase in efficiency, new manufacturing techniques, use of new materials, declining production costs, and shift of manufacturing bases to low-cost regions in Asia. However, in most mature markets such as Australia, Japan, Germany, Spain, Australia, and the U.S., the main driver has been the establishment of enabling policies, solar promotion programs, and incentives to increase penetration of solar power applications.

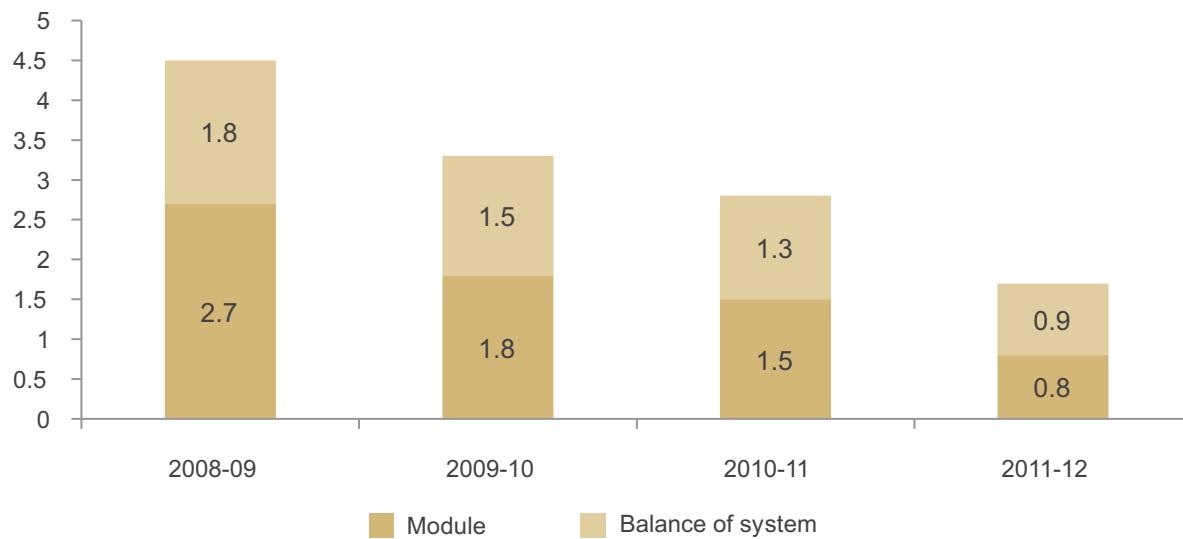
**Figure 2: Growth in solar PV global capacity**



**Source:** REN21's Renewables Global Status Report 2013

Due to increasing production scales and advances in technology, there has been a rapid decline in the cost of solar PV system installations from \$3.50 to \$4 per watt-peak in 2004 to about \$1 per watt-peak in 2012.<sup>1</sup> Figure 3 shows the declining trend in solar PV system prices globally between 2008 and 2012.

**Figure 3: Solar PV system price trends**



**Source:** The Rising Sun, Grid parity gets closer - A point of view on the Solar Energy sector in India, September 2012, KPMG (<http://www.kpmg.com/IN/en/IssuesAndInsights/ArticlesPublications/Documents/Rising-sun-2-full.pdf>)

## Global Deployment of Grid-connected Solar Energy Installations

The development of grid-connected solar programs has followed two broad approaches (table 1): one under which utilities or third-party developers undertake solar energy development to fulfill renewable purchase obligations or preferential tariffs, as in the U.S. and India, and the second where retail customers drive solar energy development to benefit from attractive and facilitating policies and regulatory environments, as in Germany.

<sup>1</sup> Reconsidering the Economics of Photovoltaic Power, available at <http://www.bnef.com/WhitePapers/download/82>

**Table 1: Two key approaches followed globally to develop grid-connected solar programs**

Utility/third-party-driven programs	Customer-driven programs
<p>Utilities or third-party developers undertake projects primarily to address regulatory and policy requirements (for example: renewable purchase obligations). These projects are usually large megawatt scale with a focus on optimizing costs. These projects are usually developed either by the utilities themselves or by third party developers who enter into long-term power purchase agreements with the utility. The cost of procurement is eventually spread out and passed on to customers served by the utility.</p>	<p>Governments and regulators create facilitating policies and regulations to encourage consumers to invest in and develop small solar projects on their premises.</p> <p>Decentralized, distributed solar generation models have become popular among consumers due to the declining cost of solar energy, proliferating fiscal incentives like feed-in tariff, net metering and tax rebates, and increased costs of grid-based conventional energy.</p>

Several hybrids of the above approaches have emerged in specific markets, depending on regulations, market opportunities, and role of intermediaries. Most markets, including Germany, Spain, and the U.S., have developed their solar industries using a combination of large grid-connected solar plants and small decentralized solar projects located on consumer premises. Globally, there has been remarkable growth in small rooftop and other small-scale PV installations. Germany is the world's biggest small-scale PV user with an installed capacity of 32 gigawatt, as of September 2012. Of this, approximately 60 percent of the capacity is installed on rooftops: 9 percent (1-10 kilowatt) mostly on private buildings, 26 percent (10-100 kilowatt) on social, commercial, and agricultural buildings, and 24 percent (above 100 kilowatt) on large commercial buildings (figure 4).

## Figure 4: Share of rooftop solar PV installations in overall installed capacity of solar PV in Germany



**Source:** Jorg Mayer (May 17, 2013), German Solar Industry Association, BSW Solar, "The German Solar PV Rooftop Market," Dutch 20GW Challenge, Amsterdam

Australia, Italy, and the U.S. are other countries with significant shares of rooftop installations. Of the 3,500 megawatt of photovoltaic capacity in the U.S., 1,000 megawatt is large scale and owned by utilities. The rest is installed on rooftops of either commercial buildings, like those atop big-box stores, accounting for about 1,500 megawatt of capacity, or on residential buildings with 1,000 megawatt of installed capacity. The average system size (for residential buildings) varies from 2 to 5 kilowatt.<sup>2</sup> This has prompted several developing countries to work on developing their own solar promotion programs. The next section, *Rooftop Solar Market Development Phases*, discusses the trends followed in the development of the rooftop solar PV segment in countries that have now reached a mature market.

<sup>2</sup> <http://grist.org/news/the-government-finally-figures-out-how-much-rooftop-solar-there-is>



## ROOFTOP SOLAR MARKET DEVELOPMENT PHASES

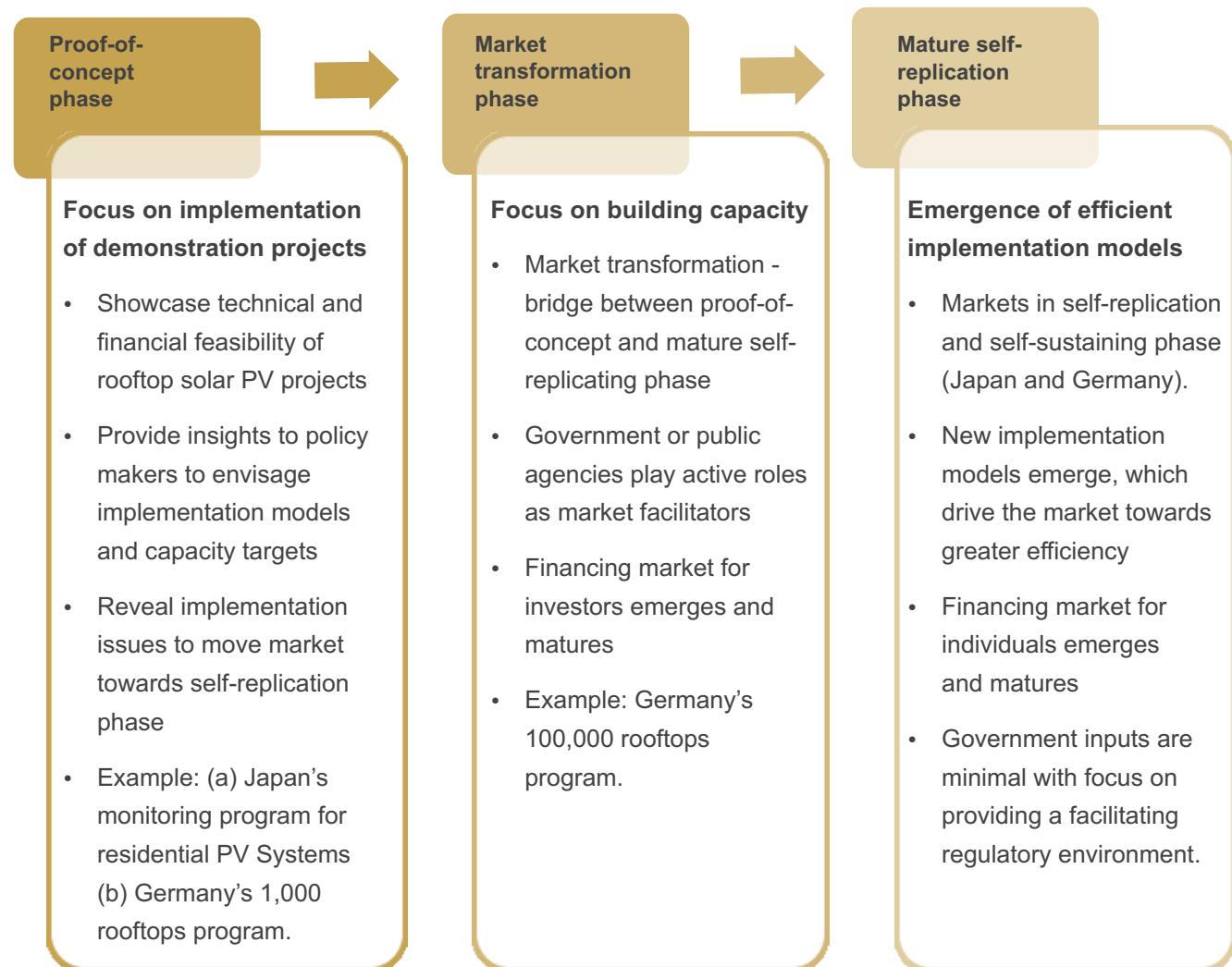
This section looks at the path followed by countries around the world to promote the growth of the rooftop solar sector. It identifies trends and lessons from their experiences that can be used by policy-makers to address challenges faced in developing countries.

Rooftop solar PV market development can be divided into three phases, as depicted in figure 5.



Photo: Anjali Garg

**Figure 5: Rooftop solar PV market development phases**



## Proof-of-concept phase

This phase consists of the implementation of demonstration projects to primarily accomplish the following three objectives:

- Showcase technical and financial feasibility of pilot rooftop solar PV projects
- Highlight implementation issues, such as permit procedures, technical standards, metering and interconnection mechanisms, and appropriateness of tariffs, which will have to be addressed to move to the next phase
- Enable policymakers to transpose lessons learnt from these projects to envisage implementation models and capacity targets, enabling them to make appropriate policy and incentive choices to move the market forward.

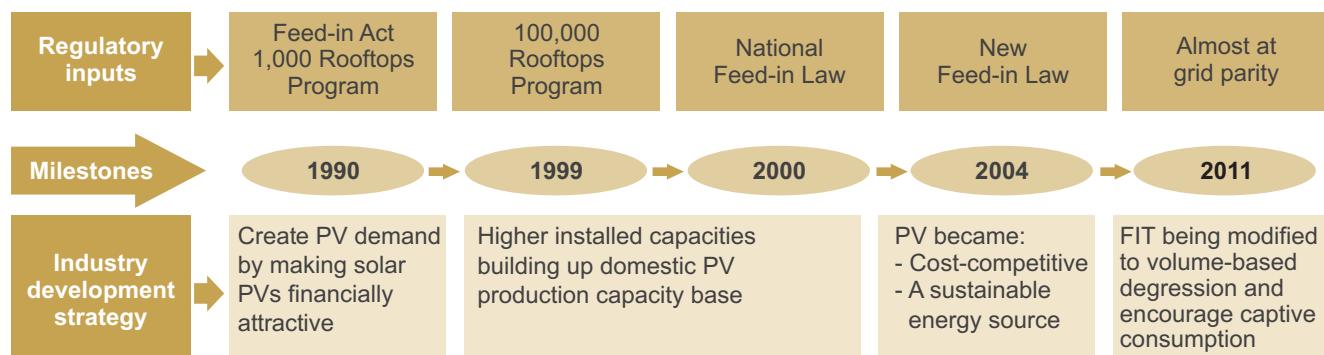
### Box 1: Example of “Proof-of-concept phase” development in rooftop solar PV

Germany launched the Thousand Rooftops Program in 1990, the first major solar installation initiative in the world. Under this program, rebates of up to 60 percent of system costs were offered to owners. Approximately 2,250 systems with a total capacity of 5.25 MW were installed by 1995. The program monitored the performance of the systems to identify issues in project design and execution. This program attracted worldwide attention from countries interested in implementing similar programs. Several issues came up during implementation, including financing barriers, grid technical standards, and levels of incentives. These were addressed successfully in subsequent phases. Japan began to invest in solar PV research and development following the first oil crisis in 1974. Its rooftop solar PV program, called the ‘Monitoring Program for Residential PV Systems,’ paid 50 percent of installation costs. The number of participating households rose from 539 in 1994 to 1986 two years later. This program demonstrated the technical feasibility of grid interconnection and helped identify incentives to promote rooftop solar PV systems. Germany, Japan, and the U.S. established legal frameworks and guidelines at early stages for grid-interconnection of small and dispersed renewable systems, along with safety procedures.

## Market Transformation Phase

The market transformation phase is the bridge between the ‘proof-of-concept’ and the ‘mature self-replicating’ phases and involves government or public agencies playing the roles of market facilitators. The most successful examples of this are Germany and Japan. After the successful 1,000 rooftops program, Germany launched the 100,000 rooftops program in 1999 that provided concessional, ten-year loans along with attractive feed-in tariffs to further incentivize households to participate. This created the effective market pull needed for the program, and targets were achieved a year ahead of schedule, in 2003. The overall development of the German solar market, where about 60 percent of all installations are rooftop-based, is highlighted in figure 6.

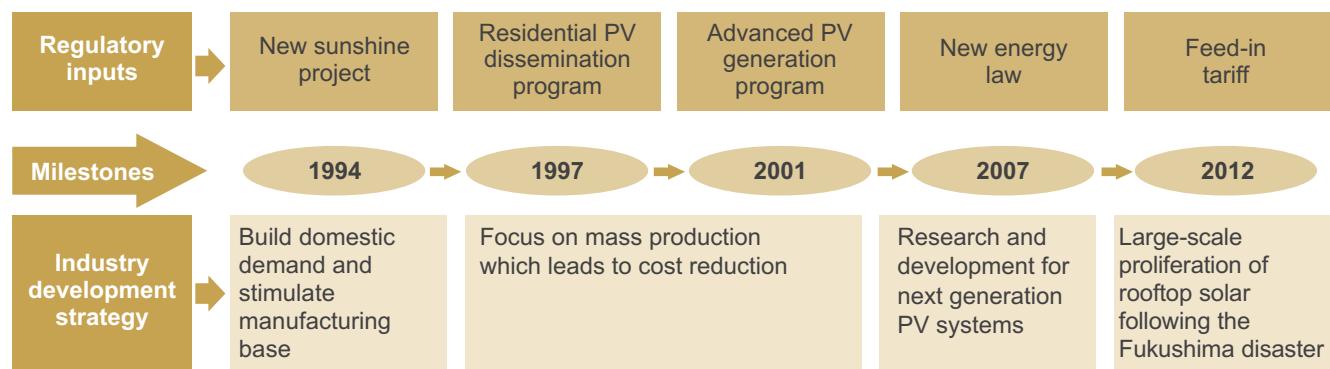
Figure 6: Key phases of development of the German solar industry



Japan facilitated the development of its rooftop solar PV sector with a coordinated effort to grow both the solar industry and rooftop solar market through publicly-funded research, demonstrations, and deployments. Research and development activities were undertaken on the supply side while, on the demand side, capital subsidies and self-owned net metering schemes encouraged households to adopt rooftop solar systems. Subsidy programs for residential PV systems started in 1994 under which subsidies were provided to individuals as well as owners and developers of housing complexes. While the subsidies ended in 2005, it was reestablished in 2009 and extended in the fall of 2011 following the Fukushima disaster. In July 2012, Japan implemented a new feed-in tariff (FIT) system under the Act on Special Measures Concerning the Procurement of Renewable Energy by Operators of Electric Utilities. Under the terms of the feed-in tariff system, power utilities must purchase electricity at a fixed price for a given period from renewable energy sources, including solar, wind, hydro, geothermal, biomass, and others, generated by certified power-generating facilities.

The high cost of retail power also encouraged the installation of these systems. The development path of the Japanese rooftop solar PV market is given in figure 7.

**Figure 7: Key phases of development of the Japanese solar industry**



## Market Maturity and Self-replication

Today, markets like Japan and Germany are near a stage where the development of rooftop solar PV installations is self-sustaining. In Germany, the new FIT regime requires utilities to procure not more than 80 percent of rooftop power production. The remaining 20 percent is consumed by the rooftop owner, which is relatively attractive as FIT rates are almost similar to utility retail tariffs.

On the other hand, California - the largest market in the United States for solar projects, though not at the stage of grid parity - has implemented new models and ownership structures with greater maturity and capacity for replication. California has been promoting the third-party ownership model coupled with tax rebates and net metering to expand the installation base. This model has increased total PV market demand by addressing issues like financing, upfront adoption costs, technology risks, and administrative complexities. It represents an evolved intermediary-driven market, where third-party service providers have led the expansion of rooftop projects. It is worth noting that the third-party PV market grew significantly in California only after tax benefits were offered.

In 2011, New Jersey added the second highest number of solar installations after California. The state had a cumulative capacity of 306.1 megawatt at the end of 2011, up from a capacity of 132.4 megawatt at the end of 2010.<sup>3</sup> It started with an extensive system of subsidies, which were phased out in favor of performance-based incentives. Until 2008, New Jersey had a subsidy program to encourage solar installations, subsidizing residential installations at \$5.50 per watt in 2005 and \$43.50 per watt in 2007, before phasing these out in 2008. Subsidies still in place in New Jersey include exemptions from sales tax and value-added property tax for installations. The key policy instrument that New Jersey has used is the Renewable Portfolio Standard, which requires utilities or suppliers to have 22.5 percent share of renewable power, out of which solar has a specific share. New solar installations are guaranteed participation in the state-wide solar renewable energy credit (SREC) market for a significant period of time (15 years) and utilities must pay fines for shortfalls in SREC compliance obligations.<sup>4</sup> Individually owned as well as third-party leasing systems exist in New Jersey. Third-party leasing companies have become significant players in the residential solar market in New Jersey, and offer 15 to 20-year leases to consumers with nil down-payments.<sup>5</sup>

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<sup>3</sup> US Market Trends 2011, Interstate Renewable Energy Council, August 2012

<sup>4</sup> Renewable Energy Credit (REC) is a credit awarded for the generation of 1000 kWh of renewable energy (such as solar, wind, geothermal). To meet renewable energy targets, utilities must accumulate RECs through renewable energy production or by purchasing credits from others. Solar Renewable Energy Credit (SREC) is 1000 kWh (kilowatt hour) renewable energy credit that is specific to the production of solar power.

<sup>5</sup> Griffith, A.B., M.Higgins, J.M. Turner. A rooftop revolution? A multidisciplinary analysis of state-level residential solar programs in New Jersey and Massachusetts. Journal of Environmental Studies and Sciences December 2013. 10.1007/s13412-013-0156-6

## Measures Facilitating the Penetration of Rooftop Solar Projects

Three markets - Japan, Germany, and California - have followed similar trajectories of penetration of rooftop solar power in their energy mix. However, each was based on different legal, policy, regulatory, and commercial paths, reflecting the market policies and regulatory preferences typical to each country. Table 2 highlights the approaches of different programs across the globe that have successfully addressed the pre-requisites for rooftop market development.

**Table 2: Measures to facilitate development of rooftop solar PV**

Supporting factors	Germany	Japan	California
Regulation of grid interconnection	The Renewable Resources Act provides guidelines for interconnection, and mandates the connection of renewable systems on priority basis. VDE 4105 Code of Practice is mandatory from January 2012 for interconnection with the low-voltage grid	Grid interconnection technical requirement guidelines and the Electricity Utility Industries Act provides provisions on safety	Interconnection, operating, and metering requirements for generating facilities to be connected to Southern California Edison's distribution system were provided
Financial incentive structures	FIT, periodically updated	Capital subsidy, renewable purchase obligation	Incentives, <sup>6</sup> tax credits
Sustainable business models	<ul style="list-style-type: none"> <li>• Long-term FIT guarantee</li> <li>• Soft financing</li> <li>• Streamlined interconnection and administrative approval processes</li> </ul>	<ul style="list-style-type: none"> <li>• Soft financing</li> <li>• Streamlined interconnection and administrative approval processes</li> <li>• Savings in electricity bills</li> </ul>	<ul style="list-style-type: none"> <li>• Emergence of third-party service providers who take on the risks associated with the development and performance of the system</li> <li>• Savings in electricity bills for households or rooftop owners</li> <li>• Lease payments and tax benefits to project developers or owners</li> </ul>
Metering arrangements	Gross metering to encourage solar project development, independent of captive loads of consumers	Net metering due to very high consumer tariff coupled with promotion of captive consumption	Net metering to facilitate the development of decentralized solar systems

<sup>6</sup> California solar incentive payments are disbursed in one of two ways: (i) Expected performance-based buy down (EPBB): The applicant receives the entire incentive payment at the time the system is installed, and the payment is based on expected electrical output of the system. (ii) Performance-based incentive (PBI): The applicant receives a portion of the incentive payment every month over a period of five years, and the payment is based on the actual metered output of the system.

