Stanford | Steyer-Taylor Center for Energy Policy and Finance

REACH FOR THE SUN

How India's Audacious Solar Ambitions Could Make or Break its Climate Commitments

Varun Sivaram

Gireesh Shrimali

Dan Reicher

December 8, 2015

Table of Contents

List of Figures

Executive Summary

At the 2015 Paris Climate Change Conference of the Parties, India's climate policy has emerged as a top concern, because its greenhouse gas emissions are projected to rise far into the future and could overtake those of the United States and China by mid-century. Under Prime Minister Modi, India plans to produce more power from coal, from both domestic and imported sources, greatly expanding its largest source of carbon emissions. At the same time, the Prime Minister has committed India to dramatically increase its deployment of solar power to 100 gigawatts (GW) by 2022, equal to more than half of all solar capacity installed world-wide as of 2014.[1] And at the Paris Conference, the Prime Minister announced the International Solar Alliance, a coalition of 121 countries that India will lead to promote worldwide collaboration on developing and deploying solar power.

This study assesses the feasibility of Prime Minister Modi's solar ambition and the opportunities it presents for India and the world. The study reaches three important conclusions. First, for solar power to succeed as a serious climate tool in India, it will also need to **deliver an array of domestic co-benefits** — from improving power reliability and access to electricity to cutting air pollution and energy imports-thereby building significant political support and investment to dramatically ramp up solar deployment. Second, **three very different segments of the solar industry—utility-scale, distributed, and off-grid solar** —will be required to deliver both climate results and domestic co-benefits to India.

This study assesses the feasibility of Prime Minister Modi's audacious solar ambition and the opportunities it presents for India and the world

Third, the Indian national and state governments, with the support of countries and institutions around the world, can advance the development of these diverse segments of solar by **pursuing four building blocks of a successful solar strategy**: reform the utility sector; harmonize federal and state policies; secure substantial and cost-effective financing; and foster the diffusion of technology and standards from abroad. With these building blocks in place, India can greatly accelerate the deployment of solar power and with it progress toward the world's climate imperative.

Framework of the Report

This report explains the promise of solar to address India's various energy challenges in **Chapter 1**, "Solar: India's Ultimate Solution?" Although the Modi administration has set an ambitious target for overall deployment of solar, this chapter divides solar into three essential but very different segments—utility-scale, distributed, and off-grid—and makes the case for why all three are needed to advance India's international climate commitments as well as deliver key domestic co-benefits.

Chapter 2, "Climate and Solar Action in the Indian Context," provides background on India's positions in international climate negotiation, assesses recent progress in deploying solar, and describes the different challenges India will face in scaling up all three segments of solar. The chapter lays out four key building blocks that the Indian federal and state governments, along with international players, should pursue to accelerate solar deployment and have a decent prospect of meeting the 100 GW target.

Chapter 3, "The Path Forward: Achieving Success in Three Segments of Solar," takes deep dives into each of the three solar segments: utility-scale, distributed, and off-grid solar. Within each segment, the chapter describes the specific climate benefits and domestic co-benefits that could arise from rapid deployment and details segment-specific challenges that could obstruct progress. For each solar segment the chapter then discusses how to implement the four building blocks of a winning solar strategy, offering specific recommendations to enable progress toward the Modi administration's ambitious solar goals.

Finally, **Chapter 4**, "Conclusion and Future Research Priorities," highlights areas of ongoing policy uncertainty that require further research. This chapter aims to convey the magnitude of the task ahead for India and the importance of continued analysis to help guide the Modi administration toward achievement of its goals, as well as to raise awareness of international players who can support India in its ambitious solar mission.

1 Solar: India's Ultimate Energy Solution?

Woman installs off-grid solar in Tinginaput, 2009 (UK Department for International Development)

In remarks to India's top scientists in August, Prime Minister Narendra Modi hailed solar power as the "ultimate solution to India's energy problem," targeting over 100 Gigawatts (GW) of solar connected to the power grid by 2022, up from less than 5 GW today and more than half of all the solar power that was deployed world-wide as of 2014.[2,3] A bold vision, it has enabled the Modi administration to promise greater energy access, reliability, and security to domestic audiences as well as offer tangible commitments to confronting climate change to the international community. Indeed, at Paris, India announced that it will spearhead an International Solar Alliance of 121 countries to aggregate demand, improve product performance, and reduce the costs of solar power.[4]

Solar could also be crucial to help offset the Modi administration's pledge to simultaneously double domestic production of coal. In addition to offsetting substantial coal imports, the expanded domestic coal production will fuel a 40 percent increase in coal-fired power generation by 2022 to meet India's growing electricity demand and with it a serious increase in greenhouse gas emissions.[5,6] How, then, can the international community—at the Paris climate negotiations and beyond—help India realize the potential of solar power to curb its greenhouse gas (GHG) emissions?

