Rooftop Revolution: Unleashing Delhi's Solar Potential

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ACKNOWLEDGEMENT

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Photograph by Anand Pathanjali/Greenpeace India

PREFACE

Delhi, the world's greenest capital?

"Rooftop Revolution – Unleashing Delhi's Solar Potential" is an in-depth analysis of the potential for rooftop solar in Delhi, a city that has often claimed to be the world's greenest capital. The report comes at a time when India's political nerve-centre and national capital is facing a potential electricity crisis. Demand in the city is expected to reach an all-time high of 6,000 MW this summer while more than 17 states, many of which the city relies on for its power, will face significant power shortages. With the country's eyes on Delhi to be India's answer to the world's sustainable city concept, the crippling power supply situation reminds us that there is an urgent need to rethink electricity generation and supply in the city.

Within the last decade, Delhi's electricity demand rose by an average 6% every year. From 20 billion units in 2002, the demand in all likelihood will reach over 33 billion units by 2017, a 65% growth. This poses a fundamental question of how to ensure a consistent electricity supply. The city's many shopping malls, Delhi Metro and state-of-the-art health facilities currently get three-fourth of their electricity supply from outside the state, relying mostly on environmentally unsustainable fuels like coal. A shift from centralized, fossil fuel based power sources to decentralized, renewable sources like solaris then the best way to overcome these hurdles, while achieving other substantial benefits like the creation of jobs in the green sector and independence from other states for energy supply.

From 20 billion units in 2002, the demand in all likelihood will reach over 33 billion units by 2017, a 65% growth.

Delhi can "Switch on the Sun"

As the capital and second richest state in the country, Delhi is in a very good position to take the lead in transitioning to a decentralized, sustainable energy paradigm. With this conviction, we have launched the "Switch on the Sun"campaign. Our goal is to emphasize the effectiveness of solar energy as a solution to Delhi's emerging power crisis. In the coming days, the campaign seeks to bring together all the stakeholders in the city: distribution companies, government decision makers, regulatory bodies and electricity consumers.

As the capital and second richest state in the country, Delhi is in a very good position to take the lead in transitioning to a decentralized, sustainable energy paradigm.

The campaign has so far received an excellent response. Through our interactions with resident welfare associations (RWAs), we have had individual colonies like Sukhdev Vihar in Delhi pledge their commitment to rooftop solar. The power minister of the city has agreed with our message and initiated government administrators to move ahead on solar with a sense of urgency. It is also encouraging to see that national level bodies like the Central Electricity Authority are already drafting regulations that will bring responsibility-focused equitable delivery of energy through decentralized renewable energy systems. We are confident that the Delhi Electricity Regulatory Commission will take the cue from our campaign and initiate the required regulatory changes outlined here at the city level to ensure renewable energy supply reaches its desired level.

While clear targets on renewable energy at the national level would certainly help build investors' confidence and create a mandatory domestic market, a realistic and rationalized differential Renewable Purchase Obligation (RPO) would help in creating energy equity in the country's energy delivery system. Though effective implementation of the RPO mechanism in each state is essential to ensure renewable energy projects are actually producing electricity and are not just tax evasion models, there is also a need to revise each state's RPO target with a more rational approach so that intra-country energy equity will be established in line with India's professed international position of "common but differential responsibility." In this regard, Delhi, the second richest state and third highest per capita energy consumer, can set a precedent by initiating a rooftop solar revolution by 2020 and usher in a new era of a democratic energy delivery system that runs on equity, justice and human aspiration.

We hope that this report will provide the city's stakeholders with the insights and data needed to ensure that Delhi truly lives up to its title of the world's greenest capital.

The enthusiasm to support solar in Delhi exists, and through our campaign we will ensure that it will continue to grow. What was still lacking is a Delhi specific, in-depth assessment of the opportunities and challenges for the effective adoption of rooftop solar. The first step towards positioning rooftop solar energy as a solution is to understand its potential in the city. We have initiated this report written by BRIDGE TO INDIA to serve that purpose. We hope that it will provide the city's stakeholders with the insights and data needed to ensure that Delhi truly lives up to its title of the world's greenest capital.

Abhishek Pratap
Senior Campaigner
Greenpeace India

1 EXECUTIVE SUMMARY

In this report, we propose that Delhi can be a 2 GW solar city by 2020. This may sound bold when compared to the reality of existing solar installation in leading cities such as Berlin (98 MW[1]), New York (14 MW[2]) or San Francisco (23 MW[3]) or the overall achievement of 1.5 GW in India as a whole until mid-2013. However, it is not so bold, if we assume that the landscape of power supply is changing fundamentally: Grid power prices continue to rise and the power supply deficit in India is widening. Given the dramatic fall in the cost of solar power (by as much as 50% in the last two years), solar has moved into the mainstream and become a viable option. Theoretically, the total land area on which Delhi is built could support 123 GW of solar PV. Therefore, 2 GW requires only 1.6% of the city's land.

Our case does not rest on government subsidies (although we also give a scenario involving them). Instead, we look at parity between the levelized cost of solar photovoltaic (PV) systems and consumer grid prices. Assuming a fairly conservative 5% p.a. reduction in the cost of solar power and a 6% p.a. increase in grid prices, parity will be reached in all the tariff segments by 2018. Solar will be a smart investment choice for consumers as well as for third party investors. What is needed is, above all, a level playing field. For this, grid-connectivity of rooftop solar will be the key.

2 GW requires only 1.6% of the city's land.

We arrived at our 2 GW target for Delhi by combining three perspectives. We first looked at the available rooftop space to reach a geographic potential. Then, we looked at the economic viability of solar for different tariff groups and system sizes. Lastly, we assessed how much grid-connected solar power the grid could handle. For the geographic potential, data was difficult to come by, so we used different mapping sources (the Delhi Master Plan 2021, Delhi Development Authority data) and geo modeling of samples (individual buildings and colonies based on Google Earth, Google Maps and the Eicher map of Delhi) and extrapolated from that based on assumptions. Our methodology is explained in the appendix. For the viability perspective, we used our in-house financial models for different sized solar power plants and data from actual solar projects in India.

Assuming a fairly conservative 5% p.a. reduction in the cost of solar power and a 6% p.a. increase in grid prices, parity will be reached in all the tariff segments by 2018.

The grid perspective is complex and there is hardly any reliable information available. As per our knowledge, there has been no detailed study on the ability of the Delhi grid to handle distributed, intermittent power sources. Even in countries such as Germany or the USA, where studies have been conducted, there is no clear indication of what a grid of specific characteristics can handle. A frequently read estimate is that 15%-20% of distributed, intermittent power in the grid is not harmful (it might even stabilize the grid). In 2013, Germany has seen days when renewable power made up more than 50% of overall power and the grid has taken it well.

In our analysis, we have not considered storing of solar power. Given currently available technology, stored solar power would be economically attractive

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1 Installed solar capacity until December 2012. Source: Agentur für Erneuerbare Energien accessed at http://bit.ly/14ivVhJ on May 22nd 2013.

2 Installed solar capacity until March 31st 2013. Source: San Francisco Solar Map accessed at http://sfenergymap.org on May 22nd 2013.

3 Installed solar capacity until December 2012. Source: New York Solar Map accessed at http://nycsolarmap.com accessed on May 22nd 2013.

only after 2020. In our roadmap, we suggest that 2 GW of solar power on the grid would be reached by 2020. Solar power would not exceed 20% of the load expected on the grid by 2020. So, storage is perhaps not necessary, from a grid perspective. However, more research should be conducted on understanding the effect of large-scale solar deployment on the grid. It is also reasonable to assume that over the next years, new technologies and the experiences of grid operators across the world will provide new solutions.

Solar, as a locally available, environmentally friendly and increasingly viable source of power can provide Delhi with an attractive long-term power supply option.

Economic and demographic growth in India's capital Delhi has been accompanied by a significant expansion of the city's infrastructure. The Delhi government has been committed to improving energy supply. In recent years, Delhi has achieved a very high availability of power. Blackouts have become rare. However, given India's growing power deficit, the rising cost of power and Delhi's rapidly growing power demand[4], it will be difficult to maintain this level of supply stability in the years to come. Solar, as a locally available, environmentally friendly and increasingly viable source of power can provide Delhi with an attractive long-term power supply option, reducing the city's reliance on power imported from other states (more than 70% of Delhi's power comes from outside the state) and fossil fuels (more than 50% of Delhi's power comes from coal generation).

We believe that going solar is not so much a choice but an inevitability for Delhi. It will be driven by the increasingly favorable economics of solar and by customer demand. Entrepreneurs will develop business models to serve Delhi's power consumers as long as there are no regulatory hurdles placed in their path. The other stakeholders, the regulators, the utilities and the financing community should help to actively shape this change and make it their success, too. A good starting point for the Delhi government to show that it wants to lead and is ready to embrace a paradigm change in the way electricity is generated, distributed and consumed, is to state higher, but still perfectly achievable solar RPO targets. We believe that they can be at least 0.50% in 2014 and 9.75% in 2020 without requiring significant extra investments from the government, the utilities or the power consumers[5].

We believe that going solar is not so much a choice but an inevitability for Delhi.

This report is meant to provide arguments, analysis and data to the Delhi government, its distribution companies (DISCOMS) and the people of Delhi to show why solar makes sense for the city. We also provide a roadmap for achieving 2 GW of installed rooftop solar in the city by the year 2020. I hope you will find this report interesting.

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4 Delhi's current economic growth rate is over 11% and is expected to remain so for the next five years. This is partially driven by its total population growth of 21% in the past decade (currently Delhi has over 16 million inhabitants); data as per Census of India 2011

5 As per our Roadmap for parity driven rooftop PV in Delhi - Delhi's consumption is expected to be 26,669 MUs in financial year 2014-15 and 31,057 MU in 2020-21, while solar generation potential is 149.9 MU in 2014 and 3,027.7 MU in 2020.


Photograph by Anand Pathanjali/Greenpeace India

2 INTRODUCTION

2.1 SOLAR IN INDIA

Solar power plants in India in 2013 are still almost exclusively ground-mounted PV plants. Such plants are typically larger than 5 MW in size and supply electricity to the grid. Central government policies like the Jawaharlal Nehru National Solar Mission (NSM) and the Gujarat Solar Policy have provided preferential Feed-in-Tariffs (FiT) to incentivize the installation of over 1.5 GW – almost exclusively photovoltaic (PV) –in the past two years[6]. The NSM alone wants to add another 3.6 GW by 2017. Additionally, an ever-increasing number of Indian states offer solar policies or directly allocate projects. These include Karnataka, Rajasthan, Tamil Nadu, Andhra Pradesh, Punjab, Madhya Pradesh, Chhattisgarh, Uttar Pradesh and Orissa. We expect these policies to facilitate an additional installation of over 6 GW in the next four years[7].

The Central Electricity Regulatory Commission (CERC) suggests that, 0.25% of solar should be achieved by 2012-13, which should increase to 3% by 2021-22.

In order to accelerate the growth of solar, supply-side incentives such as preferential FiTs are complemented by demand-side measures: Solar Renewable Purchase Obligations (RPO) define a minimum amount of solar power (MWh) that obligated entities – distribution licensees, open access and captive consumers (1 MW and above) – have to buy as a percentage of their total power sold/consumed. The Central Electricity Regulatory Commission (CERC) suggests that, 0.25% of solar should be achieved by 2012-13, which should increase to 3% by 2021-22. However, the actual targets are set by states and vary across the country. Since solar has a lower Capacity Utilization Factor (CUF) than the average of conventional sources of power, the required RPO by 2012-13 in installed capacity terms (MW) exceeds 0.25% and is nearer to 1% of the total installed capacity in India. Thus, if as of March 2013 India has 215 GW[8] of installed capacity for total power generation, it needs around 2 GW of installed solar power to meet its cumulative solar RPOs. In 2022, if India will have more than 300 GW of installed capacity and the solar RPO will be around 3%, India will need nearer to 30 GW of solar power. Obligated entities can meet their obligation by purchasing the required quantity of solar power directly from producers or producing it themselves. Alternatively, they can buy solar Renewable Energy Certificates (REC) to fulfill their RPO.

Today, the financially viable price (excluding incentives such as capital subsidies or tax benefits) of solar power in India is between ₹6.5-8.5 (€0.1-0.13, $0.13-0.17)/kWh, depending on the size of the plant, cost of debt, cost of land and the irradiation at the plant location.

Today, the financially viable price (excluding incentives such as capital subsidies or tax benefits) of solar power in India is between ₹6.5-8.5 (€0.1-0.13, $0.13-0.17)/kWh[9], depending on the size of the plant, cost of debt, cost of land and the irradiation at the plant location[10]. At this price, solar power is still more expensive than the average pooled purchase cost of power, i.e. the average price paid by DISCOMS to purchase electricity from power generators. Solar RPO requirements and the general lack of power in many parts of the country are currently the main drivers for individual states to initiate their own solar policies and provide incentives.

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6 Source: BRIDGE TO INDIA, as of May 3rd 2013

7 Based on the BRIDGE TO INDIA market model

8 Source: Central Electricity Authority

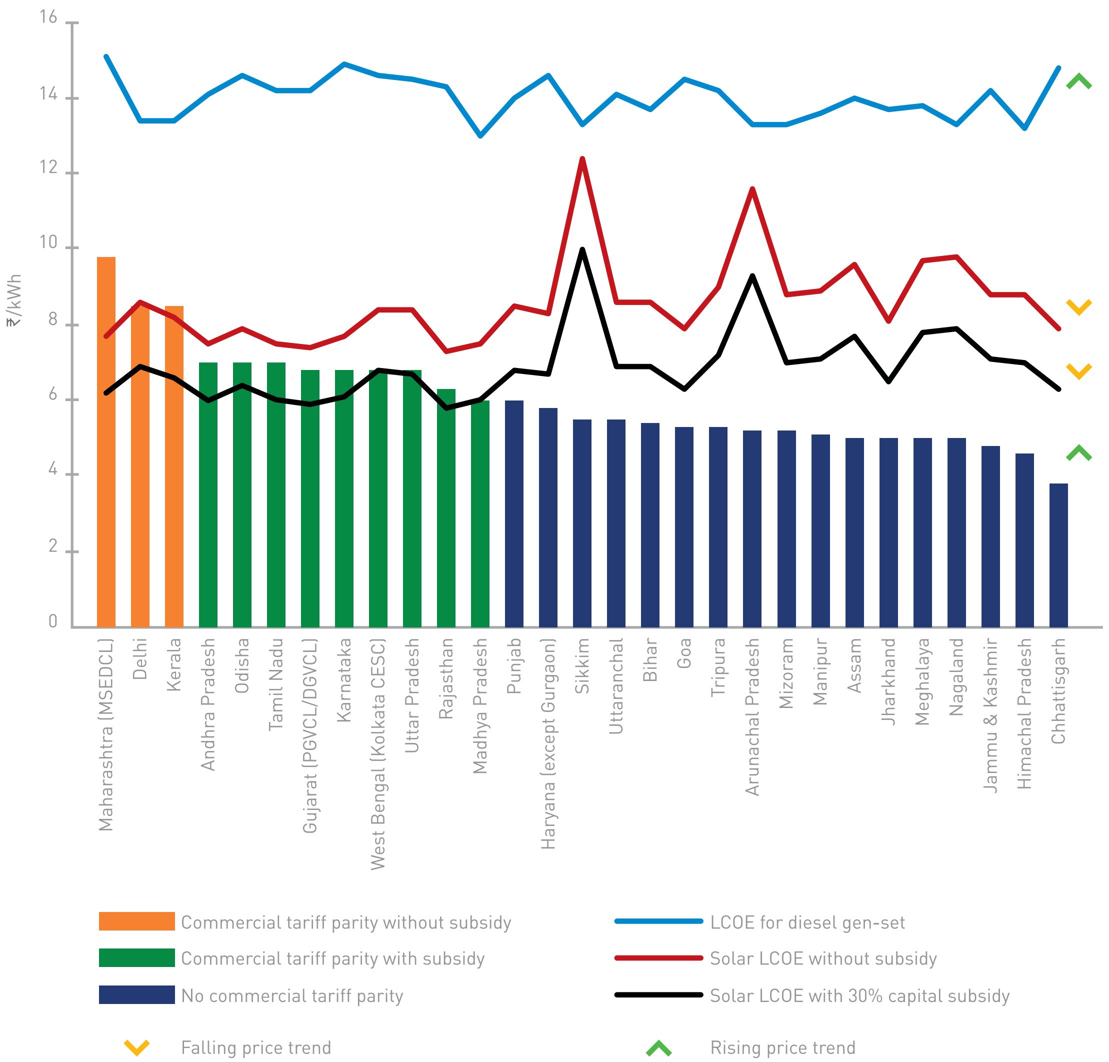
9 Based on the BRIDGE TO INDIA financial model, excluding the seven states of the Northeast of India and Jammu and Kashmir, Himachal Pradesh and Sikkim and the cities of Delhi and Mumbai.

10 Solar for large, grid-connected plants is being offered in some states for as little as ₹6.2/kWh, a price currently unviable without additional tax benefits, without compromising on plant quality.

* Rates of €1 = ₹65 and $1 = ₹50 have been used throughout this report.

In some states, however, solar has already reached parity with commercial and industrial tariffs[11]. In addition, in many states, electricity supply is erratic and unreliable with widespread power cuts. To grapple with this challenge, many consumers rely on expensive back-up power. As a result, their levelized cost of energy (LCOE) rises and can be higher than the price for solar. There are, therefore, already markets where solar energy is viable without support from the government.

Figure 1: State-wise commercial tariff vs. LCOE of solar power (100 kWp system without battery) and diesel generation (100 kVA system)



Source: State tariff orders, market interviews, BRIDGE TO INDIA financial model and analysis

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11 Tariff groups comprise of 'Domestic Consumers', 'Non-Domestic Consumers' (all non-domestic establishments such as hotels, educational institutions, hospitals and banks), 'Industrial Consumers' and 'Agriculture Consumers'. There are different tariffs for different purposes as well, such as public lighting, railway traction and advertisements and hoardings.

Apart from large, grid-connected plants, the government also supports smaller, rooftop-based installations of less than 1 MW. Such support includes the Ministry of New and Renewable Energy's (MNRE) subsidy scheme (100 MW a year), the "Solar Cities" program by the MNRE (no capacity limits), Tamil Nadu's solar policy with a FiT for rooftop plants (350 MW), Kerala's rooftop power program that offers a subsidy (10 MW) and the Gujarat solar policy's rooftop program that offers a FiT (30 MW). Further, rooftop PV is well suited to serve commercial consumers and those with a high LCOE. We expect the market for such smaller PV projects without government support to exceed 1 GW by 2016[12].

2.2 POWER IN DELHI AND WHY SOLAR MAKES SENSE

The National Capital Territory of Delhi (NCT; hereon referred to only as Delhi)[13] has a solar RPO set by the Delhi Electricity Regulatory Commission (DERC). For the financial year 2013-14, this stands at 0.20% and increases to 0.35% by 2016-17[14].

The National Capital Territory of Delhi has a solar RPO set by the Delhi Electricity Regulatory Commission (DERC). For the financial year 2013-14, this stands at 0.20% and increases to 0.35% by 2016-17.

The city has four power distribution utilities (DISCOMS): Tata Power Delhi Distribution Limited (TPDDL), BSES Yamuna Power Limited (BYPL), BSES Rajdhani Power Limited (BRPL) and the New Delhi Municipal Council (NDMC). Together, these companies provide 100% of the power consumption needs of Delhi. Given their cumulative expected power sales of 25m MWh[15] in 2013-14, they have a current requirement to purchase 50,000 MWh of solar energy, for which they require 35.5 MW of installed solar capacity[16]. However, the installed capacity of solar PV in Delhi as of March 9th 2013 was only 2.5 MW[17]. This currently leaves the Delhi utilities with the option of either purchasing solar power from outside the state, purchasing RECs or – when enforced – paying a penalty for non-compliance.

The installed capacity of solar PV in Delhi as of March 9th 2013 was only 2.5 MW.

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11 Tariff groups comprise of 'Domestic Consumers', 'Non-Domestic Consumers' (all non-domestic establishments such as hotels, educational institutions, hospitals and banks), 'Industrial Consumers' and 'Agriculture Consumers'. There are different tariffs for different purposes as well, such as public lighting, railway traction and advertisements and hoardings.

12 Based on the BRIDGE TO INDIA market model

13 Delhi consists of a larger metropolitan area consisting of the city of Delhi and adjoining satellite areas of Baghpat, Gurgaon, Sonepat, Faridabad, Ghaziabad, Noida, Greater Noida and other nearby towns. Delhi, along with the satellite cities is called the National Capital Region (NCR). The city of Delhi is known as the National Capital Territory (NCT). This report focuses on the National Capital Territory of Delhi, which is referred to as "Delhi" through the report.

14 According to the Delhi Electricity Regulatory Commission (Renewable Purchase Obligation and Renewable Energy Certificate Framework Implementation) Regulations, 2011 accessed at http://www.derc.gov.in/Main%20Page%20Matter/draft_RPO_5_8_2011/DERC_Final_RPO_Regulations.pdf on March 13th, 2013

15 According to the Average Revenue Reports of 2011-12 filed by the DISCOMS with the DERC and BRIDGE TO INDIA's projections.

16 At CUF of 16%

17 Source: MNRE State-wise solar installed capacity break- up - http://bit.ly/18ZeW7x accessed on May 14th 2013

Table 1: Delhi's solar RPOs and required solar capacity (per FY)[18]

	2013-14	2014-15	2015-16	2016-17
Power consumption (MWh)[19]	25m	26m	28m	30m
Solar RPO[20]	0.20%	0.25%	0.30%	0.35%
Required solar capacity (MW)[21]	35	46	60	75

Other states in India have set higher solar RPO targets than Delhi. Haryana, Gujarat and Uttar Pradesh, for example, each aim for 1% solar power in the current financial year (2013-14). A supposed lack of available space for solar PV in a highly urbanized and congested city like Delhi is often considered to be a key barrier to a more ambitious solar RPO. However, this holds true only if we consider the installation of large, ground mounted power plants. As this report shows, the potential for rooftop-based solar PV systems is significant in Delhi.

The total area of Delhi (only the NCT) is 1,483 km^2.

The total area of Delhi (only the NCT) is 1,483 km^2 [22]. If such an area were unused and exclusively available for solar installations, it could support 123 GW of installed capacity which, at peak power production, would be more than 20 times Delhi's expected peak power demand of 6 GW[23] for 2013 and more than half of India's installed capacity in 2013 of 215 GW[24]. 50% or 700 km^2 of Delhi's total area is built-up[25] and theoretically available for rooftop PV systems. Based on our analysis in this report, we have estimated that of the 700 km^2 of built-up space in Delhi, 31 km^2 or 4.42% of Delhi's rooftop space is actually available for PV systems. This much space gives Delhi a geographic solar potential of 2,557 MW.

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The power plants existing within the confines of Delhi in 2013 have a capacity of 1,345 MW (55% coal and 45% gas) . This leaves Delhi with a shortfall of 4,297 MW from its highest peak demand so far of 5,642 MW witnessed in 2012. About 58% of the shortfall is met by purchasing power through long-term power purchase agreements (PPA) with power generators in other states. A further 13% of the shortfall is met by purchasing power on a short-term basis from other states or on the spot market. At the moment, India faces a high and rising power deficit, expected to be 13% by 2017. States that Delhi relies on for its additional power need to bridge their deficits and might be less willing in the future to meet Delhi's continued and growing need for power.

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18 The financial year (FY) in India runs from 1st April to 31st March.

19 According to Average Revenue Reports of 2011-12 filed by the DISCOMS and BRIDGE TO INDIA's projections

20 Yearly targets for 2014-16 have been assumed based on the target of 0.35% by 2017 set by the DERC

21 MWh values for solar have been converted to MW by considering the power generation capacity of a 1 MW solar plant that produces power at a Capacity Utilization Factor (CUF) of 16%. CUF for solar is the ratio of actual energy generated by a plant over the year to the equivalent energy output at its rated capacity over the yearly period.

22 Source: Census of India 2011 provision data, accessed at www.census2011.co.in/density.php on March 13th 2013

23 Source: Delhi Transmission Company

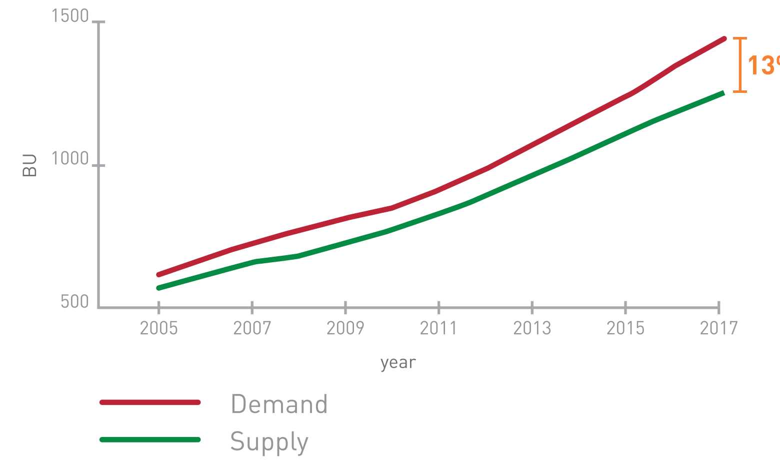
24 Source: Central Electricity Authority

25 Source: Master Plan for Delhi 2021

26 Refer to the chapter on "Why rooftop solar makes sense for DISCOMS" for details on power generation sources

27 As of October 2012, Source: Delhi TRANSCO Annual Report 2011-12, more recent data unavailable

Figure 2: India's structural power deficit



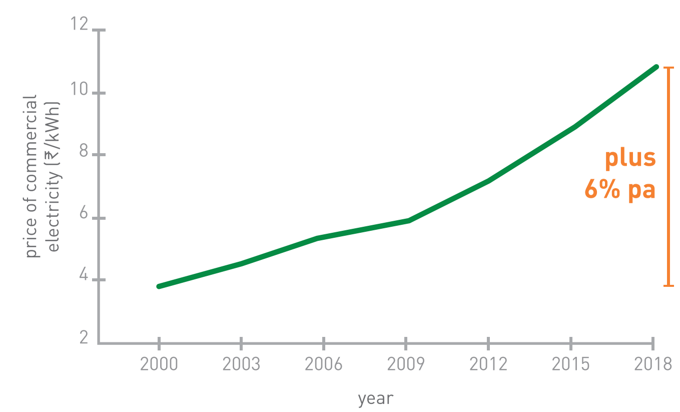
Source: CEA, BRIDGE TO INDIA projections

Power bought on the spot market can cost as much as ₹8 (€0.12, $0.16)/kWh.

Power bought from generators in other states has to be wheeled through these states' grids, incurring extra charges and making Delhi's power supply dependent on their grid infrastructure and management. Power bought on the spot market can cost as much as ₹8 (€0.12, $0.16)/kWh.

Prices across India are going to continue to rise, driven by rising fuel costs (coal and diesel), a structural underinvestment into new generation capacity and grid infrastructure and increasing pressure on state electricity boards to balance their books. States reeling under power deficits will increase upward pressure on spot market prices to meet their own demand for short-term peak power.

Figure 3: India's rising power costs (2000-2018)



Source: State tariff orders, BRIDGE TO INDIA projections

By utilizing the large potential for solar energy, Delhi could drastically reduce its dependency on external power sources as well as its vulnerability to the kind of massive grid failure that took place in July 2012.

By utilizing the large potential for solar energy, Delhi could drastically reduce its dependency on external power sources as well as its vulnerability to the kind of massive grid failure that took place in July 2012[28]. Further, Delhi now enjoys near constant availability of power. This comes at the cost of rising electricity prices. They have increased by an average of 20% across consumer

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28 In July 2012, the country's northern and eastern grids failed due to excess demand.

By switching to solar, the city can hedge against future increases in grid electricity prices.

groups in the year 2012 alone[29]. Price hikes will likely continue as the demand in the city increases. Solar installations on the other hand, last 20 years or more, with the cost of power remaining unchanged for the entire lifetime of a plant. By switching to solar, the city can hedge against future increases in grid electricity prices.

Investing into solar requires up front funds as the share of the capital expenditure significantly outweighs the share of the operating expenditure for each kW. Delhi has funds. The city's annual per capita income in 2012 was ₹176,000 (€2,708, $3,200) – the third highest among the states and union territories and three times the national average[30].

Solar rooftop installations are already beginning to take off across India. While the installed capacity in 2013 is still only a little over 100 MW[31], there has been a surge in new projects and market participants. The south Indian states especially are ready for fast growth in rooftop PV.

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29 Source: State tariff orders, BRIDGE TO INDIA analysis

30 Economic Survey of Delhi 2012013 accessed at http://bit.ly/19KHeBw

31 Source: MNRE, assuming off-grid projects under the subsidy mechanism are rooftop based

32 Source: NASA Surface meteorology and Solar Energy accessed at https://eosweb.larc.nasa.gov/sse/RETScreen/ on May 22nd 2013.

33 Source: MNRE India Solar Resource Maps accessed at http://mnre.gov.in/sec/solar-assmnt.htm on May 22nd 2013.

34 India Solar Resource Map 2010 NREL

3 SOLAR RESOURCE AVAILABILITY FOR DELHI

Solar irradiation is the amount of radiant solar energy available per unit area and is usually expressed in terms of kilowatt-hours per square meter per day (kWh/m²/day). As sunlight streams through the atmosphere, only some of it reaches the ground, with the rest being reflected, absorbed and scattered. The amount that actually reaches the ground depends on a number of factors such as latitude, season, time of day, air quality and other atmospheric conditions (e.g. clouds, aerosol particles, etc.). This can be used to generate power by way of technologies such as solar PV systems.

The average solar irradiation of Delhi according to the RET Screen database is around 5 kWh/m²/day.

Table 2: Annual irradiation data for Delhi

Source	RETScreen[32]	MNRE[33]
Month	**Solar Radiation kWh/m²/d**	**Solar Radiation kWh/m²/d**
Jan	3.8	3.4
Feb	4.6	4.7
Mar	5.8	6.0
Apr	6.3	6.8
May	6.4	7.0
Jun	6.0	6.3
Jul	5.2	5.4
Aug	4.8	5.3
Sep	5.0	5.3
Oct	4.8	4.9
Nov	4.2	3.9
Dec	3.5	3.3
Annual	**5**	**5.2**

Delhi receives higher irradiation in relation to many other cities of the world that make a dedicated effort to go solar.

The average solar irradiation of Delhi according to the RET Screen database is around 5 kWh/m²/day[34]. Such a level of solar irradiation is good, but not as high as might be expected due to the high levels of dust in the city. The highest irradiation in the world is 7-8 kWh/m²/day in, for example, North Africa. The solar irradiation in Delhi is lower than that of western and southern states of India, like Rajasthan, Gujarat, Tamil Nadu, Maharashtra, Andhra Pradesh and Karnataka, which have average irradiation of 6-7 kWh/m²/day and are considered to be the most solar suitable regions in the country. But the city of Delhi receives higher irradiation in relation to many other cities of the world that make a dedicated effort to go solar, including Berlin (98 MW installed[35]), Munich (27 MW[36]), New York (14 MW[37]), or Beijing (close to 15 MW installed by the end of 2013)[38].