The three markets are well on their way to achieving grid parity, and government initiatives have played a major role in leading the rooftop solar PV segment to maturity. The German government has led the way in developing the domestic supply chain for the solar segment through private sector participation. The German FIT model has helped in developing a well-structured private industry, leading to strong distributor and dealer networks with well-trained installers and good customer-support capabilities. Germany has become the leading PV manufacturer in Europe with around 40 manufacturers of silicon, wafers, cells, and modules, more than 100 PV material and equipment suppliers, numerous manufacturers of other system components, and over 50 PV research institutes as well as a number of project development, system integration, and installation companies.

In the United States, utilities have played an important role in market development. Incentive programs such as subsidies and high retail electricity rates have created a well-developed solar PV service delivery industry, with a large number of local suppliers and qualified installers across the country.

The paths followed by each country have varied in terms of implementation models and market organization, reflecting the policies and regulatory preferences typical to each country. While Germany and Japan provided incentives initially by subsidizing system costs, the market in California grew significantly only after tax benefits were offered. FITs, concessional loans, renewable purchase obligations, and tax rebates are other policy instruments used by countries to encourage the success of rooftop programs. The role of incentives and policy support to help the market transition from proof-of-concept phase to market transformation and then self-replication is evident in the way the segment has developed in these countries. This will be analyzed in greater details subsequently in this paper.

The next section assesses the benefits that emerging economies may find by developing rooftop solar PV projects, and the constraints that may hinder their growth.

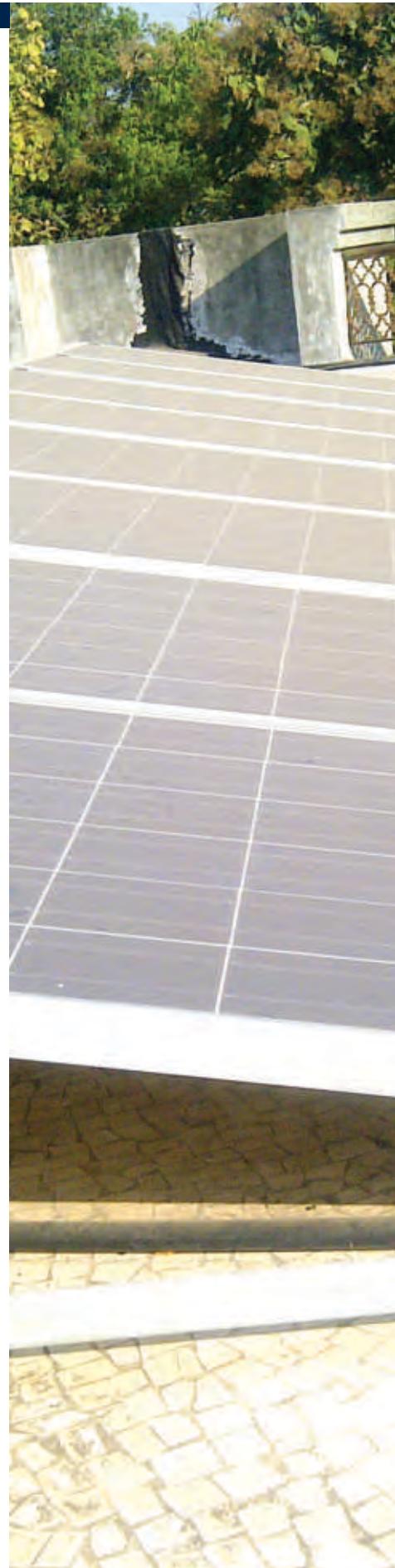


## WHY IT MAKES SENSE TO GENERATE POWER ON ROOFS

This section discusses the key opportunities to develop rooftop solar PV projects and constraints in frontier markets, including gaps in policy and regulatory frameworks. It draws extensively from lessons learned during the implementation of the rooftop solar program in Gujarat, India, and other initiatives by the government of India. Table 3 captures the opportunities and challenges that are described in more detail here.

**Table 3: Opportunities and challenges in solar rooftop market development**

Opportunities	Challenges
<ul style="list-style-type: none"><li>• Flexible model enabling large-scale self-replication</li><li>• Enhancing power supply reliability and supporting energy efficiency</li><li>• Ease of implementation (permits, site selection, and clearances)</li><li>• Creating value from underutilized rooftops and saving of productive land for alternative uses</li><li>• Savings in transmission and distribution losses</li><li>• No new transmission infrastructure required.</li></ul>	<ul style="list-style-type: none"><li>• Higher capital cost differential between ground-mounted and rooftop solar PV plants</li><li>• Need for policy and regulatory framework to encourage market development</li><li>• Need for roadmap and implementation models to drive market growth</li><li>• Need for robust and well-defined technical standards to ensure quality installations matching the asset life and sustainable grid interconnections</li><li>• Technical adequacy of the distribution grid including grid availability.</li></ul>



**Photo:** Sivaram Krishnamoorthy

## Benefits of Grid-connected Rooftop Solar PV

Rooftop solar PV systems can be permitted and installed faster than most ground-mounted systems as interconnection and site eligibility norms for rooftop systems are easier to execute. Not only do these systems provide a clean, quiet, and visually unobtrusive source of power, they also improve the reliability of power supply without the need to establish long-distance transmission lines associated with large-scale solar generation plants. As illustrated in the section *Rooftop Solar Market Development Phases*, several European nations, Germany in particular, have moved away from large-scale ground-mounted PV plants that need large land masses to distributed rooftop solar PV installations.

### Value Creation from Under-utilized rooftops

Rooftop solar PV systems on unused rooftops can lead to potential savings and generate income. In some models, third-party developers lease roof surfaces from building owners, which provides long-term rental income. Internationally, third-party developers provide rooftop owners an opportunity to monetize unutilized roofs, without making upfront investments. A recent study in Massachusetts shows that a homeowner installing an average-sized residential rooftop solar PV system (say 6 kilowatt) could enter into a lease for approximately \$75 per month; her/his first year energy cost saving would be \$108. Assuming energy costs and lease amounts increase at 3 percent a year, over 20 years savings would be \$2900. Alternatively, such a system could generate two streams of revenue for a homeowner: first, cost savings from electricity generation (6,300 kilowatt hours at the rate of \$0.16 per kWh) and second, revenue from sales of solar renewable energy credits (six SRECs at the rate of \$200 per SREC).<sup>7</sup>

<sup>7</sup> Griffith, A.B., M.Higgins, J.M. Turner. A rooftop revolution? A multidisciplinary analysis of state-level residential solar programs in New Jersey and Massachusetts. *Journal of Environmental Studies and Sciences* (December 2013). 10.1007/s13412-013-0156-6

## Savings in Network Losses and Costs of Transmission Infrastructure

The electricity sector in most developing countries is plagued with high transmission and distribution losses. Distribution losses in India, for instance, range from 15 to 45 percent across utilities in various states, representing both technical as well as commercial losses.<sup>8</sup> Although accurate estimates of technical losses of most Indian utilities are not available in the public domain, it is commonly accepted that they range from less than 10 percent in a few efficient urban areas to well above 15 percent elsewhere. Rooftop solar projects have the advantage of supplying energy close to load centers as opposed to energy from large-scale generators that has to be sent across significant distances to load centers. Rooftop solar PV systems can significantly benefit distribution systems with high network losses.

Large-scale ground-mounted solar power plants need significant land resources. As a result, they are invariably located at a distance from load centers and urban areas. Adequate transmission infrastructure is needed to connect ground-based solar projects with power grids at extra high voltage levels, which means augmenting existing infrastructure to deliver power to load centers. Thus, the tariff difference between rooftop and ground-mounted solar PV projects can be bridged when savings on transmission and distribution losses and transmission connectivity costs are also added to the equation.

In India, potential savings by reducing transmission and distribution losses through rooftop solar PV can vary from Indian rupees 1.24 (\$0.02) per kilowatt hour (kWh) to Indian rupees 1.87 (\$0.03) per kWh, depending on the level of losses (figure 11).<sup>9</sup> Similarly, potential savings from avoiding transmission infrastructure - which increases with distance from generating sources to load centers - can vary from Indian rupees 0.78 (0.01\$) per kWh (for 50 km) to Indian rupees 0.88 (\$0.014) per kWh (for 100 km) for an assumed 300 megawatt solar park.

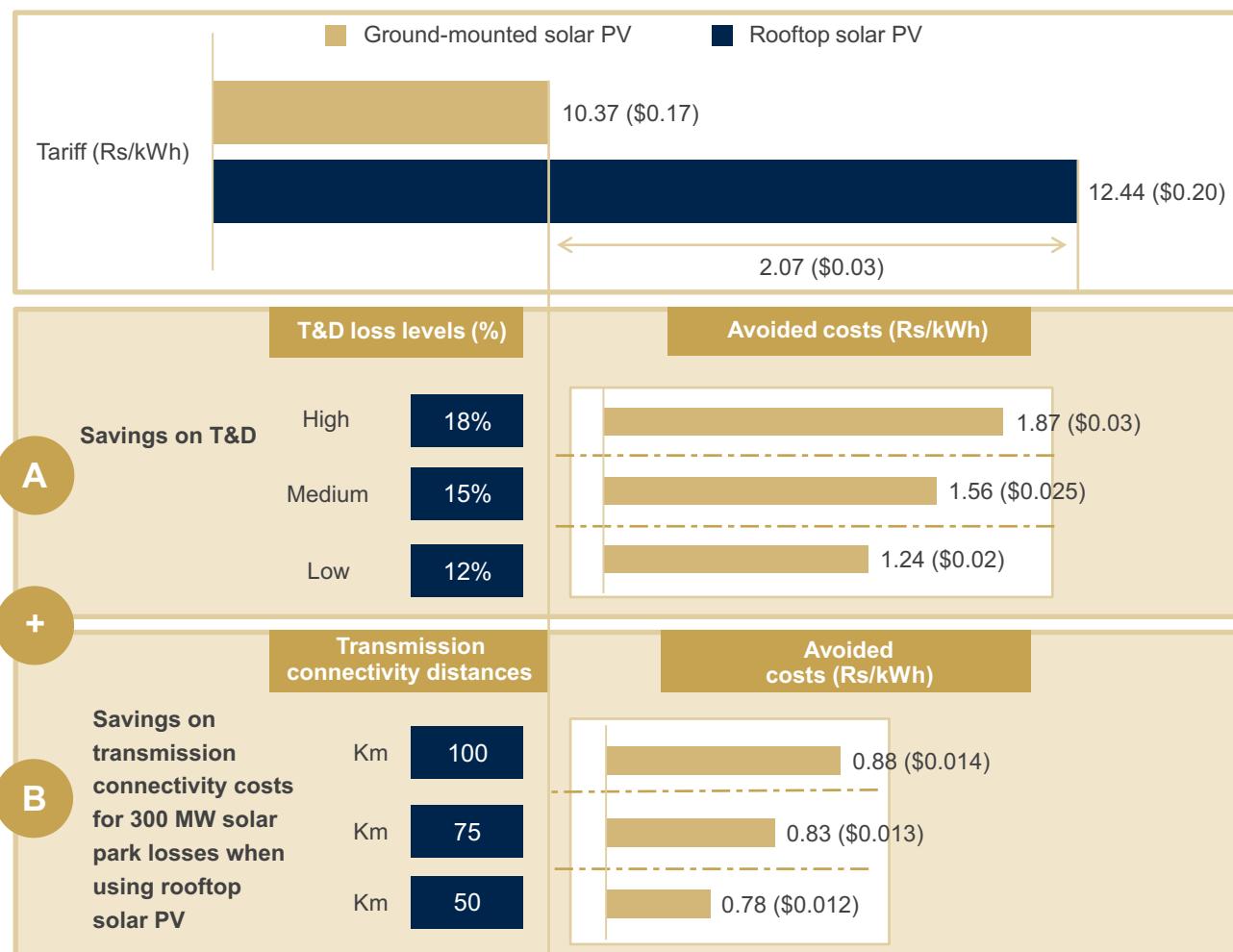
<sup>8</sup> Network loss of utilities in India is typically reported in the form of transmission and distribution loss, which reflects both network-related energy losses (owing to factors such as copper loss in power lines, and core losses in transformers) and unaccounted leaks due to unauthorized consumption of electricity.

<sup>9</sup> Exchange rate of \$1=Indian rupees 60.33 (as on May 2, 2014; Reserve Bank of India)

This analysis is based on the tariff order issued by the Gujarat Electricity Regulatory Commission (Order No.1 of 2012, issued on January 27, 2012). The order outlines a tariff differential of Indian rupees 2.07 (\$0.03) per kWh between rooftop solar (Indian rupees 12.44, about \$0.20, per kWh) and large-scale ground-mounted solar plants (India rupees 10.37, about \$0.17 per kWh). While savings from transmission and distribution network losses will depend on the actual losses, this analysis assumes three scenarios: high, medium, and low. Potential savings accruing from rooftop systems have been quantified for these three scenarios.

Figure 8 shows that a solar park of 300 megawatt capacity requiring transmission evacuation through a single-circuit 220 kilovolt line and a 33/220 kilovolt sub-station is comparable to a rooftop solar system in terms of cost per unit of delivered energy, if transmission charges saved per unit of generation are taken into account.

**Figure 8: Tariff difference between rooftop and ground-mounted solar PV projects**



**Source:** Based on 2012 GERC tariff order

In Germany, the costs of rooftop PV systems fell to \$2.20 per watt by mid-2012 from approximately \$6.50 per watt in 2007. PV system costs declined so rapidly that previous projections of cost reductions became obsolete in a very short time. Industry projections from the European Photovoltaic Industry Association in 2012 suggest a slowdown in cost reductions of PV systems, with residential rooftop systems in the most competitive European markets falling to \$1.80-2.40 per watt by 2020.<sup>10</sup> FIT for small-scale rooftop systems in Germany has declined from \$0.26 per kilowatt hour in 2012 to \$0.18 per kilowatt hour by December 2013.

### **Enhancing Supply Reliability and Supporting Energy Efficiency**

Electricity shortfalls, especially in developing countries, result in poor supply, both in terms of quantity and quality, jeopardizing economic growth and livelihood. Inadequate investment in distribution network infrastructure, even in urban areas, adds to the problem. In 2011-2012, the Central Electricity Authority of India estimated that India had an energy deficit of 10.2 percent. Bangladesh fared much worse, suffering from a peak deficit of 37 percent in 2009-2010 (Ministry of Power, Energy, and Mineral Resources). Rooftop solar power systems offer a long-term solution to meet peak loads in great measure. The European Photovoltaic Industry Association estimates that 40 percent of the EU's total electricity demand by 2020 could be met by rooftop PV (Prayas Energy Group<sup>11</sup>). Incorporating rooftop solar systems should play a critical role in the design and development of buildings, particularly green buildings where energy conservation measures are an integral part of the design aimed to reduce overall energy consumption.

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<sup>10</sup> IEA-ETSAP and IRENA 2013, Solar Photovoltaics Technology Brief, E11 - January 2013 (available at <http://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E11%20Solar%20PV.pdf>)

<sup>11</sup> Solar Rooftop PV in India, Prayas Policy Discussion Paper, November 2012

## **Ease of Development (Permits, Site Selection, and Clearances)**

Large projects face significant hurdles and delays due to land acquisition and clearances and approvals from various authorities. In India, for example, several authorities, from the village level to the departments of rural development and revenue at the state level, need to be consulted for land-related approvals such as change in land use and ground water extraction where applicable. Sanctions are also required for power for construction from the local distribution utility and infrastructure for grid-interconnections.

In comparison, rooftop solar PV projects require relatively few clearances; projects are usually permitted through automatic standard provisions in most countries. Site selection and related clearances under building by-laws can also be standard rather than project-specific. Most clearances required for rooftop solar projects pertain to structural and fire safety, pollution control, and electrical safety. Clearly, rooftop solar projects are easier to permit and simpler to develop.

Quality assessments along the project life cycle are a critical element for successful commissioning and operations of any system. In the Indian context, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the Ministry of New and Renewable Energy, Government of India, have developed a web database that provides support to all stakeholders involved in solar projects by explaining necessary administrative/legal formalities and regulatory framework, from conceptualization to commissioning (<http://www.solarguidelines.in/>).

## **Ability to Self-replicate**

A key attribute of rooftop solar PV initiatives is that successful projects can easily be replicated on a large scale, provided policy, regulations, financing, and technical conditions make it feasible for rooftop owners to opt for such systems on their own. Rooftop solar PV systems are modular, relatively easy to install, and require low maintenance. Individual rooftop owners, residential or commercial, can easily deploy systems of all sizes, making its propagation broad-based and fast. It does not depend on a few limited large developers. This is the reason why they have become so popular in countries such as Germany, Japan, Spain, and the U.S.

## Key Challenges in Development of Rooftop Solar PV Projects

Rooftop solar, like any new sector, experiences teething challenges. This was the case in Germany, which faced issues at every stage of the sector's growth. A key barrier in most developing markets is the absence of clear capacity targets for grid-connected rooftop solar PV development. In India for instance, while the Jawaharlal Nehru National Solar Mission<sup>12</sup> provides an enabling framework, a definite roadmap has not yet been outlined, creating substantial ambiguity in implementation. The following section discusses some key challenges in emerging markets.

### **Capital Cost Differences between Ground-mounted and Rooftop Solar PV Plants**

The capital costs per megawatt of rooftop solar PV systems are approximately 20 percent higher than that of large-scale PV systems. This is due to higher installation costs, small-sized components, lower economies of scale, and a smaller base on which to spread fixed costs. This is because rooftop solar PV projects consist of a number of small solar energy systems scattered across a number of rooftops. On the other hand, large ground-based solar plants typically use fewer but large-sized components, reducing the total project costs.

The cost of leasing rooftops, including developmental charges, or the opportunity costs in case of self-owned rooftops in urban areas, is higher than the annualized value of land costs. To address this issue, some state electricity regulators in India have provisioned higher tariffs for rooftop solar projects compared to large-scale ground-mounted projects. As demonstrated above, the tariff difference between rooftop and ground-mounted projects evens out if potential savings on transmission and distribution losses, and transmission connectivity costs, are taken into account.

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<sup>12</sup> Jawaharlal Nehru National Solar Mission (JNNSM), also known as the National Solar Mission, is a major initiative by the Government of India and state governments to promote ecologically sustainable growth while addressing India's energy security challenges. It was launched in January 2010 and has set an ambitious target of deploying 20,000 megawatt of grid connected solar power by 2022. It aims at reducing the cost of solar power generation in the country 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.

## Regulatory Framework

Government policies and incentives are vital to facilitate implementation of rooftop solar PV in any jurisdiction. Favorable policies and regulatory environments are critical precursors to the development of vibrant solar rooftop markets, even with dramatically reduced technology costs.

A key factor to ensure financial sustainability of the sector is determining tariffs for the rooftop solar segment by regulators, which is different from ground-mounted large-scale solar projects. Given the cost differences between the two, separate tariffs for rooftop projects are required for gross-metered systems. For example, many states in India do not have separate tariffs for rooftop projects, and therefore failed to create the right incentive structure for the market to develop. However, some states have determined separate tariffs for this segment (Maharashtra, Gujarat, and Karnataka among others).

Several measures must be taken to create a strong framework conducive for rooftop solar PV projects. These are

- **Metering arrangement:** The type of metering arrangement for energy accounting, whether it is single meter or dual meter, needs to be defined under FIT and net-metering schemes respectively.
- **Net metering:** Rooftop owners consume electricity generated from net-metered rooftop PV systems, and use the grid to store excess power. These installations should not be treated as captive generation in the strict sense. In India, if a project is developed by a third party, it does not qualify as captive generation<sup>13</sup> under the Electricity Act 2003. It is treated as 'open-access' power transmission, attracting wheeling and cross-subsidy surcharges (box 2). 'Open access' and the consequent cross-subsidy charges should be waived to make third-party ownership models viable.

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<sup>13</sup> Captive generation under the Electricity Rules, 2005, require the captive user to own at least 26 percent of the equity in the captive generating plant and to consume at least 51 percent of the electricity output, determined on an annual basis. Captive users are exempt from payment of cross-subsidy surcharges.