As national leaders assemble in Paris, the question of India's rising emissions trajectory will represent one of the most unresolved elements of the climate change negotiations. To put this in context, China, the world's top emitter, has pledged declining emissions from 2030 onward, and the United States, the world's second largest emitter, has committed to reduce emissions substantially over the next decade.[7,8] India is in third place, but it contributes the lowest emissions per capita of the top ten national emitters, and its commitments do not include a future reduction in aggregate emissions, unlike the U.S. and China. Indeed, the Modi administration noted in its climate action plan ahead of the Paris conference that increasing per capita energy consumption is crucial "to provide a dignified life to its population and meet their rightful aspirations."[9] The Modi administration has pledged instead to reduce India's "emissions intensity", i.e. its emissions per unit of economic output, while its aggregate emissions will likely rise as its economy grows.[10] Consequently, India is on track to overtake the United States and then China by mid-century to become the top GHG emitter in the world.[11]

The Modi administration has maintained that India's climate targets are "ambitious but achievable" in the context of a developing country, estimating that the total cost of climate mitigation and adaptation efforts over the next fifteen years will total $2.5 trillion.[12] Moreover, the administration has highlighted its renewable energy efforts to demonstrate India's willingness to lead on climate, and its strategy is to increase per capita energy consumption while controlling emissions growth.[13] At the center of this renewable energy push is Prime Minister Modi's strong focus on solar power. His administration's ambitious 100 GW solar target could generate over 10 percent of India's electricity in 2022, up from less than 1 percent today.[14] In fact, solar accounts for a majority of India's total renewable energy goal of 175 GW by 2022 (the goal also targets 60 GW of wind energy by 2022, up from 25 GW today).[15,16,17] Emphasizing the audacity of the 100 GW target, Prime Minister Modi highlighted solar in a joint January 2015 announcement with U.S. President Barack Obama on clean energy cooperation, and, most recently, in India's October climate commitment ahead of the Paris summit.[18,19,20]

India is willing to lead on climate, and its strategy is to increase per capita energy consumption while controlling emissions growth

1.1 Solar's Potential to Address India's Energy Challenges

The Modi administration's sustained focus on solar as the "ultimate solution" follows from the attractive benefits of solar power in meeting India's critical energy challenges:

Energy access: Over 400 million Indians have access to fewer than four hours of electricity per day. This figure has persisted despite long-standing efforts to extend the electricity grid to remote areas. Because of its modularity, solar power could present a rapidly scalable solution for both on-grid and off-grid applications.[21]

Air pollution: Over half of India's population lives in urban areas where air pollution cuts life expectancy by over three years on average.[22] Solar power is a zero-emission alternative to fossil fuels—coal, natural gas, diesel, and kerosene—that are burned in India for power, heat, and light.

Supply gap: India's electricity demand exceeds the supply of power by nearly 10 percent, according to official estimates, and more than 20 percent based on external analysis, explaining India's chronic rolling blackouts.[23,24] Solar is a promising resource to close the supply gap because of its vast potential. Thanks to India's plentiful sunlight, the government estimates that a small fraction of underutilized land could support 750 GW of solar, which would generate more electricity than India's entire power plant fleet at present,[25] although doing so would require careful land management practices.[26]

Import reliance: India imports 30 percent of its coal, 52 percent of its natural gas, and 86 percent of its oil, with its energy import bill increasing from 2 to now 10 percent of GDP over the past decade.[27] Solar power presents a domestic alternative to imported fuels, with the potential to improve energy security.

The Modi administration's sustained focus on solar as the "ultimate solution" follows from the attractive benefits of solar power in meeting India's critical energy challenges

GHG emissions: India is currently the world's third largest emitter of GHGs but is on track to overtake the United States and China by mid-century if its emissions continue to grow alongside its economy.[28] Solar is an attractive option for policymakers looking to rein in emissions.