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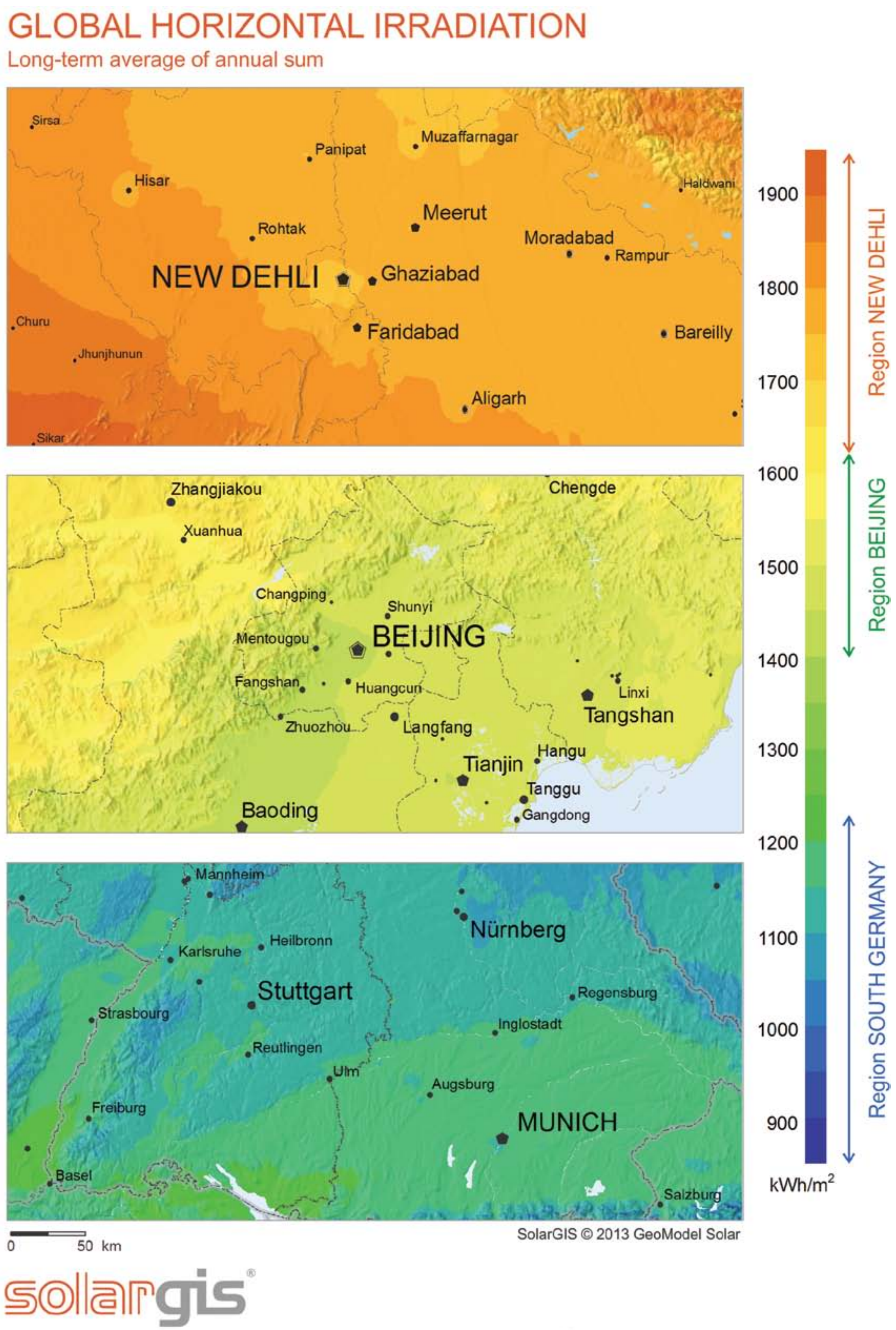
35 Installed solar capacity until December 2012. Source: Agentur für Erneuerbare Energien accessed at http://bit.ly/14ivVhJ on May 22nd 2013.

36 Installed until April 2012. Source: SolarBundesliga accessed at http://bit.ly/11t8Ur9 on May 22nd 2013

37 Installed solar capacity until March 31st 2013. Source: San Francisco Solar Map accessed at http://sfenergymap.org on May 22nd 2013.

38 Source: www.china.org.cn/bjzt/2013-05/27/content_28923106.htm accessed on May 22nd 2013

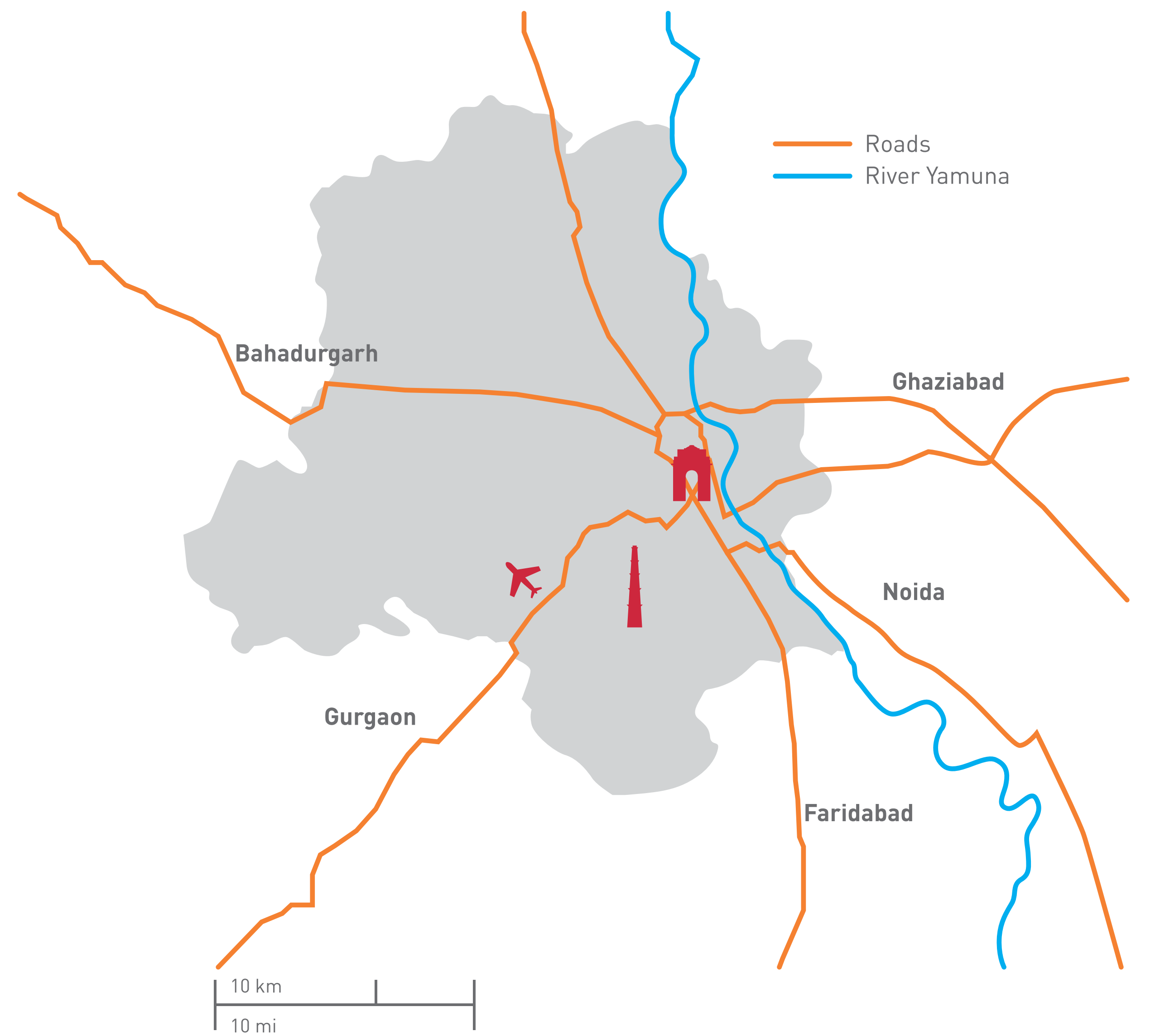
Figure 4: Irradiation maps of Delhi, Beijing and Munich



4 DELHI'S GEOGRAPHIC POTENTIAL FOR SOLAR ROOFTOP INSTALLATIONS

Delhi has the potential to build around 2.6 GW of solar PV on its rooftops. We have only assessed rooftop space for solar PV panels. Other technologies, such as building-integrated PV (BIPV) could additionally make walls of buildings available for solar power generation, but are still too far from commercial viability to be considered here.

Figure 5: Map of Delhi (NCT)

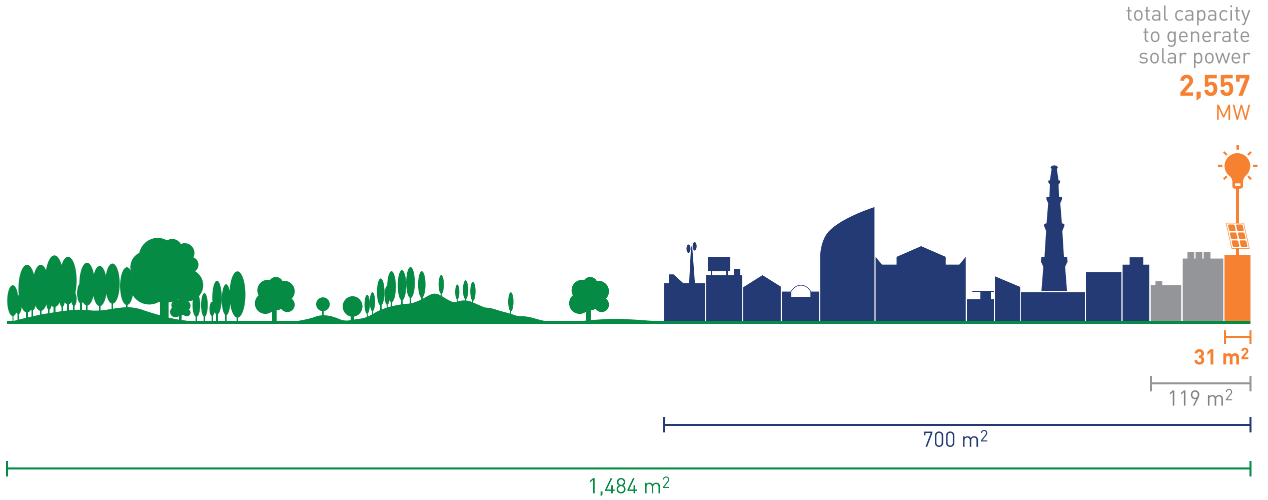


Source: BRIDGE TO INDIA

The solar-suitable rooftop space is the unobstructed and shadow-free rooftop area that receives optimal sunlight for solar power generation.

Delhi borders the Indian states of Haryana on the north, west and south and Uttar Pradesh to the east. The total land area of the National Capital Territory is around 1,484 km^2 with around 700 km^2 of built area.[39] Delhi's built area/ raw rooftop space that is potentially available for solar power generation is around 119 km^2. Raw rooftop space includes only built structures that can accommodate the size and weight of solar installations.[40] Out of this, the estimated, actually available solar-suitable rooftop space is around 31 km^2, which could fit 2,557 MW of solar power[41]. The solar-suitable rooftop space is the unobstructed and shadow-free rooftop area that receives optimal sunlight for solar power generation[42].

Figure 6: Deriving Delhi's rooftop space for solar



Source: BRIDGE TO INDIA

Delhi's residential buildings represent 49% of the solar potential.

Delhi's residential buildings represent 49% of the solar potential. They are followed by industrial buildings with 15% of the potential. Government buildings, commercial buildings and public and semi-public facilities have 13%, 10% and 13% of the total potential, respectively. Transport facilities such as airports and railway stations have a mere 0.1% of the potential - but can make great pilot projects. Green stretches, water bodies, historical buildings and public utilities have been excluded from the analysis.

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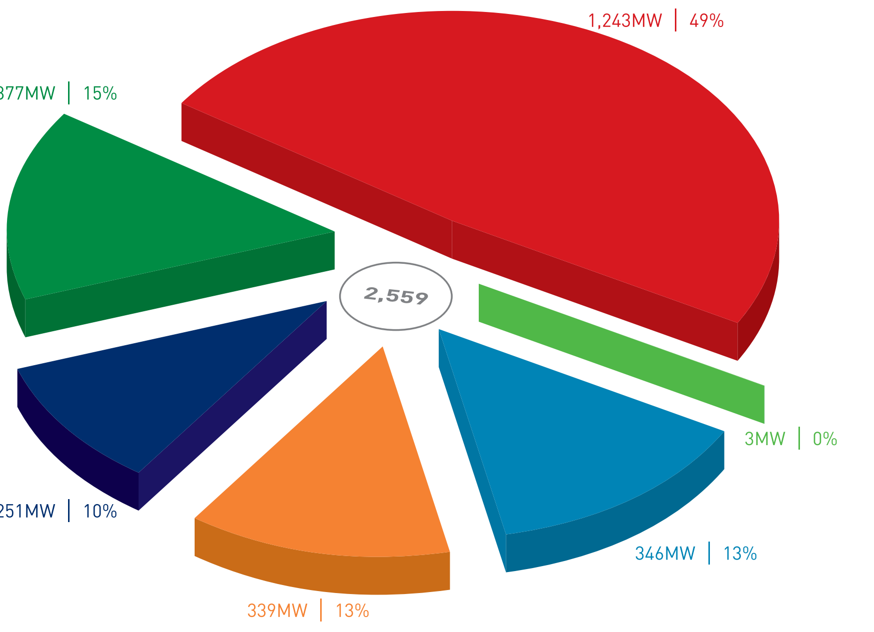
39 As per the DDA Master Plan 2021

40 Raw rooftop space is computed after excluding poorly constructed or unfit building structures, roads, green patches and irrelevant sub categories such as poultry farms or religious buildings. (Refer to the appendix chapter "Methodology for calculating the solar rooftop potential in Delhi" for details on the calculation.)

41 Based on Bridge to India's estimate that 12 m^2 of rooftop space is required for a 1kW solar power installation

42 Solar suitable roof top space excludes parts of the rooftop that are obstructed by objects and rooftop structures like water tanks, storage rooms, air-conditioning units, water heating units, etc. as well as parts of the roof that have a shadow. This space estimation varies for different land area types. (Refer to the appendix chapter "Methodology for calculating the solar rooftop potential in Delhi" for details on the calculation.)

Figure 7: Potential of rooftop solar power generation in Delhi for different land area types (MW)



Source: DDA's Master Plan 2021, Delhi Zonal Plans and BRIDGE TO INDIA analysis

Table 3: Solar suitable rooftop area available in different land area types

Land area type	Total qualified rooftop area (km^2)	Solar suitable rooftop area (km^2)	% of solar suitable rooftop space	Solar potential (MW)[43]
Residential	74.5	14.9	49%	1,242
Commercial	10.9	3	10%	251
Industrial	11.3	4.5	15%	377
Government	10.2	4.1	13%	339
Public and Semi Public Facilities	11.9	4.2	13%	346
Transport	0.2	0.03	0.10%	2.6
TOTAL	**118.9**	**30.6**		**2,557**

Source: BRIDGE TO INDIA

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43 Based on Bridge to India's estimate that 12 m^2 of rooftop space is required a 1kW solar power installation. 1 MW (1,000 kW) of solar requires 0.012 km^2 (12,000 m^2) of space.

4.1 RESIDENTIAL BUILDINGS

Such buildings have a solar potential of 1,242 MW, the largest among all other buildings types. Residential buildings include those under the jurisdiction of the Municipal Corporation of Delhi (MCD), the New Delhi Municipal Council (NDMC) and the Delhi Cantonment Board (Delhi Cantt.). The colonies under the MCD are further categorized from A to H, as per the circle rate[44] applicable to each colony. Colonies under the categories E, F, G and H are excluded from our analysis, as they were unsuitable for solar power generation[45]. The total built area available for rooftop solar installations is around 74 km^2 [46]. The solar suitable rooftop space is around 15 km^2 [47]. To arrive at this number, the solar suitable rooftop space was assumed to be around 20% of the total rooftop area[48]. This percentage is based on samples and discounts for the space occupied and shadows created by water tanks, ventilating shafts, dry clothes lines and storage units that occupy most of the area on a typical residential rooftop[49].

The total solar potential of commercial buildings is around 251 MW.

4.2 COMMERCIAL BUILDINGS

The total solar potential of commercial buildings is around 251 MW. Commercial consumers can be categorized into two types, those with an electricity consumption of 10-200 kW ("type-1") and those with a consumption of greater than 200 kW ("type-2"). The two types of consumers pay different tariffs and thus the viability of solar differs[50]. Their total built-up area is 11 km^2 [51]. Rooftops of commercial buildings tend to be occupied with cooling towers, ventilating shafts, water heating systems and tanks. The solar suitable rooftop space for type-1 commercial buildings is assumed to be 30% and that of type-2 is 20% of their respective rooftop areas. The total solar suitable rooftop space for commercial buildings is 3 km^2 [52].

A few large-sized, commercial buildings have already installed rooftop solar power installations in order to meet part of their power needs, as solar power is economically viable for such users. For example, DLF promenade, a shopping mall in Vasant Kunj with a total raw rooftop space of 9,000 m^2 [53] and solar suitable roof space of around 1,800 m^2, has installed a 50 kW solar rooftop installation[54].

Industrial buildings have a solar potential of 377 MW.

4.3 INDUSTRIAL BUILDINGS

Industrial buildings have a solar potential of 377 MW. Like commercial customers, we also categorize industrial customers into two types: those with 10-100 kW of load requirement ("type-1") and those with 100-200 kW of load requirement ("type-2"). The two types also pay different tariffs, which impacts the financial suitability of solar power[55]. Based on market interviews and due to a lack of specific data, we assume that half of the rooftop space

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44 Circle Rate is the minimum rate per sq. meter area on which stamp duty has to be paid by the purchaser. This rate is decided by the government authorities for valuation of land in a particular area.

45 Refer to Table A2 "Assessment of colonies under the jurisdiction of the MCD" for details

46 Refer to the appendix chapter "Computation of the solar suitable rooftop space - Residential buildings" for details

47 Ibid, 48 Ibid. 49 Ibid.

50 Refer to Chapter 5 on "The viability of rooftop solar PV" for details

51 Refer to the appendix chapter "Computation of the solar suitable rooftop space - Commercial buildings" for details

52 Ibid. 53 As per measurements taken from Google Earth

54 Refer to the Appendix for details on the approach and assumptions of the analysis

55 For details, refer to Chapter 5 on "The viability of rooftop solar PV"

belongs to type-1 and half to type-2 power consumers[56]. This gives each a potential of 188.5 MW. The rooftop characteristics of the two consumer types are assumed to be comparable. Their total, combined rooftop area is 11.3 km^2 (after discounting for old buildings that might not be able to support solar). Out of this, the solar suitable area after discounting for rooftop obstructions and shadowing is assumed to be 40%. Accordingly, the total solar suitable rooftop space is 4.5 km^2 [57].

4.4 GOVERNMENT BUILDINGS

These buildings have a solar potential 339 MW. The total qualified built-up area of government buildings is around 10 km^2. The solar suitable rooftop space offered by government buildings is assumed to be around 40%, which is larger than many other land area types, considering their rooftop space is commonly free from elevator shafts and storage units[58]. Accordingly, the solar suitable rooftop space is 4 km^2.

The total qualified built-up area of government buildings is around 10 km^2.

4.5 PUBLIC AND SEMI-PUBLIC FACILITIES

Public and semi-public facilities can be government owned or privately owned. Accordingly, they pay different prices for electricity and the viability of solar differs[59]. Based on market interviews and sampling, we assume that 70% of the facilities are government owned and 30% privately owned[60]. Such facilities have a total potential of generating 346 MW of solar power: 242 MW on government buildings and 104 MW on private buildings. The total qualified rooftop area is around 12 km^2. Out of this area, the solar suitable rooftop space is around 4 km^2 [61]. The solar suitable rooftop space on public facilities is assumed to be 35%, taking into consideration that rooftops of most public facilities are largely occupied by water heating systems (mandatory as per government regulations) and elevator and ventilating shafts. In addition to that, the structure of most buildings in this land area type is such (elevated at some levels) that significant area is shadowed. In the following analysis, the government-owned facilities are included in the overall "government" potential, while the privately-owned facilities are included in the "commercial (type-2)" potential.

4.6 TRANSPORT FACILITIES

Transport facilities have a conservatively assessed solar potential of only 2.6 MW.

This land area type has a conservatively assessed solar potential of only 2.6 MW. The rooftop space available is around 0.2 km^2. The solar suitable rooftop space is around 0.03 km^2 [62]. The solar suitable roof area is assumed to be 20% of the total raw rooftop area as most transport facilities have roof sheeting and the little concrete space left is occupied by shafts and monitoring units[64]. Since this sector has some landmark buildings such as the Delhi Airport (where 2 MW of solar is to be built on the surface around the runways), we have included it in the geographic analysis. However, because the solar potential is negligible compared to other segments, we have excluded it from the further viabilty analysis and computation of the overall potential.

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56 Refer to the appendix chapter "Computation of solar suitable rooftop space – Industrial buildings" for details

57 Refer to the appendix chapter "Computation of the solar suitable rooftop space - Industrial buildings" for details

58 Refer to the appendix chapter "Computation of the solar suitable rooftop space - Government buildings" for details

59 Refer to Chapter 6 on "The viability of rooftop solar PV" for details

60 Refer to the appendix chapter "Computation of the solar suitable rooftop space – Public and semi –public facilities" for details

61 Ibid. 62 See appendix for details

63 Refer to the Appendix for details on the approach and assumptions of the analysis

5 DELHI'S EXISTING SOLAR POLICIES AND INCENTIVES

The Delhi government currently has no specific policy for supporting rooftop solar power.

There exists no Delhi solar policy in 2013. Delhi had formulated a draft rooftop solar policy in 2011 to promote rooftop, small-scale, decentralized solar power generation to meet its solar RPO. The policy envisioned that homeowners could either lease their roofs to a developer or install a system themselves. The government was planning to offer a FiT of ₹17 (€0.26, $0.34)/kWh for the power generated by the PV plant. We assume that at the time the cost of a 5 kW system without storage was around ₹900,000 (€13,846, $18,000).[64]

However, the Delhi rooftop solar policy was not implemented. In 2011, the economics were not favorable. The cost of diesel power was only ₹12 (€0.18, $0.24)/kWh[65], which was significantly lower than the proposed solar FiT. As a result, the government was concerned that cheaper diesel power would be fed into the grid, disguised as solar power, in order to artificially inflate the revenue of the PV system. Today, however, such concerns are no longer valid. The cost of diesel power as of May 2013 has risen to ₹14 (€0.21, $0.28)/kWh[66], an increase of 17% since October 2011. The capital cost today for a 5 kW system has fallen by 39% to ₹550,000 (€9,231, $12,000). At this cost, a FiT of ₹11.6 (€0.17, $0.23) /kWh is viable[67], which is lower than the cost of diesel power today.

A rooftop solar policy by Delhi can set a benchmark by creating a policy that addresses the need for grid-connectivity and achieves significant capacity addition (up to 2 GW), at the limited cost.

The Delhi government currently has no specific policy for supporting rooftop solar power. As part of the first phase of the NSM, central government support has been available in the form of the 30% MNRE subsidy on the PV system cost or a low cost loan at 5% interest, repayable within five years. Such support was applicable up to March 31st 2013, and has been offered in the draft policy for the second phase of the NSM as well. Pending finalization of the draft, there is no certainty yet on whether the support will continue in the second phase. The central government also provides direct tax benefits. One such benefit is accelerated depreciation of 80%[68], attractive to profit making business entities, paying tax in India that own a PV system. Another is a 10-year income tax exemption for PV power generators and indirect tax benefits such as excise duty and custom duty exemptions or concessions on solar energy devices and equipment.

The central government support for rooftop solar has been successful but limited: support was initially pledged only for 100 MW (124 MW has actually been installed in India)[69]. It is available only for off-grid systems. There is no policy framework to allow rooftop systems to connect to the grid, something that can impact viability significantly.

A rooftop solar policy by Delhi can set a benchmark by creating a policy that addresses the need for grid-connectivity and achieves significant capacity addition (up to 2 GW), at the limited cost[70].

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64 This capital cost is an assumption based on our historical understanding of the market in 2011. There is no publically available information on the capital cost considered by the government for its FiT in 2011.
65 For a 15 kVA system that consumes 3.5 liters of diesel/hour. Considering diesel prices to be ₹40.91/liter as on October 2011
66 For a 15 kVA system that consumes 3.5 liters of diesel/hour. Considering diesel prices to be ₹48.63/liter as on April 2013
67 Refer to the section on "Viability of solar rooftops for residential consumers" in Chapter 5 of this report
68 On the book value of assets in the first year and the written-down value thereafter, under section
32 Rule 5 of the Income Tax Act
69 Source: MNRE
70 Refer to the chapter "Delhi solar roadmap: reaching 2 GW by 2020" in this report for more details

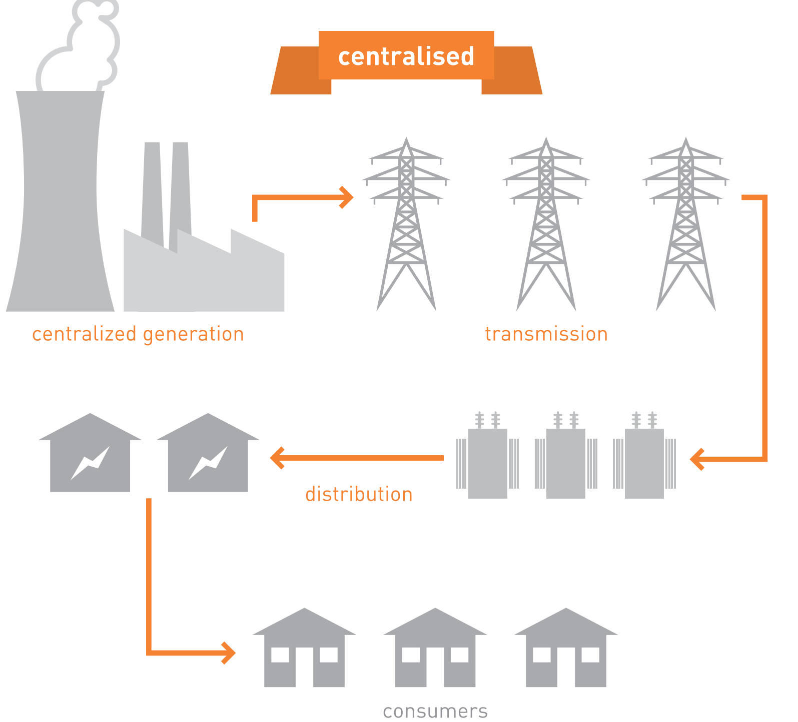
6 INTEGRATION OF SOLAR PV WITH THE GRID

Integration of a rooftop solar PV system with the grid is not a technical requirement as it could also provide a purely captive solution, where the entire power generated could either be consumed immediately or stored for later use at the site of generation. However, grid connection can be a key driver for rooftop PV as it allows systems to avoid storage (which can increase system costs by 25% or more) and offers more off-take options (i.e. the grid through, for example, net-metering or FiTs).

Power grids were originally designed for the one-way supply of power from a central source of power generation to the consumers.

Power grids were originally designed for the one-way supply of power from a central source of power generation to the consumers. The security, control, protection, power flows and earthing of the network were based on this centralized generation model. Distributed generation technologies[71], such as solar PV systems, when connected to the larger distribution network of the grid create a two way supply of power, from the grid to the consumer and from the consumer to the grid. This requires a re-thinking of the way the grid is regulated and managed.

Figure 8: Centralized vs. mixed (centralized and distributed) power generation



Source: BRIDGE TO INDIA

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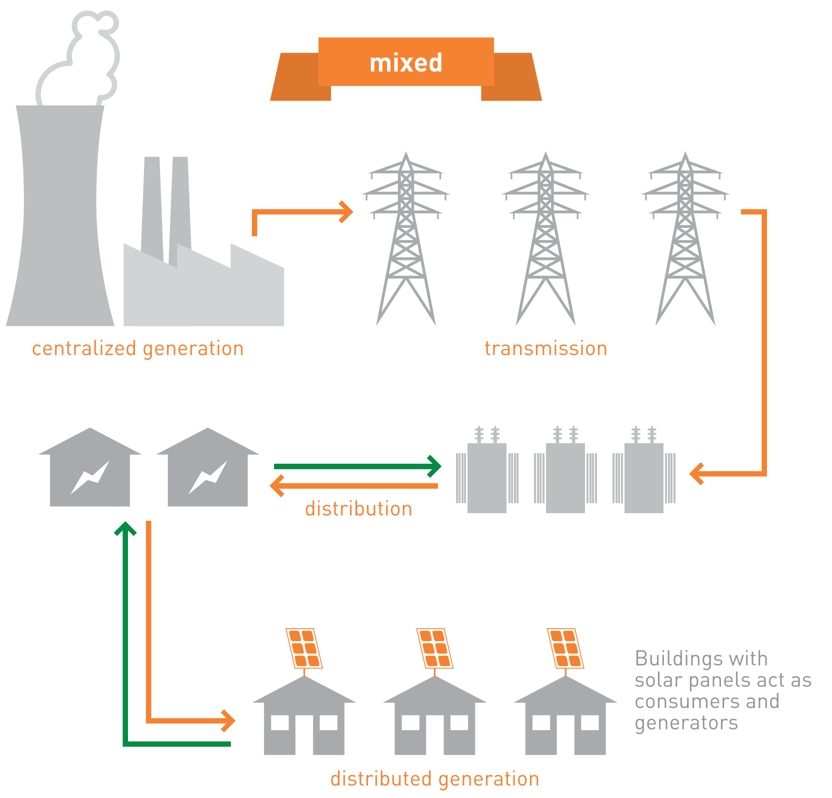
71 Distributed generation technologies are small power generating units that are placed at or near the point of energy consumption, unlike traditional "centralized" systems, where electricity is generated at a remotely located, large-scale power plant and then transmitted down power lines to the consumers. Distributed energy encompasses a wide range of technologies including wind turbines, solar PV, fuel cells, micro turbines, reciprocating engines, load reduction technologies, and battery storage systems. Source: www.nrel.gov/learning/eds_distributed_energy.html accessed on May 22nd 2013



Source: BRIDGE TO INDIA

Beyond a certain limit of PV penetration, traditional grids can be destabilized.

Traditional grids are not designed for a two way supply of power. Beyond a certain limit of PV penetration, traditional grids can be destabilized due to e.g. the intermittent quality of solar power, reverse power flow (when a PV system at the consumers end generates more power than the consumer can use) and voltage imbalances[72].

Decentralized PV systems can alter the load profile of the network as the power from such systems can be consumed on site as well as injected in to the grid.

Decentralized PV systems can alter the load profile of the network as the power from such systems can be consumed on site as well as injected in to the grid. High on-site PV consumption by consumers could reduce the load on the network during the day, while increasing it at night (because of an absence of PV generation). Further, the load on the grid can also fluctuate as PV generation is highly weather dependent and can drastically drop in the case of a cloud cover. High levels of grid-connected decentralized PV penetration can present a significant load management challenge for the DISCOMS.

As per estimates, a traditional grid can accommodate up to 15% of the peak load from distributed solar PV without being destabilized, while managing load fluctuations easily[73]. This places a "grid limit" on the rooftop solar PV capacity in Delhi that can be connected to the grid. However, this "grid limit" is recognized as being conservative. Simple, low-cost measures like introducing specific standards for PV inverters, guidelines for grid connectivity and better load forecasting and planning can make a difference in the amount of PV penetration possible in Delhi. The Central Electricity Authority (CEA) has already drafted a report on the integration of solar PV systems in to the grid that addresses such measures[74]. The authority is developing more detailed recommendations in its final report, which is currently being assessed by the forum of regulators and could be released by late 2013. By adopting the recommendations of the report and by better forecasting demand, we estimate that the possible PV penetration limit in Delhi would be at least 20%[75].

We estimate that the possible PV penetration limit in Delhi would be at least 20%.

In the future, the grid's capacity for PV can be increased drastically if the grid is upgraded with smart grid management/monitoring solutions (including advanced forecasting, scheduling and load management) and centralized or decentralized storage[76]. Countries like Germany, with an already advanced grid infrastructure, have reached 40% of decentralized PV in the power mix by adding intelligent transformers and storage devices that regulate the quality of power and stabilize the grid[77]. Such solutions increase the hosting capacity of the grid, but require significant investments.

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72 Refer to the Appendix, chapter "Solar PV grid connectivity challenges and solutions" for further details.

73 The US Federal Energy Regulatory Commission recommends that PV generation should not exceed 15% of the annual peak load. This is based on a rationale that voltage deviations due to the intermittency of solar and the problems specific to grid integration of distributed PV have a negligible impact on the grid, if the combined PV power on a line section is always less than the minimum load. The minimum load usually does not exceed 30% of the peak load. Therefore, 15% or half of the minimum load is taken as a conservative number acceptable to ensure that there is no risk of PV capacity having a negative impact on the grid. Source: https://solarhighpen.energy.gov/article/beyond_15_rule.