**Box 2: Provisions in the Indian regulatory framework for open access and their impact on development of solar rooftop PV projects**

- Third-party-owned solar rooftop PV projects generate electricity for captive use and provide electricity to the grid. Under the Indian legal/regulatory framework (Electricity Act, 2003), a project of this kind may either be a captive plant or an ‘open access’ project that utilizes the transmission/distribution network of a licensee to provide energy to its consumer(s). According to the Electricity Act, 2003, a captive project should have at least 26 percent owner equity and 51 percent of the energy must be captive consumption. Solar rooftop PV projects may not meet both conditions simultaneously all the time and, therefore, these projects would fall under the category of ‘open access’ projects.
- All intra-state ‘open access’ projects in India are saddled with wheeling and cross subsidy surcharges. This is because general intra-state ‘open access’ consumers utilize electricity lines of the distribution licensee. Since solar rooftop PV projects do not do so, imposing those charges on such projects is regressive.
- **Interconnectivity:** The point of interconnection needs to be defined for kilowatt-scale projects at different voltage levels. This is critical to maintain grid safety. Connecting various small generation projects without specified interconnection standards to the grid is a threat to the safety of the grid and the overall project. In addition, the sharing of interconnection costs and any associated network capacity enhancements needs to be clarified with the local distribution utility.

Interestingly, despite being one of the early leaders in adopting rooftop solar PV systems, the U.S. continues to allocate resources to tackle regulatory barriers hindering the growth of this market segment. The United States Department of Energy has identified barriers that still constrain the development of the rooftop solar market: restrictive interconnection and net metering rules, regulatory uncertainty regarding PV financing mechanisms, including third-party ownership, community solar, and property-assessed financing, absence of renewable portfolio standards, and PV siting restrictions in local codes, ordinances, and covenants. The U.S. Department of Energy through its ‘SunShot Initiative: Rooftop Solar Challenge’ aims to address these issues and reduce costs of rooftop solar energy systems through improved permitting, financing, zoning, net metering, and interconnection processes for residential and small commercial PV installations (<http://www.eere.energy.gov/solarchallenge>).

## Technical Standards

The technical standards for the specification, installation, and maintenance of rooftop projects must be clearly defined to ensure installations are of high quality, safe, and reliable. This helps ensure efficiency and maximizes life of the assets. Technical standards for interconnection equipment are also essential to ensure reliability and safety of the low-voltage grid. This is of particular concern in developing countries where availability of the grid at the low-tension level, its monitoring on a real-time basis, and functioning of the power evacuation facility, all have commercial implications.

With increasing interest in rooftop solar PV projects, the following important operating conditions have to be carefully considered, and standards and regulations designed to address them.

- Handling reverse flows on electrical distribution networks
- Addressing variability in energy production and transients due to partly cloudy weather conditions (PV modules respond instantaneously to changes in solar irradiance).

Modern day inverters handle grid interface functions including synchronization, over or under voltage and over or under frequency-related disconnects, and PV array control function (maximum power point tracking). It is thus essential to define standards for PV inverters, keeping long-range penetration scenarios in mind. For example, voltage instability and output fluctuations due to higher PV penetration can be addressed to an extent by specifying some degree of reactive support by inverters while maintaining real power service.

This approach has been followed in high PV-penetration markets like Germany, where recent connection regulations require PV systems connecting to the low-voltage grid to provide ancillary services support vide mandatory VDE<sup>14</sup> 4105 code of practice. For this, power electronics and energy storage capacitors must be suitably oversized to provide reactive production, or inverters must have absorption features. Common standards should be devised for distributed generators connecting and operating in parallel with the low voltage grid. For instance in India, the Central Electricity Authority has powers under section 73 (b) and 73 (c) of the Electricity Act, 2003 to specify technical standards for construction of power plants and their interconnection with the grid.

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<sup>14</sup> VDE-AR-N 4105: Generators connected to the low-voltage distribution network: Technical requirements for the connection to and parallel operation with low-voltage distribution networks.

## **Technical Adequacy of the Distribution Grid**

Given the intermittent nature of solar power, the distribution grid's capacity to absorb this power and withstand transient and possible reverse flow is critical. As increasing numbers of solar PV systems get embedded within established networks, issues of technical adequacy will impact the stable operation of the grid.

Electricity networks are designed to ensure that power flows in only one direction; from the utility substation to the consumer premises. In case of a reverse power flow, network protectors (like switch gears and circuit breakers) disconnect the faulty supply feeder, isolating the fault to prevent equipment damage.

In grid-connected solar PV systems, when a customer's rooftop installation produces more power than the customer can use, excess power is fed into the grid causing reverse power flow.

Network protectors get into action, causing equipment wear. A short-term solution to this issue is to adjust network protector settings to be less sensitive to reverse power flow. However, as more PV installations start connecting with the grid, utilities will need to monitor, exchange information, and control network protectors and PV systems. This can be done either through remote adjustable network protector settings, or by periodic curtailing of solar PV production to reduce reverse power flow.

California was among the first states in the U.S. to adopt a standard practice to connect distributed energy resource devices to the power grid. Known as Rule 21, it initially proposed that a project not exceeding 15 percent of the peak load on the line section<sup>15</sup> be fed into the grid through non-schedulable power sources such as solar. The 15 percent rule was adopted as an approximation of 50 percent of the minimum load on the line section. Some statistical analysis suggested that the annual minimum load on a line section is approximately 30 percent of the annual peak load. A load flow study would have to be conducted for every connection above that capacity.

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<sup>15</sup> 15A line section is the next size down from the circuit level, which itself is the next structure down from the sub-station level.

The Federal Energy Regulation Commission of the U.S. recently adopted this rule for the entire nation. However, the commission changed the 50 percent minimum load rule to 100 percent, which effectively doubles the size of projects eligible for fast tracking. This means the U.S. has pre-defined interconnection regulations/standards for distributed generation systems with capacities up to 30 percent of peak load on a line section (low tension level). For any capacity above that, load-flow studies and case-specific arrangements can be made.<sup>16</sup>

California Public Utilities Code, Section 2827(c) (1) limits net metering-based projects to 5 percent of the utility's "aggregate customer peak demand." This means that if the sum of individual customer peak demand is 1000 megawatt, the maximum net metering-based projects that can be connected to the utility's network is 5 megawatt.

As grid penetration increases at low voltage levels, power flows could reverse towards distribution sub-stations and result in increased voltage levels. In such situations, capacitor banks and voltage reactors in particular can boost voltage above standard limits. Beyond certain levels of penetration, strengthening networks is essential to accommodate additional PV projects. Hence, current flows need to be monitored (load flow analysis) at each level of penetration and networks upgraded as needed. Upgrades may range from installing automatic tap-changing transformers to changing feeder architecture from radial to loop or mesh, to increasing diversity of load and reducing variations.

Looming energy shortages, rising fossil fuel prices, and falling prices of solar PV clearly make the case for countries to increase the share of solar energy in their generation mix. Within the solar PV market, the rooftop segment offers several advantages: savings in network losses and transmission infrastructure costs, ease of development (permits, site selection, and clearances), ability to self-replicate, enhanced supply reliability, and energy efficiency. There is a clear need and economic rationale for countries to develop this market segment. However, flexible enabling frameworks that do not constrain expansion of the private sector and the emergence of innovative and sustainable business models need to be developed.

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<sup>16</sup> [https://solarhighpen.energy.gov/article/beyond\\_15\\_rule](https://solarhighpen.energy.gov/article/beyond_15_rule), <http://www.greentechmedia.com/articles/read/ferc-adopts-new-california-fast-track-interconnection-rules-nationwide>

The next section discusses in detail possible business models for the sector, some of which have already been tested and adopted by markets around the world.



**Photo:** Anjali Garg



## ROOFTOP SOLAR PV - IMPLEMENTATION MODELS

The different approaches to support the emergence of rooftop solar PV installations around the world can be broadly split into two, based on the type of ownership: utility-driven models and customer-driven models. Local legislative frameworks, regulations, and natural market maturation also has led to the development of hybrid and innovative models making greater use of intermediaries.

Figure 9 highlights the typical implementation models in rooftop solar PV project development, classified on the basis of ownership of the solar systems.



**Photo:** Sivaram Krishnamoorthy

**Figure 9: Implementation models for solar rooftop projects**



## Utility-driven Implementation Models

Here, the utility's involvement is in the form of direct ownership, participation, or financing of solar rooftop projects. The energy generated can be fed directly into the grid or consumed by the rooftop owner on-site, with or without provision for surplus generation to be exchanged with the grid.

Table 4 provides a few examples of utility-based ownership models.

**Table 4: Examples of utility-based ownership models**

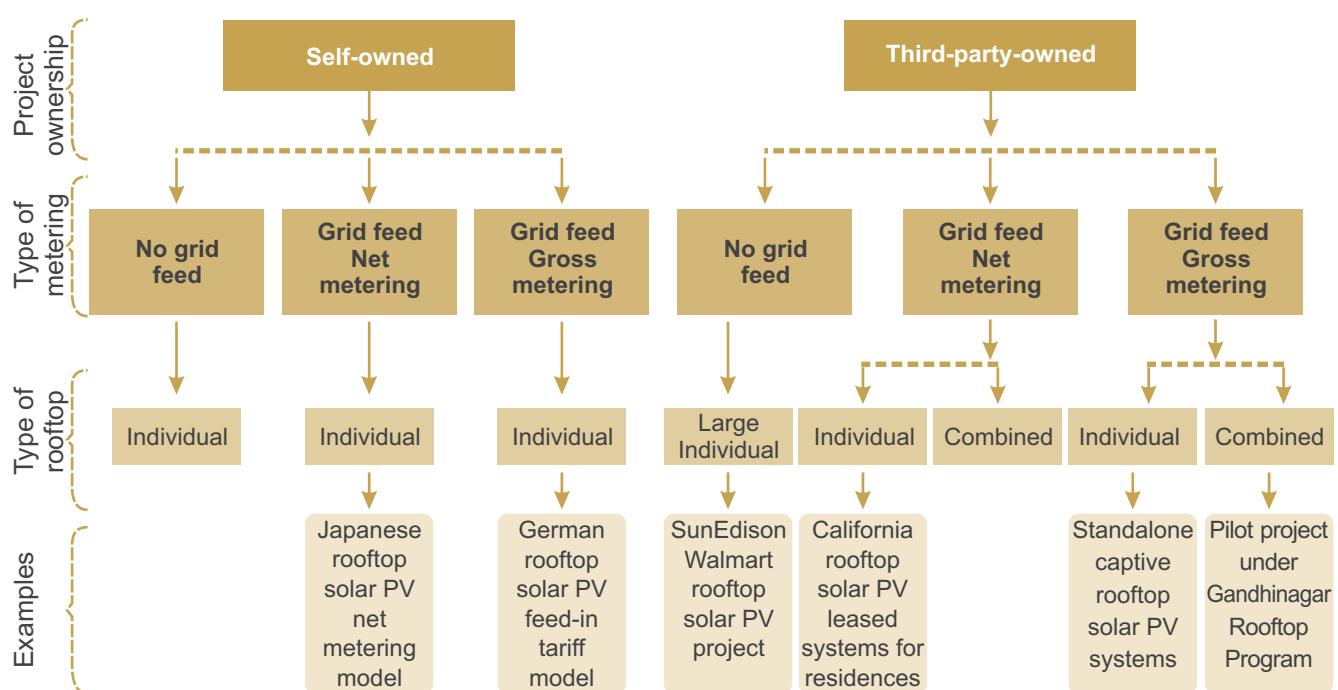
Utility	Description
San Diego Gas & Electric (SDG&E)	SDG&E installed solar PV systems at customer sites, which are connected to the utility side of the meter and the electricity flowing directly into the grid. There is no net metering and no effect on the customer's electricity bill. The building owner can obtain credits towards the Leadership in Energy and Environmental Design Program and points for the Collaborative for High Performance Schools program.
Sacramento Municipal Utility District (SMUD)	SMUD launched one of the first "community solar" programs in the U.S. SMUD's SolarShares program allows customers to sign up for "shares" in a larger, offsite solar power system, and receive credits on their bills commensurate with their "portion" of the larger system.

Utility-based implementation models gain prominence when utilities start viewing decentralized rooftop solar generation as potential competition. Utilities can build on existing relationships with consumers to play an active role in solar generation and supply. Given their access, scale, size, and industry knowledge, utilities are in a significantly advantageous position to play a role in the lifecycle of designing, financing, developing, and maintaining such projects.

## Customer-driven Implementation Models

Customer-driven implementation models have led the accelerated development of rooftop solar PV projects in countries such as Germany, Japan, and the U.S. In this model, grid connected and/or off-grid projects are owned either directly by the consumer or by a third-party player utilizing the consumer's premises. These models can apply to all consumer categories (domestic, commercial, industrial, and institutional). They are largely dependent on supporting instruments such as capital subsidy, renewable purchase obligation, FIT, and tax incentives to increase their financial sustainability and achieve desired penetration level in the long term. The model has been implemented in India in the off-grid and captive power categories. It can be applied in the distributed rooftop models based on gross or net metering alike. Figure 10 presents several sub-models, based on how the power generated is consumed, that is, either within the premises where it is produced, or fed into the grid. Each sub-model is explained in detail in the following section.

**Figure 10: Customer-driven implementation models for rooftop solar PV projects**



## **Sub-model 1: Self-owned rooftop solar PV installations: Captive generation and consumption (no grid feed)**

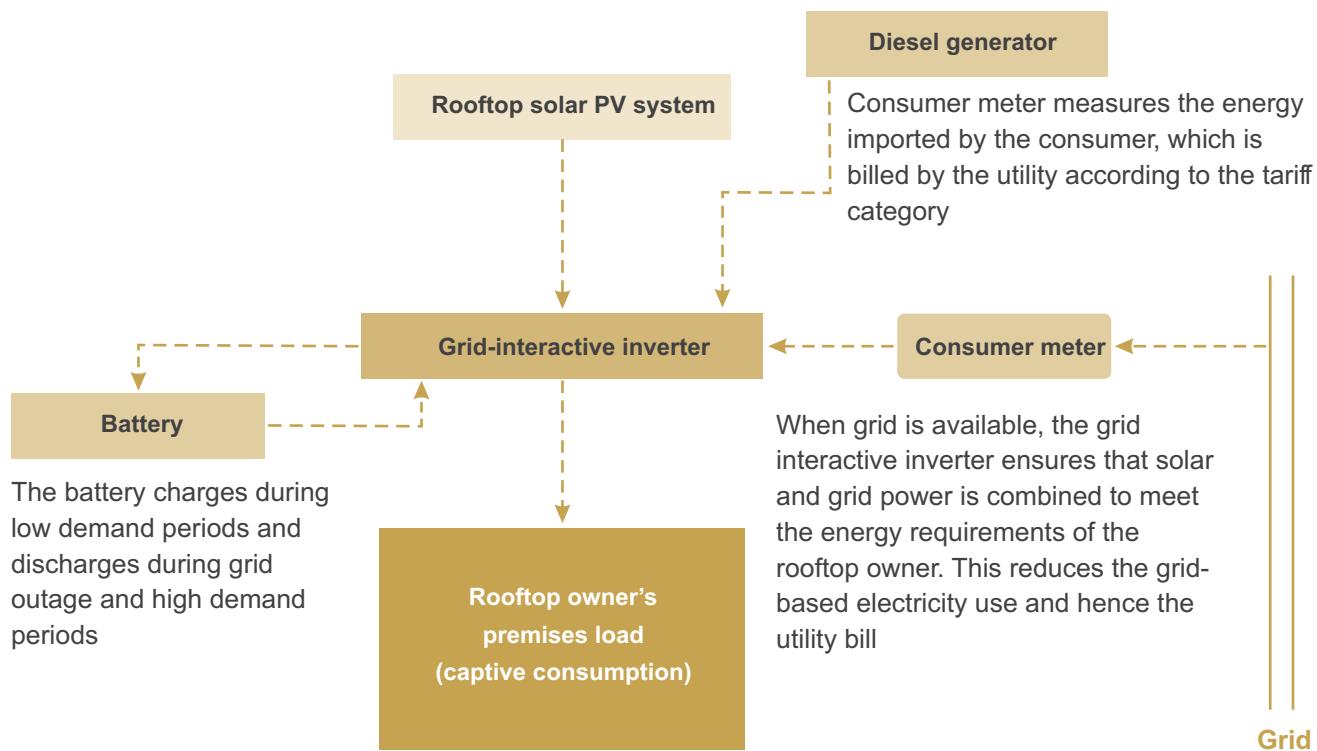
- **Description:** In this sub-model (figure 11), the rooftop owner consumes all power generated from the rooftop. This system is connected to the household through specialized grid-interactive inverters and is not designed to feed any energy into the grid. The rooftop system owner may continue to buy electricity from the grid and is billed by the utility.
- **Applicability/key consumer segments:** Since these systems are for captive use, they find applicability across several consumer segments, both in rural and urban areas, depending on the financial and operational attractiveness vis-à-vis the alternative it seeks to replace. It is particularly attractive in situations where it seeks to abate expensive fossil fuel-based generation. Examples of this model exist across several public buildings in India, where rooftop solar projects were deployed under the solar cities program of the government of India. Several private corporations<sup>17</sup> have also deployed such projects in India. Some rural institutions<sup>18</sup> have opted for this in areas where grid power is erratic.
- **Pros and cons:** The key benefit of this scheme is that rooftop owners can use solar power for specific loads, improving the reliability of power supply for these loads. However, in the absence of grid feed, excess solar generation has to be curtailed or costly energy storage sub-systems such as batteries and charge controllers have to be installed to optimize output. The model has a limited role to play in proliferation of rooftop systems. Most deployments have been in a regime where there are no enabling policies, regulations or grid standards to facilitate grid feed or areas with poor grid availability.
- **Tariff methodology, financial incentives, and regulatory regime:** This sub-model is usually prevalent in a regime where adequate regulations have not been developed around grid connectivity of rooftop systems. There is no exchange of electricity with the grid and no tariffs to be paid by the utility. Consumers opt for systems after comparing life cycle (or levelized) costs of solar energy with energy that consumers normally depend on. Governments in many countries do make provisions for capital subsidies for such systems, which improves their economic viability for consumers.

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<sup>17</sup> SunEdison has installed such a project on the Standard Chartered Bank's captive BPO office building in Chennai, Tamil Nadu, India.

<sup>18</sup> Teacher training institutes in Bihar are considering rooftop solar deployment to avoid diesel generating sets.

**Figure 11: Self-owned rooftop solar PV installations: Captive generation and consumption (no grid feed)**



#### **Sub-model 2: Self-owned rooftop solar PV installations: Captive generation and consumption, with excess power fed into the grid (net metering)**

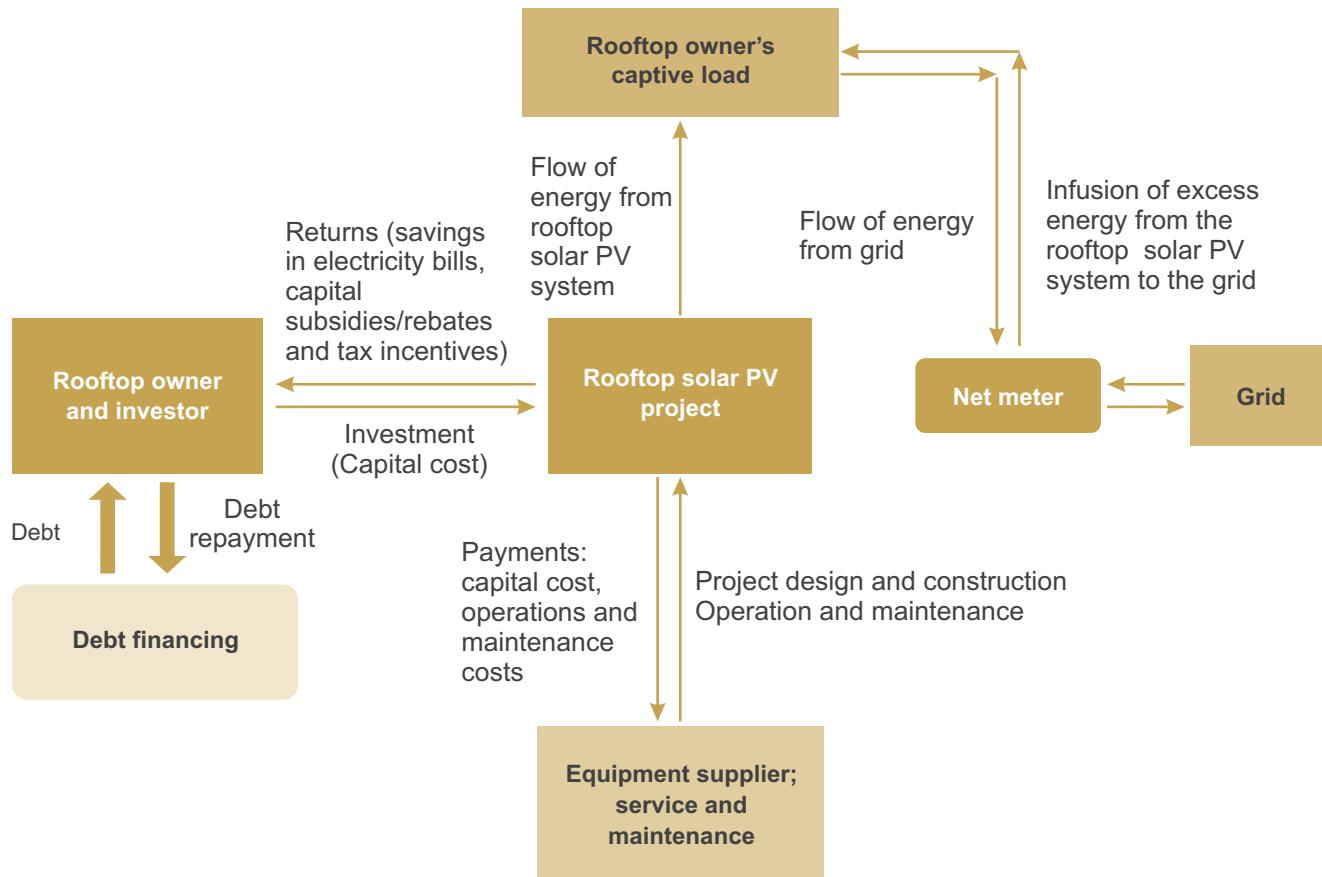
- Description:** In this sub-model (figure 12), the rooftop owner is also a grid consumer and invests capital to install the rooftop solar PV system, either independently or through a third-party supplier/financier. Energy generated by the system is first used to service captive loads within the consumer premises. Power in excess of the owner's consumption is fed into the grid through a bi-directional meter (net meter). The positive net generation received by the grid is then credited to the owner's account and adjusted against consumption from the grid over a defined settlement period. In effect, solar energy from the rooftop system displaces the consumer's consumption from the grid over a settlement period and is compensated by the retail tariff applicable to the specific consumer. Net metering examples across the world have variations. In most cases, generation in excess of consumption is capped and excess injection is not compensated. In some cases a carryover to the next settlement period is allowed, or a specific tariff is paid for excess generation if permitted by regulations.