1.2 Three Complementary Segments of Solar

Solar appears to be a silver bullet—a single solution to India's multitude of challenges—but the reality is far more complicated. In fact, three very different segments of solar deployment are needed to address India's energy and climate challenges. Pursuing any one segment in isolation will only address a subset of India's looming problems and, importantly, may not garner enough political support to sustain the government's ambitious push for more solar deployment. The Modi administration has recognized the importance of all three solar segments, at least on paper, by setting individual targets for each:

Utility-scale solar: Solar farms greater than 1 megawatt (MW) and interconnected to the high-voltage transmission grid. The Modi administration has targeted 60 GW of utility-scale solar by 2022 and so far has heavily concentrated on this segment.

Distributed solar: Solar installations less than 1 MW that are connected to the low-voltage distribution grid and often are on the customer side of the meter, most commonly on a rooftop. This category also includes grid-connected "microgrids," which are networks of generators serving multiple homes or businesses. The Modi administration has set a target for "rooftop solar"—a subset of distributed solar—at 40 GW by 2022.

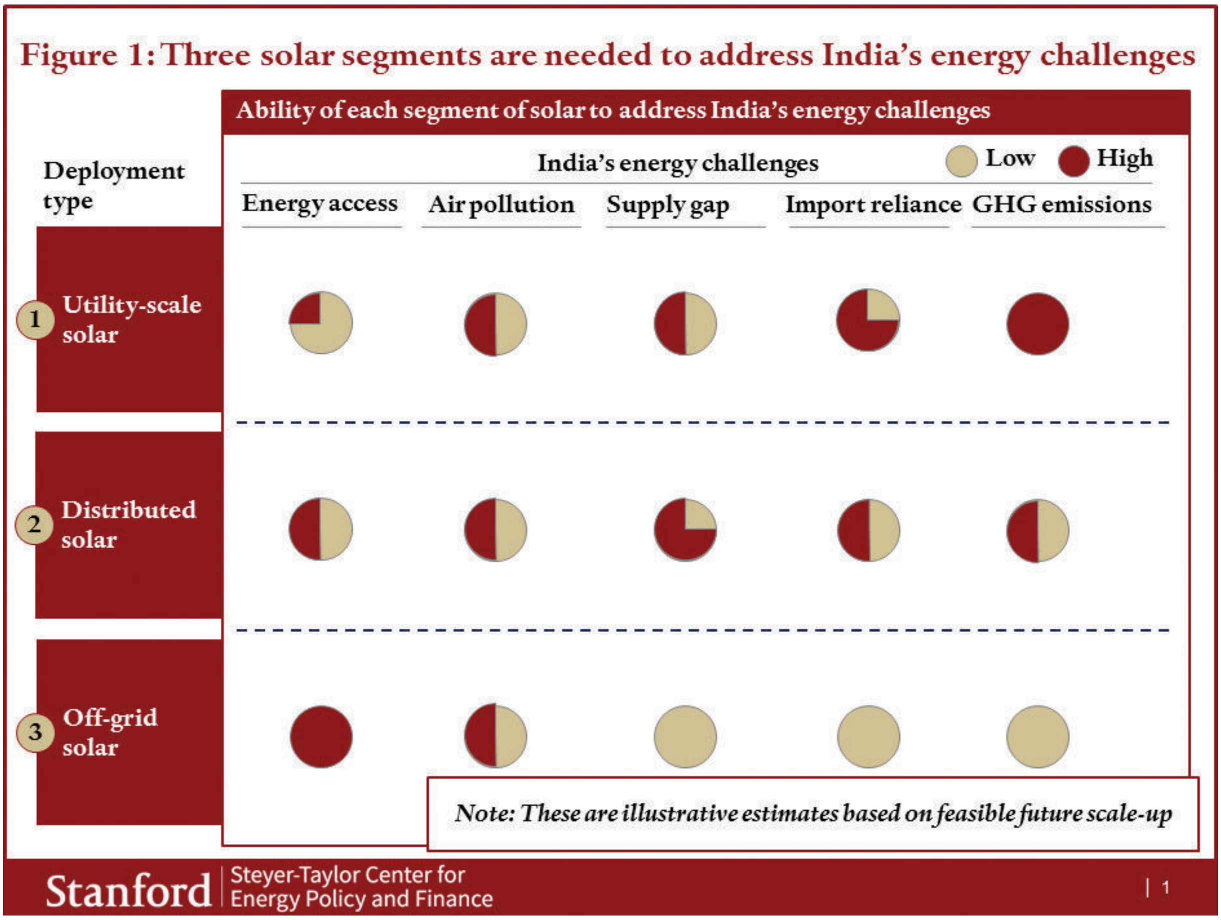
Off-grid solar: Solar installations that are not connected to the grid but rather operate in isolation or embedded in an off-grid microgrid. These installations range from single home systems rated at less than 1 kilowatt (kW) to systems of 100 kW or more serving multiple homes and businesses. Typically, these systems are deployed in rural areas not reached by the electricity grid. The Modi administration's off-grid solar target is 3 GW by 2022, which while smaller in magnitude than other targets, ambitiously entails electrifying tens of millions of Indian households whose power needs are typically much less than 1 kW each.