74 Source: CEA "Integration of solar systems with thermal/hydro power stations and connectivity of solar rooftop systems with the grid" accessed at http://www.cea.nic.in/more_upload/task_force_solar_report.pdf on May 22nd 2013.

75 According to the NREL study on "Interconnecting PV on New York City's Secondary Network Distribution System", PV penetration levels of 20-30% are considered safe for radial distribution grids, like the one in Delhi. The study was accessed on May 22nd 2013 at http://www1.eere.energy.gov/wip/pdfs/46902.pdf . The CEA, DISCOMS in Delhi and leading energy experts have shared this view with us while conceding the need for a more detailed study on the matter, specific to Delhi.

76 For more details about challenges of PV penetration and suggested solutions see the report "Connecting the Sun", November 2012 by the European PV Industry Association accessed at http://bit.ly/13bL9lH accessed on May 22nd 2013.

77 PV systems have contributed to up to 40% of peak demand in Germany (http://bit.ly/11mwWko) "High Penetration PV Cases in California, US" http://1.usa.gov/185cGvY both sites accessed on May 22nd 2013

7 THE VIABILITY OF ROOFTOP SOLAR PV

Based on the geographic analysis in chapter 1, Delhi's electricity consumers can be divided into four categories: commercial, industrial, residential and government. Together, these customer groups can accommodate 2.5 GW of solar on their rooftops. Commercial consumers include type-1 commercial buildings and type-2 commercial buildings combined with privately owned public and semi-public facilities. Industrial (type-1 and type-2) and residential buildings are each a consumer category in themselves. Finally, government consumers include government buildings and public and semi-public facilities owned by the government.

There are three types of electricity tariffs in Delhi: non-domestic, industrial and domestic.

There are three types of electricity tariffs in Delhi: non-domestic, industrial and domestic. Commercial consumers pay non-domestic prices. Industrial consumers pay industrial prices. Residential and government consumers pay domestic prices.

Table 4: Consumer categories for rooftop solar PV

		Building types	Potential (MW)	Tariff (₹/kWh)
Non-domestic	Commercial consumers	Commercial type-1	205	8.5 (€0.13, $0.17)
		Commercial type -2 (type-2 commercial buildings and privately owned public and semi-public combined)	149	7.15 (€0.11, $0.14)
Industrial	Industrial consumers	Industrial type-1	189	6.6 (€0.10, $0.13)
		Industrial type-2	189	8.35 (€0.13, $0.17)
Domestic	Residential consumers	Residential	1,242	6.4 (€0.09, $1.3)
	Government facilities	Government buildings and government owned public and semi-public	582	6.4 (€0.09, $1.3)

While power prices in Delhi have kept quite constant between 2005 and 2011, they have increased steeply since 2011. During the entire interval, domestic prices have increased from ₹4.65 (€0.07, $0.09)/kWh in 2008 to ₹6.4 (€0.98, $0.13)/kWh in 2013, a rise of 27%. Similarly, industrial prices have increased by 37% and non-domestic prices have increased by 33% during the same period[78]. There are two main drivers for these price rises. Firstly, there has been a 50% rise in the cost of international procurement of coal for Indian power producers since 2004[79]. Secondly, Delhi has seen a drive to making power available to the city almost 24/7. As a result, DISCOMS need to match peak demand and manage demand fluctuations, which often lead to wastage of power reserves and the need to buy more high cost (peak) power.

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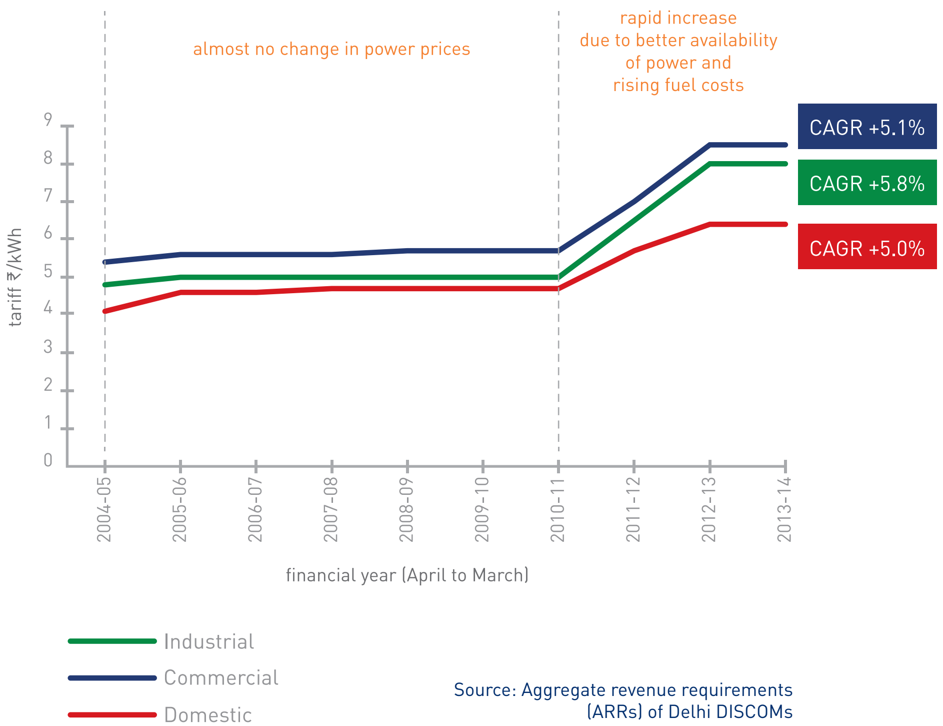
78 Source: ARRs and tariff orders of Delhi's DISCOMS

Figure 9: Historical grid tariff price trend[80]



Source: Aggregate revenue requirements (ARRs) of Delhi DISCOMs

While grid power prices have risen, the cost of solar power has declined sharply in the past two years. At the beginning of 2011, a ground mounted MW-scale project in India cost around ₹140m (€2.15m, $2.8m) per MW. Today, this has fallen by almost 50% to around ₹70m (€1m, $1.4m) per MW. The cost reduction has been driven largely by a drop in module prices from ₹50 (€0.77, $1)/Wp in 2011 to ₹32.5 (€0.5, $0.65)/Wp today. Module prices have fallen globally due to a condition of acute oversupply. Against global demand for 30-35 GW of solar power in 2012, available supply was 50-60 GW, most of it from China.[81]

While grid power prices have risen, the cost of solar power has declined sharply in the past two years.

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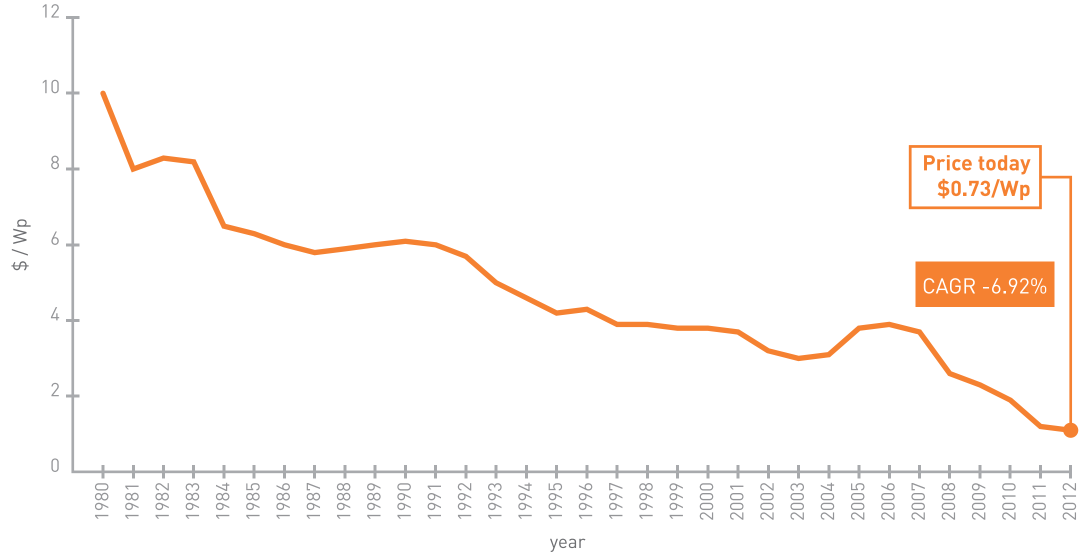
79 Source: ARRs of Delhi DISCOMs

80 Tariff orders by the Delhi Electricity Regulatory Commission (DERC) accessed at http://www.derc.gov.in on May 22nd 2013

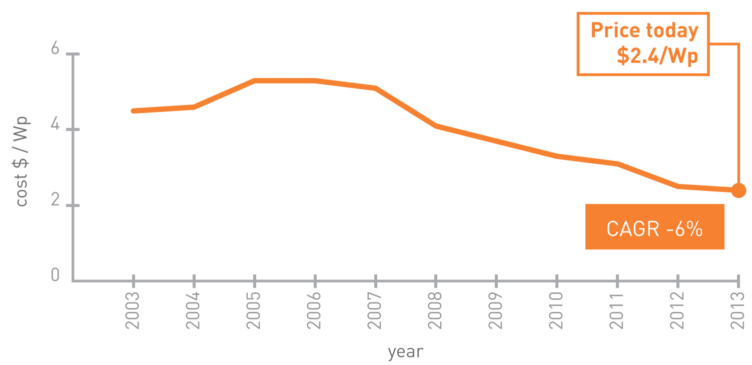
81 Source: Reuters article "China's bailouts darken horizon for solar panel sector" accessed at http://reut.rs/WUn1no on May 22nd 2013

Figure 10: Falling prices of solar PV modules over the past 32 years



Source: BRIDGE TO INDIA analysis.
Source of data NREL[82]

Figure 11: System prices have fallen over 47% in last 10 years



Source: Module prices data from Renewable Energy World[83], BRIDGE TO INDIA analysis

The unusually rapid fall in solar prices in the recent years and an increase in grid prices has made solar competitive.

The unusually rapid fall in solar prices in the recent years and an increase in grid prices has made solar competitive. However, we assume that now the cost curve will again follow its long-term trajectory. The timing for investing into solar is, therefore, ideal.

While increasingly competitive on a per kWh basis, solar still requires significant upfront capital investments and hence liquidity. Capital expenditure on PV plants can range from ₹550,000 (€8,462, $11,000) for a typical 5 kW system for residential consumers to ₹140m (€2m, $2.8m) for a 2,000 kW, bundled installation for government consumers (cost per Wp reduces as system sizes increase).

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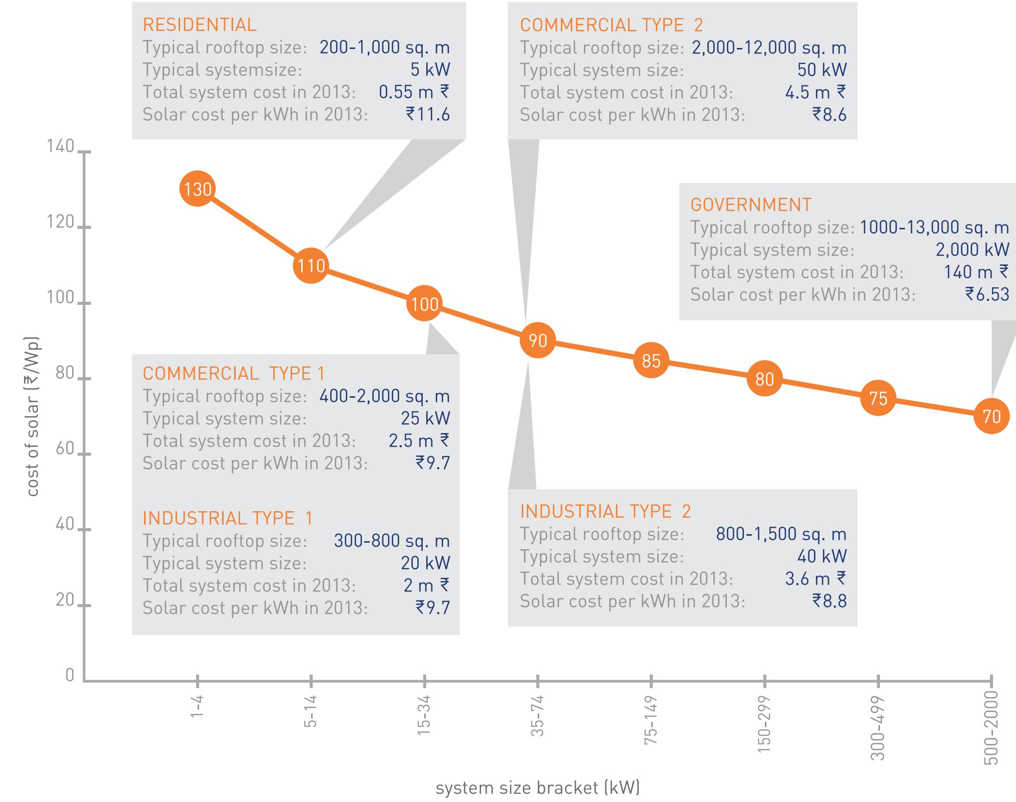
[82] Source: NREL accessed at http://www.nrel.gov/docs/fy12osti/51847.pdf on May 22nd 2013
[83] Source: Renewable Energy World accessed at http://bit.ly/WimCXG on May 22nd 2013

Figure 12: Solar costs in India in 2013 for different system sizes (without storage)



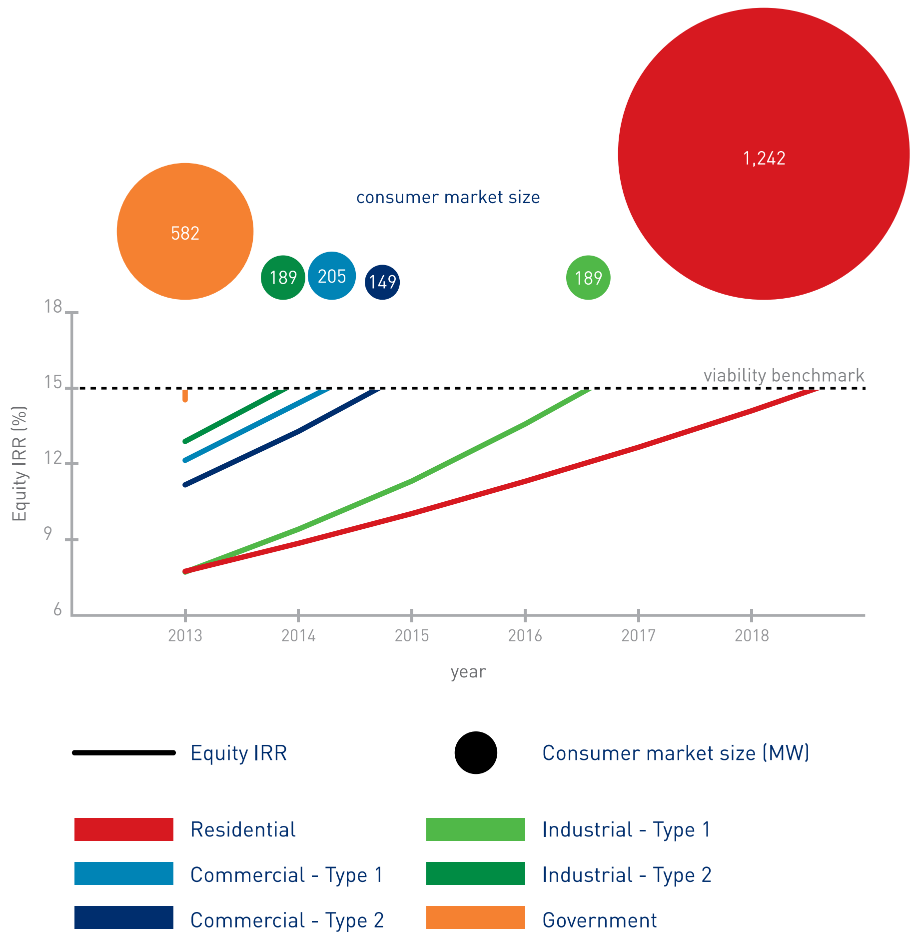
Source: Market interviews, BRIDGE TO INDIA financial model and analysis.

With such high investment costs, rooftop solar needs to be financially viable for consumers investing directly in to their PV plants, or for businesses investing into providing solar energy as a service to end consumers. Viability means that the investment into a solar PV plant can provide a return on investment akin to alternate investment opportunities.

The graph and table below summarize the viability of solar for different consumer types, followed by a detailed analysis.

Rooftop solar needs to be financially viable for consumers investing directly in to their PV plants, or for businesses investing into providing solar energy as a service to end consumers.

Figure 13: Delhi rooftop solar market size and viability



Source: BRIDGE TO INDIA financial model and analysis

Table 5: Viability of rooftop solar PV in Delhi in 2013

		Commercial		Industrial		
	Residential	Type 1 (medium)	Type 2 (large)	Type 1 (micro)	Type 2 (small)	Government
Geographic Potential						
Total potential (MW)	1,242	205	149	189	189	582
Input Factors 2013						
Typical rooftop size range (sq m)	200 to 1,000	400 to 2,000	2,000 to 12,000	300 to 800	800 to 1,500	1,000 to 13,000
Solar suitability of rooftop (%)	20%	30%	20% - 35%	40%	40%	35%-40%
Typical solar potential per rooftop (kW)	3 to 17	10 to 50	33 to 350	10 to 27	27 to 50	29 to 433
Typical system size (kW)	5	25	50	20	40	2,000
System size cost bracket (kW)	5 to 14	15 to 34	35 to 74	15-34	35-74	500 to 2,000
Cost of solar (INR/Wp)	110	100	90	100	90	70
Cost of a typical solar system (m INR)	0.55	2.50	4.50	2.00	3.60	140
Grid tariff in 2013 (INR/ kWh)	6.4	8.5	7.15	6.6	8	6.4
Capacity Utilisation Factor (CUF) (in %)	16%	16%	16%	16%	16%	16%
O&M expenses (INR/ year/entire average system)	5,000	25,000	35,000	20,000	40,000	6,00,000
Equity:Debt	100% equity	30:70	30:70	30:70	30:70	30:70
Loan period (years)	n.a.	12	12	12	12	12
Cost of debt (%)	13%	13%	13%	13%	13%	13%
Required Equity IRR (%)	15%	15%	15%	15%	15%	15%
Viability Analysis 2013						
Achieved equity IRR (%)	**7.75**	**12.15**	**11.18**	**7.72**	**12.9**	**14.55**
Required price for solar per kWh in 2013 (@ 15% EIRR)	11.6	9.7	8.6	9.7	8.8	6.53
Viability gap (INR per kWh)	5.2	1.2	1.45	3.1	0.8	0.13
Viable in 2013?	**NO**	**NO**	**NO**	**NO**	**NO**	**YES**
Viability 2013-2020 (additional input factors)						
Assumed annual grid tariff escalation (%)	5%	5%	5%	5%	5%	5%
Assumed annual reduction in solar costs (%)	6%	6%	6%	6%	6%	6%
Parity year reached	**2018**	**2014**	**2015**	**2016**	**2014**	**2013**

Note: Straight-line depreciation and net-metering has been assumed for all consumers .
Source: Market interviews, BRIDGE TO INDIA analysis and financial model

7.1 VIABILITY OF ROOFTOP SOLAR PV FOR COMMERCIAL CONSUMERS

Commercial consumers pay the non-domestic tariff for electricity, which can be as high as ₹8.5 (€0.13, $0.17)/kWh[84]. Based on their load requirement, commercial consumers fall into two tariff categories. Type-1 consumers (e.g. a small office complex) with a load demand between 100-200 kW pay a higher tariff of ₹8.5 (€0.13, $0.17)/kWh. Type-2 consumers (e.g. a mall like DLF promenade, a privately owned hospital like Apollo Hospitals) with a load demand higher than 200 kW pay a lower tariff of ₹7.15 (€0.11, $0.14)/kWh.

The viable solar tariff (including a return expectation of 15%) for a 25 kW solar plant constructed in 2013 is ₹9.7 (€0.15, $0.18)/kWh, which is only slightly higher than the current grid tariff of ₹8.5 (€0.13, $0.17)/kWh.

Based on the load requirements and available rooftop sizes, we considered an average system size of 25 kW for type-1 consumers and 50 kW for type-2 consumers[85]. The viable solar tariff (including a return expectation of 15%) for a 25 kW solar plant constructed in 2013 is ₹9.7 (€0.15, $0.18)/kWh[86], which is only slightly higher than the current grid tariff of ₹8.5 (€0.13, $0.17)/kWh. Type-1 commercial consumers reach parity in 2014. Solar will be viable for them as it will provide returns comparable to the returns a typical small or medium business would aim to generate in India (16-18%) and higher than the cost of debt (13%).

For a 50 kW solar PV system the viable solar tariff is ₹8.6 (€0.13, $0.17)/kWh[87], whereas the current grid tariff is ₹7.15 (€0.11, $0.14)/kWh. The difference in solar tariff is due to the scale effect that lowers the per kW cost. Solar power is still more expensive than grid power for type-2 commercial consumers. They will reach parity only in 2015. Solar will then be an attractive investment proposition.

For a 50 kW solar PV system the viable solar tariff is ₹8.6 (€0.13, $0.17)/kWh, whereas the current grid tariff is ₹7.15 (€0.11, $0.14)/kWh.

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84 Source: Annual Revenue Requirements of Delhi's DISCOMS

85 Refer to the chapter in the appendix on "Rooftop solar PV systems" for details

86 As per the BRIDGE TO INDIA financial model. We are assuming that there will be net-metering, providing an off-take for solar power also on Sundays and holidays, when commercial establishments like small offices will be shut. On working days, the consumers will completely consume solar power on site as their load (100-200 kW) is more than the assumed standard installed solar capacity (25 kW).

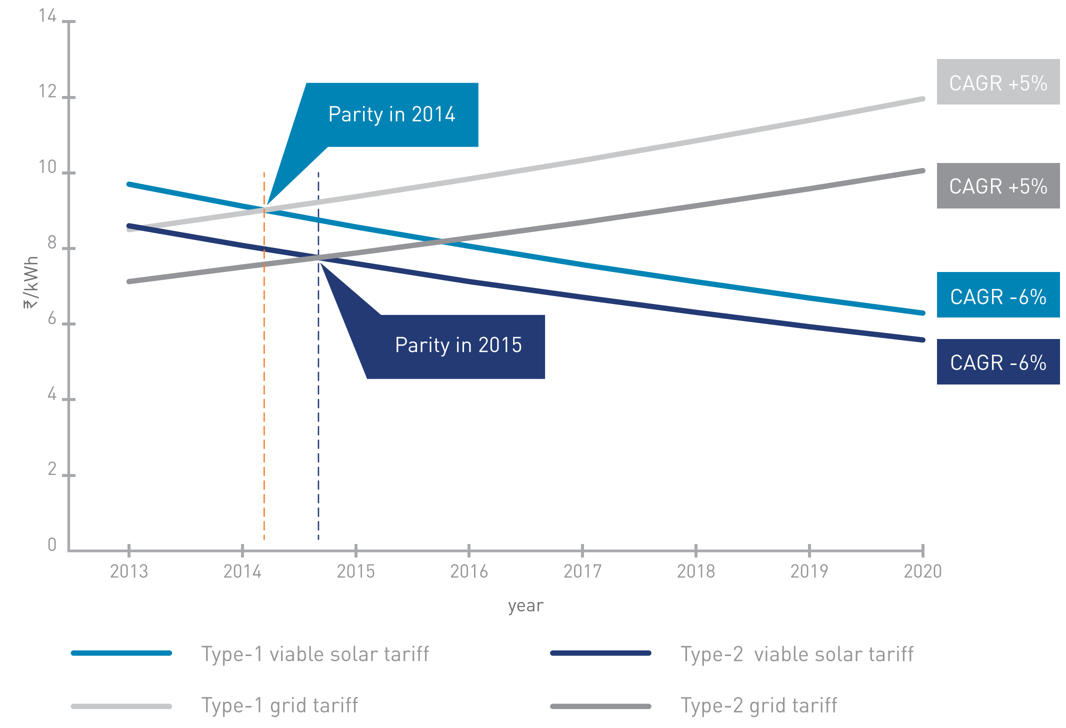
87 As per the BRIDGE TO INDIA financial model. We are assuming that there is a complete daily off-take of the solar power, i.e. that the power is consumed also on Sundays and holidays, as this is usually the case for commercial establishments like hospitals and malls. Further, the consumers will completely consume solar power on site as their load (greater than 200 kW) is more than the assumed standard installed solar capacity (50 kW).

88 Assuming a 5% annual rise in electricity and 6% fall in solar system costs per year

89 Classification of industries by the government of India is based on the total investment into machinery or services. An industry, which invests less than ₹2.5m (€38,462, $50,000) into machinery or ₹1m (€15384, $20,000) into services is a "micro scale industry". An industry, which invests between ₹2.5m (€38,462, $50,000) and ₹50m (€769,230, $1,000,000) into machinery or between ₹1m (€15,384, $20,000) and ₹20m (€307,692, $400,000) into services is a "small scale industry".
Source: www.dcmsme.gov.in/faq/faq.htm accessed on May 22nd 2013

90 Source: Ministry of Small and Medium Enterprises accessed at http://bit.ly/1b73m78 on May 22nd 2013.

Figure 14: Viable solar tariff for commercial consumers vs. non-domestic grid tariff (type-1 and type-2)[88]



Source: DERC tariff orders, BRIDGE TO INDIA analysis

7.2 VIABILITY OF ROOFTOP SOLAR PV FOR INDUSTRIAL CONSUMERS

Delhi has no registered medium to large-scale industries[89] – only small and micro-scale industries.[90] Based on their electricity load, they pay different electricity tariffs. Type-1 consumers (e.g. small-scale textile units and printed presses) have a load requirement between 10–100 kW. Type-2 consumers (e.g. auto-parts manufacturers and chemicals manufacturers) have a load requirement between 100-200 kW.

The equity internal rate of return (IRR) of an investment into a solar PV system for a type-1 consumer today would be 7.72%, lower than the typical IRR expectation of 16-18% for a business in India.

For type- 1, for the purpose of our analysis, we are considering a PV system size of 20 kWp and 40 kWp for Type- 2[91]. The viable solar tariff for a 20 kW system constructed in 2013 is ₹9.7(€0.15, $0.19)/kWh[92], which is significantly higher than the current grid tariff of ₹6.6 (€0.10, $0.13)/kWh. The equity internal rate of return (IRR) of an investment into a solar PV system for a type-1 consumer today would be 7.72%[93], lower than the typical IRR expectation of 16-18% for a business in India. Type-1 consumers reach parity only in 2016, at which point solar will become a viable investment option.

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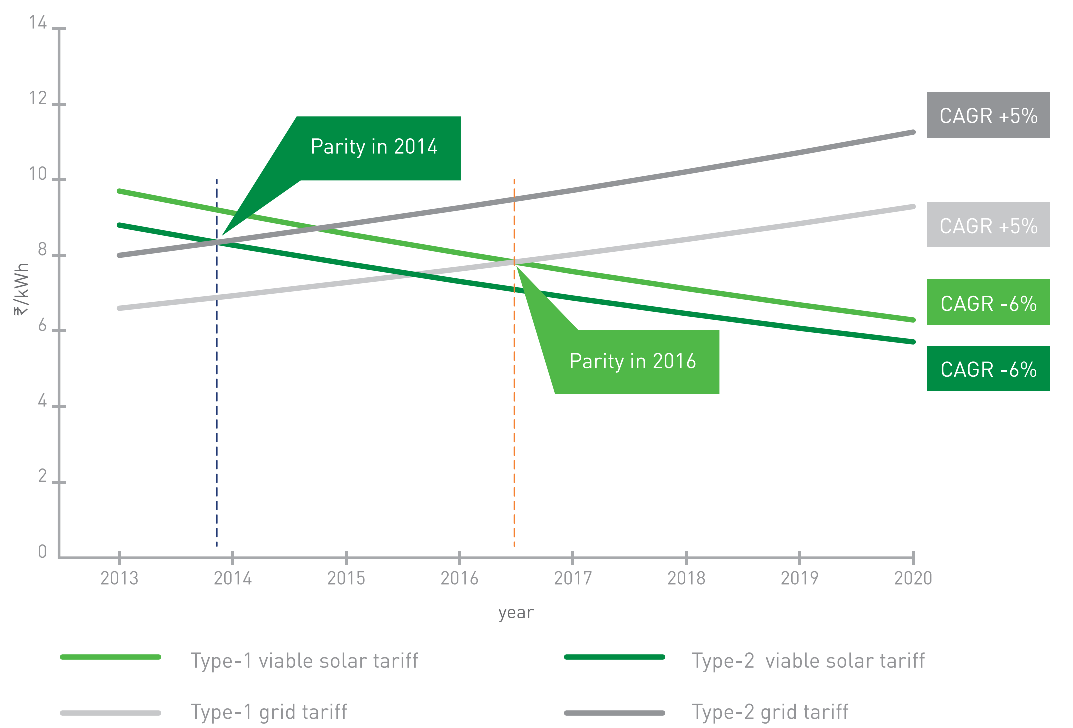
91 Refer to the chapter in the appendix on "Rooftop solar PV systems" for details

92 As per the BRIDGE TO INDIA financial model. We are assuming that there will be net-metering, providing an off-take for solar power also on Sundays and holidays, when industries might be shut. Net metering will also provide an off-take in case a consumer's load is lower than the assumed standard solar installation of 20 kW.

93 As per the BRIDGE TO INDIA financial model.

Figure 15: Viable solar tariff for industrial consumers vs. industrial grid tariff (type-1 and type-2)



Source: DISCOM tariff orders, BRIDGE TO INDIA analysis

Type- 2 industrial consumers reach parity in 2014, when the equity IRR for an investment into a solar power plant would be 15%.

The viable solar tariff of a 40 kW solar PV system in 2013 is ₹8.8 (€0.14, $0.18)/kWh[94], which is slightly higher than their current grid tariff of ₹8 (€0.12, $0.16)/kWh. Type- 2 industrial consumers reach parity in 2014, when the equity IRR for an investment into a solar power plant would be 15%[95]. As in the case of commercial consumers, the equity IRR for type- 2 industrial consumers is comparable to the returns a typical small or medium business would aim to generate in India (16-18%) and higher than the cost of debt (11-13%). Thus, we believe that for these customers, PV is a sufficiently attractive investment proposition.

7.3 VIABILITY OF ROOFTOP SOLAR PV FOR RESIDENTIAL CONSUMERS

Residential consumers in Delhi pay the domestic tariff for electricity, which is ₹6.4 (€0.09, $1.3)/kWh[96]. It is the segment with the highest rooftop potential for solar installations at 1.24 GW.

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94 As per the BRIDGE TO INDIA financial model. We are assuming that there will be net-metering, providing an off-take for solar power also on Sundays and holidays, when industries might be shut. On working days, the consumers will completely consume solar power on site as their load of 100-200 kW is more than the assumed standard installed solar capacity of 40 kW.