- **Applicability/key consumer segments:** Viability of net metering is linked to retail tariffs applicable to consumers. Thus, it is attractive to consumers who pay higher retail tariffs. For instance, in India, tariffs for commercial and industrial consumer segments in most states cross-subsidize other consumer segments such as domestic and agricultural consumers. A net metering system is therefore attractive to commercial and industrial consumers in India, even with minimal or no fiscal incentives from the government. In Japan, the relatively higher retail tariffs for household consumers combined with capital subsidy make such systems attractive to home-owners.
- **Pros and cons:** This sub-model allows development of solar energy projects without additionally burdening other consumers of the utility. Since generation from net-metering-based projects is effectively compensated at prevailing retail tariffs, implications for the utility are to the extent of a reduction in consumption from the grid. It is not in the nature of absorbing costlier generation, as is the case in the system based on FIT. However, with a spurt in penetration of such systems over the years, utilities in developed countries have become increasingly vocal about charging the full cost of services extended to such consumers. This includes the cost of being the supplier of last resort, “banking” of electricity with the grid, and technical and commercial implications of absorbing variable electricity from rooftop solar systems.
- **Tariff methodology, financial incentives and regulatory regime:** For this sub-model to work, clear permitting provisions need to be prescribed to allow rooftop solar PV systems to interconnect with the distribution grid through a metering scheme including a net meter.

Net metering projects with upfront capital subsidy or tax rebates have their economics linked to current and future retail tariffs, which are beyond the control of the rooftop solar PV developer. This introduces an element of uncertainty. This incentive mechanism can have a negative effect on the developer's behavior, who may be driven primarily by large upfront subsidies, resulting in poor maintenance and sub-optimal efficiency during the life of the assets. As an alternative to the capital subsidy, generation-based incentives for the developer will reduce uncertainties associated with rooftop projects. This incentive is in addition to applicable retail tariffs.

Since net generation is to be credited to consumer accounts, fiscal incentives are required to bridge the difference between the higher cost of solar generation and retail tariffs. Different incentives have been tried out across the globe for net-metering schemes. Japan's net metering scheme worked with a capital subsidy while in the case of the U.S., tax rebates are the primary incentive mechanism for rooftop developers.

**Figure 12: Self-owned rooftop solar PV installations: Captive generation and consumption, with excess power fed into the grid (net metering)**



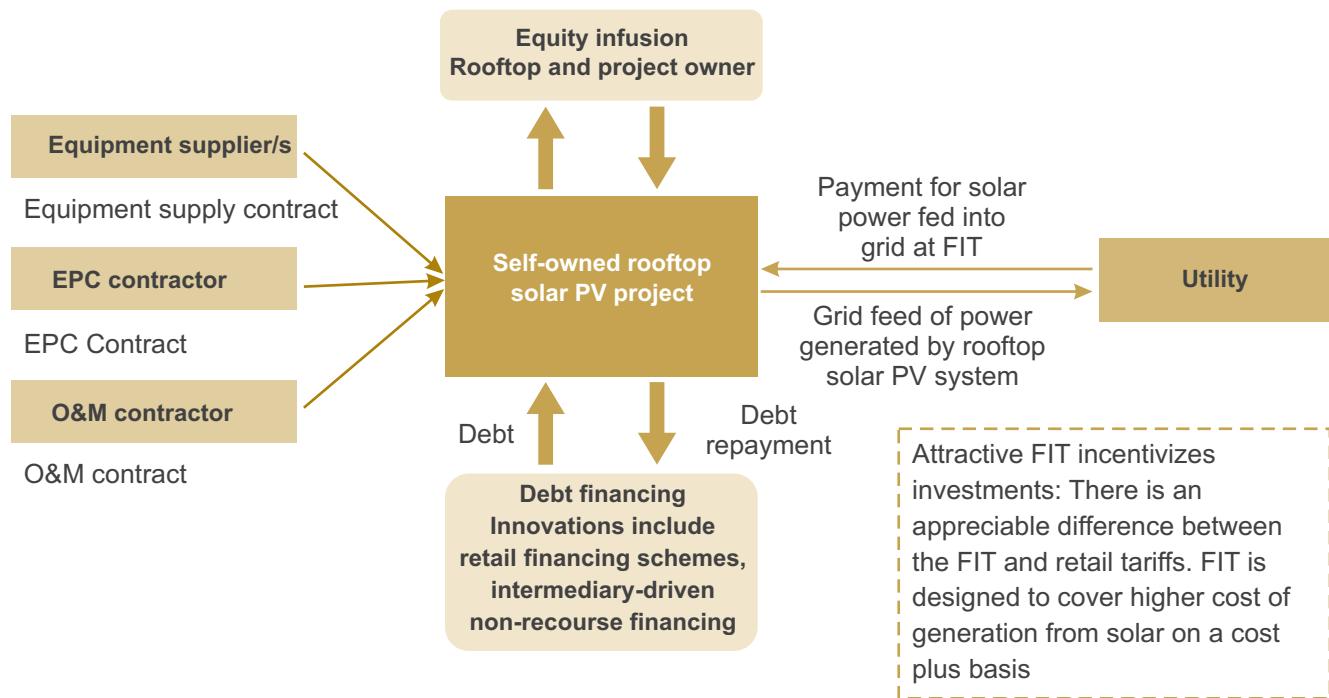
### Sub-model 3: Self-owned rooftop solar PV installations: Grid feed (gross-metering)

- Description:** In this sub-model (figure 13), the rooftop owner installs the system, which generates and supplies energy entirely into the grid. The system can be supplied and installed by specialized intermediaries who provide complete engineering, procurement, and construction services. The generator is compensated at a pre-determined FIT approved by the regulator. Countries that have adopted gross-metering/FIT models include Germany, Italy, and Spain.
- Applicability/key consumer segments:** With a clear FIT specified, the scheme can be adopted by anyone owning a suitable rooftop. In practice, the market gets shaped over time by intermediaries, since rooftop owners may have little knowledge or means to develop and finance rooftop solar installation and maintenance.

- **Pros and cons:** The primary benefit of this sub-model is that project economics and commercial mechanisms can be worked out with certainty for investors. Intermediaries or third-party marketers can play a more active role in this sub-model as the primary customer is the utility and tariff payments can be securitized, offering opportunities for intermediaries to innovate on supply, financing, development and maintenance of solar systems for home-owners. The primary criticism of a gross-metering-based approach is that it does not offer any opportunity for rooftop owners to use the solar power produced for their own use thereby losing opportunities to reduce grid costs. Also, as the FIT gets compared with wholesale electricity prices, which are much lower than average retail tariffs, gross-metering-based systems take longer to achieve grid parity and thus require longer periods of financial support from the government.
- **Tariff methodology, financial incentives, and regulatory regime:** Permit provisions for gross-metering have to be specified by the regulator with a clear, well-differentiated FIT for gross-metering-based rooftop solar systems. Rooftop systems do not compare favorably with centralized, large-scale projects as the cost of generation is higher, thus requiring rooftop FIT to be set up separately from ground-mounted projects. In India, where renewable purchase obligation and FIT are applied concurrently to encourage renewable energy projects, gross-metering-based rooftop solar projects require a specific renewable purchase obligation along with differentiated FIT.

Germany was the first country to try out FIT. It resulted in a significant expansion of the market for rooftop solar PV projects. Appropriate facilitating interventions by the government helped ensure its overall success. These included soft loans and investment incentives, fiscal incentive programs, tax incentives, and export promotion programs (refer section titled, Facilitating Private Sector Participation in Rooftop Solar PV, for more details). For example, the German Renewable Energy Act, 2000 gave priority to solar for access to the grid (transmission and distribution networks), mandating grid operators to purchase electricity produced from solar and other renewable energy sources. Planning and permit procedures for smaller-scale PV installations ( $\leq 5$  kilowatt) are also fairly simple under existing regulations. Financing of such projects in Germany has also been possible through the securitization of the tariff stream.

**Figure 13: Self-owned rooftop solar PV installations: Grid feed (gross-metering)**



## Third-Party-Owned Rooftop Solar PV Installations

Rooftop solar PV systems owned by third parties are widespread in the U.S. In this model, large third-party developers own solar generation systems installed on public or private rooftops. The third party can either lease the system to the rooftop owner for her/his own use or generate electricity from the system and sell it to the grid. Third-party developers are typically specialized solar industry players with better understanding of solar PV systems. They can access specialized financing at lower costs, better manage technical risks, and make use of economies of scale to take advantage of government incentives more efficiently. Third-party developers typically manage all aspects related to installation of the systems, and are responsible for their ownership, long-term operation, and maintenance.

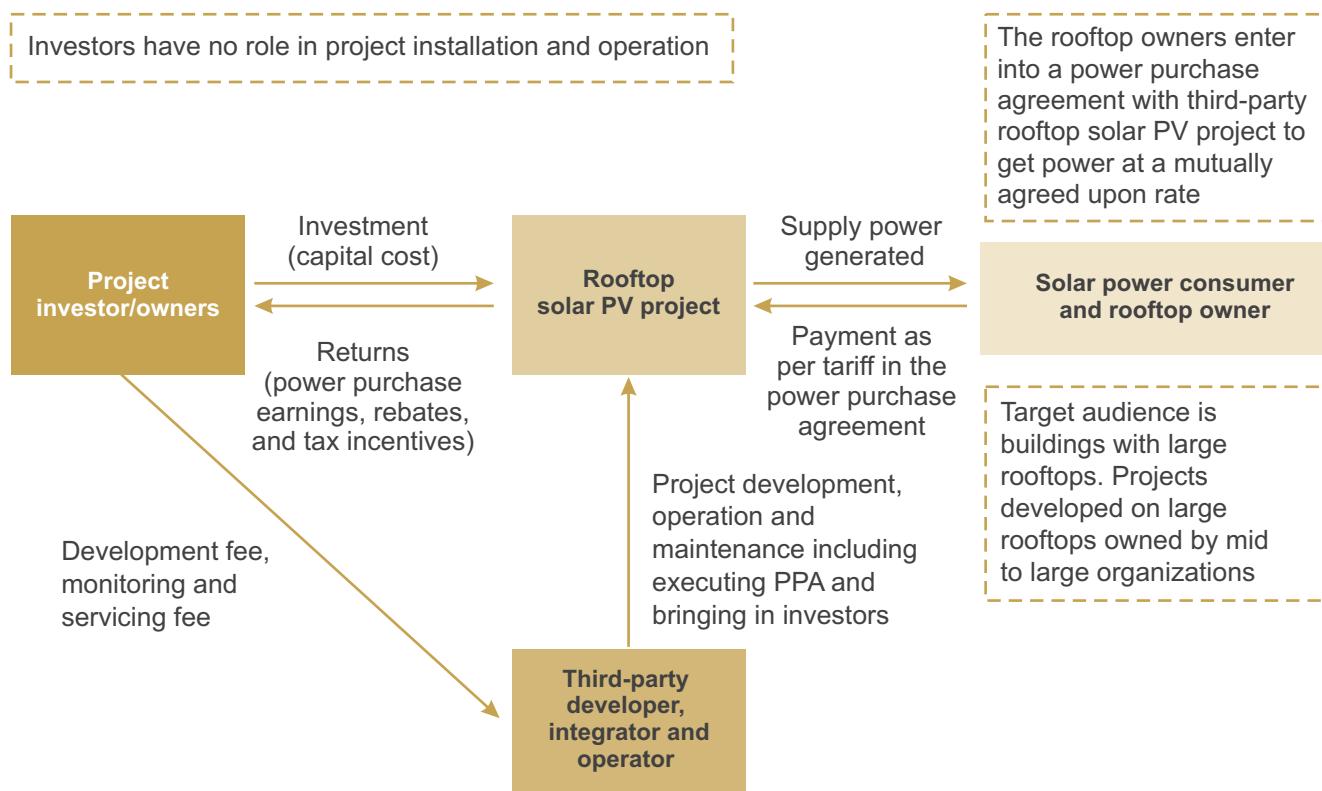
The rooftop owner's involvement is limited to providing roof space and, in some cases, purchasing some or all of the electricity generated from the system.

Since such projects involve large third parties, financing is not a significant concern. Large and established intermediaries are better able to tap into the benefits of incentives and tax credits offered by the government and finance the balance capital costs through a blend of equity and debt. The third party then supplies solar energy at a rate below the retail tariff under a power purchase agreement.

#### **Sub-model 4: Third-party-owned, large individual rooftops, no grid feed**

- **Description:** This sub-model (figure 14) is prevalent mostly in the U.S. Here, the rooftop owner enters into an agreement with a third-party project developer on a build-own-operate model. The developer sells the electricity generated to the rooftop owner at a fixed price under a long-term power purchase agreement. Rooftop owners, thus, avoid the large upfront costs of solar development while procuring clean green energy at a levelized tariff over the long term. A well-known example of this model is SunEdison LLC's agreement to supply power to Wal-Mart Stores using the company's rooftops at several locations. Under the agreement with Wal-Mart, SunEdison finances, owns, builds and operates the solar energy systems. The solar energy systems are leased out to the retailer under a power purchase agreement (at a pre-specified tariff) which generally requires no capital outlays from the retailer. Wal-Mart wishes to utilize 100 percent green energy for its retail stores. It also gains by paying lower tariffs for its power.
- **Applicability/key consumer segments:** This is primarily applicable to large commercial/institutional consumers with adequate rooftop space. Time-of-use tariffs can make this sub-model particularly attractive to consumers if peak tariffs and consumer loads tend to coincide with solar generation hours.
- **Pros and cons:** The primary benefit of this sub-model is that it offers the opportunity to rooftop owners to lower electricity costs. This sub-model is quite successful in markets which have high electricity tariffs and where 'time-of-use tariffs' makes it even more expensive during peak hours, which coincide with solar generation hours.
- **Tariff methodology, financial incentives, and regulatory regime:** These implementation models require regulatory permissions for third-party owners to claim available fiscal incentives (for example, tax credits in the U.S.) for rooftop solar projects operating without interacting with the grid. Under existing laws in India, for such a sub-model to work, either the consumer would need to be large enough (connected load in excess of one megawatt or any lower value permitted by the appropriate regulator from time to time), or own the system to qualify as a captive consumer.

**Figure 14: Third-party-owned large individual rooftops without grid feed**

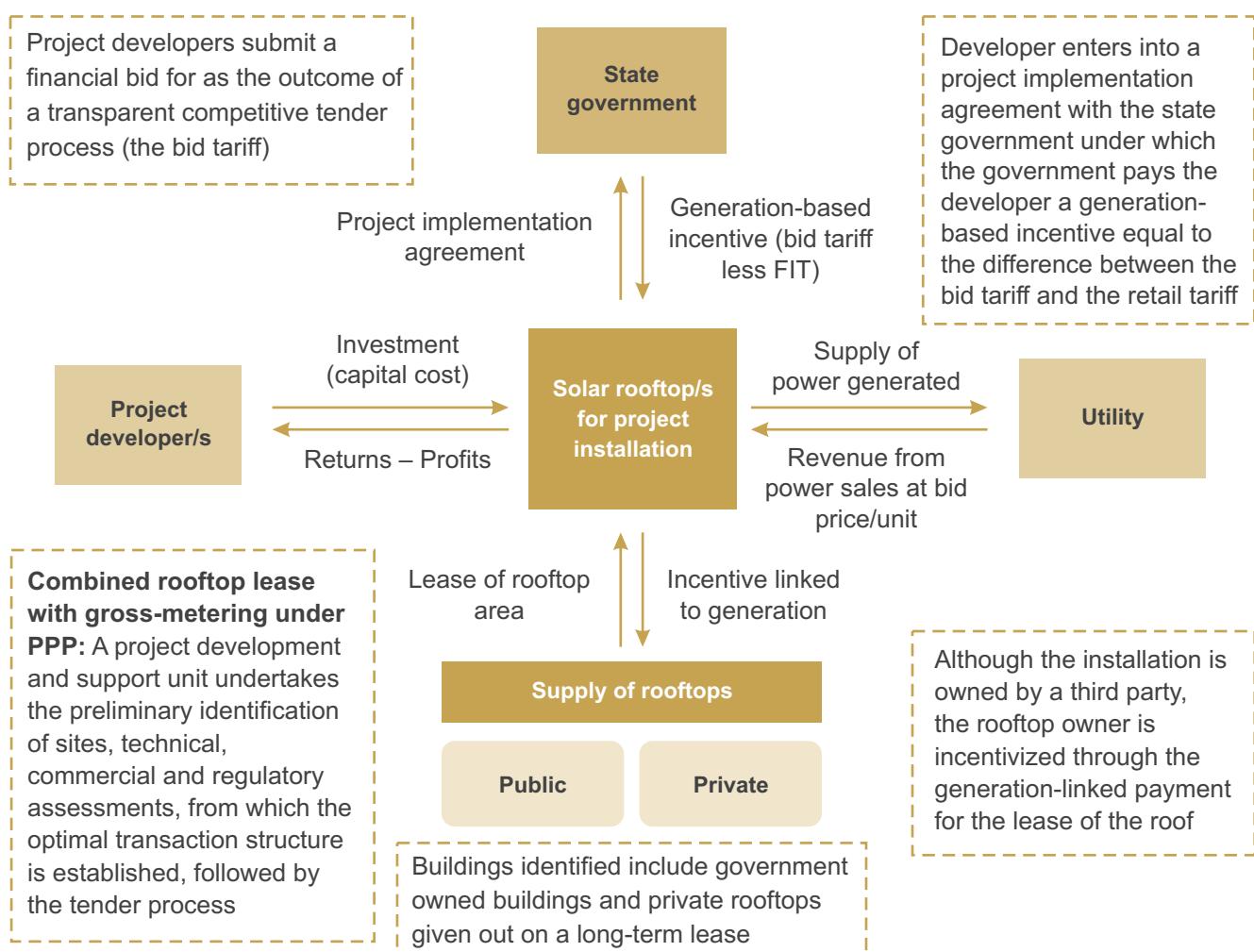


#### **Sub-model 5: Third-party-owned, combined rooftop lease with grid feed (gross-metering)**

- Description:** In this sub-model (figure 15), the developer implements the project by aggregating and leasing out several individual rooftops to reach an acceptable project size. This model lends itself well to be developed as public-private partnerships (PPP), undertaken by large and experienced developers. Energy generated from these projects is fed entirely into the grid. The project developer makes the entire upfront investment to set up the systems, and is compensated at pre-determined tariffs approved by the regulator or as per the PPP contract. The supply of rooftops is a mix of those identified and provided by the public authorities and private rooftops that the project developer has to identify and lease from rooftop owners. Typically, these contracts are for 25 years. Rooftop owners who lease out rooftops are compensated through rents, which can be fixed per month or incentive linked to generation from the system.
- Applicability/key consumer segments:** This sub-model can be implemented across all categories of consumers although developers would prefer to lease out large rooftops to save on transaction costs associated with dealing with a large number of small rooftop owners.