It is worth noting that the Modi administration's 100 GW target applies to "grid-interactive" projects, referring to utility-scale and distributed solar systems, which are connected to the central grid. The 3 GW off-grid solar target is separate and additional, implying that India's solar target is actually 103 GW of cumulative capacity.[29] Since most government and media references to the 2022 solar target use the round 100 GW figure, this report will adopt the same convention, recognizing that the sum of three segment targets is actually slightly more ambitious.

To date, total solar deployment in India is roughly 4.5 GW, compared with 36 GW in Germany, 28 GW in China, and 18 GW in the U.S. at the end of 2014.[30] Importantly, India's deployment has come almost exclusively in the form of utility-scale installations, composing over 85 percent of the existing installed solar capacity.[31] The remaining capacity comprises roughly 350 MW of rooftop solar and 200 MW of off-grid solar.[32] Thanks to economies of scale, utility-scale solar is the least costly of the three segments, and to date centralized administration of pro-solar policies have lent themselves most naturally to supporting fewer large projects rather than many smaller ones.

Solar appears to be a silver bullet—a single solution to India's multitude of challenges—but the reality is far more complicated

For solar to play a significant role in cutting India's contribution to climate change, it must also deliver other benefits, requiring successful deployment of all three segments of solar



However, as **Figure 1** illustrates, all three segments of solar, not just utility-scale, are necessary to address the full range of India's energy challenges. Off-grid solar could be a crucial resource to increase energy access for the more than 400 million consumers that the electricity grid has failed to reach or underserves.[33] By contrast, utility-scale solar can only improve energy access if its deployment is paired with often-expensive expansion of the electricity grid. A diverse mix of solar deployment is needed to inspire rural support for the overall solar vision.

Next, as indicated in Figure 1, each of the three solar segments can help address air pollution. By displacing coal power, utility-scale solar can reduce concentrations of sulfur dioxide (SO_2) and nitrous oxides (NO_x) that cause chronic respiratory diseases.[34] Distributed solar can displace power from back-up diesel generators prevalent in urban areas, which also produce health-degrading pollutants (e.g., particulate matter).[35] And off-grid solar, by displacing the use of diesel generators and kerosene lighting in rural areas, can also reduce air pollution.[36] The combined effect of all three segments on lowering air pollution across India, a tangible benefit of solar, could build momentum to accelerate solar deployment.

Meeting each of India's remaining challenges requires one of the three segments to play a starring role but depends on support from other segments to maximize progress. Distributed solar, for example, is often better suited to help close the energy supply gap between the power demanded by consumers and the quantity that the grid is able to deliver. This is counterintuitive, given that utility-scale solar capacity is easiest to scale up. But shortfalls in delivered energy principally arise from problems with the electricity grid and the utilities that run it rather than from inadequate generation capacity. In other words, even if there is enough centrally generated power to meet on-grid consumer demand, a significant amount of that power is lost as it travels through troubled electricity grids, and in many cases utilities are not even able to purchase all of the power generated by power plants.[37] This can happen when state utilities struggle under high debt burdens, lose revenue by subsidizing consumers, and are therefore unable to pay for the full supply of energy for which they have contracted.[38] So although utility-scale solar can increase energy supply, each additional unit of centrally generated energy may still face economic and technical obstacles to actually reach consumers.[39] By contrast, distributed solar is generated on-site, bypassing the grid and the utilities that operate it. Therefore, it can improve the reliability of a consumer's power supply by supplementing grid power, and it can do more to reduce unmet demand, because locally sited solar can compensate for shortfalls from the grid. And with cost-effective storage, distributed solar could further address the supply gap.