95 As per the BRIDGE TO INDIA financial model.

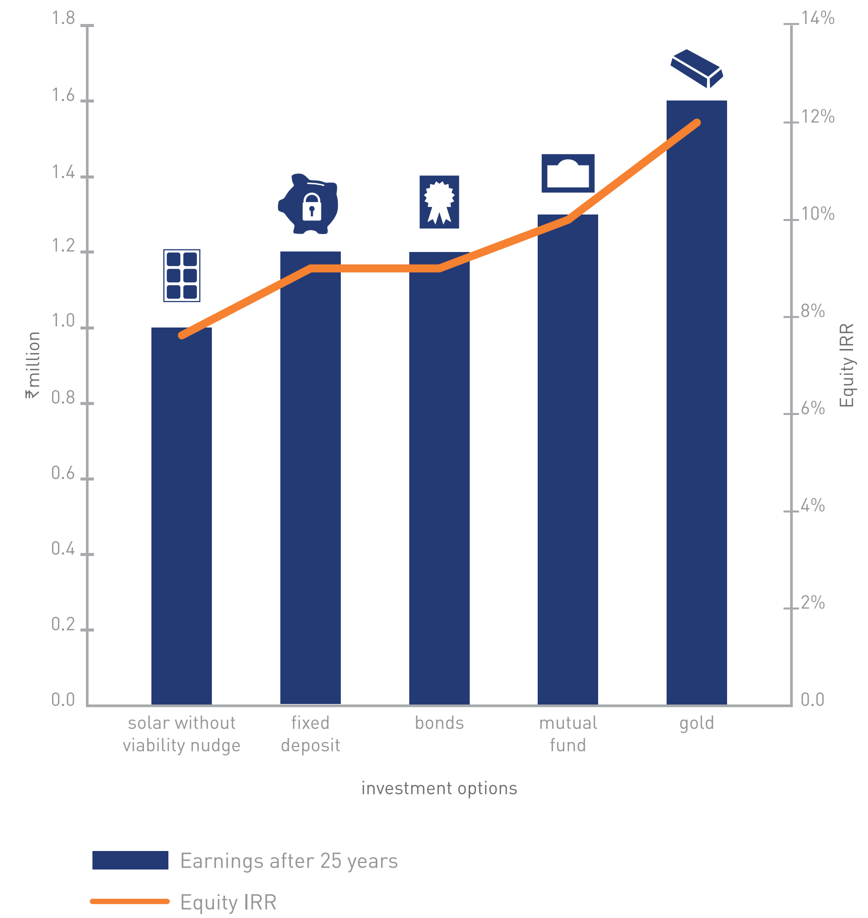
96 Tariff for residential consumers who consume above 400 units per month

A small-scale rooftop system of 5 kW (average) for a residential consumer[97] costs ₹550,000 (€8,461, $11,000)[98] or ₹110 (€1.69, $2.20)/Wp. At this cost, the viable solar tariff for a residential consumer is ₹11.60 (€0.18, $0.23)/kWh[99]. This is 81% higher than the grid tariff of ₹6.4 (€0.09, $0.12)/kWh.

If investing in a PV plant today, a residential consumer can earn an equity IRR of only 7.75%[100]. This return is not much higher than the inflation rate of 5% and falls short of other low-risk investment options like fixed deposits or mutual funds that can give returns of 9% and above, making solar unviable for residential consumers today.

The viable solar tariff for a residential consumer is ₹11.60 (€0.18, $0.23)/ kWh. This is 81% higher than the grid tariff of ₹6.4 (€0.09, $0.12)/kWh.

Figure 16: Residential solar investment compared to similar low-risk investment options[101]



Source: Market interviews, BRIDGE TO INDIA analysis

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97 Refer to the chapter in the Appendix on "Rooftop solar PV systems" for details

98 According to our market information, as of May 2013, a 1 kW PV system costs ₹120,000 (€1,846, $2,400)

99 As per the BRIDGE TO INDIA financial model. We assume net metering is available, providing an off-take to the consumer in case their load is below the assumed standard solar installation of 5 kW.

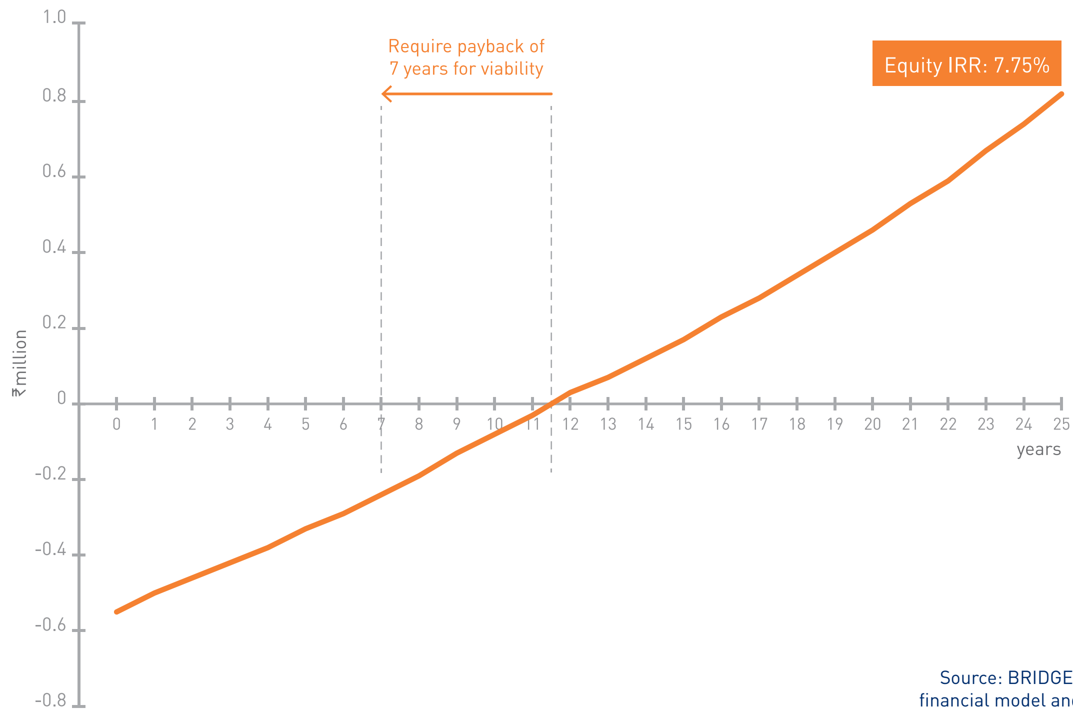
100 As per the BRIDGE TO INDIA financial model.

101 Investment of ₹550,000 (€8,461, $11,000) required for a typical 5 kW residential system has been considered for analysis. Returns calculated after 7 years. 20% tax on fixed deposit. Return on gold calculated based on past 15 year data

At today's prices, residential solar has a payback period of 12 years.

In addition to the IRR, the payback period, i.e. the amount of time it will take for the system owner to recover his cost, is also an important decision-making factor for a household. Delhi is a rapidly developing city where buildings might undergo major construction work every decade. The PV system needs to at least realize a payback for the owner before the owner moves or the building is structurally changed. At today's prices, residential solar has a payback period of 12 years.

Figure 17: Payback from investment in a 5 kW residential system (2013)



Source: BRIDGE TO INDIA financial model and analysis

For solar to be acceptable to residential consumers, a payback period of 5-7 years is preferred[102]. A seven-year payback for 5 kW PV system also corresponds to an equity IRR of 15%[103], which would make returns from solar significantly higher than alternate, low-risk investments. Under these conditions, residential solar will reach parity in 2018.

For solar to be acceptable to residential consumers, a payback period of 5-7 years is preferred.

7.4 VIABILITY OF ROOFTOP SOLAR PV FOR GOVERNMENT FACILITIES

Delhi has several government buildings that belong to the central government, state government and city administration. The major advantages of government buildings are that they are located next to each other, typically in the same complex, and that they have large rooftops (e.g. Krishi Bhawan in Delhi could accommodate 430 kW and Nirman Bhawan 330 kW[104]). The proximity between buildings facilitates the bundling of projects. Hence project sizes (of bundled sites) of 2,000 kWp and above become possible[105]. This brings

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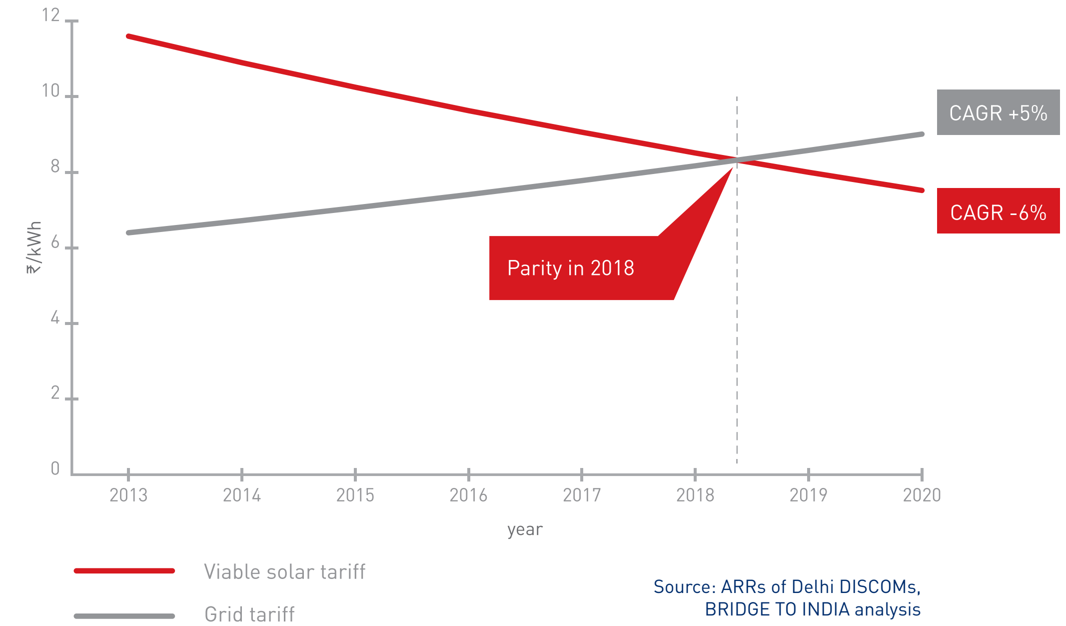
102 Based on market interviews

103 Source: BRIDGE TO INDIA financial model

104 As per BRIDGE TO INDIA analysis and mapping of rooftops through Google Earth

105 Refer to the appendix chapter "Rooftop solar PV systems" for details

Figure 18: Viable solar tariff for residential consumers vs. domestic grid tariff

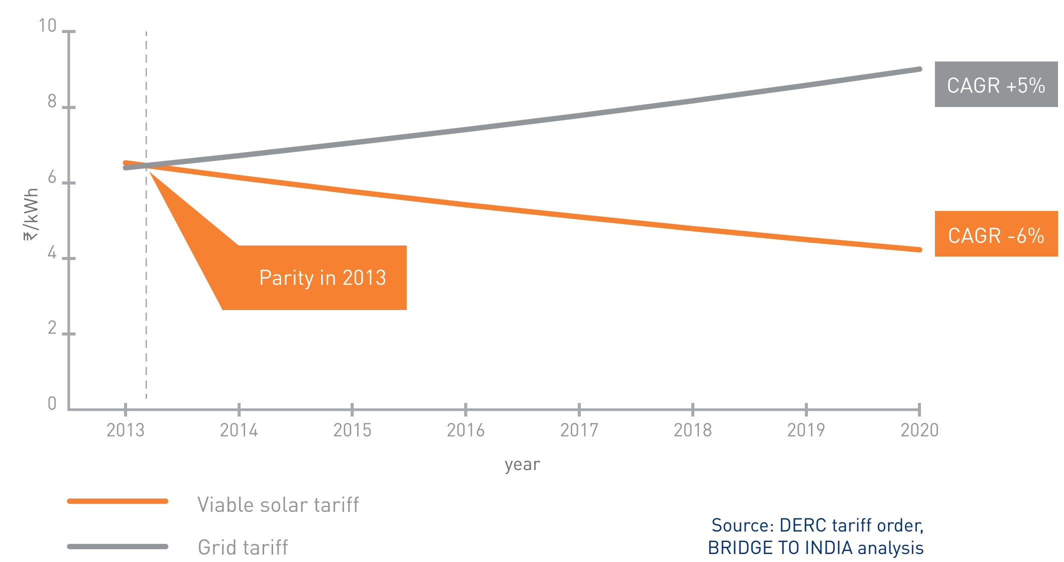


Source: ARRs of Delhi DISCOMs, BRIDGE TO INDIA analysis

down the cost per kW significantly, giving government buildings a strong viability push.

Government buildings are currently paying the domestic consumer tariff of ₹6.40 (€0.09, $0.12)/kWh. The viable solar tariff for a 2,000 kWp system is currently ₹6.53 (€0.10, $0.13)/kWh[106], making solar already viable for government consumers in 2013.

Figure 19: Viable solar tariff for government buildings vs. domestic grid tariff



Source: DERC tariff order, BRIDGE TO INDIA analysis

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106 As per the BRIDGE TO INDIA financial model. We are assuming that there will be net-metering, providing an off-take for solar power also on Sundays and holidays, when some government buildings might be shut. Net metering will also provide an off-take in case consumers' loads are lower than the assumed bundled solar installation of 2,000 kW.

8 BUSINESS MODELS FOR ROOFTOP SOLAR

8.1 STRAIGHT-FORWARD SALES MODEL

The main drawback of the CAPEX model is that the plant owner needs to be able to finance the entire plant.

The most common business model for solar deployment in India today is to simply sell either a complete plant, usually by an Engineering, Procurement and Construction company (EPC), or individual components (such as modules or inverters) to an installer or end customer. The plant owner pays 100% of the PV system cost upfront. This model (sometimes referred to as the "CAPEX[107] model") is pursued by the majority of solar companies, including TATA Power Solar, EMMVEE Photovoltaics or Moserbaer.

The model can be extended by, for example, developing specific, standardized solar kits[108] for specific customer types perhaps in the range of 1-50 kWp. Consumers can purchase these kits from suppliers and have them installed by a local installer[109].

The main drawback of the CAPEX model is that the plant owner needs to be able to finance the entire plant. Solar has a heavily "front loaded" cost structure, with a high initial investment and very low operating costs. A customer might not have the required liquidity to finance a system upfront or get the best debt terms.

A key USP of this model is that it allows industrial and commercial consumers to own the system and claim tax depreciation benefits. With regards to smaller consumers, this business model has not achieved scale in India yet. This might be due to the cost. However, a lack of customer awareness and sales channels also plays a key role. Another concern is that the customer who buys the plant might not always have the skills to maintain it properly.

In a city such as Delhi, where the household income is high, such a model could work with residential consumers as well.

In a city such as Delhi, where the household income is high, such a model could work with residential consumers as well. Standardization, aggressive marketing and information campaigns, easy availability of PV equipment, credible product guarantees and operation and maintenance plans as well as consumer finance are needed to provide a conducive market environment. The model can be bolstered through e.g. the emergence of rooftop aggregators or agents that can connect customers and installers, offering lower PV costs to groups of customers and functioning as sales channels for installers or equipment manufacturers. An example of this is the "One Block off the Grid" initiative in the US.

Case Study

"One Block Off The Grid" (launched in 2008)

"One Block off the Grid"[110] (1BOG) is a US for-profit organization that aims to bring solar power to owners of small buildings by reducing the cost per kWh of solar through collective buying of solar PV systems. 1BOG first approaches systems installers (and module manufacturers in some cases) to negotiate a discount for a significantly larger capacity than an individual household could. It then encourages homeowners to go solar and sign up for the discount by educating them (through the website) about the costs and benefits associated with a solar system installation.

1BOG, acts as an agent that connects buyers to sellers. It charges a referral fee from the system installer. The first 1BOG initiative[111], enabled around 41 citizens of San Francisco to go solar with a group discount of 20%.

In order to organize communities to sign up for the pre-arranged discount, 1BOG runs "campaigns". These campaigns encourage rooftop owners to bring in additional participants to receive further discounts. The benefits of the discounts are availed by communities as a whole, thus motivating all participants to spread the word. The campaign lasts for a few months, during which the company canvasses, employs social media marketing techniques and uses local advertising (such as placards or lawn/road signs) to capture customers.

1BOG also encourages households in states that do not yet have solar targets or solar incentives to push lawmakers and local government authorities to create solar policies to reduce the carbon footprint and create green jobs. An interactive map on the 1BOG website allows power consumers to enquire about discounts available in their state. If the particular state does have any policies supporting solar, the consumer is urged to contact government authorities to push for solar[112]. 1BOG now operates in over 40 states in the United States[113].

8.2 RENEWABLE ENERGY SERVICE COMPANY (RESCO) MODEL

Under a RESCO model, a third party investor comes in to invest into a PV plant on a rooftop and sells solar power to a power consumer. There is no investment required from the consumer. If solar power is viable, as discussed before[114], the consumer can benefit from savings on the electricity bill right from the start. Under this model, the investor and the consumer agree on a tariff (per kWh of solar power) and timeline of a power purchase agreement (typically between 15-25 years). Operations, repair and maintenance of the system could be carried out by the RESCO company rather than the consumer.

The RESCO model is applicable particularly to such commercial and industrial consumers in Delhi who are not willing or able to invest e.g. ₹2.5m (€38,461, $50,000) for a 100 kW system, but are ready to commit to an attractive long-term power purchase agreement.

This model becomes more feasible with larger project sizes (either of individual large plants or of many small one's bundled together) as the transaction costs would prevent most investors from investing into individual small plants. The model is applicable particularly to such commercial and industrial consumers in Delhi who are not willing or able to invest e.g. ₹2.5m (€38,461, $50,000) for a 100 kW system, but are ready to commit to an attractive long-term power purchase agreement.

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107 CAPEX is the capital expenditure or expenditure on the total cost of a power plant.
108 Ready to install kits which consists of all components required for installation.
109 Such a model is followed by e.g. SunEdison: www.sunedisonemea.com/installers/ accessed on May 22nd 2013
110 For more information, see: http://about.1bog.org

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111 Source: New York Times accessed at http://nyti.ms/PFfy on May 22nd 2013
112 Source: CBS News accessed at http://cbsn.ws/1b73y6e on May 22nd 2013
113 Source: 1 Block off the Grid accessed at www.about.1bog.org/faq/#eligible_cities on May 22nd 2013
114 Refer to the chapter on "Viability of rooftop solar PV" for details.

To make this model attractive for the consumers, the investor should offer a solar tariff lower than the current grid electricity tariff. Equally, the escalation of the solar tariff should be lower than the expected escalation of the grid-electricity tariff.

The key concern in the RESCO model is the credit-worthiness of the power off-taker (and hence the bankability of the project).

The key concern in this model is the credit-worthiness of the power off-taker (and hence the bankability of the project). To invest into a power plant on someone else's premises and sell power exclusively to them under a 15 or 25 year PPA requires a lot of faith in the customer.

The key USP of this model is that the consumer gets electricity at a tariff lower than the grid tariff without having to invest into the plant. The consumer, moreover, has very limited risks (mostly related to potential leakages on the rooftops), no hassle and does not need to get involved in a new solar business case. Hence, the investor should find it easy to convince consumers to go solar and save without spending.

8.3 LOCAL MICRO UTILITY MODEL

One way to reduce the off-take risk for a RESCO investor is to give solar power generators easy and cheap access to the distribution grid and allow them to sell power to third parties. Then, solar power developers could rent large, bundled roof spaces from building owners in a designated area, install PV systems and sell the power generated to the rooftop owners, other consumers or the DISCOMs at a pre-negotiated tariff. Having more off-take options would greatly reduce the risk to the project developer and improve the bankability of the project.

The project developers would particularly target those consumers who might not have the resources or would be unwilling to invest in rooftop solar. Developers can offer building owners a lease income on their rooftop space.

Through economies of scale, the cost per kWh of solar power can be significantly reduced and made viable for residential rooftop owners.

This model allows project developers to bundle rooftop space in a community and thereby minimize the legal, commercial and technical transaction costs by increasing the size of individual plants. This makes the model especially useful for the deployment of solar for residential consumers. The viable solar tariff in 2013 for a 50 kW plant is ₹8.6 (€0.13, $0.17) (close to the grid tariff for residential consumers) compared to the much higher viable solar tariff of ₹11.60 (€0.18, $0.23) for a 5 kW plant. Through economies of scale, the cost per kWh of solar power can be significantly reduced and made viable for residential rooftop owners (see also the earlier case study of 1 BOG).

Building owners will be able to generate new income through leasing their roofs for a period of time (e.g. 15 years). Renting homes is common in Delhi. The tenant might be disinterested in investing into a PV system that might have a payback period and a lifetime significantly exceeding the lease period. Such a leasing model would incentivize landlords who are renting out a building, to still make available their rooftops for PV plants.

Such a model can be combined with the RESCO model, wherein the project developer could sell power back to the building owner as well. In such a case, the lease for the rooftop might be waived in favor of a lower solar power tariff.

The key drawback in this model is the shifting of building owners from time to time. In case the owner of the building sells the building and the new owner would not like the roof to be utilized for solar, the project developer might have no other option but to shift the system to another location. Shifting an existing system to another roof would create significant additional costs and would push back the viability of solar (there is perhaps an attractive opportunity for a "smart", easy to move mounting structure and balance of system design). Another challenge to the model is a current lack of regulatory support for selling distributed power directly to end customers or utilities in Delhi.

They key USP of this model is that it unlocks a greater number of residential rooftops for PV systems, by providing economies of scale to the developers and an easy income opportunity to a rooftop owner.

They key USP of this model is that it unlocks a greater number of residential rooftops for PV systems, by providing economies of scale to the developers and an easy income opportunity to a rooftop owner.

The city of Gandhinagar in Gujarat, has initiated a pilot project that has some characteristics of the solar rooftop leasing model described above.

Case Study

Gandhinagar solar rooftop program (2012 and on-going)

Gujarat has launched a pilot project in Gandhinagar to demonstrate the working of grid connected rooftop solar power generation. The 5 MW project is based on a Private Public Partnership[115] (PPP) model. If successful, it is to then be replicated in five other cities of Gujarat. As per the PPP agreement, the Gujarat government has appointed the private project developers Azure Sun Energy India Private Ltd. and Avantha Solar Power Maharashtra Private Ltd. to build, finance, own, operate and maintain grid connected rooftop solar PV systems on approved rooftops of government buildings (4 MW) and private residences (1 MW)[116]. The developers feed the power into the grid at a pre-determined feed-in tariff of ₹11.21 ($0.22, €0.17) /kWh for Azure and ₹11.78 ($0.23, €0.18)/kWh for Avantha Solar. The PPA counterparty is Torrent Power, the private utility that services Gandhinagar. Torrent Power fulfills its solar RPO obligation, enforced by the state of Gujarat through this agreement. The project developer will pay a "green incentive" of ₹3 ($0.06, €0.05/kWh), as rent to the rooftop owners. The duration of the PPA is 25 years. The implementation of this program was facilitated by the Gujarat Power Corporation Limited (GPCL).

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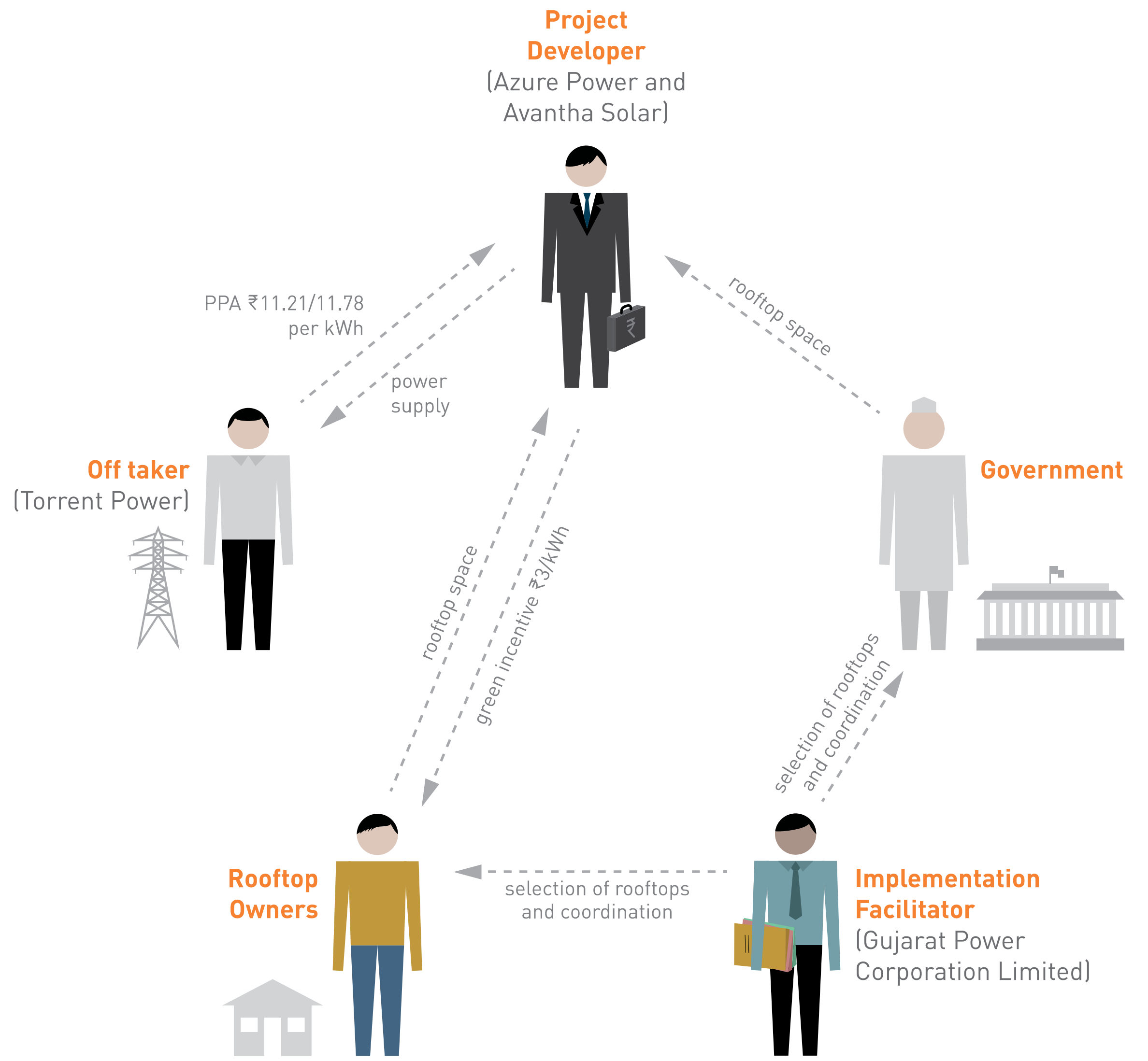
115 PPPs broadly refer to long-term, contractual partnerships between the public and private sector agencies, specifically targeted towards financing, designing, implementing, and operating infrastructure facilities and services that were traditionally provided by the public sector (Asian Development Bank 2006)

116 For more information, please see: http://bit.ly/16LUBTm . Source: The World Bank

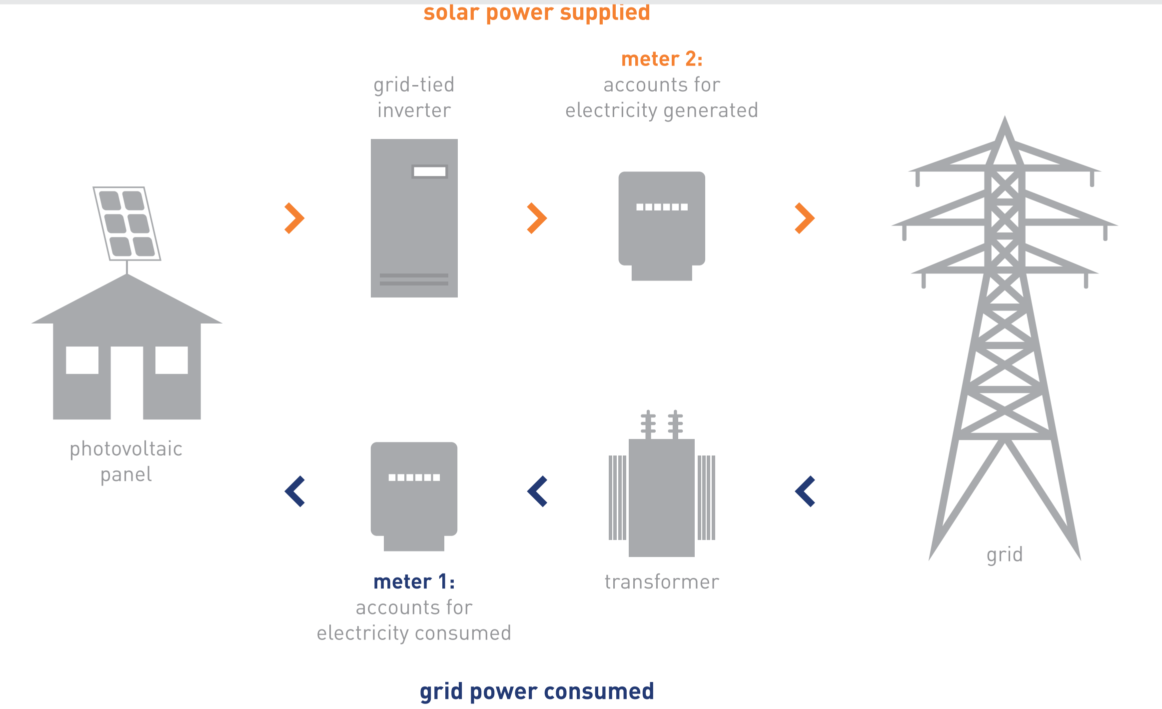
Figure 20: The implementation structure of the Gandhinagar Solar Rooftop Program



Source: Gandhinagar Rooftop Program, BRIDGE TO INDIA

The metering scheme adopted by the program is called "gross metering" (as opposed to "net metering"). The energy generated by the PV system is metered separately from the consumption of electricity from the grid. As shown in figure 2, "meter 1" measures the electricity consumed from the grid by the rooftop owner and "meter 2" accounts for the electricity generated by the PV system that is fed into the grid to be sold to the utility. At no point is the power from the PV system consumed by the rooftop owner. Since a FiT is offered as part of the program, a gross metering system makes more sense then a net metering system. The danger is that the two circuits might be fraudulently linked in such a way that grid power is sold back to the utility again through the solar meter, at a premium. Addressing this challenge will become more important if the model is scaled.

Figure 21: Gross metering



Source: International Finance Corporation (IFC), BRIDGE TO INDIA

The Gandhinagar rooftop pilot project will be launched in two phases of 2.5 MW each. The project is still at a nascent stage. Only 150 kW has been installed as on April 2013[117].

The program makes rooftop PV for residences viable through the enforcement of the solar RPO requirement and the resulting willingness of the utility to pay a higher tariff. Given the higher grid tariffs in Delhi, such an approach is not needed: parity-driven solar will work with net-metering without additional incentives. However, the Gandhinagar rooftop model is a good pilot: The leasing model enables a rooftop owner to benefit from solar PV through earning rent in the form of the "green incentive". The utility is able to meet its solar RPO and provides a bankable off-take for the PV system. Solar power generation is not limited by the load requirements of the building the plant is constructed on. Thus, available space can be optimally used. The tariff is, however, quite high and Torrent Power should be able to meet its solar RPOs in a cheaper way by buying solar power from one of the many large, ground mounted solar plants in the state or by buying RECs.

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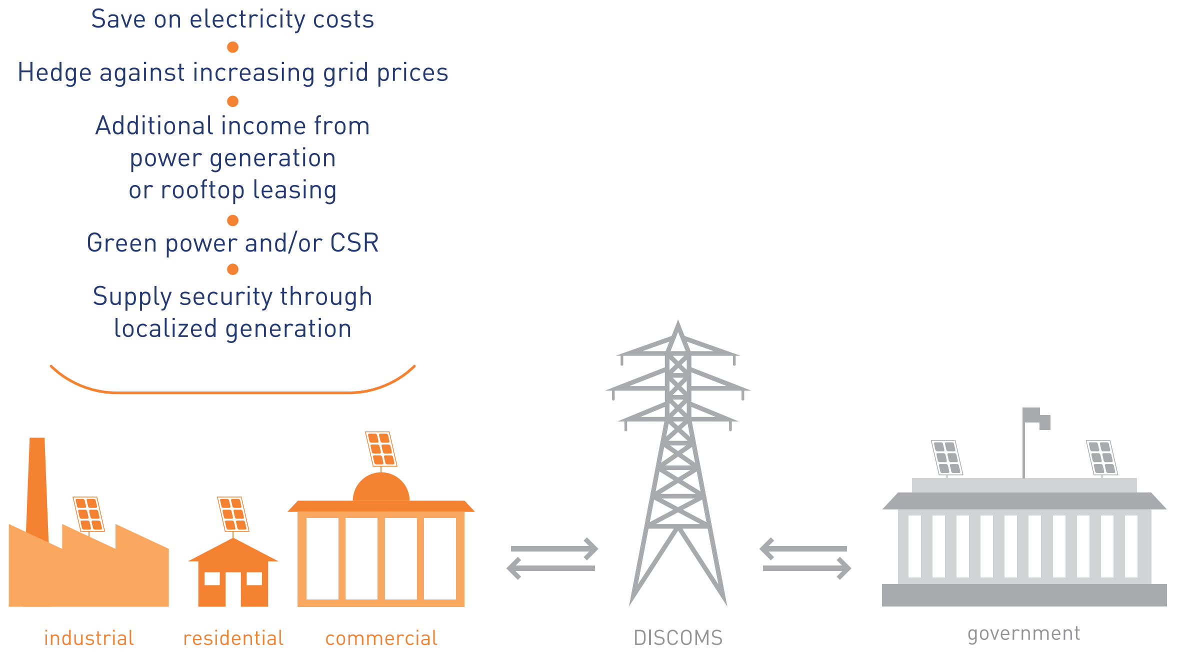
117 Source: The Statesman accessed at http://bit.ly/185dwcg on May 10th 2013. No official source available.