- **Pros and cons:** The primary benefit of this sub-model is that it leverages the technical skills and experience of large and reputable developers. Their involvement demonstrates technical feasibility and financial viability of such projects. If the government is willing to offer its own rooftops, large-scale rooftop solar projects (for an entire city for instance) can be successfully structured as a public-private partnership. This will help establish policy, regulations, and technical standards that will encourage a rapid proliferation phase. This sub-model works best in the early stages of rooftop development and should ideally jump-start a self-replication phase.
- **Tariff methodology, financial incentives, and regulatory regime:** Very often policies, regulations, and standards are not fully developed when these projects are conceived. The primary objective of furthering such projects is that enabling frameworks get established with support from government, regulators, and utilities.

**Figure 15: Third-party-owned, combined rooftop lease with grid feed (gross-metering) under a public-private partnership contractual relationship**



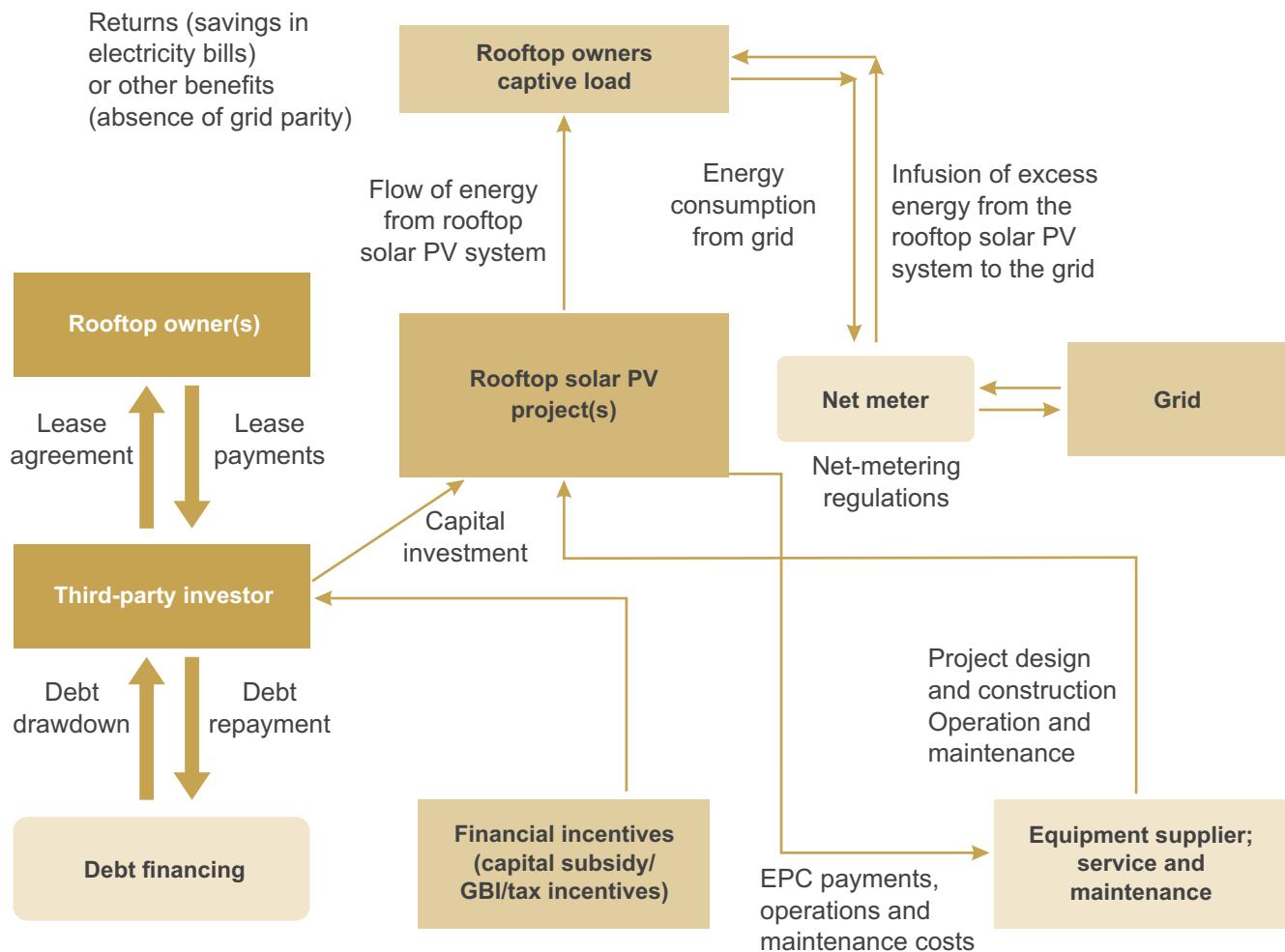
## **Sub-model 6: Third-party-owned captive generation and consumption, with excess power fed into the grid (net metering)**

- **Description:** In this sub-model (figure 16), the rooftop owner leases out the rooftop to a third-party investor who invests capital to install and operate the rooftop solar PV system, either independently or through a third-party supplier/financier. The energy flow in this model is similar to sub-model 2 (under self-owned net metering) where the energy generated by the system is first used to service captive loads within the consumer's premises. Excess power is fed into the grid through a bi-directional meter (net meter). The positive net generation received by the grid is credited to the owner's account and adjusted against consumption from the grid over a defined settlement period. The rooftop owner benefits from savings in electricity bills while the third-party investor is paid by the rooftop owner (either through a lease agreement and/or through a power-purchase agreement). In the absence of grid parity, the third party also benefits from financial incentives such as capital subsidies or generation-based incentive schemes, renewable energy certificates, and/or special tax incentive schemes allowed by governments.
- **Applicability/key consumer segments:** The viability of this sub-model is similar to sub-model 2 and is linked to retail tariffs applicable to the rooftop owner/consumer. It is more attractive to those consumers who pay higher retail tariffs. In India, this model would be good for commercial and industrial consumer segments where tariffs are high when compared to costs of generating solar energy, with minimal or no fiscal incentives from the government. However, for other consumer segments such as residential and agricultural, incentives like capital subsidy, generation-based incentive, tax incentives or other financial incentives are necessary to attract third-party investors.
- **Pros and cons:** The primary benefit of this sub-model is the leveraging of technical skills and experience of large and reputable developers to implement and operate rooftop solar PV projects. The large-scale development by private developers contributes to demonstration of technical feasibility, economies of scale, and financial viability. If the government is willing to offer its own rooftops, large-scale rooftop solar projects (for an entire city for instance) can be successfully structured as a public-private partnership. Such structures help establish policies, regulations, and technical standards that encourage a rapid proliferation phase. Pilot projects will lead to establishing clear permit provisions that will allow rooftop solar PV systems to interconnect and operate with the distribution grid. It will also establish metering schemes including a net meter. However, for the automatic rollout of this sub-model in consumer categories where the tariffs are

low, other financial incentives need to be offered so as to make a business case for third-party developers. Savings for rooftop owners through lease agreements or power-purchase agreements may not be sufficient to generate enough returns for private investors.

- **Tariff methodology, financial incentives, and regulatory regime:** Very often policies, regulations and standards are not fully developed or not developed at all when such projects are conceived. The primary objective of furthering such projects is to establish frameworks with support from the government, regulators, and the utilities. Once established, these frameworks can propel rooftop solar development towards a self-replicating phase.

**Figure 16: Captive generation and consumption, with excess power fed into the grid (net metering), possible public-private partnership contractual relationship**

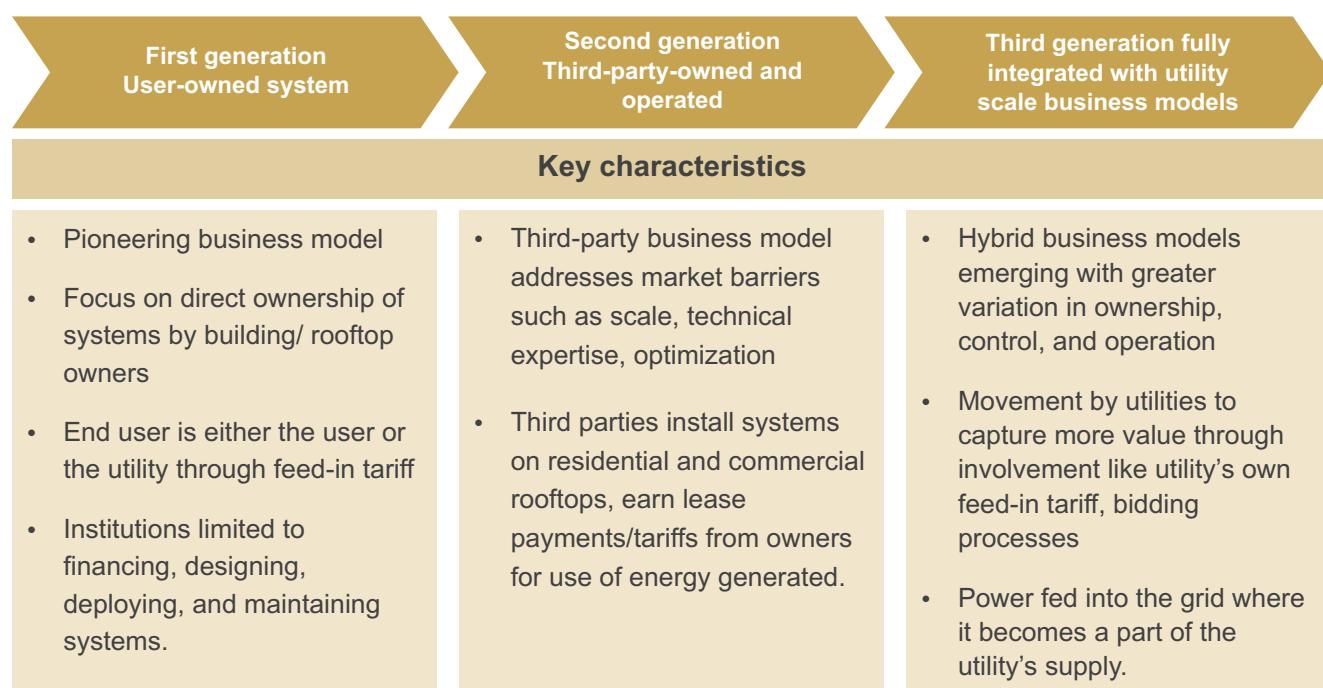


## Evolution of Models

The exploration of this new market segment generally starts with customer-driven models. Utilities are generally passive actors, with roles limited to providing net metering and roll out of standardized and simplified interconnection schemes mandated by regulatory requirements. Utilities have no role in system operations in these first-generation models. However, with growing solar PV market penetration, the scale of solar energy generated has an impact on grid operations, grid planning, and utility profitability. This has led utilities to increase their participation in customer-based projects through third-party providers of turnkey contracts or specialized services. This transition to second generation models is highlighted in figure 17. Large markets for decentralized solar project developments include Australia, Germany, Japan, and the U.S. Of these, the U.S. is the most active in developing all three options. This is because tax rebates and incentives available in the country encourage third-party players to enter the market.

Ultimately, the market model reaches a fully integrated utility-scale approach, or third-generation model that is characterized by utilities being in the driving seat and rooftop solar PV installations becoming a fully integrated part of their businesses. Examples of this are found in Germany, Japan, and the U.S.

**Figure 17: Evolution of decentralized solar PV models**



A comparative assessment of the applicability of different models in different market conditions is displayed in table 5.

**Table 5: Comparative assessment of the applicability of different models in different market conditions**

Implementation model	Sub-model	Metering	Attractive feed-in tariff	High retail tariff	Presence of tax rebates and incentive programs	Time-of-day metering	Suitability for project financing
Self-owned	Captive with no grid feed	Not mandatory		✓	✓	✓	
	Grid feed (gross metering)	Gross	✓				✓
	Grid feed (net metering)	Net		✓	✓	✓	
Third-party-owned	Large individual rooftops with no grid feed	Not mandatory		✓	✓	✓	✓
	Individually-leased systems with grid feed (net metering)	Net		✓	✓	✓	
	Combined leased rooftops with feed into the grid (gross metering)	Gross	✓				✓

\* The type of financing required may vary according to implementation model.

Solar leasing offers creditworthy customers the benefit of rooftop solar PV without incurring the upfront costs associated with financing, installing, and operating the panels themselves. For solar leasing schemes to be effective, well-defined standards are needed to evaluate solar systems and assess their suitability for financing. The evaluation will look into use of certified systems, credible and pre-approved installers, appropriate insurance, and operations and maintenance packages.

Solar leasing companies, in developed markets such as California, arrange financing by aggregating large numbers of small projects to attract potential investors (private equity and commercial lenders). Leasing companies require scale and efficiency to be viable and have historically invested much more in customer acquisition than traditional installers. It is thus critical for such companies to reduce costs of acquiring consumers and installing systems through standardized assessing of credit-worthiness (for example, leasing companies in the U.S. use FICO<sup>19</sup> scores to qualify consumers), using certified systems, pre-approved installers, etc. The role of public finance to jump start lease financing options is critical and can help scale up programs significantly. Permits, inspection, and interconnection-related delays, while acting as barriers to leasing companies, are often more effectively managed by them, as they have more scale, resources, and incentives to manage these processes compared to individuals.

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<sup>19</sup> FICO scores are credit rating scores assigned to individuals by credit rating agencies based on re-payment history. These scores are used to assess credit worthiness of individuals seeking financing by lenders and financiers for various forms of product financing (for example: car loans, home loans, and credit cards)



## THE INDIAN EXPERIENCE WITH ROOFTOP SOLAR PV DEVELOPMENT

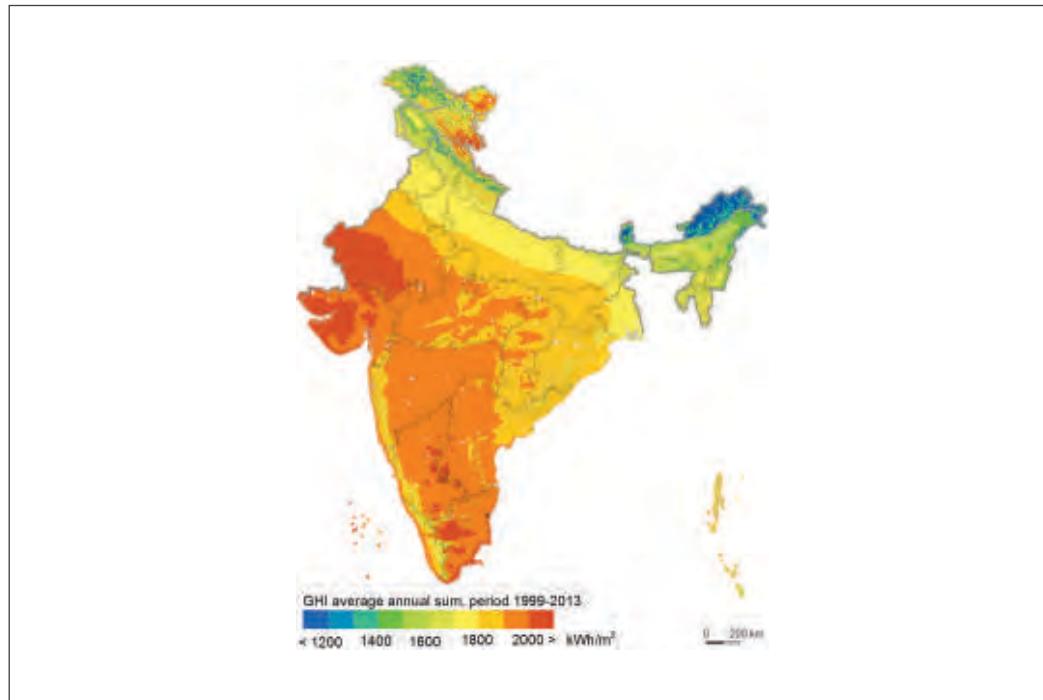
Indian presence on the global solar energy scene started in 2008 with the launch of the Government of India's National Action Plan on Climate Change (NAPCC), which stressed the need for widespread diffusion of renewable energy technologies in India with specific focus on solar energy. India is endowed with rich solar energy resources. Being a tropical country, it has significant potential for solar power generation. India receives on an average 4-7kWh/m<sup>2</sup> of solar energy daily with an average of 250-300 sunny days in a year. Image 1 shows solar radiation levels in different parts of India. Images 2, 3, and 4 show solar radiation levels in different parts of Japan, Germany and the U.S.



Photo: Sivaram Krishnamoorthy

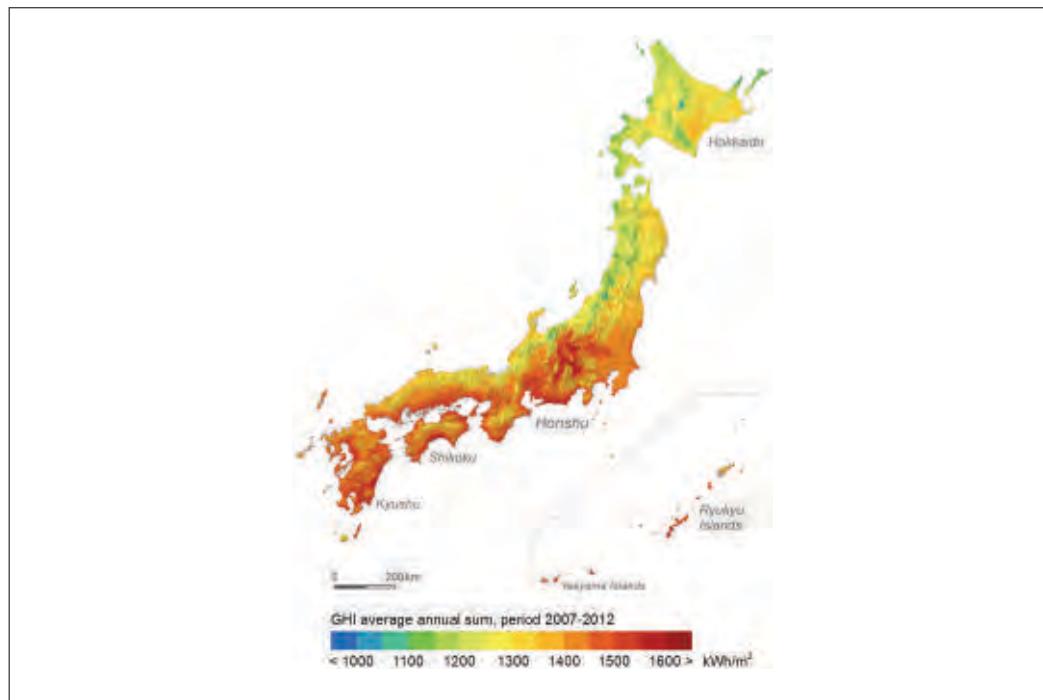


**Image 1: Solar resource map for India**



This map was created by the National Renewable Energy Laboratory for the U.S. Department of Energy.

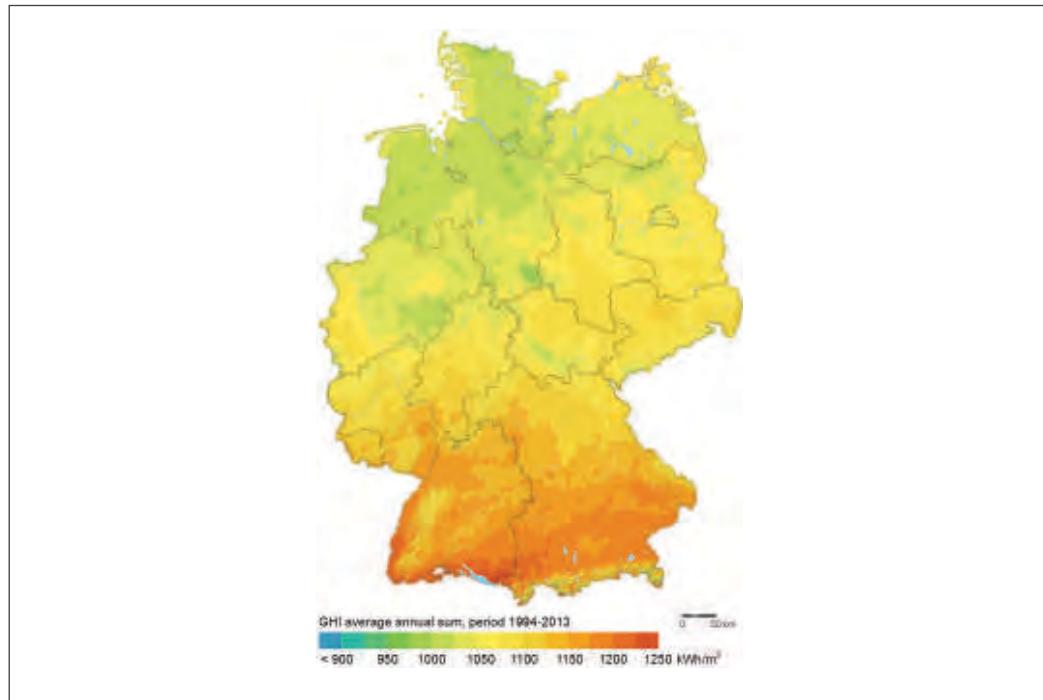
**Image 2: Solar resource map for Japan**



Courtesy: SolarGIS Global Horizontal Irradiation Map (c) 2014 GeoModel Solar

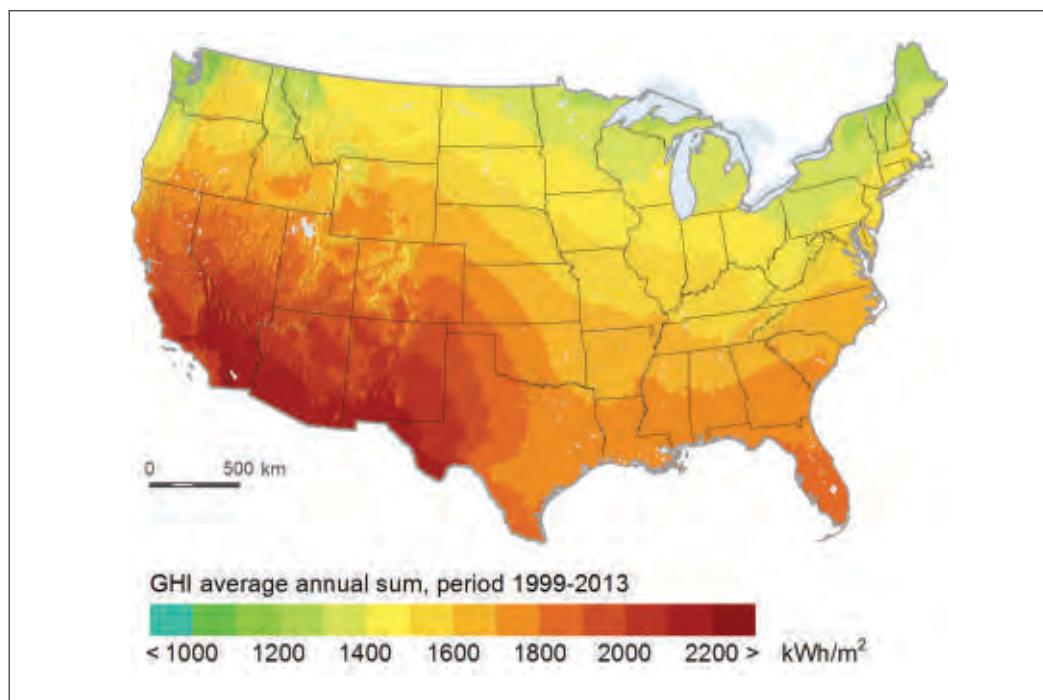


**Image 3: Solar resource map for Germany**



Courtesy: SolarGIS Global Horizontal Irradiation Map (c) 2014 GeoModel Solar

**Image 4: Solar resource map for the U.S.**



Courtesy: SolarGIS Global Horizontal Irradiation Map (c) 2014 GeoModel Solar

Recognizing the wide availability of solar resources in the country and the range of applications possible, the government of India identified development of solar energy as a thrust area to enhance India's energy security and combat climate change. The Jawaharlal Nehru National Solar Mission (JNNSM) was launched under the NAPCC to significantly increase the share of solar energy in India's energy mix. Launched in January 2010, it encouraged a number of states, including Gujarat, Karnataka, and Rajasthan, to develop their own solar energy policies. Today, JNNSM and the Gujarat state solar policy are key initiatives leading the way for solar development in India.

As a result of those policy efforts, India has added over a gigawatt capacity of solar energy in the last three years and has reached an installed capacity of 2,632 megawatt.<sup>20</sup> The government of India plans to add around 20 gigawatt of solar power generation capacity over the next decade. The draft guidelines for JNNSM's second phase sets a target of 1,000 megawatt of rooftop projects both at off-grid and grid-connected levels during 2013-17. MNRE launched a pilot scheme in 2013 for grid-connected rooftop PV power projects, which is being implemented by the Solar Energy Corporation of India.<sup>21</sup> The scheme allows system sizes from 100kW to 500kW and aggregation of capacity from smaller roofs. Under the scheme, 30 percent of the cost is provided as subsidy and 70 percent is to be met by the consumer, with surplus solar power to be fed into the grid. India has decided to follow the dual path approach by provisioning schemes and programs that encourage development of large-scale grid-connected projects as well as small and medium ground-mounted and rooftop-based projects. Although national and state policies have successfully kick-started the development of utility-scale solar power projects in India, the small-scale segment is still in a nascent stage of development.

In 2010, the Gujarat government initiated its rooftop solar program and chose Gandhinagar to be developed as a model solar power city. To achieve this goal, it decided to promote the development of distributed rooftop-based solar PV projects, and to start with a pilot project in that city. The state implemented two pilot projects through a public-private partnership (PPP) route to prove concepts,

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<sup>20</sup> Ministry of New and Renewable Energy, Government of India, April 2014: State-wise solar installed capacity break-up, [http://mnre.gov.in/file-manager/UserFiles/workshop-Solar-RPO\\_RECs-Framework-IE-24042014.htm](http://mnre.gov.in/file-manager/UserFiles/workshop-Solar-RPO_RECs-Framework-IE-24042014.htm), accessed on June 20, 2014

<sup>21</sup> Solar Energy Corporation of India (SECI) was set up on September 20, 2011, as a not-for-profit company under Section-25 of the Companies Act 1956 as an implementation and facilitation institution dedicated to the solar energy sector. SECI is established under the administrative control of the Ministry of New and Renewable Energy, Government of India. SECI's mandate allows wide-ranging activities to be undertaken with an overall view to facilitate implementation of JNNSM and achieve the targets set therein. The Corporation has the objective of developing solar technologies and ensuring inclusive solar power development throughout India.

help firm up policy and regulatory frameworks, and develop a potential developer base. These pilot PPP projects are envisaged to lead market transformation towards self-replication of rooftop projects in the city, and beyond. Following its success in Gandhinagar, the Gujarat government is in the process of scaling up the initiative in five cities across the state, namely, Bhavnagar, Mehsana, Rajkot, Surat, and Vadodara.

Besides Gujarat, no major grid-connected rooftop solar PV projects of megawatt scale has been implemented in India, despite provisions being made in states' tariff orders for rooftop solar systems. However, a few initiatives have been launched recently in this market. Rooftop solar PV deployment in India is impacted by the lack of distinct policy and tariff frameworks that address specific requirements of the sector vis-à-vis large grid-connected MW-scale projects. Solar power is primarily used to meet renewable purchase obligations of distribution utilities, either through a feed-in tariff or competitive procurement based on auctions.

International experience indicates that rooftop solar PV installations have played a significant role in solar capacity development. For example in 2011, 60 percent of all solar generation capacity added in Germany was through rooftop solar projects. Today, German rooftop solar installations number more than one million. Likewise in Japan, the solar program has grown primarily through rooftop installations and more recently by incorporating solar cells into the façades of buildings, complementing or replacing traditional view or spandrel glass.<sup>22</sup> Some of the key factors supporting the expansion of rooftop solar PV installations are:

- The sector's ability to proliferate under conducive policy and enabling regulatory environments
- The absence of land-related issues
- The ability of rooftop solar PV projects to feed directly into load centers, thus reducing transmission and distribution losses and avoiding costly transmission evacuation infrastructure.

The objective of this section is to trace the path being followed by India to develop its solar market, with rooftop installations in particular, and highlight potential areas of focus for future development.

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<sup>22</sup> Spandrel glass is an architectural material used to cover construction materials, disguise features like arches and columns, and present a finished, seamless, and sleek exterior to buildings.

## National and State-Level Policies

In India, JNNSM has identified rooftop solar PV as one of the three broad categories of solar projects to be encouraged. It states as follows.

*"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<sup>23</sup> per kWh with 3 percent p.a. escalation."*

In June 2010, MNRE 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 6.

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<sup>23</sup> \$0.09

**Table 6: Select state rooftop solar policies and targets for rooftop solar power generation**

Parameter	Type	Capacity target	Incentives for rooftop owner	Metering
Gujarat	Grid-connected	5 megawatt in Gandhinagar <sup>24</sup>	Incentive linked to rooftop solar power generation	Gross
Karnataka	Grid-connected	250 megawatt	Tariff of Indian rupees 3.40 (\$0.06) per kilowatt hour	Net
Tamil Nadu	Grid-connected	350 megawatt	Generation-based incentive of Indian rupees 2 (\$0.03) per kilowatt hour for the first two years; Indian rupees 1 (\$0.02) per kilowatt hour for the next two years and Indian rupees 0.50 (\$0.01) per kilowatt hour for subsequent two years	Net
Andhra Pradesh	Grid-connected	-	-	Net
Uttarakhand	Grid-connected	5 megawatt	Feed-in tariff of Indian rupees 9.20 (\$0.15) per kilowatt hour	Net
Kerala	Grid-connected	10 megawatt	Indian rupees 93,000 (\$1541.52) per 1 kW system	Net

**Source:** Respective state government solar policy documents

Despite significant thrust given to rooftop solar in policy frameworks in Rajasthan, Tamil Nadu, Karnataka, and Madhya Pradesh, and successful initiatives in Gujarat, Karnataka, and Tamil Nadu, these policies do not outline a clear roadmap. As a result, there is no detailed implementation framework, including permit mechanisms, technical codes, and commercial arrangements. India's rooftop solar PV potential thus remains largely unexploited due to these deficiencies in the enabling environment.

The Central Electricity Regulatory Commission issued draft tariff guidelines for rooftop solar PV plants (projects of capacity of less than 2 megawatt) in June 2010. Several state electricity regulatory commissions issued orders that put the tariffs for large ground-mounted projects at par with those of small-scale rooftop solar PV projects. However these uniform tariffs do not adequately reflect the cost difference between the two types of installations and tariff expectations. State regulators have begun to acknowledge this difference, and have specified differentiated tariffs accordingly. Table 7 summarizes differentiated tariffs in the three states that have recognized this difference, namely Gujarat, Madhya Pradesh, and Maharashtra.

<sup>24</sup> Additional 25 megawatt is proposed to be developed under the ongoing replication project covering five cities in Gujarat (Bhavnagar, Mehsana, Rajkot, Surat, and Vadodara).

**Table 7: FIT framework for ground-based and rooftop-based solar project development  
(applicable in fiscal year 2013)**

State	Large grid-based solar PV tariff (not availing AD)	Rooftop solar PV tariff (not availing AD)	Large grid-based solar PV tariff (availing AD)	Rooftop solar PV tariff (availing AD)
Gujarat	Indian rupees 9.64 (\$0.16)	Indian rupees 11.57 (\$0.19)	Indian rupees 8.63 (\$0.14)	Indian rupees 10.36 (\$0.17)
Madhya Pradesh	Indian rupees 15.35 (\$0.25) (for plants > 2 megawatt)	Indian rupees 15.49 (\$0.26)	Indian rupees 14.38 (\$0.24) (for plants > 2 megawatt )	Indian rupees 14.08 (\$0.23)
Maharashtra	Indian rupees 8.98 (\$0.15)	Indian rupees 9.48 (\$0.16)	Indian rupees 7.69 (\$0.13)	Indian rupees 8.19 (\$0.14)

\*AD - Accelerated Depreciation: The Indian government allows for accelerated depreciation at the rate of 80 percent on a written-down value basis for various renewable energy items under Section 32, Rule 5 of the Income Tax Act. Accelerated depreciation is limited to solar and, in some cases, biomass projects across India.

**Source:** Tariff orders issued by respective state electricity regulatory commissions

Rooftop solar projects in India started as captive projects, most availed capital subsidies from the government. In almost all cases, solar developers played the role of engineering, procurement, and construction (EPC) contractors, and still do. However, it did not witness the growth of the ground-mounted segment. More recently, different models where energy is fed into the grid availing benefits other than capital subsidies have started to emerge. The rooftop solar program of Gujarat is one such. Here the concept of "feed-in tariff" based on "gross-metering" as an incentive has been introduced for the first time in India. The project has shown that the private sector can perform the long-term role of a developer - in addition to engineering, procurement, and construction roles - when facilitated with the appropriate framework.

Andhra Pradesh, Tamil Nadu, Karnataka, and Uttarakhand have also drafted state-specific regulations and guidelines including enabling provisions that encourage the private sector to further this role. 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 without open access or wheeling charges. A conducive policy and regulatory framework is therefore emerging, which is 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 project across the country under gross metering or captive schemes. This is attracting the private sector.

Hemant Bhatnagar, Senior Advisor in ComSolar, a project under Indo-German Energy Program of GIZ, says, "Rooftop solar photovoltaic energy is a promising alternative that addresses the increasing demand for electricity, while reducing dependence on fossil fuel-based generation. Many countries across the globe, have formulated encouraging policies to promote rooftop solar markets. Germany is the leader with approximately 65 percent of capacity implemented on rooftops, followed by Japan and Italy where new markets for rooftop solar facilities are emerging. Major development in the solar segment in India was witnessed after the setting up of the National Solar Mission. The government has successfully concluded phase I of the mission and has started formulating schemes for phase II."

"As expected desired attention has been given to rooftop solar, both in grid-connected and off-grid segments. A few states, including Uttar Pradesh, Madhya Pradesh, and Delhi, have started discussing the formulation of separate policies to encourage rooftop solar photovoltaic projects in their respective states. Even the distribution licensee of Madhya Pradesh is encouraging the implementation of rooftop solar projects to comply with solar purchase obligations. Considering the geographic size of the country India has huge potential for the implementation of rooftop solar projects if encouraging policies are appropriately formulated and, more importantly, complied with by stakeholders."

The proof-of-concept stage is most critical to pave the way to sustainable large-scale development. For this, India can rely on several demonstration and pilot rooftop solar projects that have, in the last few years, established technical feasibility for both captive and grid-connected systems with the participation of private sector players. Table 8 presents projects which contributed to proving sustainability of the concept. Apart from these, nodal agencies in states such as West Bengal, Punjab, and Gujarat have successfully deployed captive rooftop solar PV systems on government buildings.

**Table 8: Private and public sector rooftop solar PV projects in India**

Project	Developer or asset owner	Power-purchase agreement or tariff	Capacity in kilowatt	Remarks
Rooftop Solar PV Project, New Delhi	New Delhi Power Limited	Tariff based on the rooftop solar PV policy of Delhi*	1000	Grid-connected model with FIT and capital subsidy under solar PV policy of Delhi. Developed on multiple rooftops
Thyagaraj Sports Complex, Delhi	Reliance Industries Ltd., RIL Solar Group	Tariff under rooftop solar PV policy of Delhi	1000	Grid-connected model with FIT and capital subsidy under solar PV policy of Delhi
SunPV Energy Project, Bangalore	SunPV Energy	Power purchase agreement with Bangalore Electricity Supply Company Limited	2	Grid-connected net-metering model with capital subsidy. Per unit tariff for surplus power fed to the grid is around Indian rupees 6 (\$0.10)
Mahindra Solar Project, Chennai	Mahindra Solar	Capital subsidy under JNNSM off-grid scheme	75	Off-grid system for diesel abatement with capital subsidy under JNNSM off-grid scheme
SunEdison-Standard Chartered Bank Project, Chennai	SunEdison	Power-purchase agreement with building owner	100	Off-grid system with power-purchase agreement (price confidential)
Pandit Deendayal Petroleum University	Gujarat Energy Research and Management Institute	Power-purchase agreement with distribution licensee	15	On-grid system with power-purchase agreement with distribution licensee

\* This policy was later scrapped

"Rooftop solar is typically the most straight-forward option for solar. I would suggest that stakeholders in India approach future solar programs with a clear focus on rooftop solar opportunities," says Todd Hranicka, Director, Solar Energy, Public Service Electric & Gas Company, Newark, New Jersey. He told the authors of this paper, "Rooftop solar was one of the most important components of PSE&G's Solar 4 All™ Program, which was approved by the New Jersey Board of Public Utilities in 2009. We currently have 17.3 megawatts-DC of grid-connected solar capacity installed on roofs and another 2.4 megawatts-DC installed on solar canopies throughout our service territory. We also have 20.3 megawatts-DC of grid-connected ground-mounted solar capacity in our fleet. For our Solar Loan Program, the vast majority of the financing that we provided went towards installing rooftop solar systems."

## Barriers to Rooftop Solar Development in India

Several barriers constrain the development of rooftop solar projects in India. The first phase of JNNSM did not result in any rooftop solar project in spite of a separate scheme for small-sized and rooftop projects. This scheme addressed solar PV projects of a maximum of 2 megawatt on ground or rooftops. The scheme had a maximum capacity limit of 100 megawatt and around 90 megawatt of projects was installed. The projects were to be connected at 33 kilovolt and similar tariffs were fixed for both ground-mounted and rooftop projects. The scheme garnered enthusiastic response in the ground-mounted segment, but almost none in the rooftop segment. Similarly, while solar tariff orders in several states provide for grid-connected rooftop projects, not many have been taken up. Since the same technology and systems are used for both ground-mounted and rooftop projects, the lack of inclination towards the rooftop projects clearly shows that regulatory and grid interconnection issues are hindrances to deployment.

### **Non-recognition of the Capital Cost Difference and hence Lack of Optimized Feed-in Tariff**

The JNNSM scheme fixed similar tariffs for both ground-mounted and rooftop projects. The tariffs were based on notified tariffs of the Central Electricity Regulatory Commission, valid for that year (2010-2011). The Central Electricity Regulatory Commission specified tariff was for solar PV technology, irrespective of mounting system, ground or rooftop. The Gujarat Electricity Regulatory Commission GERD on the other hand, realistically provided different capital costs and tariffs for rooftop projects.<sup>25</sup> The capital costs for rooftop projects was considered a little higher and led to higher tariffs for rooftop projects.

### **Regulatory Uncertainty with Reference to Net Metering**

The ambiguous regulatory framework and the absence of technical guidelines to connect small-scale distributed power generation systems into the grid acted as a barrier to extensive deployment of net metering systems. The net metering arrangement conflicts with some legal clauses in the Electricity Act 2003, including regulations on captive generation and consumption, open access, and renewable purchase obligations. These needed to be addressed through a separate regulation on net metering that was issued in August 2013 by the Forum of Regulators (draft model regulation for rooftop solar grid interactive systems based on net metering). Moreover, net metering requires implementation standards for important parameters like voltage, flicker, synchronization, islanding, and protection.

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<sup>25</sup> Gujarat Electricity Regulatory Commission Solar Tariff order date January 29, 2012

The Central Electricity Authority of India issued a draft regulation on interconnection of small-scale generating systems with the grid late in 2012, which was notified recently. The inability of utilities to pay for excess electricity being fed into the grid is a big issue. The result is generation that is sized exclusively to meet individual building demands, not to meet the overall demands of the system.

### **Lack of Sustainable Business Models**

Although the technology for rooftop solar systems is well proven, the market lacks sustainable business models. Individual households as well as commercial rooftop owners lack knowledge, information, and financial incentives to install these systems to optimal standards. India lacks pilot projects developed jointly by public and private sector, to serve as proof-of-concept to encourage future segment growth.

### **Gujarat Rooftop Solar Initiatives**

Gujarat has a long-term goal of making its capital, Gandhinagar, a solar-powered city. It has already installed 500 megawatt of solar capacity to benefit from over 300 sunny days per year. Most of this is large-scale ground-mounted installations, but 5 megawatt is installed on rooftops. Another 25 megawatt is likely to be installed soon across various cities in the state. Gujarat's rooftop solar program started 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. in particular), small-scale grid-connected rooftop solar projects, such as the pilot in Gandhinagar, are path-finding solutions in India. It is innovative and addresses the challenges and 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, as illustrated in the figure 18.