9 WHY ROOFTOP SOLAR WORKS FOR THE STAKEHOLDERS

9.1 WHY ROOFTOP SOLAR WORKS FOR DELHI'S POWER CONSUMERS

Figure 22: Benefits to consumers



Source: BRIDGE TO INDIA

Based on current trends, electricity tariffs can be expected to rise by a further 25% in the next five years for domestic (residential and government consumers) and non-domestic (commercial consumers) segments and 29% for the industrial segment in Delhi.

Delhi's power consumers are worried about the recent trend of rapidly rising power prices. Solar can allow them to become more independent and, whenever parity is reached for a consumer segment, it can reduce their power costs. Based on current trends[118], electricity tariffs can be expected to rise by a further 25% in the next five years for domestic (residential and government consumers) and non-domestic (commercial consumers) segments and 29% for the industrial segment in Delhi.

On the other hand, solar prices are expected to decline at the long-term rate of 5-8% driven by technology improvements (e.g. on module efficiency and manufacturing improvements)[119]. Balance-of-system (BOS) costs (inverters, mounting structures, installation costs) will drive future plant cost reductions. Thus by switching to solar, residential, commercial, industrial and governmental power consumers, can hedge against increasing electricity prices in Delhi. Also, if they are allowed to sell power to third parties or if a rooftop leasing model takes hold, solar offers a new income stream to rooftop owners in Delhi.

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118 As explained in the chapter "Viability of rooftop solar PV"

119 The rate of decline of solar prices will reduce from the 50% decline seen in the past two years as the drastic module oversupply situation is easing and will be corrected in the next years globally.

For commercial and industrial consumers, going solar can be a good way of improving the "Corporate Social Responsibility" (CSR) footprint. It can communicate a company's concern about the community and the environment it operates in. Given that solar is viable, it is a CSR initiative that also makes economic sense. As an example, Shoppers Stop in Mumbai, a mall, installed a 30 kW solar system to promote itself as a "green" company and to hedge against rising costs of power in Mumbai[120]. Some global corporations that have already shown the way in other countries are Wal-Mart, IKEA and P&G. Since 2008, Wal-Mart has set up solar installations on 31 facilities in California and Hawaii and has reduced energy costs by ₹50m (€0.76m, $1m)[121].

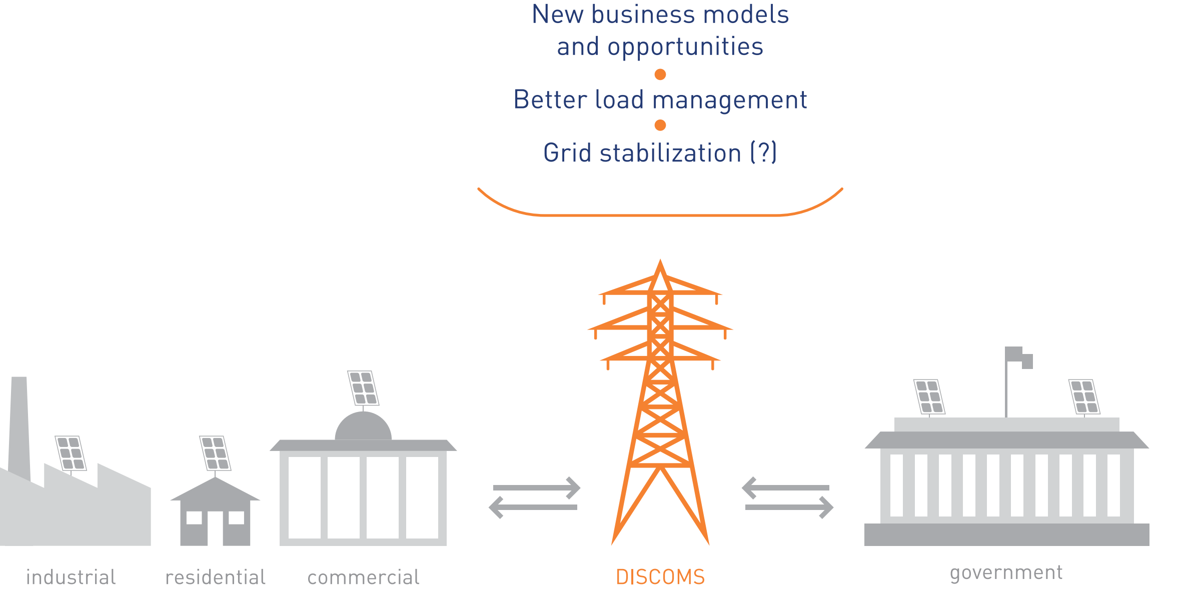
As per the Companies Bill 2011[122], companies with a profit of ₹5 billion (€0.07 billion, $0.1 billion) or more, a turnover of ₹10 billion (€0.15 billion, $0.2 billion) or more, or a net profit of ₹50m (€0.76m, $1m) or more, in a fiscal year, are mandated to spend 2% of their net profit on CSR activities. "Ensuring environment sustainability" is one of the nine activities that qualify as a CSR initiative, according to the bill's directives. The CSR obligation is likely to be enforced soon. Apart from being an obligation for larger corporations, CSR is increasingly being viewed by large and small businesses as a part of the overall business strategy. Going solar can provide industries with an additional "sustainability edge" in marketing their products in India and (perhaps more effectively) globally.

As a local, de-centralized source of power, rooftop solar allows consumers to be more in control of their electricity supply.

Currently, many power consumers in Delhi have stable power supply. However, it is not clear, if this will continue in the future. As a local, de-centralized source of power, rooftop solar allows consumers to be more in control of their electricity supply. Consumers can produce and consume their electricity on-site, making their electricity supply very reliable and secure.

9.2 WHY ROOFTOP SOLAR WORKS FOR DELHI'S DISCOMS

Figure 23: Benefits to the DISCOMS



Source: BRIDGE TO INDIA

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120 Source: The Economics Times accessed at http://bit.ly/OCarHB on May 22nd 2013

121 Source: USA Today accessed at http://usat.ly/110x6OA on May 22nd 2013

122 Refer http://www.mca.gov.in/Ministry/pdf/The_Companies_Bill_2011.pdf for more details

DISCOMS should not view solar as an additional burden, but rather as a new business opportunity and as a chance to be at the leading edge of what utilities will likely be in the future: integrators of a smart grid with many different sources of power generation and consumption.

DISCOMS should not view solar as an additional burden, but rather as a new business opportunity and as a chance to be at the leading edge of what utilities will likely be in the future: integrators of a smart grid with many different sources of power generation and consumption. Fossil fuel supplies remain strained and carbon emissions need to be curtailed, while power demand continues to rise[123]. Significantly, rooftop solar PV is already financially viable for government consumers today and will be for commercial, industrial and residential consumers in the coming years. Adopting decentralized solar now is a good opportunity for Delhi's DISCOMS to begin preparing for the future.

And more than that: utilities are ideally placed to capture a large part of this new market, for example, if they become part of the third party investment market (the RESCO or aggregator models described above).

In Delhi, often, the actual peak summer demand exceeds the planned, causing power outages for consumers. In addition, at times the power drawn from other states fails due to inter-state grid problems, causing outages. Delhi's grid infrastructure, too, collapses at times under the strain of excess electricity loads during peak summer months.

Given acute power shortages in Northern India, Delhi's DISCOMS might be able to better plan loads and hence reduce the cost of buying power and maintaining the high level of power availability, if they explore alternatives to sourcing power from large, conventional plants located outside the city. Localized, distributed renewable generation is a readily available answer. 2 GW of rooftop solar PV would make a significant difference. Also, distributed solar power, if implemented well, might help to stabilize the Delhi grid.

In order for the utilities to making the transition from an "old" to a "new" power system with significant distributed solar PV, they will need clear political leadership with a dependable roadmap and guidelines as well as support in building required infrastructure additions.

In order for the utilities to making the transition from an "old" to a "new" power system with significant distributed solar PV, they will need clear political leadership with a dependable roadmap and guidelines as well as support in building required infrastructure additions. Successfully implementing such a transition in Delhi will put them in a very strong position to replicate the model in other markets.

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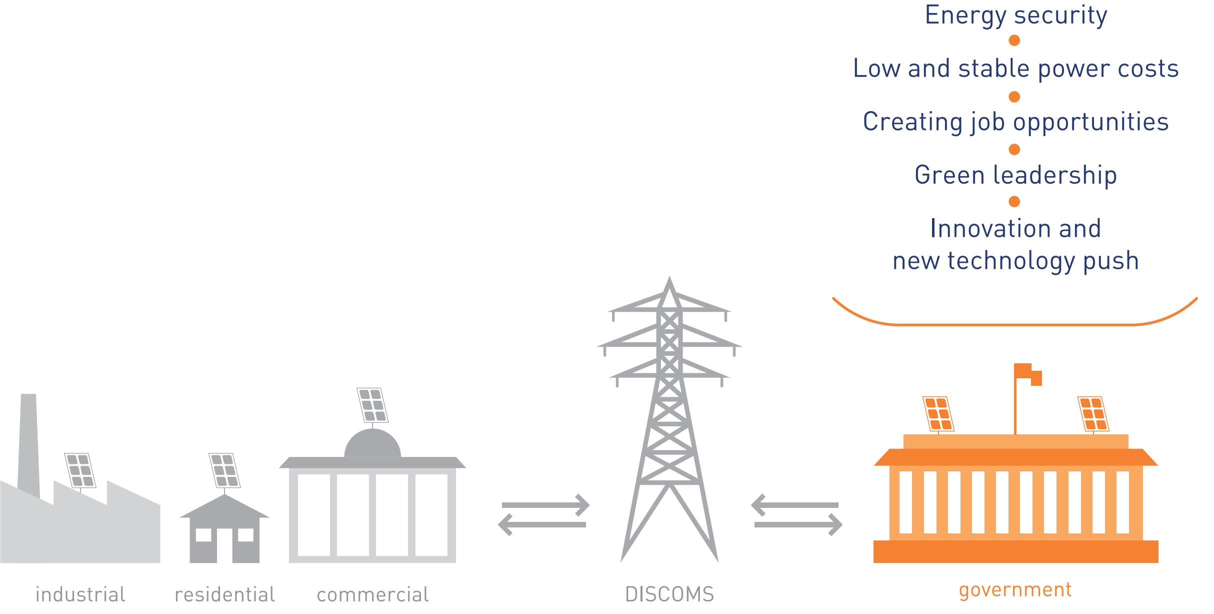
123 Refer http://bridgetoindia.com/blog/?p=1638 for more details

9.3 WHY ROOFTOP SOLAR WORKS FOR DELHI'S GOVERNMENT

Figure 24: Benefits to the government



Source: BRIDGE TO INDIA

Taking a progressive approach to the adoption of solar in Delhi could yield numerous advantages for the Delhi government. It would be a strategic choice to take an early and bold step into a new energy future. Solar can help Delhi increase its energy security and limit consumer power price rises. It could also create an ecosystem for innovation, job-creation and learning to propel Delhi to the forefront of a modern energy system.

Solar can help Delhi increase its energy security and limit consumer power price rises.

Delhi's peak power demand has increased from 3,097 MW in 2002 to 5,642 MW in 2012[124]. While the power demand has increased, the power generation capacity within the state has not kept pace. In 2002, Delhi had a power generation capacity of 527 MW. This has increased to only 1,344.7 MW by 2012, supplying only 28% of the city's demand[125]. Delhi's demand is expected to reach over 11,000 MW in 2022[126]. At the moment, the only expected additions in power generation capacity in the city are a 1,370 MW gas based plant and a 94.8 MW coal based power plant. Land in Delhi is expensive and unavailable to set-up large conventional power plants.

A large part of Delhi's peak power demand is met by purchasing power from generators in other states through long-term PPAs (meeting 58% of Delhi's demand) and purchasing short-term power through power exchanges and

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124 BRIDGE TO INDIA analysis based on CEA data. www.cea.nic.in/more_upload/epsr_17_highlights.pdf accessed on May 22nd 2013
125 Source: DERC tariff orders.
126 BRIDGE TO INDIA analysis based on CEA data. www.cea.nic.in/more_upload/epsr_17_highlights.pdf accessed on May 22nd 2013

from generators in other states (meeting 13% of Delhi's demand). Relying on external sources, however, has made the city's power supply vulnerable. 82% of Delhi's power from external long-term PPAs is from gas and coal. Gas supplies are short[127]. Increased supply of large quantities of gas will only be possible with new pipelines that might not be built, and even if they are, will take time. In addition, there is a shortage of coal supplies in India. Coupled with water shortages, this leads to a fall in generation in coal plants. In December 2012, the northern region faced a power deficit of 8.2% owing to such shortages[128]. Delhi was directly affected by such shortages in October 2011, when production of coal plants supplying power to Delhi from outside the state fell by over 1,000 MW, leading to severe power cuts in the city[129]. The city's DISCOMS partly compensate for such drops in generation by overdrawing from the northern grid, purchasing short-term power from other states and the spot market.

Rooftop solar is the only locally available power generation option available to the government.

Purchasing short-term power from the northern grid presents a serious risk to the city's power supply. In the financial year 2012-13, the northern grid faced a peak deficit of 12.3%[130]. This summer, states like Uttar Pradesh will lack almost 7,000 MW and Punjab 3,000 MW[131]. Such states will draw on power from Rajasthan, Jammu and Kashmir (facing its own power deficit of 50%) and Gujarat. Delhi, too, relies on these and other states for short-term power, sources that will be strained and increasingly unavailable in a scenario of continuing power deficits. The reliance of Delhi's DISCOMS on power from the northern grid only further exposes the city to the kind of massive grid failure that took place in July 2012[132]. Rooftop solar is the only locally available power generation option available to the government.

As per the World Health Organization's (WHO) data, covering 1,000 cities in 91 countries[133], Delhi is the 12th most polluted city in the world. The respirable suspended particulate matter (RSPM) and the concentration of Nitrogen Oxide (NOx) are above permissible levels[134]. This in turn has led to an increase in the number of respiratory disorders and cases of hypertension. It is important for the government to make a gradual shift to a cleaner source like solar to improve the health parameters of its residents. Solar could give the city the room for manoeuver that it needs to shut down the heavily polluting, coal fired power plants within the city.

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127 Refer http://bit.ly/18QC05L accessed on May 22nd 2013

128 Source: CEA

129 Source: The Hindu accessed at http://bit.ly/19KI8xR on May 22nd 2013

130 Source: CEA Load Generation Balance Report 2012-13 accessed at http://bit.ly/11GsqMv on May 22nd 2013

131 Source: Ministry of Power

132 Refer The New York Times article at http://nyti.ms/Mwq7Xj accessed on May 22nd 2013

133 Using air monitoring data from 2003-2010 Source: Slate accessed at http://slate.me/W2zWmT on May 22nd 2013

134 RSPM in the Capital's air is touching 250 micrograms per cubic meter (ig/ m^3) when the permissible level is 60 micrograms per cubic meter and concentration of nitrogen oxide (NOx) is 50-55 ig/ m^3 well above the permissible upper limit of 40ig/ m^3. Source: India Today accessed at http://bit.ly/Ngk0YM on May 22nd 2013.

Adoption of solar would also be accompanied by the creation of new employment opportunities for the city. The solar industry is capable of developing an ecosystem that creates jobs for system installers, transporters, project developers, system maintainers, grid monitors and power quality controllers. The solar industry has the capacity to create 32 job-years/MW[135] that implies that 62,000 new full-time jobs can be created by installing 2 GW of solar power. With an annual influx of 70,000-80,000[136] migrants to Delhi, and an unemployment rate of 4.8%[137], these new jobs could absorb a considerable amount of the workforce.

By focusing on energy security, cleaner energy and job creation, the Delhi government can project itself as a progressive administration.

By focusing on energy security, cleaner energy and job creation, the Delhi government can project itself as a progressive administration. The aggressive adoption of solar can enable Delhi to take up the role of a green leader and set an example for other states as it did in the case of Compressed Natural Gas (CNG). The city of Delhi also has the capability of becoming the center for solar research and development or an "innovation hub" for the country. For this, it can exploit the knowledge pool of top universities such as the Indian Institute of Technology (IIT), located in the city.

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135 As per the reports "The work that goes into renewable energy" by Renewable Energy Policy Project -2001 and "Putting renewables to work" by University of California, Berkley -2004 around 5 jobs (excluding manufacturing of modules, inverters and cables) can be created by 1MWa of solar. With 16% efficiency, 32 job-years can be created by 1MW of solar installed. Refer http://bit.ly/19KJby2 and http://bit.ly/nCvEne accessed on May 22nd 2013

136 Economic survey of Delhi 2012-2013 accessed at http://bit.ly/11GtcJl on May 22nd 2013

137 Source: http://bit.ly/10Sg4pg accessed on May 22nd 2013

10 DELHI SOLAR ROADMAP: REACHING 2 GW BY 2020

Delhi can become a leading solar city in the world without any significant investment into either incentives or the grid, based on the commercial viability of solar power and the existing infrastructure.

What is required to reach that goal, however, is a fundamental shift in the way that consumers, DISCOMS and regulators think about the provisioning of power. Distributed solar power should not be regarded as a nuisance, as being irrelevant, a regulatory challenge or cost factor. It is neither of these. It is rather a viable, achievable, significant part or the solution to Delhi's long-term power requirements.

We have outlined two scenarios for the implementation of 2 GW by 2020. The priority scenario is based only on grid parity and does not involve any incentives by the government. The optional scenario is based on an aggressive approach with significant capacity addition even before parity is reached.

We have outlined two scenarios for the implementation of 2 GW by 2020. The priority scenario is based only on grid parity and does not involve any incentives by the government. The optional scenario is based on an aggressive approach with significant capacity addition even before parity is reached. This would require incentives from the government and would make sense only, if there is an acute concern about energy security.

10.1 PRIORITY SCENARIO (PARITY BASED)

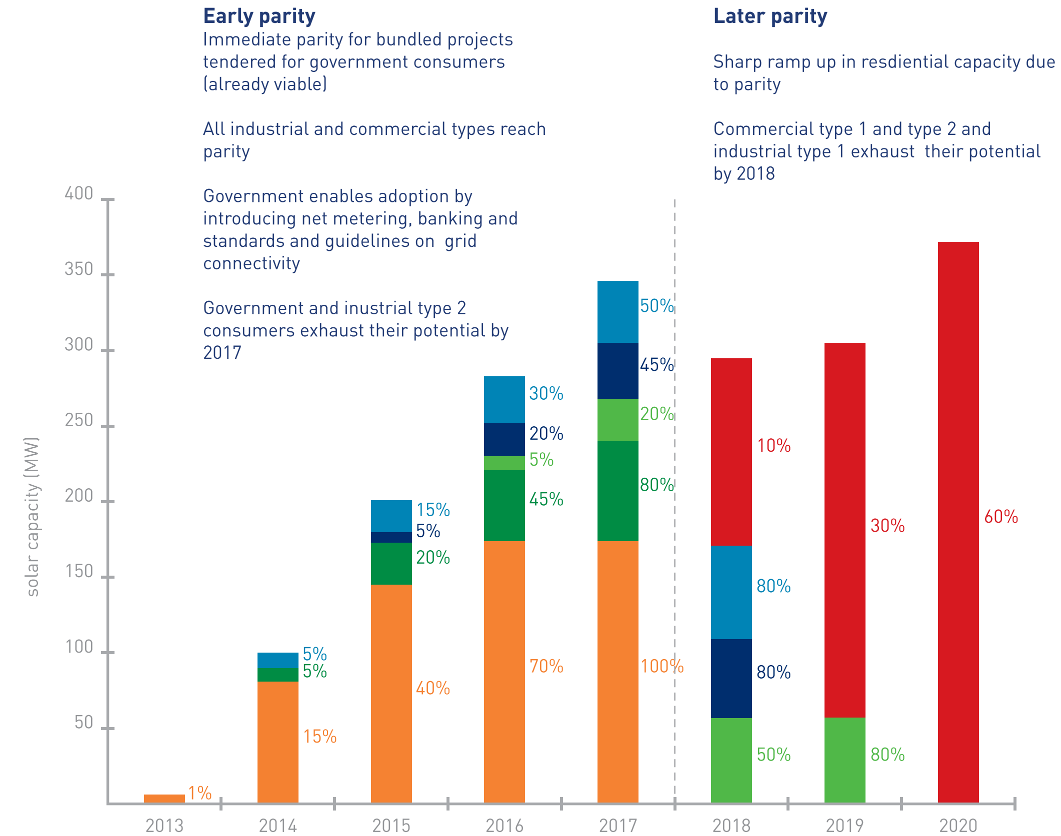
In this scenario, the solar installations are purely based on commercial viability once parity is reached for a consumer category. Solar is already viable for government consumers today, if projects are bundled and tendered together. For commercial type-1 and industrial type-2 consumers, solar will be viable in 2014 and they should be ready to switch to it. In the course of the following five years, the other three power consumer categories (commercial type-2, industrial type-1 and residential) also reach parity.

We foresee two major growth periods: one between 2014 and 2017 when the government buildings go solar and one between 2018 and 2020, when residential installations will come into the market. The graph, on the facing page, shows the expected annual solar capacity addition per tariff category.

In predicting the growth rate, we have made the following assumptions:

1. Growth will be driven by parity only (and not by incentives). Therefore, only once parity has been reached for a tariff group will solar be installed.
2. We assume annual "adoption rates". Once parity has been reached, it will still take time until all customers are ready to go solar. This lag might be related to e.g. unavailability of financing options, uncertainty about building ownership/use or a lack of awareness.
3. We assume a relatively low initial adoption rate (of e.g. 5% for commercial type-1 consumers and 5% for industrial type-2 consumers) that will finally max out at 80%, assuming that there will always be a residual group that will not adopt solar (an addition to the other discount factors included in the calculation of the potential).
4. Because the residential segment reaches parity late, it does not achieve 80% by 2020.

Figure 25: Priority scenario expected annual solar capacity additions (in MW)



	2013	2014	2015	2016	2017	2018	2019	2020
Residential	0	0	0	0	0	124	248	372
Commercial - Type 1	0	10	21	31	41	62	0	0
Commercial - Type 2	0	0	7	22	37	52	0	0
Industrial - Type 1	0	0	0	9	28	57	57	0
Industrial - Type 2	0	9	28	47	66	0	0	0
Government	6	81	145	174	174	0	0	0
Total (y on y)	**6**	**101**	**202**	**284**	**347**	**295**	**305**	**372**

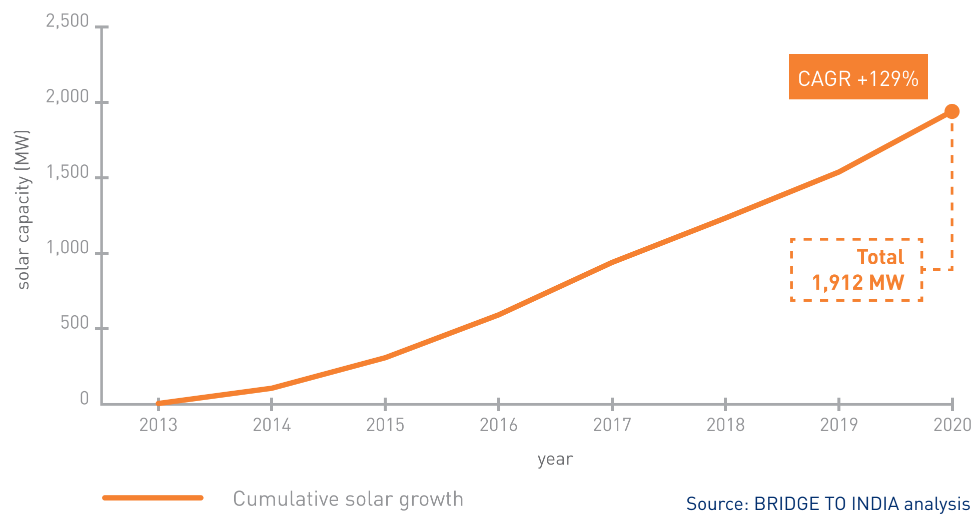
Consumer parity year

% Cumulative percentage of the total potential realized up to a year

Source: BRIDGE TO INDIA analysis

5. Our approach is slightly different for the government sector. We assume a 1% adoption in 2013, because we suggest that the government should do a trial tender in 2013 to learn the ropes. Following that, the adoption rate of the government is fast, because we assume that a transition to solar power can be managed through a limited number of actors. For the same reason, we assume that 100% of the potential can be converted by 2017.

Figure 26: Priority scenario cumulative solar rooftop growth until 2020



Source: BRIDGE TO INDIA analysis

10.2 OPTIONAL SCENARIO (GOVERNMENT INCENTIVES)

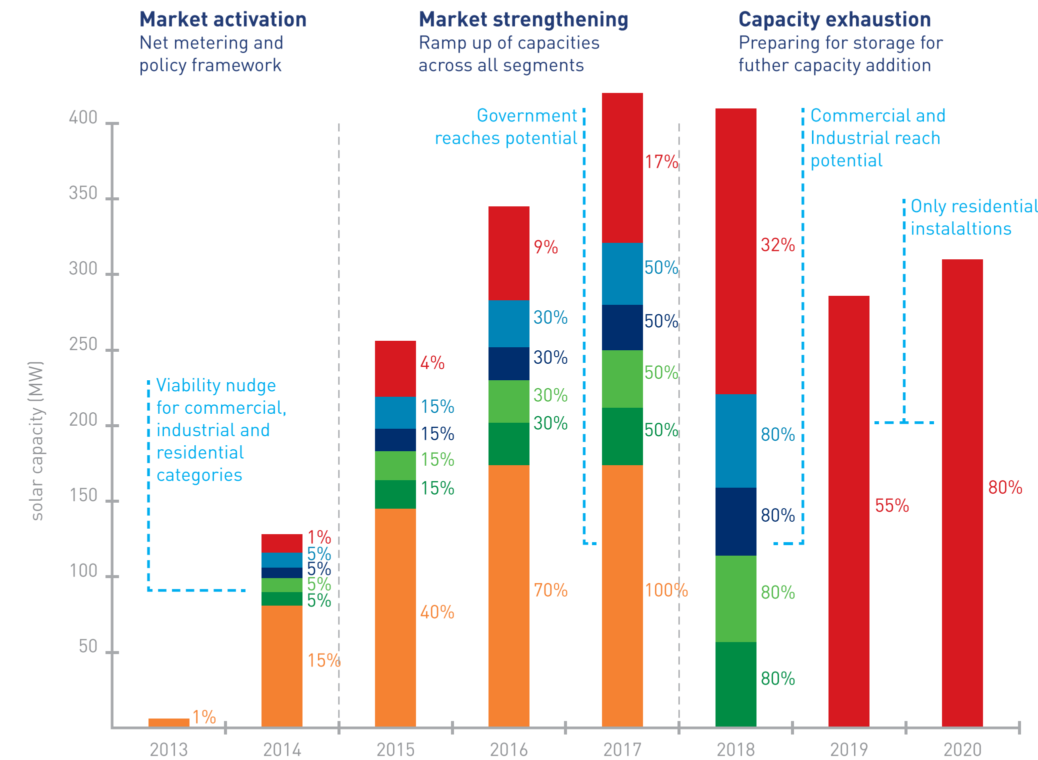
If the government wants to address energy security challenges more urgently through solar, it will have to provide a "viability nudge" through incentivizing the adoption of rooftop solar.

If the government wants to address energy security challenges more urgently through solar, it will have to provide a "viability nudge" through incentivizing the adoption of rooftop solar. This will lead to parts of the potential of rooftop solar being realized even before parity is reached. Once parity for a particular consumer category is reached, no further incentives are needed. Due to incentives, solar will be adopted by all the categories of consumers by the year 2014. The installations reach a peak in 2017 and by 2018 all the categories, except residential consumers, reach their potential. The graph on the facing page shows the expected annual solar capacity addition.

In predicting the growth rate, we have made the following assumptions:

1. The government will provide incentives to all the consumers that are yet to reach parity such that they can achieve a 15% internal rate of return on their investments (or a 7 year payback for residential consumers). The incentives will reduce every year to factor the increase in grid tariffs and reduction in solar costs over time.
2. As in the priority scenario, industrial and commercial consumers will adopt 80% of their potential. Residential consumers too will adopt up to 80%, unlike in the priority scenario where they only reach 60%. This is because they will adopt early due to a viability nudge, and will adopt more of their potential over a longer period of time than other consumers.
3. The initial adoption rate is 5% across commercial and industrial consumers as there is lack of awareness and the market for these consumers will take time to strengthen. These adoption rates will makes out at 80% assuming that there will always be a residual group that will not adopt solar (an addition to the other discount factors included in the calculation of the potential).
4. As in the main scenario, the government will initiate adoption in 2013 by performing a small, trial tender for government buildings. The adoption in government projects will be similar to that in the parity scenario.