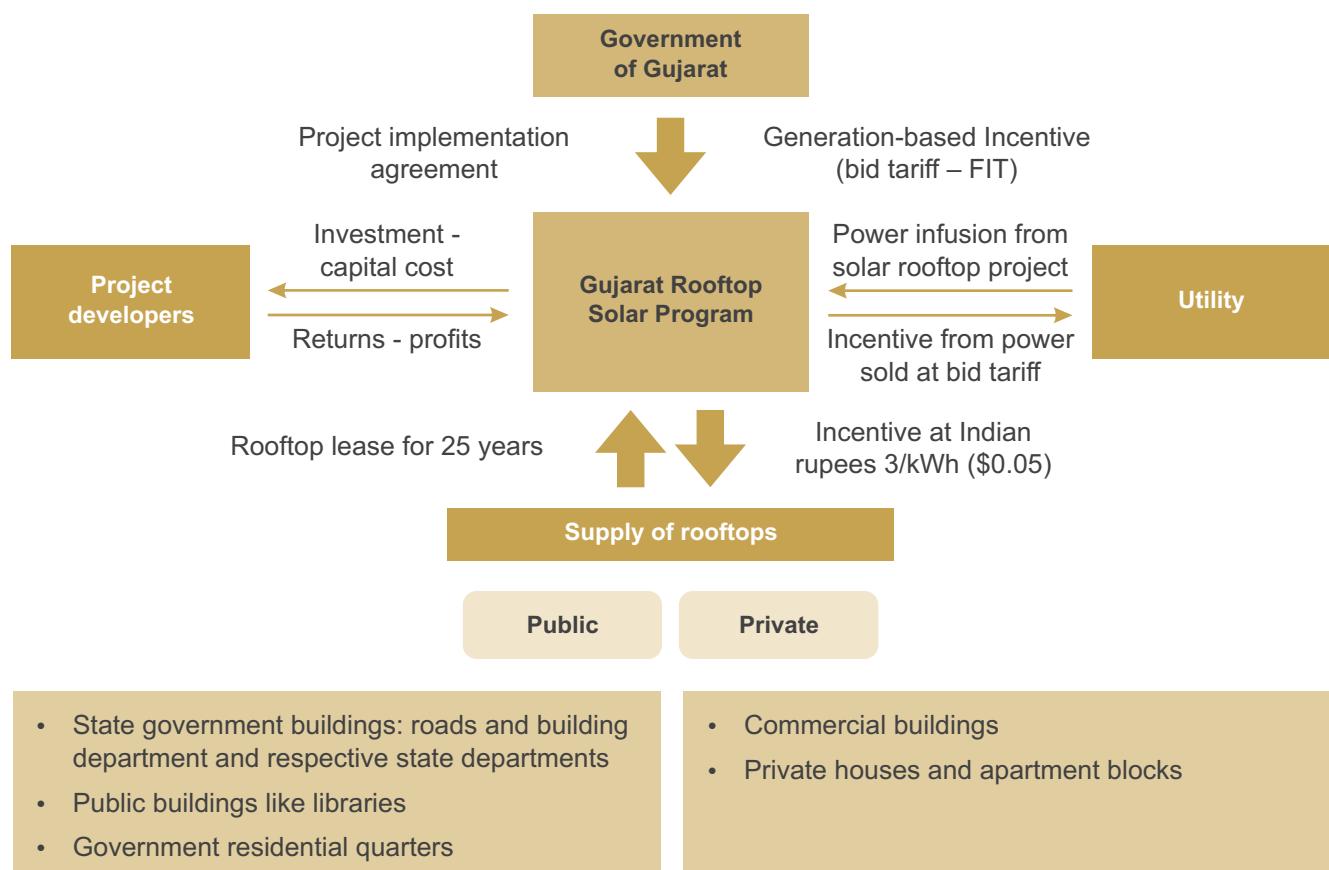
**Figure 18: Factors constraining the scaling up of solar rooftop market in India and possible solutions**

<p><b>Challenge</b></p> <ul style="list-style-type: none"> <li>• No regulatory/policy framework in place yet to implement small grid-connected kilowatt-scale projects</li> <li>• No financing market available yet</li> <li>• Little long-term operation and maintenance expertise with the government and rooftop owners</li> </ul>	<p><b>Solution:</b> Public-private partnership structure</p> <ul style="list-style-type: none"> <li>• Private partner acts as an aggregator of small individual rooftops into a bankable package. Leverages private sector efficiencies in accessing multiple rooftops</li> <li>• Tap into private sector's operation and maintenance competencies and economies of scale</li> <li>• Easier project management</li> </ul>
<p><b>Challenge</b></p> <ul style="list-style-type: none"> <li>• Lack of policy framework enabling net metering</li> <li>• No grid parity</li> <li>• Limited financing</li> </ul>	<p><b>Solution:</b> Gross-metering, generation-based incentives</p> <ul style="list-style-type: none"> <li>• Low implementation risks as compared to net metering where there was no defined policy framework</li> <li>• Developer will install solar panels on rooftops and connect power generated by the panels to the city grid and get generation-based incentive (FIT). Rooftop owners get generation-linked incentive</li> </ul>
<p><b>Challenge</b></p> <ul style="list-style-type: none"> <li>• Lack of conceptual understanding among stakeholders</li> <li>• Grid availability and stability</li> <li>• Interconnection points</li> <li>• Technical specifications of equipment for subsidies</li> </ul>	<p><b>Solution:</b> Technical due diligence</p> <ul style="list-style-type: none"> <li>• In-depth technical due diligence and technical risk assessment.</li> <li>• Consultation and capacity building at the distribution company level</li> <li>• Technical specifications of equipment up to international standards</li> </ul>
<p><b>Challenge</b></p> <ul style="list-style-type: none"> <li>• Financial viability, both from debt and equity perspective, of small-scale projects</li> </ul>	<p><b>Solution:</b> Scale and flexibility</p> <ul style="list-style-type: none"> <li>• Larger project size with broader catchment area</li> <li>• Potential to scale up</li> <li>• Allow for flexible framework, including early exit options</li> <li>• Provide for strong payment security</li> </ul>
<p><b>Challenge</b></p> <ul style="list-style-type: none"> <li>• Residual risk: rooftop availability (especially small, residential)</li> <li>• Limited incentives for small individual rooftop owners (except rentals)</li> </ul>	<p><b>Solution:</b> Adequate risk allocation and incentives</p> <ul style="list-style-type: none"> <li>• Data from the Bhaskaracharya Institute for Space Applications and Geo-Informatics</li> <li>• Opportunity to transfer system ownership to individual rooftop owners in the future, giving them access to preferred FIT</li> <li>• Incentives to rooftop owners: rental payment for idle assets, especially attractive for larger commercial/industrial rooftops</li> <li>• Other incentives for individual owners</li> </ul>

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 megawatt each, or 5 megawatt 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 competitive bids was the power sale tariffs quoted by developers. Azure Power and SunEdison each won a 25 year concession for 2.5 megawatt of installed rooftop solar power in 2012. The projects in Gandhinagar were fully commissioned as of January 2014 and are operational with 4.68 megawatt of installed capacity.

The structure for the Gandhinagar project is depicted in figure 19.

**Figure 19: PPP transaction of Gandhinagar rooftop solar PV pilot project**



The solar rooftop business model, as structured in Gujarat, allows seamless collaboration between 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 was the lead transaction advisor to the government of Gujarat to help structure this pilot project. Along with international technical and legal consulting firms, 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. Besides, 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 9.

**Table 9: Risks, possible impact, and mitigation measures of the Gandhinagar rooftop solar PV pilot project**

Risk	Risk details	Impact on project	Mitigation
Securing adequate rooftops	80 percent rooftops (by capacity) from institutional buildings secured for the project and listed in the request for proposal. Securing rooftops for the balance 20 percent rooftops is challenging and the concept of lease registration is not widely popular.	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 megawatt generation facilities in the state electricity distribution code or grid code.	Local distribution company may impose restrictive interconnection requirements post award of project.	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.

Risk	Risk details	Impact on project	Mitigation
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.
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 megawatt 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 commissions	Delay in procurement, construction and commissioning of the project by the developer in anticipation of a decline 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.

Risk	Risk details	Impact on project	Mitigation
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 payment default, developer is to get termination benefits. Besides, the utility has the regulatory requirement to continue procuring solar power to meet its solar purchase obligations.

After the success of the pilot project in Gandhinagar, the government of Gujarat is supporting the proliferation of the model to five other cities in the state. In this replication, greater flexibility is available for developers and rooftop owners to transfer ownership of plants to rooftop owners, therefore moving towards the model used in developed markets. In addition, other states in India, such as Odisha and Tamil Nadu, are disseminating rooftop solar projects in their cities. Overall, the government of Gujarat's initiative illustrates how the implementation of a pilot PPP model can have a transformational effect on a sector. In particular, it has achieved a number of milestones that will be cornerstone 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
- It puts forward an implementation model, which 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 self-replicating phase.



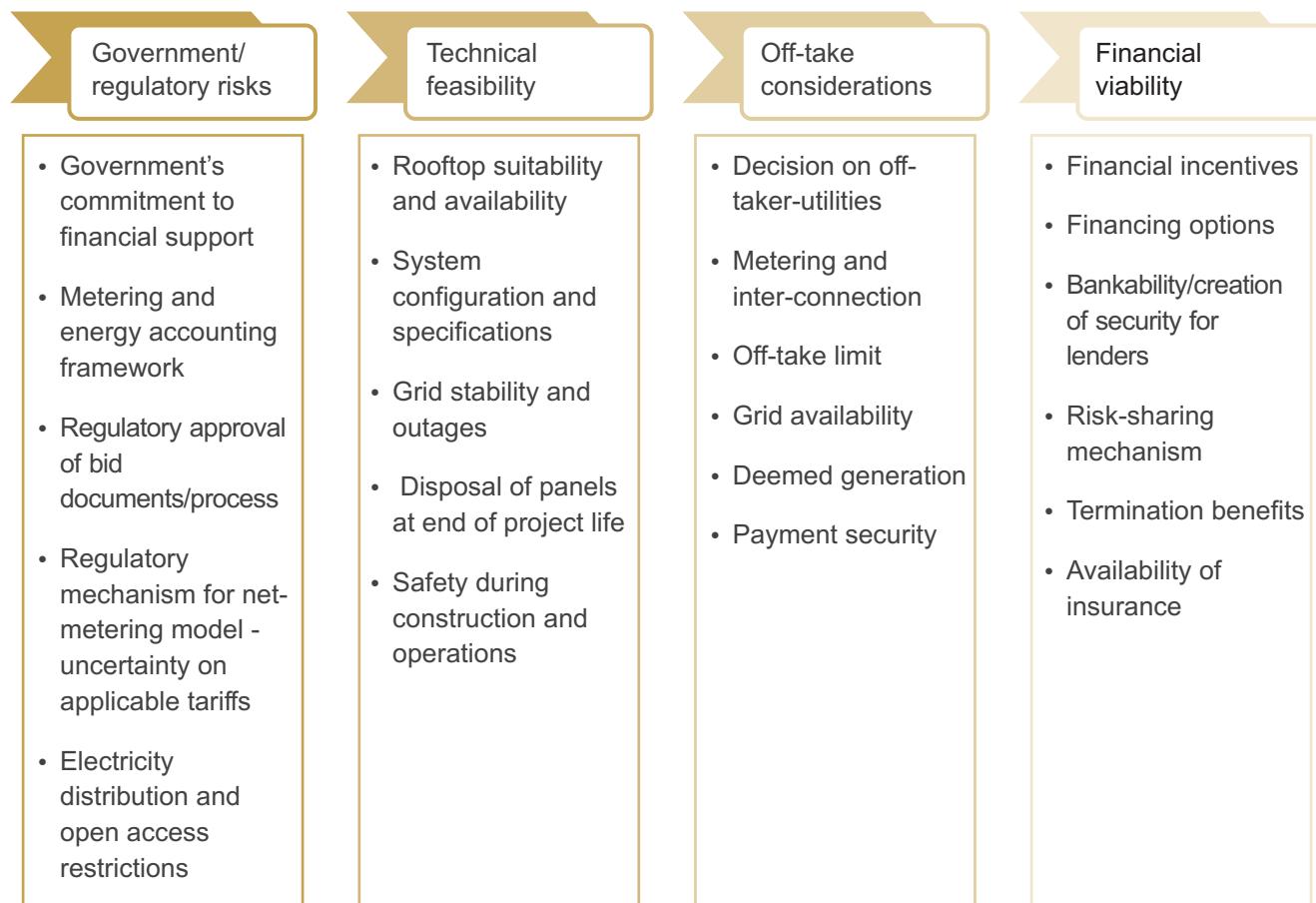
## FACILITATING PRIVATE SECTOR PARTICIPATION IN ROOFTOP SOLAR PV

Public-private partnerships (PPP) 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, that are bankable and sustainable, with adequate preparatory activities and technical due diligence, provision of scale and with equitable risk-sharing arrangements, can generate developer interest in the segment. It also helps design/streamline policy, regulations, and technical standards that can make investments feasible and sustainable. The success of PPP projects can open the doors for self-replication with innovative business models and increased participation of third-parties and intermediaries. This section discusses the key factors to be taken into account by public authorities while designing PPP projects in the segment. This is based on lessons gained from the Gujarat Solar Rooftop Program in India but has universal application across most emerging markets. The considerations described in detail in this section are presented in figure 20.



**Photo:** Azure Power

**Figure 20: Considerations while designing a PPP project on solar rooftop**



This section draws from lessons learned in developed markets such as Germany, Japan, and the U.S. and developing markets such as India. However, barriers to the private sector are similar in most countries, so these measures are relevant globally, and can be adapted to regulatory regimes and economic environments of various locations.

## Policy Actions and Institutional Arrangements

### 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 self-replicating 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. As an example, table 10 illustrates the roles and responsibilities of various public and regulatory agencies involved in the solar PV industry in Germany

**Table 10: Roles and responsibilities of various public and regulatory agencies involved in the solar PV industry in Germany**

Roles and responsibilities	Agency/agencies involved
Policy and legal: Drafting the Renewable Energy Sources Act (EEG)	Federal Ministry for the Environment, Nature Conservation, Building, and Nuclear Safety
Defining incentives structures	Federal Ministry for the Environment, Nature Conservation, Building, and Nuclear Safety, Federal Ministry of Finance
Approval and clearances standards	Federal Ministry of Transport, Construction and Municipal Development
Defining building codes	Federal Ministry of Transport, Construction and Municipal Development and local municipal authorities
Definition of grid safety and connection standards	FNN (forum of grid operators)
Renewable mix in grid studies, specifying fees and processes for grid interconnection	Federal Network Agency
Grid interconnection to PV systems	Grid or system operators
Dispute resolution	Clearingstelle EEG (clearing point for legal questions on the implementation of the German Renewable Energy Act)
Private developers association	German Renewable Energy Federation

**Source:** PV Legal Europe

Despite clarity in roles and responsibilities, the European Union continues to focus on possibilities to reduce legal and administrative obstacles to the planning and installing of photovoltaic systems. The European project PV LEGAL (started in July 2009 and ended in February 2012) was aimed at first identifying and then reducing those legal-administrative barriers that affect planning and deployment of photovoltaic (PV) systems across Europe. The PV LEGAL consortium, after analyzing barriers to development of PV in each of the 12 participating European countries, identified four main areas in which barriers hampering PV installations could be classified:<sup>26</sup>

- Barriers in permitting procedures
- Barriers related to grid connection rules and technical standards
- Barriers in grid connection procedures
- Barriers related to grid capacity issues.

This kind of comprehensive and structured assessment to identify the roles and responsibilities of different agencies and a continued effort to identify barriers, analyze their backgrounds, and advocate their removal from national frameworks is missing in developing countries.

### **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; regulatory incentives through preferential tariffs, subsidies for research and development (R&D), investment subsidies, and loans. Among the three countries, Germany has spent the most public money to develop the rooftop market. It is evident from Germany's installed capacity at the end of 2010 that public spending has helped the market grow substantially. Emerging countries need to plan financial commitments well in advance. Fiscal incentives go hand in hand with the choice of 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). Policy, legal, and market conditions are generally responsible for determining which incentives are good for which economy. In the U.S., the legal framework has largely influenced incentive structures in solar.

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<sup>26</sup> PV Legal, Reduction of bureaucratic barriers for successful PV deployment in Europe, February 2012

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 nations 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, emerging countries, moving from demonstration or early development stage to a self-replicating stage will have to adapt to market conditions and be open to making changes in incentives and/or legal/regulatory structures.

### **Encourage Participation from Rooftop Owners**

A critical issue for third-party developers is the 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. Therefore, 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. This section discusses some of these regulations in the context of the Gujarat pilot project. Specific regulations for the development of rooftop solar projects in India took off only 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 for 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 since 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.

## **Non-financial Incentives**

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, 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, 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.

## **Grid Connectivity**

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

(a) voltage levels for interconnection/evacuation, (b) standards for interconnecting equipment such as inverters, and (c) 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 till 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, 2012, provided clarity for the level of connection for kW-scale rooftop projects, as shown in table 11.

**Table 11: Level of connection of rooftop systems**

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

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

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), 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 megawatt) 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.

### **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 now 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 contracts of specific projects.

## **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 fulfilment 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.

## **Technical Appraisals to Ensure Technical Sustainability of the Projects**

### **Identify and Secure Eligible Rooftops**

Identifying suitable rooftops in an emerging market where urbanization is chaotic can prove challenging, and must take into account factors such as shade from trees, adjoining buildings, 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 12 highlights the broad approach that was adopted for the Gandhinagar project, which can be adopted in other cities.

**Table 12: 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 city-wide 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 gauging of consumer interest.	Activity to be undertaken at the geographic area by physically visiting each potential building/rooftop. Activity to be undertaken after securing buy-in from stakeholders: government departments, utility, residential associations. For each site: building data to include building address, utility consumer numbers, ownership, building height, and vintage. Roof data/measurements to 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 to 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), requirements regarding digging through roads, possible roof intruders if any.

Key tasks	Activity description and outputs
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.

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 with 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 but have to be undertaken, given that data from secondary sources is inaccurate and cannot be relied on.

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 through the following steps:

- Optimize rooftop area by concentrating structures on a particular side of the rooftop, also 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 so as to ensure 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 in 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. In emerging markets, a much wider operating range for inverters is required than normally applicable for European solar applications.<sup>27</sup>

Therefore, it is important that local grid quality data be analyzed thoroughly on parameters such as availability, voltage and frequency, 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 Standards, or the American Society for Testing and Materials and Underwriters Laboratories, for instance, specify norms for panels, balance of

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<sup>27</sup> For example, 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.

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, India, are outlined in annexure 1.

### **Structural Aspects 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; neither should construction introduce water leaks into the structure.

Here is an indicative list of key structural aspects to be considered:

- 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 millimeter above the terrace level with proper drainage.
- Any puncturing/drilling of RCC roof must be avoided.

## 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 megawatt. 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 - a large number of dispersed and small capacity rooftop systems, each connecting to the grid.

### 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 megawatt 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 get affected when power flows in the reverse direction. The incidence of current flows from low-voltage to 11 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).

### **Availability of Grid**

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 grid beyond a certain threshold may have to be incorporated.

The issues highlighted above 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 as the plants are installed on rooftops of occupied offices or residences, as well as educate occupants on safety.

## **Financing**

Financing is a major factor restricting development of the rooftop solar sector. The problem is two-fold: 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 and third-party service providers.

The second problem, which is now prevalent in emerging markets, can be handled by establishing innovative 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 which addresses the requirements of financiers, developers, third-party service providers, and consumers. The following section describes financing options applicable to rooftop solar projects. It outlines the important role of public financing in the early stages of the rooftop solar development cycle.

In most countries, few home-owners can afford the upfront costs of solar systems. They require self-financing options, third-party financing models, public financing, or a mix of these. If public finances are provided when the sector is nascent, the sector will adopt a healthy and sustainable growth pattern and attract large-scale private sector participation. It can become self-sustaining with public financing phasing out over time in favor of a deepening commercial financing pool.

This section focuses on the importance of public financing schemes in widening the solar PV market, with emphasis on what has been done in Japan, Germany, and the U.S.

In the early days of the rooftop solar sector, the lending community did not have the institutional capacity and capability to properly assess and price risks associated with rooftop solar installations. In particular, the lack of standardized technical specifications and absence of benchmarks made technical assessments of installations challenging. Also, fragmentation of the private sector at the time (small installers for instance), and the lack of certification made it difficult for banks to assess construction and operation risks. Further, it was difficult to determine acceptable securities to back repayment obligations for third-party developers and individuals. Security options available to financiers were (i) a right over the PV system itself, (ii) a mortgage on the property of the home-owner, and (iii) a right over cash flows resulting from the sale of power generated, provided this was backed by a long-term power-purchase agreement.

## **Financing Options for Self-owned Systems**

In Germany, financing instruments were created to help home-owners acquire PV systems through self-financing instruments (system-based or home-based). Some innovative financing options also utilized a mix of commercial lending subsidized with public financing (as in Japan), or a public financing scheme only, as in the U.S. Figure 21 provides details on this. In the U.S., a number of utilities and local governments launched schemes for (a) rooftop owners who did not have access to traditional commercial financing options and (b) to enhance affordability by reducing interest rates and upfront fees and relaxing lending guidelines for consumers who did not have existing relationships with local utilities.

**Figure 21: Innovative financing instruments developed in Germany, Japan, and the U.S. to facilitate development of the rooftop solar market**

System-based financing	
<b>Germany</b>	<b>Japan</b>
The German rooftop solar financing market emerged when cash flows from the sale of solar power under a feed-in tariff became secure and reliable. The role of public financing and risk-sharing in the developmental phases (1,000 Roof Program in 1990 and the 100,000 Roof Program in 1999) was crucial to build up confidence among the banking community. Under this impetus, commercial banks developed schemes to lend to project developers based on well-defined standards to evaluate the PV systems, including certified systems, credible and pre-approved installers, and appropriate insurance, and operation and maintenance packages.	Japanese commercial banks offer low-cost loans for home mortgages if they are coupled with solar rooftop systems. For example, Sumitomo Trust and Banking Co. Ltd. in 2008 offered loans at 100 to 200 bps below the market rate to finance solar installations in Sekisui and Kubota. Here, commercial banks utilize well-developed public financing schemes to provide low-cost financing support for home-owners installing rooftop solar PV systems.
Home-based financing	
<b>U.S.A.</b>	
Mortgage banks and credit unions in the U.S. leverage the equity investments made by home-owners in their properties to obtain financing for home improvements, including solar installations. The key forms of this financing include home equity loans, home equity lines of credit, and cash-out mortgage refinancing. These instruments are available for financing solar rooftop systems to home-owners with a good credit history, significant equity in the property, and adequate income to cover the loan repayment.	