Figure 27: Optional scenario expected solar capacity addition (in MW)



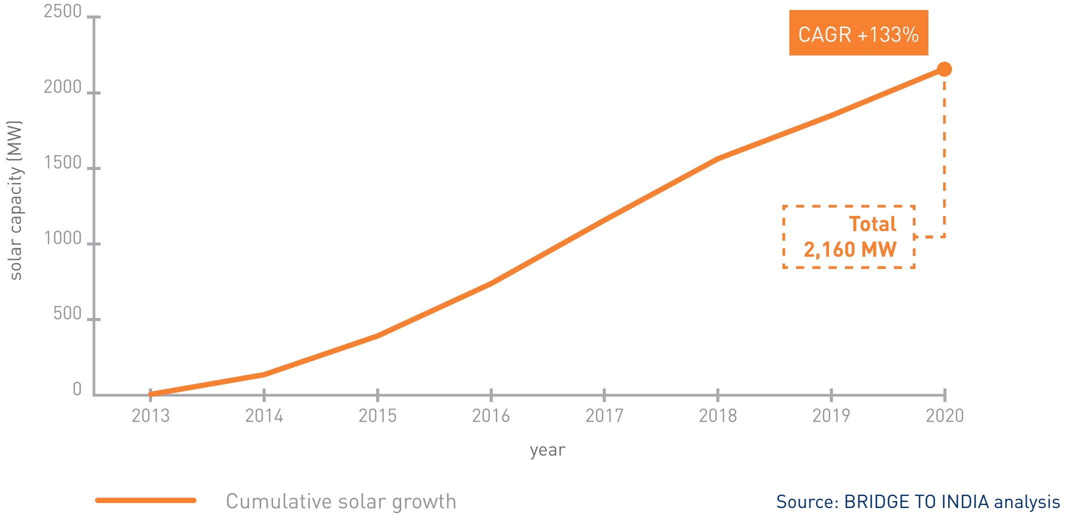
	2013	2014	2015	2016	2017	2018	2019	2020
Residential	0	12	37	62	99	186	286	310
Commercial - Type 1	0	10	21	31	41	62	0	0
Commercial - Type 2	0	7	15	22	30	45	0	0
Industrial - Type 1	0	9	19	28	38	57	0	0
Industrial - Type 2	0	9	19	28	38	57	0	0
Government	6	81	145	174	174	0	0	0
Total (y on y)	**6**	130	256	346	420	406	286	310

Consumer parity year

% Cumulative percentage of the total potential realized up to a year

Source: BRIDGE TO INDIA analysis

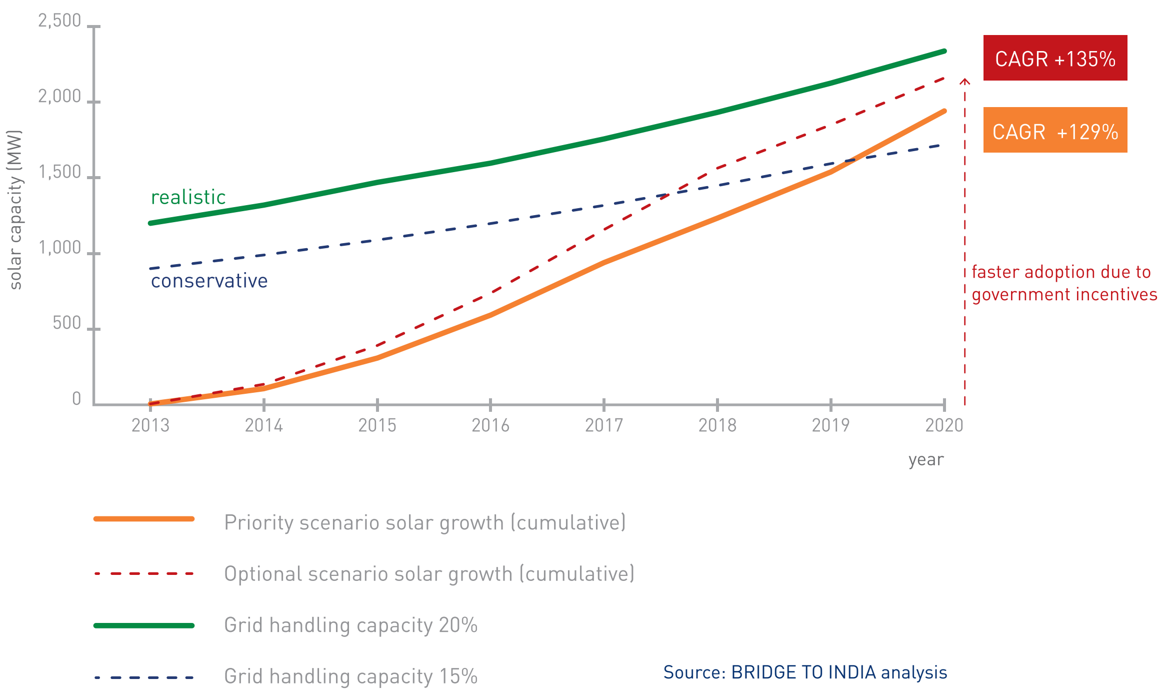
Figure 28: Optional scenario cumulative solar rooftop growth until 2020



Source: BRIDGE TO INDIA analysis

Delhi would be able to reach over 2,000 MW by 2020 (2,160 MW in the priority scenario and 2,284 MW in the optional scenario). This amount of peak power generation can be grid interactive. The grid should be able to accommodate this amount of solar power, while remaining stable. The graph below shows the cumulative amount of solar power in the grid and the ability of the grid to handle intermittent power (at 20% of total capacity). In both the scenarios, the capacity addition is not crossing the grid's solar handling capacity. In the alternative scenario, the capacity addition touches the grid handling capacity, hinting that further capacity addition would require upgrades in the grid.

Figure 29: Grid handling capacity vs. expected solar growth



Source: BRIDGE TO INDIA analysis

There are a range of factors which could advance or delay the adoption of solar as per our roadmap.

Table 6: Factors impacting rooftop solar adoption

Faster adoption factors	Slower adoption factors
Availability of low cost debt would make solar more viable. Standardized financing products e.g. for the residential market would raise the adoption rates.	Lack of financing or increases in the cost of debt would reduce the viability of solar.
A fall in the supply security of grid power would result in more on diesel back-up usage and a higher average power cost[138]. This would bring parity forward.	Legal uncertainties and other complications around ownership of rooftops would slow down the adoption of solar and reduce the overall adoption rate.
Grid tariffs rising faster than 5% p.a. or solar costs falling faster than 6% p.a. would advance parity.	If government customers receive subsidized or free power, their incentive to go solar will fall dramatically.
If market aggregators can combine projects e.g. in the residential, commercial or industrial segment, they can make use of economies of scale and reduce solar costs	Delays in metering policies and connectivity standards would reduce adoption rates especially in the residential segment, would reduce average system sizes and would push back parity for the industrial and residential segment.

Source: BRIDGE TO INDIA

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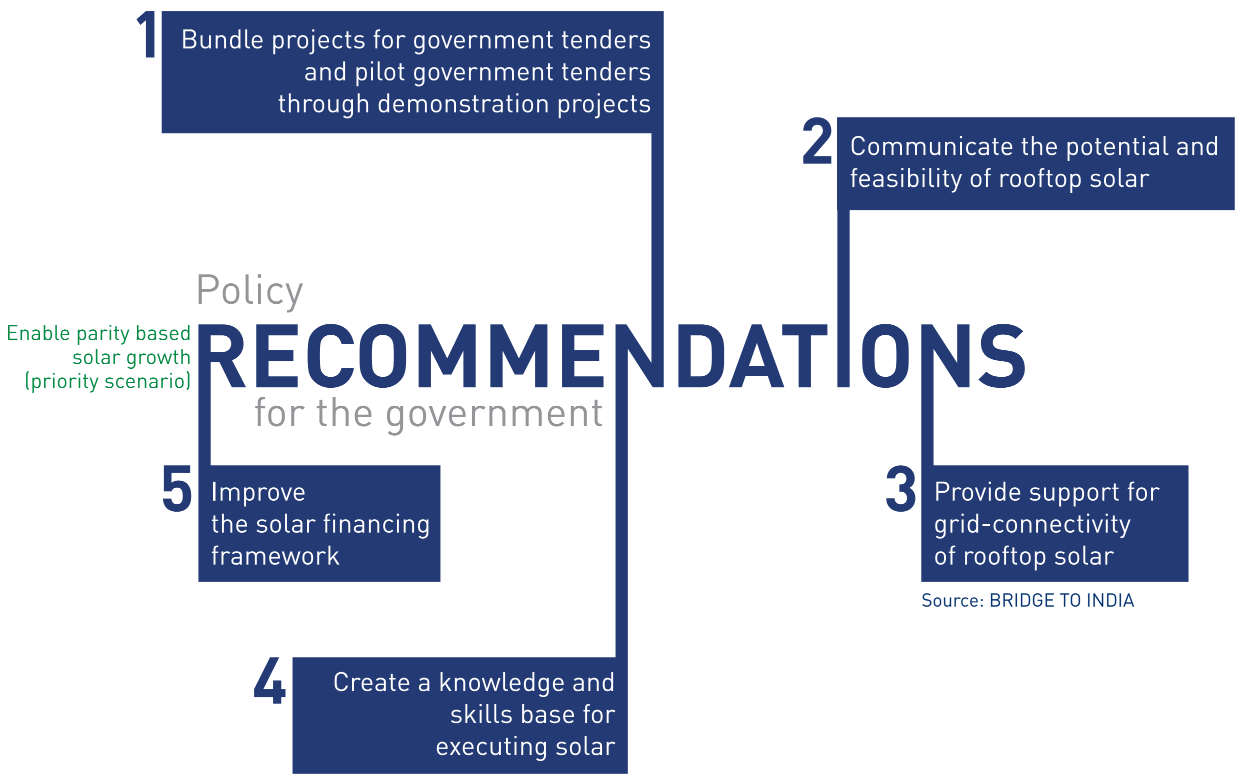
138 Diesel rates have increased by over 259% in the last 10 years. The per kWh cost of diesel is over ₹14 (€0.21, $0.28).

11 GOVERNMENT POLICY RECOMMENDATIONS

In our priority scenario we suggest a parity-driven rollout of Delhi's solar potential. In this scenario, the government of Delhi would not have to provide incentives to improve the viability of solar. However, the role of the government would still be crucial. It has to create a level playing field with respect to grid-usage and enable the growth of an eco-system that can deliver quality PV systems at competitive prices. If the government opts for the optional, accelerated scenario involving incentives, its role will become even larger.

Figure 30: Policy recommendations for the government



Source: BRIDGE TO INDIA

11.1 RECOMMENDATIONS FOR ENABLING PARITY BASED SOLAR GROWTH

1. Provide support for grid-connectivity of rooftop solar

Owners of rooftop PV systems will want to feed power into the grid during those times when their captive power consumption is low (e.g. on public holidays and weekends). Feeding power into the grid would allow for a more generous system sizing and would significantly reduce the per kWh cost of solar as no power is wasted – thus making it viable more quickly. The government would need to facilitate metering (either gross or net).

Conduct stakeholder meetings and more detailed analysis

The government should bring together the affected stakeholders of such a power shift to solar in regular stakeholder meetings. These would include the various regulatory bodies (DERC, CEA, etc.), the Delhi utilities, the utilities of the adjoining states Haryana and UP (who will be affected, too), civil society representatives (e.g. Greenpeace, academic and research institutes, Resident Welfare Associations, other customer groups), solution providing companies and financiers. In addition and perhaps steered by the stakeholder meetings, the government should commission a detailed analysis of the technical challenges and solutions of interconnecting large amounts of PV with Delhi's grid. This would prepare Delhi for the later stages of PV development (2016 onwards), but such a study should not be a pretext for slowing-down or stopping initial PV growth.

The DERC should interact with the state DISCOMS, system installers and independent consultants to frame Delhi specific standard and guidelines in-sync with the ground realities, challenges and motivations of the stakeholders.

Introduce regulations for PV components and metering (gross or net)

Metering options as well as standards and guidelines for rooftop PV systems are already being developed by the CEA in a forthcoming report on grid integration of solar PV (currently under review). However, the onus of selecting the metering policy (gross or net) for the state of Delhi would fall on the Delhi Electricity Regulatory Commission (DERC). The DERC should interact with the state DISCOMS, system installers and independent consultants to frame Delhi specific standard and guidelines in-sync with the ground realities, challenges and motivations of the stakeholders. Further, guidelines specifying technical standards of connection, procedures of applying for such a connection and configuration of meters and their arrangement also need to be formulated.

Strengthen load forecasting by DISCOMS

As per the roadmap for solar adoption in this report, 2 GW of solar by 2020 will be within the limits of the grid. However, the impact of PV on the grid in Delhi is not entirely understood. There is a need for government policy to prepare DISCOMS for the expected ramp-up of PV capacity. Government policy needs to ensure that rooftop PV's contribution is included in the power planning process of the DISCOMS. DISCOMS need to include solar into the city's energy growth forecasts. The government can support DISCOMs in developing more sophisticated weather forecasting, which would enable DISCOMs to better manage solar power scheduling.

Government policy needs to ensure that rooftop PV's contribution is included in the power planning process of the DISCOMS.

Support the managing of solar power intermittency through gas-based power

Delhi today has a little over 600 MW of gas based power generation (owned by the Delhi government). Another plant of 1,370 MW by Indraprastha Power Generation Company Ltd. (also owned by the Delhi government) is planned and could be operational in 2013. Gas based power plants can ramp up quickly and can balance the intermittency of solar. The costs of using gas power flexibly, however, would increase the per kWh cost of the gas power (as the plant is not optimally used). The government might consider stepping in with an incentive to make viable the use of gas-based power as a hedge against solar power intermittency.

Simplify installation guidelines and standardize permitting and connectivity procedures

Rooftop solar is new for government administrators as well the city's DISCOMS. It is important that rooftop solar specific guidelines are incorporated in to Delhi's building codes. The government should also set standards for the quality of installations and the structural integrity of buildings where rooftop solar is to be installed. Guidelines need to be clear and simple so as to allow consumers to meet them and officials to enforce them easily. They should also be made available on an online portal for transparent and easy access to all the stakeholders. This will help limit the complexity and time taken for setting up rooftop installations.

It is important for the government to communicate the potential, the viability and the opportunities of rooftop solar to all the stakeholders in the city.

2. Communicate the potential and feasibility of rooftop solar

Increase public awareness

It is important for the government to communicate the potential, the viability and the opportunities of rooftop solar to all the stakeholders in the city: to consumers, DISCOMS and government administrators. The government could articulate an official Delhi Solar 2020 vision document with a roadmap for Delhi to become a leading solar city globally.

Solar is still widely perceived to be an expensive source of power and there is too little knowledge about the amount of power a PV system can provide and where it can be procured. There is a need to demystify solar costs and prove to the stakeholders that it is viable. Consumer's electricity bills are a good platform to relate electricity prices with solar costs to show their viability. The government could mandate Delhi's DISCOMS to include viability analyses on consumers' power bills to raise awareness about solar.

A comprehensive, online tool that maps Delhi and offers a calculation for the benefits of solar would go a long way in encouraging especially the residential power consumers to go solar.

Provide an online "Delhi Rooftop Solar Map"

A comprehensive, online tool that maps Delhi and offers a calculation for the benefits of solar would go a long way in encouraging especially the residential power consumers to go solar. Ideally, this would be a very user-friendly tool, based on a geographical information system (GIS) mapping of rooftop PV space in Delhi. Then, a solar calculator would offer building owners a simple viability analysis based on grid power costs and available rooftop space. Such a calculator already exists for India on the website www.indiasolarhomes.com. This could be further detailed for Delhi. New York, for example, has such a map in place for its residents.

Case Study

The New York solar map

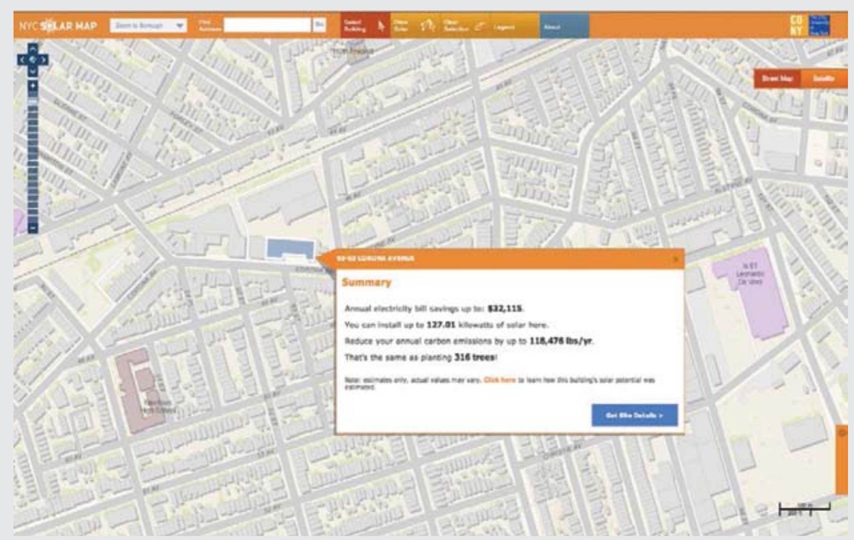
The New York solar map was introduced in 2011 to provide clarity on government policy and the potential for solar PV to assist all the stakeholders. The map provides quantitative data on installation costs, cost savings, energy savings, and local, state and federal incentives.

The map was initiated by the New York Solar America City Partnership including the City University of New York (CUNY), the Mayor's Office of Long-Term Planning and Sustainability and the NYC Economic Development Corporation. The U. S. Department of Energy (DOE) provided funding and the National Renewable Energy Laboratory (NREL) provided technical support. Work on the New York solar map began in 2010 and took about 14 months to complete. The overall cost of setting up the solar map was around ₹33m (€660,000; $858,000)[139].

The New York solar map enables homeowners to determine the potential of solar on their buildings and assess the financial viability of installing a solar system. The map also shows the existing installations, which allows installers to assess trends in adoption of solar and help them better target their business efforts. Further, utilities can use the information to estimate the amount of customers switching to solar energy. Finally, state planners and government bodies can track the progress towards achieving targets such as New York's Renewable Portfolio Standard.

San Francisco was the first city in the US to develop a solar map in 2008. After the map's launch, PV installations in the city grew by 60% in two years[140]. Since then, 18 cities in the United States have followed suit to share information related to solar with their residents.

Figure 31: Screenshots of the New York solar map



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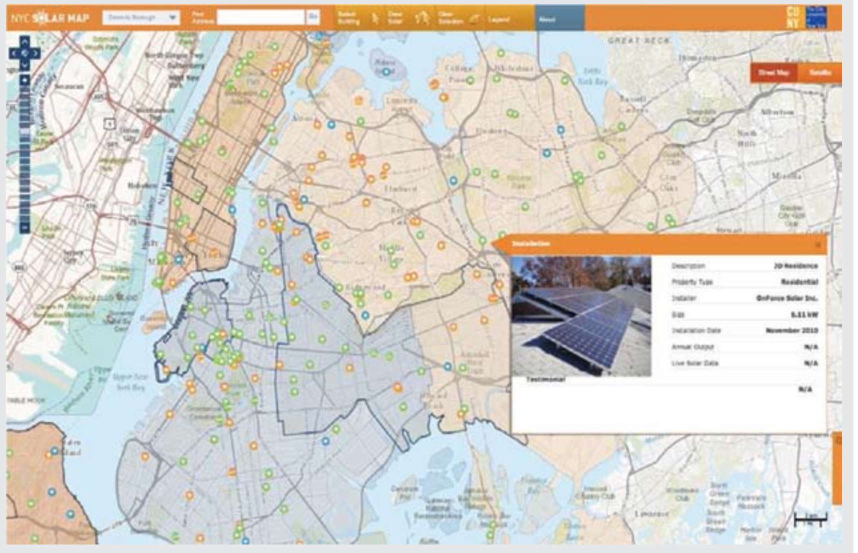
139 Source: American Planning Association accessed at http://bit.ly/UYKi6E on May 22nd 2013

140 Source: American Planning Association accessed at http://bit.ly/UYKi6E on May 22nd 2013



Source: American Planning Association NYC Solar Map[141]

Set-up demonstration projects on transport facilities in Delhi

There is a need to make the idea of rooftop solar in Delhi real for all the stakeholders through inspiring pilot projects.

At the moment, solar PV is understood primarily as a large MW, grid-connected source of power. There is a need to make the idea of rooftop solar in Delhi real for all the stakeholders through inspiring pilot projects. Transport facilities like railway stations and the Delhi airport have a low overall potential for rooftop solar as per our analysis (2.6 MW). Hence, we have not included them in the target and roadmap. However, they are excellently placed as demonstration sites with very high visibility.

The Indian Railways has a CSR obligation as per recent guidelines issued by the Heavy Industries and Public Enterprises Ministry[142]. The Delhi Airport, too, has a CSR mandate (though not enforceable) as per guidelines by the Ministry of Corporate Affairs. The Delhi Airport is already planning to build a 2 MW, ground-mounted solar power plant near the runways. The German House in New Delhi has set up a demonstration plant on its rooftop showcasing different technologies. The plant was commissioned in August 2011 and can provide a good body of actual generation data.

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141 Accessed at www./nycsolarmap.com/ on May 22nd 2013
142 Source: iGovernment article accessed at http://bit.ly/19KKtcg on May 22nd 2013

Case Study

German House solar rooftop plant, Delhi

Photograph by GIZ ComSolar

The German House in New Delhi has installed two solar PV systems with a total system capacity of 10.5 kWp on its rooftop in 2011. Q.cells, a German module manufacturer (now owned by Hanwha), financed and installed the systems as a demonstration project to showcase the technical feasibility of a PV rooftop system in Delhi. For comparative reasons, the two solar PV systems use different technologies – thin film and polycrystalline modules.

The solar power generated from the plant is connected with the internal energy management system of the building, where it is combined with electricity from the grid. The PV installation system uses a remote, wireless monitoring system, which transfers and stores generation data. The panels are cleaned thrice a week.

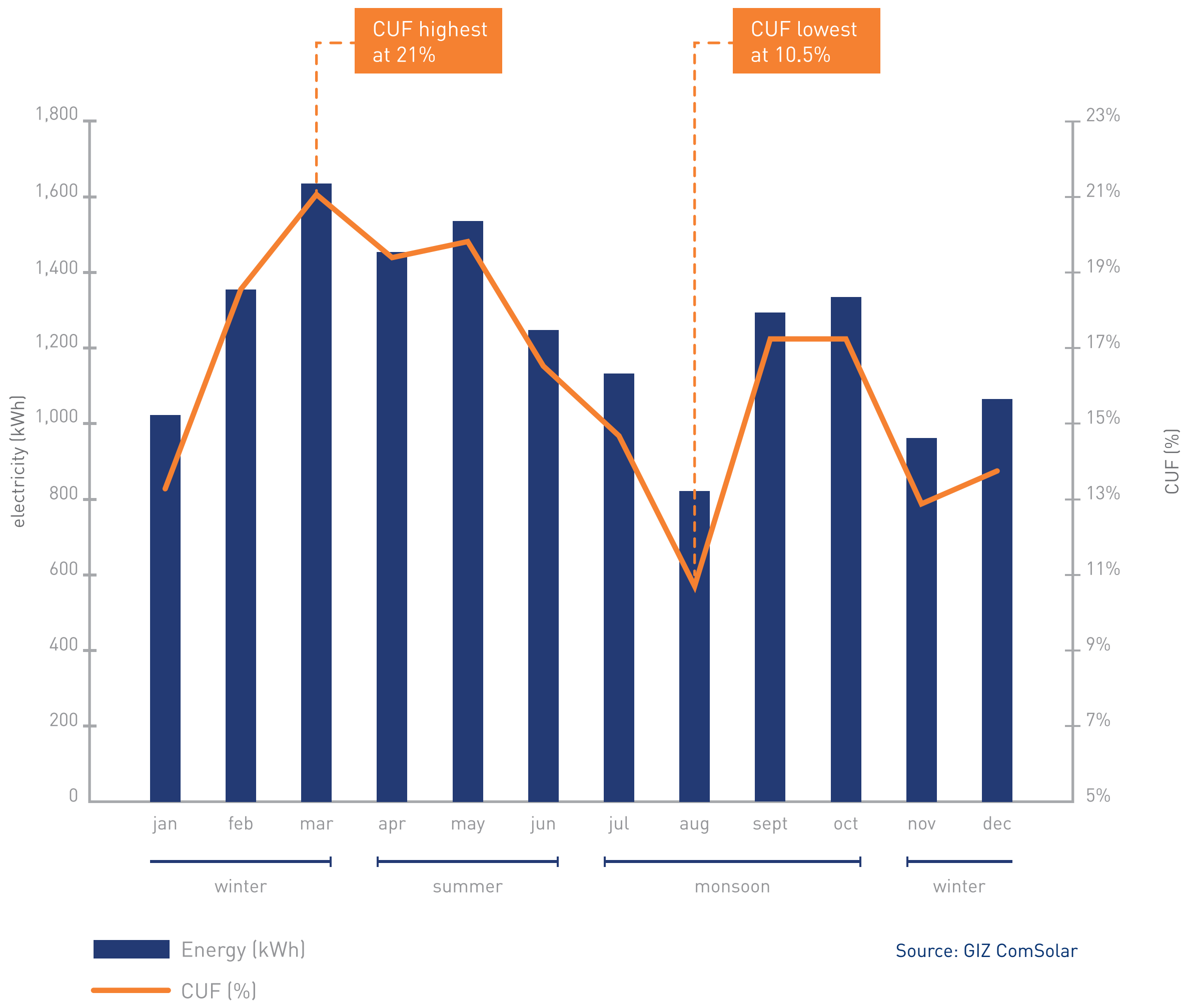
Table 7: German House solar project details

Total system capacity	10.47 kW
Commissioning date	19.08.2011
Module technology	Polycrystalline (5.52 kW) and thin film (4.95 kW)
Module area	40 m2 (polycrystalline) and 41 m2 (thin film)
Inverters	2 x SMA SMC 6000
Modules	24 x Q-CELLS Q.Base 230 and 55 x Q-CELLS Q.Smart UF 90

Storage of electricity	None
Tracking	None
Annual electricity generation	15,097 kWh
Monthly electricity generation	1,258 kWh
Cost of system	₹2,000,000 (€30,789, $40,000)
Average annual CUF	16%

Source: GIZ ComSolar

Figure 32: Electricity generation and CUF of PV plant at the German House, New Delhi



Source: GIZ ComSolar

Conduct solar feasibility workshops for commercial and industrial consumers

While rooftop solar will be viable for commercial type-1 and industrial type-2 consumers next year, it is possible that such consumers do not have enough information on the economic case for solar, are deterred by high upfront investment costs, are uncertain about the technology or worry about potential structural risks (e.g. for leakages in the roof).

There is a strong business case for third parties to invest into the PV plants of such consumers, offering solar power as a service, with no investment cost to the consumer and immediate savings on their electricity bills. However, identifying viable customers can be difficult for investors.

The government could launch a targeted program of workshops offering a free assessment of the techno-economic feasibility of solar for building owners. Such a program would benefit customers that are still unsure about the viability of solar. The government could also invite interested investors or EPC companies to participate in these workshops to propose their solutions. A similar program has been successfully executed in San Francisco.

The government could launch a targeted program of workshops offering a free assessment of the techno-economic feasibility of solar for building owners.

Case Study

The Mayor's Solar Founders' Circle Program in San Francisco, US (2008-2009)

In 2007, the U.S. Department of Energy (DOE) designated the city of San Francisco in California a "Solar America City". The city has since been aggressively promoting rooftop solar through incentives and dedicated programs. One such program was "The Mayor's Solar Founders' Circle"[143], launched in 2008. It targeted 1,500 commercial rooftop owners in the city for the installation of solar PV systems. The program offered a free personalized technical and financial analysis of the solar potential of the buildings. More than 100 companies applied for the energy audit, out of which 40 were audited[144].

The City of San Francisco partnered with the National Renewable Energy Laboratory (NREL) to train city employees and consultants to perform site assessments. A team of national lab experts gathered data and formulated individual reports.

3. Create a knowledge and skills base for executing solar

Large scale solar deployment will be successful only if there is a strong focus on ensuring quality and an adherence to technical standards in the PV installations. This requires a well-developed skills and knowledge base in the city. Delhi is in a unique position to develop this base as it has access to top engineering universities like the Indian Institute of Technology and numerous technical institutes and degree colleges. The government should initiate a program across such institutions to include technical courses on PV installations. The technical assessment and monitoring of government projects should be handed over to educational institutions so that students in PV courses practically engage with installations in the city and form the first cohort of technicians needed to support large-scale solar deployment in the city.

Large scale solar deployment will be successful only if there is a strong focus on ensuring quality and an adherence to technical standards in the PV installations.

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143 Source: Office of the Mayor, City and County of San Francisco accessed at http://bit.ly/13mZkG9 on May 22nd 2013

144 Source: US Department of Energy, Energy Efficiency and Renewable Energy accessed at http://1.usa.gov/17qEcTE on May 22nd 2013

4. Prepare projects for government tenders

Bundle government projects

Solar for government consumers in Delhi is already viable in 2013, as long as projects are bundled to a cumulative size of around 2 MW. Bundling provides scale to the installer who would save on engineering, procurement and logistics costs. The Delhi government should aggregate the buildings it owns and tender these out to RESCOs that want to invest in rooftop PV and provide the government with solar power. A tender will be a competitive process, the benefit of which will be directly passed on to the government exchequer.

The Delhi government should aggregate the buildings it owns and tender these out to RESCOs that want to invest in rooftop PV and provide the government with solar power.

Learn the ropes through demonstration projects in 2013

The government could release a small tender already in 2013. In our roadmap, we suggest three projects of 2 MW each at three different locations in Delhi. These projects will serve as a test-case for larger tenders in the upcoming years and as a demonstration to central and state government administrators of the viability of solar for government buildings in Delhi.

5. Improve the solar financing framework

In order to overcome the liquidity challenge of solar power investments, debt plays a crucial role. Debt at rates lower than the equity IRR expectations (15%) would also reduce the cost of solar on a per kWh basis, making it viable more quickly. In our viability analysis, we have assumed a debt to equity ratio of 70:30 for government, industrial and commercial projects. Residential systems we assume to be purely equity funded.

If the cost of debt for the first three projects can be brought down (from a current 13% to say, 10%) and the lending risk be cushioned to induce more non-recourse loans, the adoption of solar could be significantly accelerated.

Debt at rates lower than the equity IRR expectations (15%) would also reduce the cost of solar on a per kWh basis, making it viable more quickly.

For the government, industrial and commercial projects, the government could provide a payment guarantee.

The government could consider setting up a risk guarantee fund for banks to lend more readily. This is being done, for example, by the Solar Energy Corporation of India (SECI) for the National Solar Mission.

Banks currently place solar in their power sector/infrastructure lending portfolios. In order to unlock the residential sector, it would be crucial that banks offer consumer finance solutions for solar home systems (such as, for example, equal monthly installments (EMIs)). The Delhi government could support banks in developing such solutions through making available expertise, reacting to the risk concerns of banks, or even through setting up an own, dedicated non-banking financial company (NBFC).

11.2 OPTIONS FOR ACTIVATING EARLY ADOPTION THROUGH A "VIABILITY NUDGE"

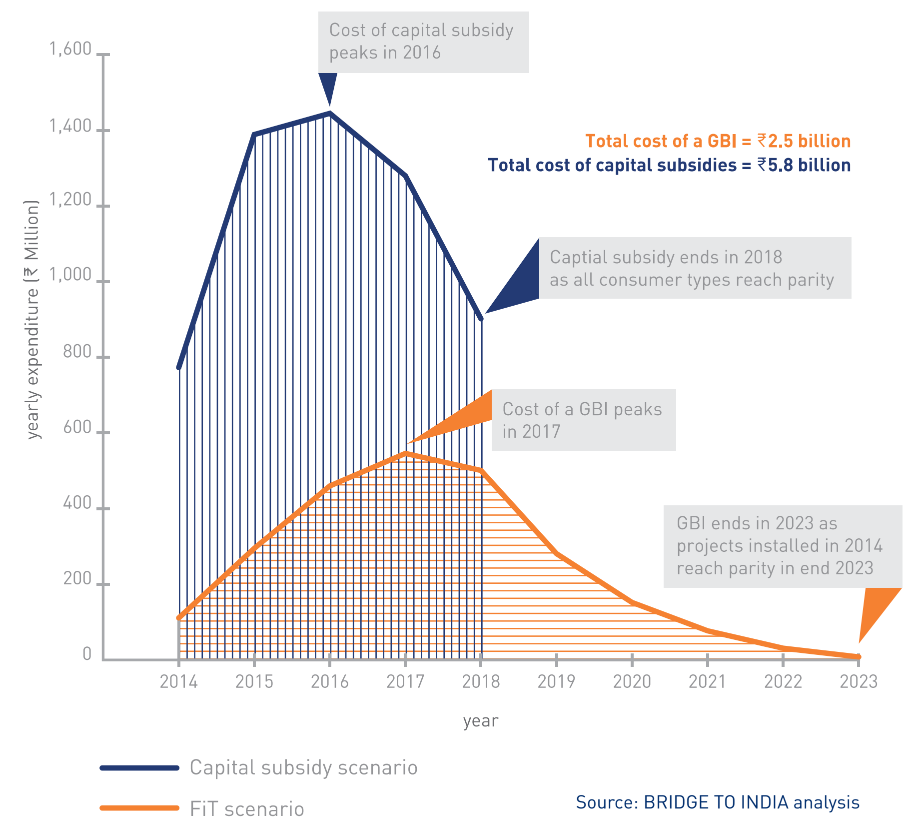
At the moment, Delhi has access to 24/7 power. But, as we explain in the chapter on making rooftop PV work for the stakeholders, there are risks to Delhi's power supply. For the government to maintain its promise of 24/7 power, it might decide that it wants to drive a more aggressive adoption of rooftop solar. Residential consumers have the largest potential (1.2 GW), but, in a parity-based scenario will begin contributing to Delhi's power supply only in the year 2018. Similarly, commercial and industrial consumers only begin in 2014 with certain types of consumers going solar as late as 2016. The key to activating the early adoption of solar by such consumers without waiting for parity is for the government to make solar artificially more attractive, providing a viability nudge.

Viability nudges from the government can be in the form of a generation based incentive (GBI) or capital subsidies.

Viability nudges from the government can be in the form of a generation based incentive (GBI) or capital subsidies (these can be further supported with tax breaks or low cost debt). We calculated the cost of both, a GBI and capital subsidies, to the government to achieve its target of 2 GW by 2020[145]. As shown in the graph below, a GBI could cost the government a total of ₹2.5 billion (€0.04 billion, $0.05 billion) by 2023. On the other hand, capital subsidies could cost a total of ₹5.8 billion (€0.08 billion, $0.11 billion) by 2018, twice the cost of a GBI.

A GBI could cost the government a total of ₹2.5 billion (€0.04 billion, $0.05 billion) by 2023. On the other hand, capital subsidies could cost a total of ₹5.8 billion (€0.08 billion, $0.11 billion) by 2018, twice the cost of a GBI.

Figure 33: Cost to the government for viability nudges



Source: BRIDGE TO INDIA analysis

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143 Source: Office of the Mayor, City and County of San Francisco accessed at http://bit.ly/13mZkG9 on May 22nd 2013

144 Source: US Department of Energy, Energy Efficiency and Renewable Energy accessed at http://1.usa.gov/17qEcTE on May 22nd 2013

145 We calculated incentives required for each consumer type to achieve a 15% IRR. We have assumed a 5% annual escalation in grid tariff and 6% annual reduction in costs of solar.

1. Viability nudge through a generation-based incentive (GBI)

The total expenditure on GBI reaches a peak in 2017, as new capacity dependent on a viability nudge will be installed only until that year (as residential consumers reach parity the last, in 2018).

Increasing the revenue from a PV system through a GBI would improve solar viability. GBI would bridge the gap between the grid price and the viable solar tariff for a consumer. In this approach, the viability nudge provided to a consumer falls over time as the grid prices rise. Finally, once parity is reached, the expenditure to the government becomes zero. Thus, the GBI for installations set up in 2014 would be phased out in 2024, when the grid tariff reaches the viable solar cost of a solar plant constructed in 2014 (at ₹10.90/kWh, €0.16/kWh, $0.21/kWh). In addition, the GBI offered by the government to new consumers would drop each year, as solar prices fall and grid tariffs increase. The GBI would be phased out for new installations once solar is competitive with residential grid prices, expected by 2018 (at ₹8.51/kWh, €0.13/kWh, $0.16/kWh)[146]. The total expenditure on GBI reaches a peak in 2017, as new capacity dependent on a viability nudge will be installed only until that year (as residential consumers reach parity the last, in 2018).

In Germany, similar generation based viability nudge (through a flat FiT that covers the entire viable solar tariff and not just the gap between the grid price and the viable solar tariff for a consumer) has been hugely successful for driving rooftop solar PV installations.

Case Study

Germany launched its first Feed-in Tariff (FiT) law, the "Stromeinspeisungsgesetz" (StrEG), in 1999. This bill required utilities to connect renewable energy generators to the grid and buy the electricity produced by renewables at 65-90% above the average retail price of electricity. By 2004, Germany announced a nationwide FiT of ₹30-40[147] (€0.46-0.62; $0.35-0.47)/kWh, independent of electricity prices, with an annual reduction of 5%. Tariff rates were to be revised every four years. In 2012, flexible tariff reduction was introduced, with a revision every quarter[148]. If the overall, newly installed capacity in the preceding 12 months was within the target corridor of 2.5-3.5 GW, the tariff would be reduced by 1%. This rate increases, if the capacity addition exceeds the upper limit of the corridor and decreases, if it falls short. The flexible reduction structure is transparent and responds to developments in the market.

The tariff structure incentivizes a potential consumer to go solar as soon as possible in order to benefit from higher incentives. The tariffs for a project are fixed for a period of 20 years, making investment returns predictable, thus reducing risks and financing costs.

Even though the German government is now in the process of phasing out the tariffs, the market has gained significant momentum, with perhaps the most competitive solar PV installation costs in the world[149]. With the deployment of 30 GW[150] in the past 13 years, benefits of scale have driven costs down – on a global level (e.g. for modules), but also for the local installation work. Further, as the country has moved along its learning curve it has created a robust ecosystem for the German solar market with simple application procedures, easy availability of information, healthy market competition, effective industrial associations like the "Bundesverband Solarwirtschaft"[151], strong research institutions such as the Fraunhofer ISE[152] and experienced government bodies. Transaction costs related to e.g. site inspections, permitting, customer acquisition and financing are among the lowest in the world[153]. The eco-system has become so strong and predictable that banks offered inexpensive loans of up to 100%[154] of the solar rooftop system cost, making the adoption of solar a "no investment" income opportunity for rooftop owners.

2. Viability nudge through a capital subsidy

The government's expenditure on subsidies is limited to five years (2014-2018), until all the consumer categories reach parity.

Another option for a viability nudge is to provide a direct, one-time capital subsidy at the time of installation of the plant. For viability in 2014, residential consumers require a capital subsidy of 38%, type-1 industrial consumers require 25% and type-2 commercial consumers require 7% as per system costs in 2014.

In the case of capital subsidies, the government would bridge the entire viability gap, upfront, at the time of installation. The government would effectively reduce the viable solar tariff to match the grid tariff by providing a subsidy. Since the full viability nudge is provided at the beginning of a project, the government will be unable to take advantage of the reducing gap between the viable solar tariff and the grid tariff over subsequent years. This is the key reason that subsidies could cost the government twice the amount required for GBI. In the graph above, the government's expenditure on subsidies is limited to five years (2014-2018), until all the consumer categories reach parity. The expenditure will be the highest in 2016 as subsidy dependent PV capacity addition peaks in that year (driven by residential consumers and some industrial type-1 consumers that will install PV before parity is reached for them mid-year).

A one-time, upfront disbursement is administratively convenient for the government. This however, does not justify the significantly higher cost than a GBI.

A one-time, upfront disbursement is administratively convenient for the government. This however, does not justify the significantly higher cost than a GBI. In the case of a capital subsidy, the government will also need to ensure that consumers do not compromise on the quality of the PV systems and take undue advantage of the subsidy by inflating on-paper system costs but keeping actual system costs extremely low. This could be achieved by setting standards for installation and contracting independent monitoring agencies to assess their implementation.

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146 Refer to Chapter 6 on "Viability of rooftop solar PV"

147 Differentiated by system size and application type (roof-mounted or ground mounted)

148 Under the amended EEG 2012, Germany will continue to adjust tariff rates periodically in an attempt to keep annual PV installations within a target "corridor." The current annual installation corridor is 2,500 to 3,500 MW. Also see : "The German Feed-in Tariff for PV"by Deutsche Bank Climate Change Advisors- May 2011accessed at http://bit.ly/11tceCt on May 22nd 2013 and "The German Feed-in tariff: Recent Policy Changes " by Deutsche Bank September 2012 accessed at http://bit.ly/1303qmc on May 22nd 2013

149 The average costs of PV systems in Germany in the second quarter of 2012 was ₹110/Wp ($2.2; €1.69) and in US is ₹275/Wp ($5.5; €4.23). Source: IRENA accessed at http://bit.ly/ZP2q6I on May 22nd 2013

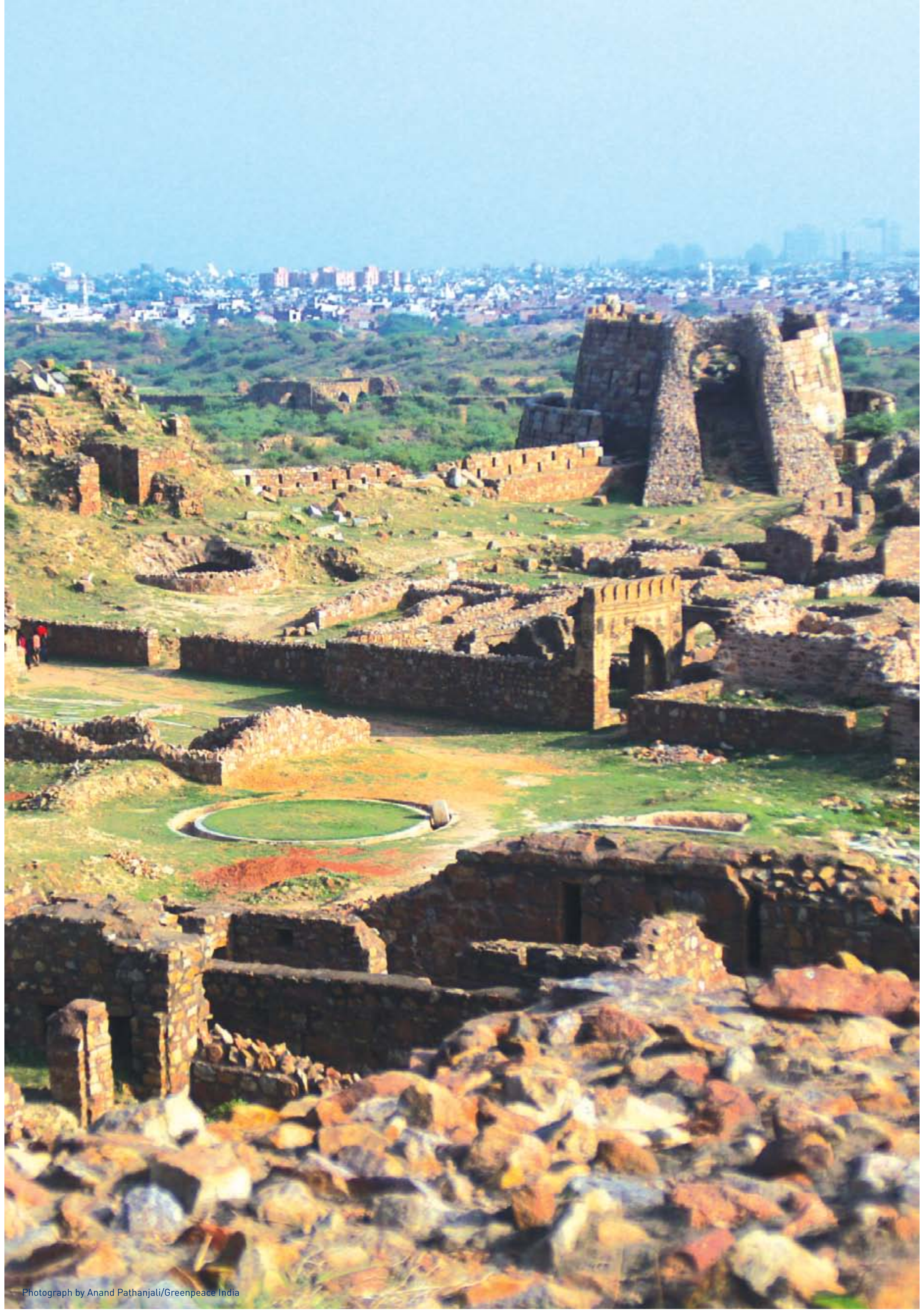
150 Source: Fraunhofer Institute accessed at http://bit.ly/SwvvdZ on May 22nd 2013

151 Source: Bundesverband Solarwirtschaft

152 Source: Fraunhofer Institute

153 Source: Bundesverband Solarwirtschaft accessed athttp://bit.ly/Od0gDu on May 22nd 2013. See also: "Why Solar Installations Cost more in the U.S. than in Germany" Dec , 2012 http://bit.ly/10haaOp

154 Press Release by kfW : http://bit.ly/15Mk2QS accessed on May 22nd 2013



Photograph by Anand Pathanjali/Greenpeace India

Photograph by Anand Pathanjali/Greenpeace India

12 APPENDIX

12.1 METHODOLOGY FOR CALCULATING THE SOLAR ROOFTOP POTENTIAL IN DELHI

In order to determine the geographic potential of Delhi to generate solar power, we have assessed the rooftop space offered by its built area. GIS is the best technology available to get near accurate measurements of area through satellite mapping. On the downside, it costs around ₹60m (€0.92m, $1.2m) and its application takes a period of almost 9-12 months, considering that Delhi is twice the size of Singapore. As we were working within a reasonable timeline of 2 months, the application of GIS was unfeasible for our analysis. Our analysis is thus based on information provided by the Delhi Development Authority (DDA), a government-run organization that has mapped and measured the entire city of Delhi as part of its land development and planning practice. DDA's Master Plan 2021 and Zonal Plans are the only official documents that provide comprehensive information on different land areas with their designated uses in the future.

More information, crucial to this analysis, such as average plot sizes, measurements of individual buildings and area occupied by roads and civic amenities, is not provided in the DDA plans. We used online mapping tools (Google earth and Google Maps) and referred to the City Map[155] for such measurements and for detailed analysis of constituent areas. Qualitative information (Such as quality of construction) about areas was obtained through site visits and from insights provided by architects and real estate developers.

Our analysis uses the framework used by the DDA Zonal plans, which classifies the entire land area of the city into 9 types: 'Residential', 'Commercial', 'Industrial', 'Recreational', 'Transport', 'Utility', 'Government', 'Green belt/ Water body' and 'Public and Semi-public Facilities'. Our analysis excludes the land area types – 'Green belt/water body' and 'Recreational', which include regional parks, water bodies and historical monuments. This is because most of these areas do not have built structures that can provide roof space. Further, any construction /alteration in such areas would require permissions from the Ministry of Culture and the Delhi Municipality. Similarly, the land area type, 'Utility' that includes areas covered by drains, sanitary landfills, power stations, sewage treatment plants and water treatment plants, was excluded from our analysis. This is because the areas covered by drains and sanitary landfills do not have built structures and are instead occupied by drainage pipes and solid waste. Water treatment plants, sewage treatment plants and power stations are also largely made up of tanks and processing units offering little or no concrete constructions for solar power installations.

For all remaining land area types, we first determined the total land area available for designated uses from the information provided by the Zonal Plans. We then discounted for roads, civic amenities, and irrelevant sub categories, if any, to reach the total plotted area. This discounting factor for trees roads and pedestrian paths ranges from 40-60% for different land area types[156]. Further, we computed the area of built structures (raw rooftop space) as per the specific development controls (coverage rates) pertaining to the type and size

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155 'Eicher Delhi City Map' was used for scaled measurements.

156 The discounting factor was considered after analyzing sample sites for each land area types and after consulting architectural experts.

of plot area. Only built structures that were of sturdy concrete constructions were included in the computation of the potential rooftop space, such that they could bear the weight of the solar rooftop installations. Finally, we discounted for space that was obstructed with objects and structures and space that was shadowed to determine the solar suitable rooftop area that receives optimal sunlight for solar power generation.

12.2 COMPUTATION OF THE SOLAR SUITABLE ROOFTOP SPACE FOR DIFFERENT LAND AREAS

12.2.1 Residential buildings

The residential area in Delhi is heterogeneous in nature and reflects the city's rapid, often uncontrolled growth. There are different types of buildings, ranging from individual houses, apartments, residential complexes, unauthorized colonies, Jhugi Jhompri (JJ) clusters[157] to slums. Further, these housing settlements have different socio-economic characteristics and development controls. The cumulative figure of the residential area, provided by the DDA, does not include qualitative information about the constituent housing structures and occupants. However, such information is essential to understand the suitability for solar in different residential colonies/areas. Thus, rather than using the land area figures provided by the DDA, we use a bottom up approach in order to analyze this land area type in detail. Using Google Maps, we first determined the area measurements of individual colonies that qualified for solar rooftop installations. Colonies that had sufficient solar suitable rooftop space, concrete constructions and occupants that could afford solar installation were qualified for analysis. We then summed up the individual figures to reach the total land area for the residences.

While pursuing the bottom-up approach, we found that information about the entire residential area in the city was available in three sections (as per the municipality governing the areas) - Residential colonies under the jurisdiction of the Municipal Corporation of Delhi (MCD), residential area under the jurisdiction of the New Delhi Municipal Council (NDMC) and residential area maintained by the Delhi Cantonment Board (Delhi Cantt.). The colonies under the MCD are categorized from A to H, as per the circle rate[158] applicable to each colony. Circle rates are indicative of the economic standing of the colonies, which further provides a sense of the income level of the occupants, the quality of constructions, the type of housing and the average plot sizes. We excluded low income colonies as they are unsuitable for solar installations[159]. This categorization provided us with tangible figures and a comprehensive list of colonies to work with. For residential areas under the NDMC, we have used cumulative figures from the DDA zonal plans. This is because the NDMC area largely has government owned colonies that have large rooftops, similar rooftop structures, with no ownership rights for the occupants. In the case of the residential colonies under the Delhi Cantonment area too we have considered all the colonies as they are government owned and have the

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157 JJ clusters are households of poorly built congested tenements with inadequate infrastructure and lacking in proper sanitation and drinking water facilities. Unlike slums, these are illegal settlements.

158 Circle Rate is the minimum rate per sq. meter area on which stamp duty has to be paid by the purchaser. This rate is decided by the government authorities for valuation of land in a particular area.

159 Refer to Table A2 "Assessment of colonies under the jurisdiction of the MCD" for details

same characteristics as colonies in the NDMC area. For these colonies, we have mapped and analyzed all of them using online mapping tools because the area of the cantonment is relatively small and hence measurable. The bottom-up approach enabled us to understand the residential area in Delhi with a fair amount of accuracy in order to reach a representative figure for the solar suitable rooftop space available in Delhi's residences. We have assumed that 20% of the total area can be discounted for having old rooftops, unable to support solar installations. This discount factor is higher than what we have considered for other categories (20% vs. 10%) because we assume that a larger proportion of residential buildings are on average older than buildings in the other categories. After this, the solar suitable rooftop space for Delhi's residences was assumed to be around 20% of the total rooftop area. This is because water tanks, ventilating shafts, drying clothes and storage units occupy most of the area on a residential rooftop leaving limited unoccupied/ unobstructed space.

Table A1: Solar suitable areas by jurisdictions

Residential areas as per municipalities governing them	Total built area/ raw rooftop area (km2)	Total qualified area after 20% discount for old rooftops (km2)	Solar suitable roof top area (km2)
Area under the MCD	79.2	63.32	12.6
Area under the NDMC	8.6	6.9	1.4
Area under the Delhi Cant.	5.3	4.3	0.85
TOTAL	**93.1**	**74.5**	**14.90**

Source: DDA's Master Plan 2021, Delhi Zonal Plans, Google Earth and BRIDGE TO INDIA analysis

Table A2: Assessment of colonies under the jurisdiction of the MCD

Colony category	Average plot size (m2)	Solar suitable area available	Income level	Principal type of housing	Quality of Construction	Qualification
A	900	180	High	Individual houses	Good	✓
B	400	80	Medium to high	Individual houses and apartments	Good	✓
C	200-600	40-120	Medium to high	Individual houses and apartments	Average	✓
D	250	50	Medium to high	Residential complexes, apartments and individual houses	Average	✓
E	100-250	20-50	Low to medium	Individual houses and apartments	Low	✗
F	150	30	Low	Individual houses and apartments	Poor	✗
G	100	20	Low	Individual houses and apartments	Poor	✗
H	50-100	Oct-20	Low	Individual houses and apartments		✗

Source: BRIDGE TO INDIA analysis

The total residential area under the jurisdiction of the MCD is classified into 8 categories, A to H. The basis for such classification is the circle rate applicable to each colony, where colonies under category A have the maximum circle rate and those under category G have the minimum circle rate. This categorization indicates the economic standings of the colonies. The economic standing further provides a sense of the income level of the occupants, the quality of constructions, the type of housing and the average size of plots. For example, a colony in category A, such as Sunder Nagar, would commonly have rich inhabitants that live in large-sized individual bungalows. We have used this categorization as a framework to assess the suitability of colonies to instate rooftop solar power installations.

In the analysis, we have considered 10 sample colonies from each category to determine the income levels of occupants, quality of constructions, type of housing and average size of pots. After analyzing these factors, we selected categories that indicate the suitability to install solar rooftop PV. Then, using Google Maps, we mapped these sample colonies to determine the average area of a colony in a particular category. The average area was further used to compute the total raw rooftop area/ built area available for solar in a particular category. The solar suitable rooftop space was then computed as 20% of the total rooftop area.

Colonies under the categories F , G and H are excluded from our analysis, as they were unsuitable for solar power generation. Using Google Maps and site visits, we found that the houses in these colonies have small plot sizes offering a solar suitable rooftop space of 20-30 m^2, which barely meets the minimum space[160] required for rooftop installation. The poor quality of constructions in such colonies will not be able to endure the weight of rooftop solar installations without significant structural improvements. Further, inhabitants of these colonies, belonging to low-income groups, will not be able to afford the upfront investment costs associated with solar installations. Some key colonies from these categories are Majnu Ka Tila, Shakarpur, Nathu Pura and Zakir Nagar.

Similarly, colonies under category E did not qualify for our analysis, as most houses in these colonies are low quality constructions. The plot sizes in this category are bigger than those in category F, G and H but are still fairly small and may not offer sufficient rooftop space suitable for solar installations. Some key colonies in this category are Paharganj, Yusuf Sarai and Inderpuri.

Colonies under category D are densely populated with residential complexes being the principal type of housing. Some key colonies in this category are Mayur Vihar, Paschim Vihar and Rajouri Garden. The residential society as a whole usually owns the rooftop space in such complexes. This may create

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160 Minimum unobstructed space required for a 1kW rooftop PV installation is 10 m^2 as per 'RENI- Renewables Insight, Energy Industry Guides'

problems when obtaining permissions to mount rooftop solar installations but may also make the solar installations affordable, as costs would be divided among a larger group of individuals. The roof space of such residential complexes is usually occupied by support services such as water tanks, shafts and other amenities that are instated for the entire building, leaving less unoccupied space. Despite such issues, with an average plot size of around 250 m^2 offering a solar suitable roof space of 50 m^2 and concrete building structures, this category qualified for our analysis. The built area/ raw rooftop area available in colonies in category D is around 48.92 km^2.

Colonies under category C, with fairly big plot sizes and good quality constructions, are also suitable for rooftop installations. The solar suitable roof space available is around 40 to 120 m^2 and occupants largely belong to medium income groups. Constituent colonies in this category commonly have a mix of individual houses and apartments/flats. Some key colonies in this category are Lajpat Nagar, Punjabi Bagh and Civil Lines. The total built area/rooftop area offered by colonies in this category is around 16.87 km^2.

Finally, Categories A and B are the most appropriate fit for solar rooftop installations. Colonies in these categories have solar suitable rooftop of up to 180 m^2, 18 times of what is required. In addition to that, the houses in these colonies are well-constructed individual houses. The wealthiest population of Delhi inhabits these colonies and is probably in a position to afford such installations by itself. Some key colonies in these categories are Friends Colony, Sunder Nagar and West End. The total built area/ raw rooftop area of colonies in this category is around 13.38 km^2. The total built area of residential colonies under the jurisdiction of the MCD is around 79.2 km^2.

Residential area under the jurisdiction of the NDMC[161]

Residential area under the NDMC mainly comprises of either government housing areas or affluent residential properties of Delhi. Some key colonies under this category are Bapa Nagar, Golf links and Kaka Nagar. Through Google Maps, we found that the plot sizes within these colonies is 500-1000 m^2 offering sufficient solar suitable rooftop space. The housing area under the NDMC comprises of well-maintained concrete buildings. All Colonies in this category are largely similar to colonies in category A of the MCD and are hence considered to have qualified for our analysis. Housing in the area maintained by the NDMC falls in the DDA zone 'D'. The DDA plans provided the best numbers to use considering that the area under the NDMC is too large for actual mapping and the fact that most constituent colonies are similar in terms of size and structure and hence are subject to similar developmental controls.

Residential area maintained by the Delhi Cantonment[162]

The Delhi Cantonment houses the Indian army Headquarters, the army golf course, military housing such as residential complexes and flats, army hospitals and public schools. All buildings within this area are well-built structures maintained by the Delhi Cantonment Board with plot sizes of around 250-500 m^2. We consider all buildings within this area to be qualified to bear solar installations as they offer solar suitable roof space of around 50-100 m^2 and have structures that can endure solar rooftop installations (checked through Google Maps and site visits). In order to determine the residential area of the Cantonment area or the area covered by military housing, we mapped the constituent colonies using Google Maps. We excluded the army hospital and mess from the mapping exercise to avoid double counting them as they might be included under the land area type 'pubic and semi-public facilities' as per the Delhi Master Plan. Manual online mapping provided a more representative figure and was used it specifically for the Delhi Cantonment, as its area is relatively small and realistically measureable. Some key colonies inside the Delhi Cantonment area are Chitral lines, Kabul Lines and Asmara Lines.

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161 NDMC or the New Delhi Municipal Council is one of the local governing bodies in Delhi that administers and maintains around 3% of Delhi's area. The government of India owns about 80% of the buildings under the jurisdiction of the NDMC.

162 Cantonment was the permanent military station in British India.

12.2.2 Commercial buildings

This land area type includes retail shopping centers, commercial centers, wholesale markets, warehouses, oil depots and cold storages. Standalone convenience stores that are integrated into the residential areas are included in the land area type 'Residential'.

To determine the solar suitable rooftop space offered by commercial buildings we have used cumulative figures provided by the DDA Zonal Plans for reasons similar to that of public and semi-public facilities. The development controls for this land area type are different for different sub heads. Ground coverage rate is 25% for district centers, community centers and city centers, 30% for hotels and 40% for local shopping centers as per the development controls in the Delhi Master Plan 2021. Average ground coverage rate taken for the analysis is 30% as a reasonable number. The total land area designated for commercial use is around 45.59 km^2 [163], which offers a built area/rooftop area of around 13.6 km^2. We assume that 10% of this area belongs to small-sized shops and commercial buildings. Such buildings have an area less than 400 m^2 and offer very little solar suitable roof space (less than 15%). In addition to that, the structures of these buildings are typically weak. These small buildings are hence discounted from our analysis, as they will not be able to accommodate the size or bear the weight of the solar installations[164]. We further discount 10% for old commercial buildings from the remaining area of commercial buildings to get the total qualified rooftop area of 11 km^2 for our analysis.

After discounting, commercial consumers are classified into two types: those with an electricity consumption of 100-200 kW that we will call type-1 consumers and those with a consumption greater than 200 kW that we will call type-2 consumers. Type-1 and type-2 consumers pay different tariffs, which impacts the financial suitability of solar power for them[165].

Type-1 consumers (medium-sized) account for 75% of the qualified rooftop area i.e. 8.2. km^2. They include buildings such as commercial complexes and shopping areas that have an average area ranging from 2,000-4,000 m^2. Type-2 consumers (large-sized), which account for 25% of the total built area i.e. 2.7 km^2, comprise of buildings such as shopping malls and hotels that have an average size upwards of 4,000 m^2. Thus, the total qualified rooftop area for commercial consumers is 11 km^2.

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163 As per the Zonal Plans developed by the Delhi Development Authority

164 The 400 m^2 cut off for small commercial buildings is double the cut off point for residential buildings 200 sq m as rooftops of commercial buildings are typically more cluttered (e.g. with cooling towers) than the rooftops of residences.

165 Refer to chapter 6 "Viability for commercial consumers" for further details

As per our analysis of commercial buildings using Google Maps, their rooftops are cluttered with cooling towers, ventilating shafts and water heating systems and tanks, reducing the solar suitable roof space. Type-1 consumers have solar suitable rooftop space that is 30% of their qualified rooftop area (8 km^2) giving a total of 2.4 km^2. Type-2 consumers have solar suitable rooftop space that is 20% of their qualified rooftop area (2.7 km^2) giving a total of 0.6 km^2. Thus, the total solar suitable rooftop space for commercial consumers is 3 km^2. The % of solar suitable space for commercial consumers has been determined after analyzing sample commercial areas such as Promenade Mall and Nehru place. The solar suitable area is smaller for larger than medium-sized commercial buildings because these larger buildings tend to have an unsuitable architecture or elevated structures ,such as domes and glass panels.

12.2.3 Industrial Buildings

The industrial area of Delhi mainly comprises of textile manufacturing units, electrical machinery manufacturing units and units that offer repair services. This area is characterized by robust concrete buildings and big plot sizes, making rooftops well qualified to bear the size and weight of solar installations.

For data related to this land area type, we used cumulative figures provided by DDA zonal plans because in industrial areas the building structures and their development controls are fairly homogenous. The total land area in Delhi that is designated for Industrial use is around 47 km^2.[166] Out of this area, 60%[167] of the area is authorized for Industrial plot development is around 28 km^2. The built area/ raw rooftop area available for solar rooftop installations is around 50%[168] of the total area available for plot development, which gives around 14 km^2. We discount 10% of the area for structures that might be old and unable to bear the weight of solar installations. Our analysis further discounts 10% for mini-micro and very large industrial buildings (that fall under <10kW and >200kW tariff group). Mini-micro industries have been excluded, as they are too small to accommodate the size of solar installations that could meet their power needs. The number of large industries on the other hand is very small and hence such buildings are chosen to be kept out of the analysis. The total qualified rooftop area after discounts is 11.3 km^2.

Industrial buildings can be categorized into two types, those with 10-100 kW of electricity consumption that we will call type-1 and those with 100-200 kW of electricity consumption that we will call type-2. The two types of consumers pay different electricity prices which can impact the financial suitability of solar power for them[169].

We roughly assume that 50% of the buildings are type-1 and 50% are type-2 consumers due to lack of information, but assuming that higher number of small industrial buildings will offset the smaller number of large-sized industrial buildings. The qualified rooftop area available for type-1 and type-2 consumers is 5.6 km^2 for each type.

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166 As per the Zonal plans developed by the Delhi Development Authority

167 As per Industry Zone Guidelines in the Delhi Master Plan 2021

168 As per the developmental controls specified in the Master Plan 2021, 50 % is the ground coverage rate pertains to plot sizes of more than 400 m^2. Our analysis assumes that on an average, plot sizes in industrial areas exceed 400 m^2

169 Refer to Chapter 6 "The viability of rooftop solar PV" for details

Based on our analysis of samples[170] through Google Maps and site visits, plot sizes in industrial areas commonly exceed 400 m^2, with roof space occupied by boilers, cooling units and shafts. None the less, there is significant unoccupied/ unobstructed rooftop space sufficient for solar rooftop installations. Accommodating for such obstructions, the solar suitable rooftop space for both type-1 and type-2 consumers is around 40% of their respective qualified rooftop area (6.3 km^2 each). This gives solar suitable rooftop space of 2.26 km^2 for type-1 and type-2 consumers each, or a total of 4.5 km^2 for industrial consumers. Some of the key industrial areas in Delhi are Okhla Industrial area, Badli Industrial area and Wazirpur Industrial area.

12.2.4 Government buildings

This land area type includes areas belonging to the President's Estate, the Parliament House, government courts (High Court, Supreme Court and the District Courts), integrated government office complexes and land allocated for undetermined government use. In our analysis, we considered unoccupied government land as built-up land based on an understanding that the city of Delhi will eventually be entirely built. Government buildings are commonly concrete structures with average plot sizes upwards of 6,000 m^2, which qualifies them for the analysis.

According to the DDA Master Plan 2021, all government buildings are subject to similar development controls hence we have used the cumulative land area figures provided by the DDA plans. The total land area designated for government use is around 47 km^2 [171] and 80% of the area i.e. 37.71 km^2 is assumed to be plotted for development. The total built area/rooftop area available for solar power installations is 30%[172] of the plotted land area, which is 11.3 km^2. We further discount 10% of the area for structures that might be old and unable to bear the weight of solar installations. Thus, the total qualified rooftop is 10 km^2. The solar suitable rooftop space offered by government buildings is assumed to be around 40%, which is fairly larger than other land area types, considering their rooftop space is commonly free from elevator shafts and cooling towers. Structurally these buildings are simple with very little shadowing.This amounts to a solar suitable rooftop space of to 4 km^2.

12.2.5 Public and semi-public facilities

Public and semi-public facilities include hospitals, education/research universities, colleges, social and cultural complexes, sports complexes, stadiums, police stations/headquarters, fire stations, disaster management centers, religious buildings, burial grounds and crematoriums. Such buildings qualified for our analysis as most facilities included in this category are large, well-built structures. In addition to that, government bodies administer many of these buildings and the government can play a direct role in ensuring that these facilities install rooftop solar installations.

We have used the cumulative figures provided by the DDA for this land area type because there are more than 200 of these facilities, which are very widely distributed across Delhi, and are hence immeasurable. Further,

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170 Samples included industrial buildings in Wazirpur, Badli and Naraina industrial area.

171 As per the Zonal Plans developed by the Delhi Development Authority

172 30% ground coverage is permissible for the government integrated office complexes and courts as per the DDA Master Plan 2021

the development controls for such facilities are almost similar and hence cumulative figures can be used to derive near accurate estimates.