## Utility and public financing

### Utility loans

These are loans for the benefit of utility customers, administered by the utility at the local, municipal, or state level. These programs are structured to be either cash-flow positive or neutral, by making the electricity savings equal to or greater than the cost of the loan. Utility loans are either linked to the consumer (called "on-bill" financing) or linked to the property ("meter-secured" financing). For instance, Powder River Energy Corporation of Wyoming offers on-bill financing to its residential customers who can take loans of up to \$2500 at a 0 percent rate of interest and repay the loan in up to 36 months. The Public Service Electric and Gas Company of New Jersey also offers utility-based loans at 6.5 percent for up to 10 years and covers around 40 to 60 percent of installed system costs. The solar system owner also has the option of repaying the loan by signing over solar renewable energy certificates to the loan provider.

### Revolving loans

An example of this is the Montana Alternative Energy Revolving Loan Program. Revolving loans provide public financing directly to rooftop owners. The loan is initially funded through public sources such as appropriations, public benefit funds, alternative compliance payments, environmental non-compliance penalties, bond sales, or tax revenues. Rooftop owners usually prefer these as they bring with them benefits such as low interest rates, relaxed lending guidelines, and extended tenors. These revolving loans are replenished over time from principal and interest repayments.

## Financing Options for Third-party-owned Systems

Alternatively, rooftop owners can have private companies act as third parties to finance and install systems. These are intermediary-based models, which typically fit well under a stable and long-term regulatory and incentive regime. The solar PV system is owned by third parties that either lease the systems to the rooftop owners (called a solar lease), or enter into power-purchase agreements (PPAs) with rooftop owners for the sale of power generated on rooftop systems directly on-site. These models have evolved considerably in the U.S. Here, the third party, usually a solar finance company, designs, purchases, installs, and operates and maintains the system. The rooftop owner purchases the energy produced on her/his roof at tariffs pre-determined in the PPA, which is typically more competitive than local utility rates. In the case of a solar lease, there is no PPA but the system is leased to the home-owner. To make the model more affordable, this is often combined with

incentives. For instance, the solar financing company can have the option of earning tax rebates and credits from the transaction or selling these leases/PPAs to other investors who then earn tax rebates and credits. Some examples of large-scale projects developed through third-party financing are listed here:

- Almost 1 megawatt of rooftop solar installations was developed on a General Motors facility in California.
- Wal-Mart has been purchasing power from rooftop solar PV installations on their roofs, which were developed by SunPower, British Petroleum, and SunEdison. At the beginning of 2008, 22 Wal-Mart-owned sites were operational.
- Macy's used self-financing and third-party-owned financing to develop 8.9 megawatt of solar PV systems on 28 stores across California (data till 2007). Eleven of these stores have installations owned by Macy's while the remaining 17 stores have systems set up by SunPower.





**Photo:** Anjali Garg

## CONCLUSION

Declining costs, combined with improved efficiency and reliability of PV systems, are making renewable energy attractive in many countries to address the challenges of climate change and energy security. The renewable energy sector across the world continues to grow, predominantly in developed markets, and is becoming a vital part of the global energy mix. In particular, there has been remarkable growth of small rooftop solar installations in some of the most advanced developed markets. In the U.S., Australia, Germany, Spain, and Japan, rooftop installations contribute a large share of solar power produced. By early 2012, an estimated one in five homes in South Australia had rooftop PV, according to the REN21's Renewables Global Status Report 2013 and approximately 60 percent of Germany's installed capacity in solar PV was set on rooftops. The positive policy and regulatory environments established by governments of these countries contributed, to a great extent, to mainstreaming renewable energy sources in the mix.

The growth of the rooftop solar market in developed markets can be tracked over three phases: proof-of-concept, market transformation, and mature self-replication. The proof-of-concept phase focuses on implementation of demonstration projects and/or subsidy-based programs, such as in Germany or in Japan. They serve to demonstrate technical feasibility of the projects, and help identify future incentives required to promote proliferation of installations. With the emergence of a well-structured and healthy private sector, these countries were able to create conditions for a market to proliferate on its own. These examples also show that the paths followed by each country have varied in terms of implementation models and market organization, reflecting the policy and regulatory preferences typical to each country. While Germany and Japan provided incentives initially by subsidizing system costs, the market in California grew significantly only after tax benefits were offered. FITs, concessional loans, renewable purchase obligations, and tax rebates are other policy instruments used.

Globally, different approaches have been used to support the emergence and growth of rooftop solar. Countries like the U.S. and Germany continue to learn from their experiences and evolve new business models suited to current environments that support scaling up. Different models are found appropriate and viable depending on the local conditions - regulatory environment, policy, strength of the private sector presence, among others. Germany is the best example of successful propagation of gross metering, in which rooftop solar projects sell electricity directly to the local grid at declared FITs. Japan and several states in the U.S., on the other hand, have implemented net metering, where energy is self-consumed before the surplus is sold to the grid. The recent trend in Japan has been to progressively move towards gross metering with a FIT mechanism.

Several subsidy-driven initiatives were introduced by countries including the U.S. following the energy crisis of 2001, but these subsidies are being cut down in recent years. Declining costs of solar energy as well as impact of subsidies on government budgets are the main reasons for these cuts. However, countries continue to focus on developing rooftop solar programs and are moving towards policies that are not heavily focused on subsidies and rebates. For example, while the California Solar Initiative rebate program is winding down, California's strong net metering policy has become increasingly central to its continued rooftop solar success.

In India, central and state policies focused originally on large-scale capacity addition through ground-mounted solar power plants. A few rooftop solar PV systems were developed, mostly on a captive basis. Grid-connected rooftop solar PV market remained underdeveloped until positive policy and regulatory frameworks started emerging. The successful implementation of several pilot projects, mostly using the gross-metering model, including in Gujarat, helped get stakeholders familiar with the concept and encouraged development of a stronger private sector. Recently, several initiatives were taken by central and state governments to promote a wider dissemination of rooftop solar projects. The objective of this new wave of projects is to develop an acceptable commercial framework to self-replicate rooftop solar projects. For example, West Bengal has initiated a net metering solar rooftop model promoting self-consumption; Karnataka under the new Karnataka Renewable Energy Policy 2009-2014, seeks to promote rooftop PV with net metering; and Tamil Nadu in its solar policy 2012 has set a target of 350 megawatt of rooftop solar PV to be installed between 2013 and 2015. Chhattisgarh has recently released a draft tariff document, adding to the list of states that have announced rooftop solar schemes.

Private sector developers have played a key role in the growth of the rooftop solar market in several countries including Germany, Japan, and the U.S. The most common of these models are intermediary-based systems where third-party developers finance, install, and operate the systems on behalf of rooftop owners. However, large scale proliferation through intermediaries and home-owners needs to be supported by innovative financing schemes, as few home-owners can afford upfront costs of solar systems. A policy maker aiming to develop the rooftop solar sector by involving the private sector needs to conduct a detailed assessment of local risks and develop appropriate mitigation measures.

For developing countries at the proof-of-concept stage, a public-private partnership approach can be an effective means to bring policymakers, regulatory bodies, investors, and utilities together to devise feasible frameworks. It helps establish permit provisions, regulations, and standards based on a consultative process. Experience gained from various implementation models also helps calibrate government policies and incentives in sync with preferred implementation models. Ultimately, all stakeholders, including government, implementing agencies, power off-takers, rooftop owners, third-party developers, and other private sector participants, must converge to achieve a well-balanced implementation model.

If enabling policy and regulatory provisions are put in place to empower rooftop owners and project developers, they can, with the right incentives, serve as a broad base for rapid proliferation, adding power-generating capacity where it is needed most, at the consumer level. 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 self-replicating 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.

While a basic enabling policy and regulatory framework is required to jump-start market transformation, the role of each key stakeholder: government, regulator, developer, financier, distribution utility, and the rooftop owner is equally important. Summarized below is the role of each stakeholder in propagating rooftop systems and specific actions needed to address their respective concerns.

**Government and Regulators:** Solar energy is a reliable, affordable, and environmentally-friendly power-supply solution, easily accessed by the greatest number of people. Appropriately planned, supported by enabling policies and regulations, and properly implemented, rooftop solar PV system programs can help solve power shortages in many developing countries at the household level. If adequate solar resources are available, key concerns and issues that a government faces are:

1. What is the most appropriate implementation model to support? Is it technically feasible?  
What is the financial implication on the budget?
2. How to ensure long term sustainability of the sector and encourage self-proliferation?

Each of the above is equally important and needs in-depth analysis. Different implementation models are appropriate and viable depending on local conditions: regulatory environment, policy, strength of the private sector, among others. Different approaches have been used globally to support the emergence and growth of rooftop solar (see section Rooftop Solar PV – Implementation Models for a detailed description of possible implementation models). Countries like Germany and the U.S. continue to learn from their experiences and evolve new business models that support scaling up in line with the current environment. Technical, legal, and financial analysis is required to determine the most optimal incentive scheme to support the sector.

Rooftop solar PV in most parts of the world is driven by fiscal incentives in the early stages of market development. An enabling policy and regulatory framework with adequate fiscal incentives is necessary to create a demand pull for rooftop solar investments. As seen in Germany, incentives can reduce as solar tariffs move closer to retail tariffs, thus limiting the government's fiscal exposure over time. Governments have to carefully estimate the quantum of rooftop solar PV deployments from year to year and make necessary fiscal provisions in line with the policies they outline. As proliferation can be quite fast once the enabling environment is laid out, governments must carefully calibrate incentives to match the overall quantum of fiscal support they can provide from year to year. Most governments with successful rooftop solar programs have opted for an unambiguous implementation model (particularly the choice between gross and net-metering-based rooftop deployment), as incentive frameworks can vary substantially between models. Depending on the implementation model adopted, support to projects could be upfront/one-time or recurring and linked to generation.

Apart from direct incentives, governments and regulators play a crucial role in addressing the risks that financiers perceive across the value chain, so that commercial financing is widely available as the market expands. This could be in the nature of ensuring standardization of components and certification of suppliers and installers, creating mechanisms to address utility defaults, regulations for inter-connections, metering and payment, as well as regulatory incentives for distribution utilities to participate. A well-established system of standardization and certification, like in the German rooftop solar industry, helps innovation in financing and also encourages participation of insurance providers.

Another key role for governments is to communicate the potential and feasibility of solar rooftops. All stakeholders need to be aware of its opportunities, potential, and viability. For instance, in Gujarat, the responsible authority developed a communication platform - that included an Internet website, easily accessible facilitation centers, and extensive media campaigns - to disseminate project concepts and key benefits.

**Rooftop Owners:** For a rooftop owner, the key benefits from implementation of a rooftop solar system are the utilization of idle rooftop space to generate power, reduction in electricity expenses, and/or additional revenues from the sale of power or from roof rentals. Rooftop solar systems have

become attractive with growing retail tariffs and a sustained decrease in the cost of solar applications. The key considerations for rooftop owners are given below:

- Is it financially viable on its own and if not, is there government support available to make it viable? Are savings in electricity bills or additional revenues enough to offer the rooftop and/or invest in the solar rooftop system?
- Is the local grid available and stable enough to allow solar rooftop systems?
- What permissions are needed to install the system?
- Is there a third party that can install and maintain the system?
- Are there any financing or leasing schemes available?
- What are the technical aspects to be considered?

Rooftop owners, who are keen on deploying rooftop solar PV, assess viability on the basis of tariffs - direct (in case of FIT) or implicit (in case of net-metering-based systems) - and other incentives that they can avail. Once viability is established, there are two major concerns, financing and simplicity of installation. Few rooftop owners are willing to bear the upfront costs of owning and installing, especially in the grid-interactive mode. Availability of systems-based or home-based retail financing schemes or leasing solutions provided by intermediaries is therefore important. Rooftop owners look forward to easy and non-discriminatory permit regimes and interconnection provisions, which make deployment faster and effective. Standards and certification systems are extremely important for rooftop owners and financiers, as it helps them address technology and performance risks in their choices. Clarity is needed, especially on permits, technical connectivity issues for grid-connected systems, and regulatory issues related to net metering systems, if allowed.

**Distribution Utility:** Utilities are among the most critical stakeholders in any grid-connected solar rooftop program. Rooftop solar PV are beneficial to distribution utilities where there is a good match in system peaks and solar peaks, particularly if there is an overall energy shortage in meeting peak demands. By injecting power at the tail-end of distribution systems, rooftop solar also helps in voltage regulation and loss reduction in distribution systems. Given the policy and regulatory mandates for renewable energy emerging in many jurisdictions, rooftop solar can effectively help meet these targets.

However, the technical benefits offered by these systems are also coupled with some key technical and financial challenges which become significant as the volumes of installations grow significantly. Several distribution utilities worldwide are waking up to the power of rooftop solar PV and have been increasingly vocal in their concerns on net-metering in particular, where consumers are allowed to obtain credits for supply of solar electricity to the grid and offset them against their consumption from the grid. With increasing penetration of rooftop solar PV, utilities find themselves with shrinking revenues and are also faced with the prospect of grid failures due to inherent variability in solar generation. These are the key considerations from the perspective of a utility:

- Impact on the local grid and technical feasibility of distributed solar generation feeding into the grid?
- Impact on revenues in case of large proliferation of net metering-based systems?
- Who is responsible for safety of the system?
- What will be the impact on transmission and distribution losses, if any?
- Will it help meet the utility's renewable portfolio obligation targets?
- What is the financial impact?

The distributed nature of rooftop solar PV systems challenges the network layout and reliability of distribution grids. Planning is key. Distribution utilities must consider the possibility of increased penetration of rooftop solar PV into local grids and make changes to grid infrastructure to be able to absorb variable solar power fed into it. Use of smarter and dynamic features to improve prediction and grid response will be needed. Distribution utilities play a crucial role in promoting rooftop solar, as they allow rooftops to connect with their grids and also pay the cost of this solar power. Transparent procedures for permits, metering, and interconnection will attract consumers to invest in rooftop solar initiatives. Incentives like RECs being attributed to the utility, administrative charges towards facilitating grid connectivity, and off-taking the produced power could compensate for possible losses in revenue streams. In the long run, it makes sense for the utilities to be willing participants in this market rather than view themselves as victims of this expanding global phenomenon. Several utilities in countries like Japan and the U.S. have recognized this and play active roles as service providers in some form or other to capture a slice of the solar value chain. They will also need to include the ramping up of this market segment into future power procurement and supply planning, and will need to undertake sophisticated load forecasting to better manage the grid and utilize power flows into the system.

### **Developers and Financiers**

Small-scale rooftop solar PV poses challenges to developers and financiers alike. In the case of large installations (typically megawatt scale), the companies involved in development and implementation are the solar EPC contractors involved in the utility-scale ground-mounted market segment as well. Their returns are secured through a power-purchase agreement signed with the distribution utility, typically supported by a FIT or generation-based incentive policy or through a power-purchase agreement signed with the rooftop owner where grid tariffs are higher than the cost of power from the rooftop. Alternatively, trading of renewable energy credits could also secure returns where there are vibrant carbon markets. Accessing financing for this segment is relatively easier.

However, in case of rooftop segments involving kW-scale projects, smaller integrators are involved as suppliers and operators or residential rooftop owners are themselves involved as developers with limited financial strength and credit-worthiness. Financing this segment, which holds the key to wider solar rooftop proliferation, is the real challenge. Clarity on grid connections, tariffs/incentive mechanisms, and availability of individual credit rating histories may help commercial banks/financial institutions to develop financing products.

For solar rooftops to self-replicate and deepen market penetration, 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. Strengthening the electricity distribution infrastructure and clear permit norms is essential to ensure maximum 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. Together, the efforts would help move towards literally placing more “power in the hands of people.”

## ANNEX 1

### Key Technical Standards: Gandhinagar Rooftop Solar PV Pilot Project

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	
<b>IEC 60947</b>	Connectors for photovoltaic systems - Safety
<b>EN 50521</b>	Connectors for photovoltaic systems - Safety
<b>IEC 60189-1</b>	Low frequency cables and wires with PVC insulation and PVC <sup>28</sup> sheath - General test and measuring methods
<b>IEC 60189-2</b>	Low frequency cables and wires with PVC insulation and PVC sheath - Cables in pairs, triples, quads and quintuples for inside installations
<b>IEC 60068-2</b>	Environmental testing of specimen to withstand specific severities of repetitive and non-repetitive nature
<b>IEC 61683</b>	Photovoltaic systems - Power conditioners - Procedure for measuring efficiency
<b>IEC 62208</b>	General requirements for empty enclosures for low voltage switchgear and control gear assemblies
<b>IEC 69947</b>	Standard test and measuring methods for PVC insulated cables for working voltages up to and including 1100V, UV resistant for outdoor applications
<b>IEEE 519-1992</b>	Recommended practices and requirements for harmonic control in electric power systems

<sup>28</sup> 28Poly(vinyl chloride)

## Specifications of Inverter/Power Conditioning Unit

Detailed specifications	
<b>Output voltage</b>	230V / 415V +10 percent/-15 percent VAC (/ +15 percent/-10 percent)
<b>Output frequency</b>	50 Hz +1.5Hz / -3.5Hz (/ +/- 0.5percent) (/+/- 5 percent)
<b>Power factor</b>	0.95 inductive to 0.95 capacitive
<b>Waveform</b>	Sine Wave
<b>Harmonics</b>	AC side total harmonic current distortion < 5 percent AC side single frequency current distortion < 3 percent
<b>Ripple</b>	DC voltage ripple content shall be not more than 3 percent
<b>Efficiency</b>	Efficiency of PCU shall minimum 90 percent at 20 percent load
<b>Losses</b>	Maximum losses in sleep mode: 2W per 5kW Maximum losses in stand-by mode: 10W
<b>Casing protection levels</b>	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
<b>MPPT</b>	MPPT range must be suitable to individual array voltages in power packs
<b>Internal wiring</b>	Copper wires shall be insulated with flame resistant material
<b>Protections</b>	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:

- A. Indian Electricity Act and rules therein
- B. Indian Electricity Grid Code
- C. 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.

- D. Unidirectional inverter/power conditioning unit
- E. Cables
- F. Earthing kits
- G. Lightening arrestors
- H. Energy meter
- I. 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
  - a. 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.
  - b. 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.
  - c. 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.
  - d. 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.
  - e. 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.
  - f. 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.

<b>Indications through LED/LCD display</b>	Inverter ON
	Grid ON
	Inverter Under/Over Voltage
	Inverter Overload
	Inverter Over Temperature
<b>Display on front panel</b>	Accurate displays on the front panel
	DC input voltage
	DC current & AC voltage (all 3 phases and line)
	AC current (all 3 phases and line)
	Power factor
	Ambient temperature
	Solar radiation
	Instantaneous & cumulative array power
	Instantaneous & cumulative output power
	Daily energy produced
<b>Certifications and compliances</b>	The PCU/inverter shall be such designed so as to meet the following standards in addition to the codes listed in IS and other relevant standards
<b>IEC 61683</b>	Photovoltaic systems - Power conditioners - Procedure for measuring efficiency
<b>IEEE 519-1992</b>	Recommended practices and requirements for harmonic control in electric power systems
<b>IEEE 928</b>	Recommended criteria for terrestrial PV power
<b>IEEE 929</b>	Recommended practice for utility interface of residential and intermediate PV systems
<b>IEC 61727</b>	Photovoltaic (PV) systems - Characteristics of the utility interface
<b>IEC 61683</b>	Photovoltaic systems - Power conditioners - Procedure for measuring efficiency
<b>IEC 62103</b>	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:

1. 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.
2. Fuses of adequate rating shall also be provided in each solar array module to protect them against short circuit.

- **Phase imbalance**

3. 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.
4. 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.
5. 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.
6. 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 armoured 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 by the successful vendor.
6	The cables shall design in such a way that voltage drop shall not be more than 1% 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. These also shall 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 1100V, 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 Lightening 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 lightening arresters as necessary.

- **Energy Meter**

Each power plant will be provided with an energy meter for accurate periodical 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**

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



**Photo:** SunEdison Energy India Pvt. Ltd. (SEIPL)





**Photo:** Azure Power

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### **About the Norwegian Trust Fund for Private Sector and Infrastructure**

The Norwegian Trust Fund for Private Sector and Infrastructure provides grant resources for World Bank Group activities aimed at mainstreaming the investment climate, providing technical assistance in areas related to governance and infrastructure services for the poor, and promoting structured cooperation on petroleum sector governance issues. The trust fund is intended to help develop World Bank Group and client country capacity, promote inclusion of cross-cutting issues into World Bank and the International Finance Corporation's operations, and to foster cooperation among different units in the World Bank Group, United Nations, Norwegian institutions and other external agencies and groups.

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