The total land area designated for public and semi-public facilities is around 81 km^2 [173]. Of this, 40% is discounted for trees, roads and other open spaces giving a plot areas of 48.81 km^2. Of the plots, 30 % is built[174] giving a total built area/ raw rooftop area of 14.64 km^2. After discounting for unsuitable public facilities such as burial grounds, dairy farms, and religious buildings[175], the total built area for public and semi-public facilities is 13 km^2. We further discount 10% of the area for structures that might be old and unable to bear the weight of solar installations (these include police stations and fire stations). This gives a qualified rooftop potential of around 11.86 km^2.

Public and semi-public facilities can be government owned or privately owned. Accordingly, they pay different prices for electricity and their viability for solar differs[176]. We assume[177] that 70% of the facilities are government owned while 30% are private based on the fact that most public and semi-public buildings facilities are government aided. The qualified rooftop space is 8 km^2 for government owned facilities and 3 km^2 for privately owned facilities. Based on our analysis through Google Maps and site visits, the solar suitable rooftop space on all public facilities is around 40%. This takes into consideration that rooftops of most public facilities are occupied by water heating systems (mandatory as per government regulations), cooling towers and elevator shafts. Thus, solar suitable rooftop space is a total 4 km^2: 3 km^2 for government owned and 1 km^2 for privately owned facilities.

12.2.6 Transport buildings

This land area type includes areas covered by airports, bus terminals/depots, railway stations, metro stations and transport movement infrastructure like train tracks. Train tracks have been excluded from the analysis. Metro stations also fall outside the purview of our analysis as these buildings are mostly made of metallic roof sheeting rather than concrete structures and thus might be unfit to bear the weight of solar installations. Bus depots are large open areas for buses to be able to park and do not have any covered, concrete structures. Railway stations and airports are the only two sub heads that qualified for analysis.

Transportation facilities in Delhi that qualify for analysis are airports and railway stations. These are limited in number hence we used online mapping tools to measure their areas. These facilities occupy large stretches of land for movement, such as runways, railway platforms and parking, but possess only limited built area, which mainly comprises of ticketing and boarding areas. The total built area/raw rooftop area under this land area type is around 0.16 km^2 that offers a solar suitable roof top space of 0.032 km^2. The solar suitable roof area is assumed to be 20 % of the total raw rooftop area as most transport facilities have roof sheeting and the little concrete space left is occupied by support services such as cooling towers, shafts and monitoring units.

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173 As per the Zonal Plans developed by the Delhi Development Authority

174 30% coverage rate is applicable to Public and semi public facilities as per the Delhi Master Plan 2021

175 Discounting factor for irrelevant sub categories is assumed to be 10% as per Bridge to India analysis. These buuldings have been discounted as they have very little built space and a solar installation may not be really wanted by them

176 Refer to Chapter 6 on "The viability of rooftop solar PV" for details

177 Rough assumption is based on the knowledge that within certain categories - e.g. hospitals - there are more government buildings than private buildings (from Eicher Delhi map)

12.2.7 Factors that could impact the potential for rooftop solar

Factors that could increase the potential	**Factors that could decrease the potential**
1.Residential colonies E, F, G and H under the jurisdiction of the MCD have been entirely excluded from our analysis. In case these colonies have some solar suitable space, the potential would increase. 2. We have assumed that different building types offer different solar suitable area. For example, average solar suitable space for government buildings and residential buildings is assumed to be 40% and 20 % respectively. If in some cases, buildings offer solar suitable spaces more than the average assumed then the potential would increase. 3. While determining the geographic potential, wherever data provided by the Delhi Master plan was insufficient or unclear, we considered the more conservative estimate. For example, while mapping the area in the Delhi Cantonment for category 'Residential', the Army hospital was excluded from the mapping exercise. This was done to avoid double counting as hospitals fall under the category 'public and semi-public facilities' as per the Delhi Master plan. If such areas can be included, the overall potential would increase. 4. We assume that the maximum space required to accommodate a 1kW solar system is 12 m2. If the space occupied by a solar system is less than this assumption, say 10 m2, the potential will increase. 5. We discount 10% for smaller shops or stand-alone stores that cannot accommodate or withstand the size and weight of solar installation. In case there are some buildings that despite being small are fit to bear the weight of the installations, the potential for solar would increase.	1. We discount 10-20% for old and structurally weak buildings. If the percentage of such buildings is larger, the potential of solar would reduce 2. In case there are buildings that have architectural structures (domes, elevations) unfit to bear solar installations or that have building regulations that do not permit solar installations or where it is not financially viable to build structure over and above the existing roof structure to accommodate solar installations, the geographic potential (that does not account for such factors) for solar in our analysis would decrease.

12.3 WAYS TO INCREASE DELHI'S GEOGRAPHIC POTENTIAL FOR SOLAR

Apart from the existing built area in the city, solar installations could be installed over other structures such as drainage pipes or nallahs[178]. In some other places, land occupied by water bodies/green belts could be utilized by building structures over them that can support solar panels. Also, metro railway tracks are laid on concrete, elevated structures. These structures could be used for solar PV installations.

Building integrated PV (BIPV) systems integrate the photovoltaic modules into the building envelope, including the façade. This system utilizes more area on buildings (not just the roof area/structure available) for solar installations and hence can increase the geographic potential for solar in the city.

12.4 ROOFTOP SOLAR PV SYSTEMS

This section deals with the overview of a solar PV system, working of a PV system, different components, their sizing and connections. Further, we have analysed relevance of storage in PV systems, the importance of net metering and the typical PV system sizes across different consumer segments.

Functioning of a PV system

A solar PV power plant converts sunlight into electricity. It does so without any moving parts (unless it has a tracking system) and without generating either noise or pollution. A solar PV system can be installed at any un-shaded location such as on rooftops of buildings, car parking sheds, empty land, or even on top of canals and roads. Typical system sizes range from 240 watts to 100 MW. There is very little difference in the technical design between small kW-sized plants (typically de-centralized, off-grid) and large, MW-sized plants (typically centralized, grid-connected). Solar plants can easily be scaled using independent, modular components such as PV modules, inverters and batteries. The rooftops of buildings would be ideal for the installation of solar PV in Delhi because of the high cost of land in the city. A typical rooftop solar PV system for a household is between 1-10kW. For larger buildings, such as offices or malls, it can reach 100 kW or more. Given Delhi's average irradiation of 5-5.5 kWh/m^2/day, a kW of installed solar PV can generate 4-4.5 kWh of power during daylight hours, equivalent to the amount of power needed for a refrigerator to run for a day.

A solar PV system consists of the following key components
1. Solar PV array (group of modules)
2. Solar inverter
3. Battery
4. Interconnecting devices (junction box, cables, distribution box)

The PV array consists of solar modules interconnected with each other. The modules convert the energy from sunlight, are held on structures made of galvanized iron, mild steel or aluminum and are inclined at a horizontal tilt, facing either south or east-west.

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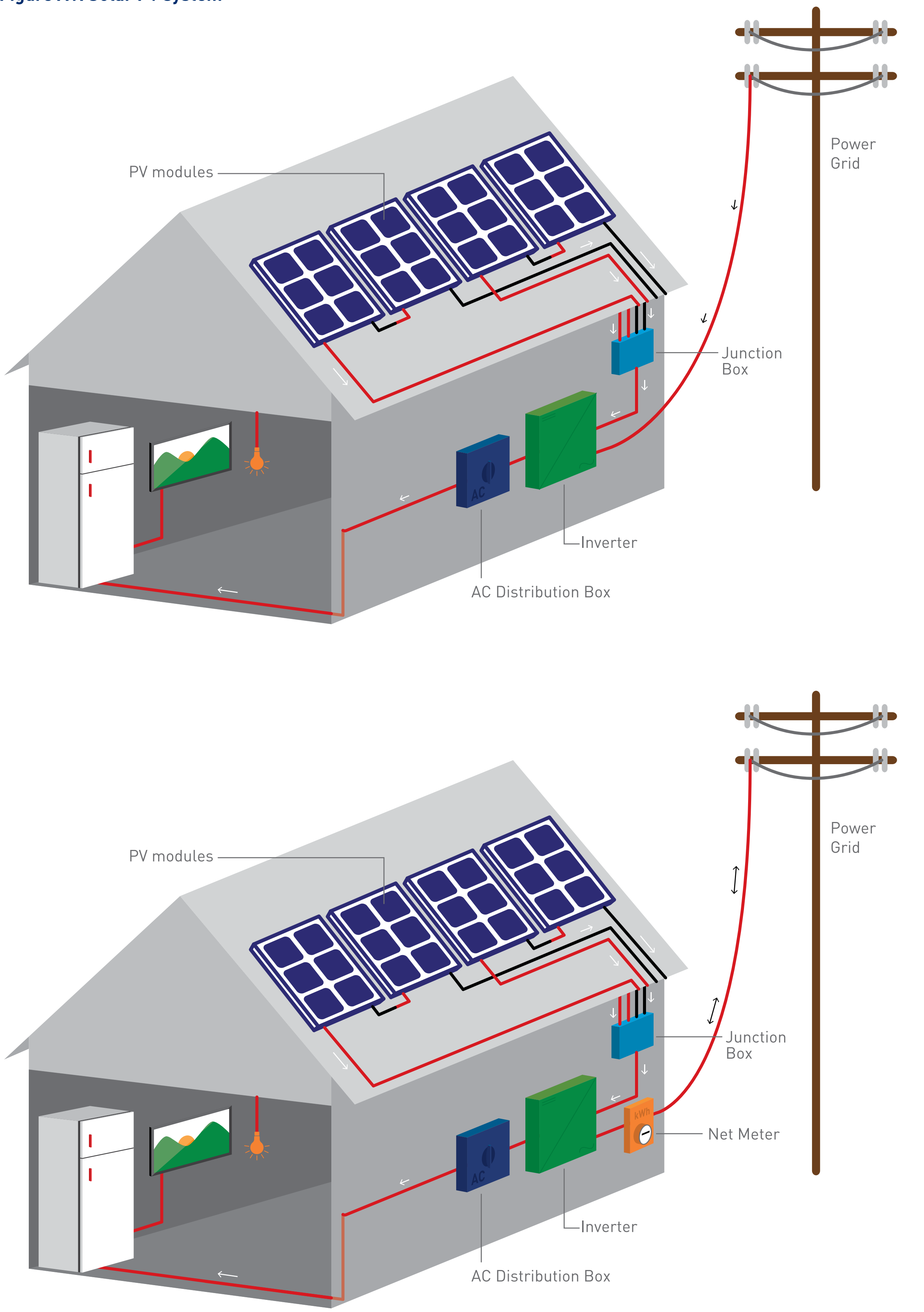
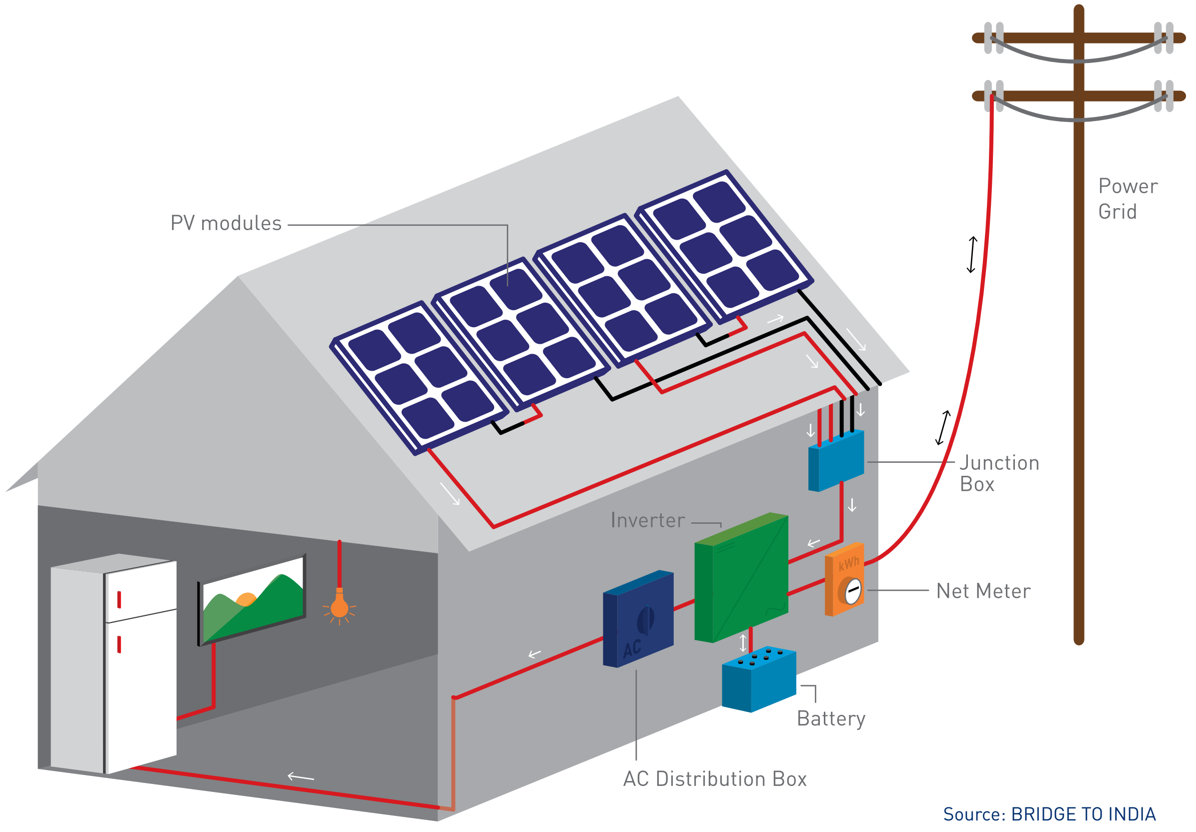
178 Nallah is an uncovered flowing sewer

Figure A1: Solar PV system



Source: BRIDGE TO INDIA



Source: BRIDGE TO INDIA

The modules are designed to generate current at either 12 or 24 volt. Inverter models can differ in their input voltage requirements in the range of 12 to 1,000 volt. A junction box connects the modules in series or parallel to achieve the optimum voltage required by the inverter.

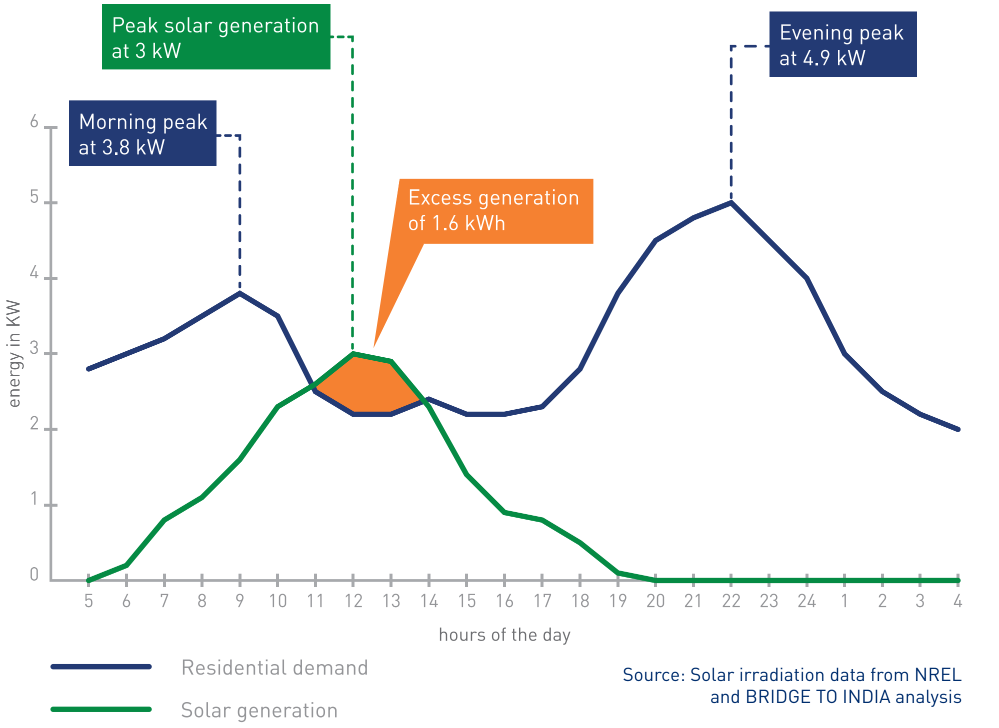
Solar modules produce direct current (DC). Almost all electrical appliances in India, however, require alternating current (AC) to operate. The function of converting DC to AC is carried out by the inverter. In the case of a battery backup system, the inverter is also connected to the batteries and is responsible for managing the charging and discharging of the batteries.

The output point of the inverter is connected to the distribution box, which consists of a meter, fuse, a miniature circuit breaker (MCB), and load connections. Cables connect the solar modules, junction boxes, inverters and distribution boxes.

The capacity of the solar PV system depends on the amount of electricity (kWh) required per day by a consumer and the shadow and obstruction free space available on the rooftop. For example, a 2 kWp load operating for 10 hours requires a PV system of 5 kWp[179] . Further, 1 kWp of solar PV requires 10 m^2 of shadow free area. Therefore, a 5 kWp system would require 50 m^2. In addition, if the consumption occurs during non-sunshine hours (6:00 pm to 6:00 am) or in case the consumption is not uniformly sufficient throughout the day[180], batteries to store energy might be added.

Another factor, which affects the system design, is the timing of electricity consumption. For example, residential consumers in Delhi have a peak demand during the morning (6:00 am – 10:00 am) and evening (6:00 pm – 10:00 pm). These are not peak sunshine hours (10:00 am – 4:00 pm). Residential demand tends to be lower during the day as household members become engaged in daily activities, mostly outside the house (e.g. adults going to work and children going to school). Thus, the peak power production of a PV system does not match the peak demand of residential consumers in Delhi. For industrial and commercial consumers, on the other hand, solar generation coincides more closely with peak demand as most of these sites operate through the day.

Figure A2: Delhi residential demand compared with solar generation[181]



Source: Solar irradiation data from NREL and BRIDGE TO INDIA analysis

Solar PV systems could be sized to not exceed the load demand during the day. If they are larger, and solar power is being generated that exceeds consumption at that point in time, wastage can be avoided by storing the excess power. Alternatively, excess power could be injected into the grid. In this case, metering would be required to measure energy transactions between the PV system and the grid. As shown in the graph above, 40% solar generation will be unused if there is no net metering.

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179 The size of a solar PV system is usually higher than the operational load as solar has an average Capacity Utilization Factor (CUF) of 18% as compared to 80% for coal power plants. 1 kW of solar gives 4 kWhs at a CUF of 18%. So, For 20 kWhs of power, we would need a system of 5 kW.

180 If loads have no fixed time of operation or might be operational over a couple of hours. For example there can be a 10 kW load being powered for just 2 hours a day. This would require a system of 5 kWp. A 5 kWp system cannot generate enough electricity to power a 10 kWp load at any time of the day; Hence we require batteries that store energy

181 Energy consumption data mapped - based on a residential house with a load of connected load of 10 kW and operating load of maximum 5 kW. Solar irradiation data of 02.08.2011, source NREL. Solar system size - 5 kWp

Rooftop solar PV with storage

Storage in solar PV systems is required to provide stable backup power when the solar energy is not available (at night) or not adequate to meet the entire load demand. Solar energy is an intermittent source of power. The power generation can vary with a change in sunshine due to, for example, a sudden cloud cover. Batteries can be used to store solar power to safeguard against a short-term fall in solar power generation. Intermittency can also be avoided by connected the solar PV system to the grid. In this case the grid provides the extra energy at times of inadequate sunshine.

Another application of storage is to protect against grid outages. During an outage it is possible that solar generation is inadequate to meet the load demand (e.g. if it occurs outside sunshine hours). In such a case, the stored energy can be utilized to provide a stable output of power. If the grid condition is good and power outages are rare, batteries would probably be avoided as they add significantly to the system cost, adding 25%.[182] Batteries also need to be replaced every three to five years.[183] Since Delhi does not experience long power cuts, batteries need not be an essential part of the PV system. Storage might, however, be an attractive option for Delhi's DISCOMs as it can be utilized to offset expensive peak load power.

Rooftop solar PV with net metering

There are two common ways in which owners of kW-scale rooftop solar PV plants can be compensated for feeding electricity into the grid: FiTs and net metering. For FiTs, solar power generated and fed into the grid is measured through a separate meter and then given a price (the FiT) through which the owner is compensated for the electricity generated. The advantage is, that the price for solar power and the amount of solar power generated can be determined independently. This method is useful where either the cost of solar power far exceeds the cost of grid power and/or where the generation of solar power far exceeds the on-site consumption needs. A risk is the potential for fraud through channeling non-solar power through the solar meter and thus inflating the amount of power for which the – usually high – solar FiT is paid. A household-level FiT is offered in, for example, Germany.

Under net metering, on the other hand, conventional electricity and solar electricity are traded at the same tariff. The billing in this case is based on the net energy imported (energy consumed minus energy generated and fed into the grid). In case more energy is generated than consumed, the utility can adjust the excess in a future billing period (this would be akin to "banking" the power), rather than giving a monetary compensation, as in the case of FiTs. However, over the long term, the amount of solar power that can be generated and monetized through net metering will be limited by the amount of power consumed, where, at most, the consumer can feed as much power back into the grid as he draws from the grid so that the electricity bill is "zero". Net metering is popular in, for example, the USA and Japan.

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182 5 kWp system with battery costs ₹750,000 (€115,384, $150,000) as compared to ₹600,000 (€92,307 $120,000) for a non battery backup system. Storage has been calculated for 2.5 kW load for 7 hours.

183 Refer to the section on "The Viability of Rooftop Solar PV" for further details

The CEA has initiated steps to set standards and guidelines for the integration of solar PV systems in to the grid. A report on grid connectivity of solar PV is under formulation at the CEA. A draft is to be shared with the public for comments by end-June. The CEA's move is based on its acknowledgement that decentralized solar PV can play a key role in bridging the country's energy deficit and is set to take off now. During our interactions with senior officials at the CEA, we were told that "solar PV is the future for this country, and we have to make sure that there are standards and guidelines in place to support its integration with the grid". Various metering arrangements covering grid interaction of a PV system with battery, without battery, with different load battery back-ups, with different load DG back-ups, and with DG and battery back-up combinations, have been laid down in the draft report. The DERC[184] though has the final authority to determine the metering arrangements that would be applicable in the city.

Rooftop solar PV system sizes

Commercial consumers in Delhi (type-1, and type-2 and privately owned public and semi-public facilities) such as malls and office complexes have an average load requirement above 1 MW. But due to the presence of cooling towers, air conditioning units, ventilating shafts, boilers and tanks, limited rooftop space is available for solar. As per our analysis on rooftop potential in Chapter 1 of this report, type-1 consumers accounting for 75% of the total built commercial area include buildings such as small office complexes have an average area of 400-2,000 m^2. These buildings offer a solar suitable roof space of 30%, which is upwards of 120 m^2. This space can typically accommodate PV systems of sizes exceeding 10 kWp[185]. Given the range, **we assume 25 kWp to be the standard system size for type-1 commercial consumers in our analyses**. Type 2 consumers, account for 25% of the total built commercial area comprising of buildings that have an average size ranging from 2,000 m^2 to 12,000 m^2. The solar suitable space offered by these buildings is 20% that amounts to solar suitable space ranging from 400 to 2,400 m^2. Type 2 consumers also include privately owned public and semi-public facilities that account for 30% of the built area of public and semi-public facilities. comprise of private hospitals and educational institutes. These buildings too typically have rooftop sizes 2,000-12,000 m^2 and offer solar suitable space of 35% or between of 700-4,200 m^2. Type-2 buildings can thus typically accommodate a PV system ranging from 33-350 kWp[186]. Given the range, **we assume 50 kWp to be the standard system size for type-2 consumers in our analyses**.

Industrial consumers have fewer obstructions as compared to commercial rooftops. As per our analysis in Chapter 1 of this report, industrial consumers have 40% of roof space available for solar. The solar suitable space for type-1 consumers ranges from 120-320 m^2 which can typically accommodate PV systems of sizes ranging from 10-27 kWp[187]. For type-1 consumers, we assume a standard system size of 20 kWp for our analyses.Type-2 consumers are bigger industrial buildings that have an average area ranging from 800-1,500 m^2. The solar suitable area of these buildings ranges from 320-600 m^2 that can typically accommodate PV system of sizes ranging from 27-50 kWp[188]. **For type-2 consumers, we assume a standard system size of 40 kWp**.

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184 DERC regulates the operation of the power system and sets standards for the electricity industry (standards related to quality, continuity and reliability of service) in the NCT of Delhi.

185 Based on Bridge to India's estimate that 12 m^2 of rooftop space can accommodate a 1kW solar power installation

186 Ibid. 187 Ibid. 188 Ibid.

Residential consumers of have rooftop areas between 200-1,000 m^2. With only 20% of their rooftops suitable for solar, the have a space availability between 40-200 m^2.This gives them a potential between 3-17 kWp[189]. Given the range, **for residential consumers we assume a standard system size of 5 kWp for our analyses**.

Government buildings such as courts and office complexes and government owned public and semi-public facilities have rooftop areas of 1,000-13,000 m^2. The solar suitable space available on government buildings is assumed to be 40% of the built area, while that on government owned public and semi-public facilities is 35%. This translates to solar suitable space between 350-5,200 m^2, which can accommodate PV systems of 29-433 kWp[190]. However, government buildings are usually in close proximity of each other, allowing for the bundling of PV systems. Bundling to create projects of a minimum 2,000 kW can reduce costs significantly. **Thus, we assume standard system sizes of 2,000 kWp for government consumers**.

12.5 SOLAR PV GRID CONNECTIVITY CHALLENGES AND SOLUTIONS

Voltage fluctuation and imbalance

The solar energy generated by a PV system is dependent on the availability of sunlight. Power generated can vary drastically throughout the day, sometimes within seconds, because of, for example, cloud-cover and weather changes. This causes rapid voltage fluctuations that can hamper devices linked to the transmission network and can, in some cases, overheat and even melt the power lines. Inverters can be designed to regulate PV system voltage and provide for communication between the grid operator and the PV inverters. Such communication can allow for improved control of voltage fluctuations in the entire grid.

Further, voltage fluctuations can take place due to the improper functioning of an inverter and can be problematic if these fluctuations move outside specified values. Excessive under-voltage can cause "brownouts" characterized by the dimming of lights and inability to power some equipment. Excessive over-voltage can damage and decrease the life of electronic equipment. To avoid such scenarios, voltage fluctuations need to stay within specific limits[191], beyond which the PV system is required to automatically disconnect from the grid.

Transmission of unwanted current into the grid

The current in the grid which is supplied for end-use is AC. The current generated by the solar PV system is DC. This is stored into the battery system (if there is one), also in DC, and then converted into AC by the PV inverter, which in turn is either fed into the grid or consumed. There is a possibility that the PV inverter passes unwanted DC current into the AC driven network of the grid, which can lead to overheating of distribution power transformers, power losses or damages. This injection of DC power into the grid can be avoided by using an isolation transformer at the output of the inverter. An isolation transformer would block transmission of DC signals from one circuit to the other, but allow AC signals to pass. Coupled with an isolation transformer, inverters are able to feed electricity into the grid with a maximum permissible DC component of 1% in the AC current.

Electrical disturbance caused by non-linear loads

Electrical disturbance (the permanent modification of the voltage and current sinusoidal wave shapes), generating harmonics, is created by the presence of non-linear[192] components in an electrical system. Harmonics in the power grid can overload equipment, interfere with telephone circuits and broadcasting and lead to metering errors. Typically, total voltage harmonic distortion, individual harmonic distortion and total current harmonic distortion produced by a PV system should not be allowed to exceed 5%, 3% and 8% respectively, such that electrical disturbances do not affect the quality of power in the grid.

Unintentional islanding

Unintentional islanding occurs when a solar PV system continues to supply electricity to the grid in the event of a larger grid failure. This can cause safety issues for technicians and the general public as a power line that might be considered off is, in fact, still powered. Unintentional islanding is a well-known problem and, therefore, most inverters now possess anti-islanding features whereby PV systems are automatically disconnected from the grid in the event of a power outage. In addition to that, a manual disconnect switch could also be provided in the PV system to isolate the grid connection. Despite these measures, unintentional islanding remains a particular concern when PV and other systems without anti-islanding features, such as diesel generators, are connected to the same line section. These machines may mimic normal grid conditions, causing the PV inverters to stay online and create unintentional islanding. At the moment, there are no finalized solutions to this problem.

Reverse power flow and voltage fluctuations

High levels of PV penetration may cause reverse power flow. Reverse power flow occurs when in the case of weak or/and long networks, voltage rises when consumption at the consumer's end is low and the power fed into the grid by the PV system is high. In such a case, voltage increase may cause the electricity to change direction and flow through the transformer to the higher voltage. This is can lead to heating up of the distribution transformer and transmission lines. Another problem can arise when the power generated by the large number PV systems reduces at once due to the inherent intermittent nature of solar. This sudden reduction in power can destabilize the grid.

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189 Ibid. 190 Ibid.

191 For step changes (which may occur repetitively) the limit stated by CEA is 1.5 %. For occasional fluctuations other than step changes the maximum permissible limit is 3%. Further, the voltage imbalance or maximum deviation from phase voltage at 33kV and is not allowed to exceed 3%

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192 Linear loads are electrical loads where the voltage and current waveforms are sinusoidal. The current at any time is proportional to the voltage. Non-linear loads are electrical loads where current is not proportional to voltage. The nature of non-linear loads is to generate "harmonics" or distortion in the current waveform. Non-linear loads include computers or refrigerators.

13 GLOSSARY OF TERMS

1BOG One block off the grid
AC Alternating Current
BOS Balance-of-system
BRPL BSES Rajdhani Power Limited
BYPL BSES Yamuna Power Limited
CEA Central Electricity Authority
CERC Central Electricity Regulatory Commission
CNG Compressed Natural Gas
CSR Corporate Social Responsibility
CUF Capacity Utilization Factor
CUNY City University of New York
DC Direct Current
DDA Delhi Development Authority
DERC Delhi Electricity Regulatory Commission
DISCOM Distribution Company
DOE Department of Energy
EPC Engineering, Procurement and Construction
FiT Feed-in-Tariffs
GBI Generation Based Incentive
GIS Geographical Information System
GPCL Gujarat Power Corporation Limited
IIT Indian Institute of Technology
IRR Internal Rate of Return
JJ Jhugi Jhompri Clusters
LCOE levelized Cost of Energy
MCB Miniature Circuit Breaker
MCD Municipal Corporation of Delhi
MNRE Ministry of New and Renewable Energy
NCT National Capital Territory
NDMC New Delhi Municipal Council
NOx Nitrogen Oxide
NREL National Renewable Energy Laboratory
NSM Jawaharlal Nehru National Solar Mission
PPA Power Purchase Agreement
PPP Private Public Partnership
PV Photovoltaic
REC Renewable Energy Certificates
RESCO Renewable Energy Service Company
RPO Renewable Purchase Obligations
RPS Renewable Portfolio Standard
RSPM Respirable Suspended Particulate Matter
TPDDL Tata Power Delhi Distribution Limited
VAT Value Added Tax
WHO World Health Organization

BRIDGE TO INDIA is a consulting company focusing on the solar market in India. The company was founded in 2008 and is based in New Delhi, Bangalore, Munich and Hamburg. BRIDGE TO INDIA offers solar market Intelligence, strategic consulting and project development services to investors, companies and institutions. As part of market intelligence, we provide comprehensive, analytical and up-to-date research on the Indian solar market through various reports. Our strategic consulting expertise lies in assisting large Indian and international clients to engage the solar market in India. We also offer solar PV project development services with a strong focus on commercially attractive rooftop business models.

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Greenpeace is a global organization that uses non-violent direct action to tackle the most critical threats to our planet's biodiversity and environment. Greenpeace is a non-profit organization, present in 40 countries across Europe, the Americas, Africa, Asia and the Pacific. It speaks for 2.8 million supporters worldwide, and inspires many millions more to take action every day. To maintain its independence, Greenpeace does not accept donations from governments or corporations but relies on contributions of individual supporters and foundation grants. Greenpeace has been campaigning against environmental degradation since 1971 when a small boat of volunteers and journalists sailed into Amchitka, an area west of Alaska, where the US Government was conducting underground nuclear tests. This tradition of 'bearing witness' in a non-violent manner continues today, and ships are an important part of all its campaign work.

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