To address the final two energy challenges—import reliance and GHG emissions—utility-scale solar is the most effective segment, but distributed solar can provide complementary benefits. By displacing coal-fired power plants, utility-scale solar can reduce expensive imports of coal for electricity, reducing India's dependence on imported fuel. Moreover, since coal-fired power generation is India's largest source of GHG emissions, utility-scale solar is best poised to curb emissions growth by out-competing the economics of new and existing coal power plants. At the same time, distributed solar provides the complementary benefit of reducing the use of back-up diesel power generators in urban settings, reducing emissions and reliance on imported diesel.

Finally, in addition to addressing India's various energy challenges, deploying multiple segments of solar can offer a bonus economic benefit: job growth. The employment benefits of solar increase as the degree of centralization decreases. That is, off-grid and distributed solar for residential applications can support more jobs per GW of solar capacity, compared with larger distributed and utility-scale installations. One report estimates that per GW, residential solar creates nearly 40,000 jobs, mostly in construction, compared with fewer than 6,000 jobs per GW for the largest solar installations.[40] Moreover, larger projects mostly create construction jobs that are short-lived, compared with greater sustained employment per MW in both initial installation as well as ongoing maintenance for smaller projects.[41]

Putting this all together, for solar to play a significant role in cutting India's contribution to climate change, it must also deliver other benefits, requiring successful deployment of all three segments of solar. Thus, off-grid solar may not materially displace fossil fuels or measurably reduce GHG emissions, but it can bring considerable political benefits by appealing to important rural constituencies. Similarly, by improving power reliability, helping close the supply gap, and reducing local air pollution, widespread distributed solar can win urban residents over to the cause of solar. And large utility-scale solar installations, generally located out of sight and with lesser job-creation benefits, can ride the political coattails of the other two segments while performing the

2 Climate and Solar Action in the Indian Context

Prime Minister Narendra Modi delivers his Independence Day Address in New Delhi on August 15, 2014 (Flickr)

2.1 Overview of India's Climate Posture

Prime Minister Modi's solar target, the centerpiece of India's climate pledge at the Paris Climate talks, represents two opposing strains in the Indian climate policy debate. The ambition of the target illustrates the Modi administration's vision of India as an international leader on climate action. However, the warning that India's solar efforts will only succeed with the help of international capital echoes India's historical reluctance to reduce its own emissions unilaterally. Still, India's pledge to accelerate solar represents a welcome shift toward greater engagement in the international climate process.

Raichur Coal Power Plant, which accounts for 40 percent of the power generated in the Indian state of Karnataka (Wikipedia)

India has participated in international climate negotiations for over two decades, signing on to the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 and going on to ratify the Kyoto Protocol a decade later in 2002.[42] However, the doctrine of "common but differentiated responsibilities" underpinning the Kyoto pact put the onus of emission reduction on developed countries.[43] India was a staunch supporter of this doctrine, and successive administrations have attributed historical responsibility for climate change and its solution to the developed world. For years, Indian governments have argued that developed countries like the United States have spent a century industrializing their economies without emission restrictions. Therefore, they have contended, fairness dictates that developing countries have an opportunity to do the same.[44]

Prime Minister Modi's arrival has reduced some of India's resistance on domestic climate action. Growing recognition of the disproportionate share of climate change impacts that India will bear, coupled with the Modi administration's resolve to improve India's international reputation on climate change, have led the administration to seriously explore pathways to decouple economic growth from carbon emissions.

The Modi administration clarified its official position in October 2015 when it announced its Intended Nationally Determined Contribution (INDC), or climate commitment, ahead of the Paris summit. In the INDC, the government committed to three actions to reduce its emissions by the year 2030: a 33–35 percent reduction from its 2005 emission intensity (GHG emissions per unit GDP); 40 percent installed power generation capacity from non-fossil fuel sources; and new forests to serve as a sink for GHGs equivalent to 2.5–3 billion tons of carbon dioxide by 2030.[45] In addition, India announced plans to invest in adaptation to climate change and to continue to seek financial and technological assistance from developed countries. The nation's combined mitigation and adaptation agenda are projected to cost $2.5 trillion over the next fifteen years.[46]

Of the three goals, India's non-fossil fuel power goal is by far the most ambitious. Although existing nuclear, and hydropower capacity already account for roughly 20 percent of India's power generation capacity today, the Indian government forecasts limited growth in those resources, and their contribution will decline as a percentage of total power capacity as India builds new coal

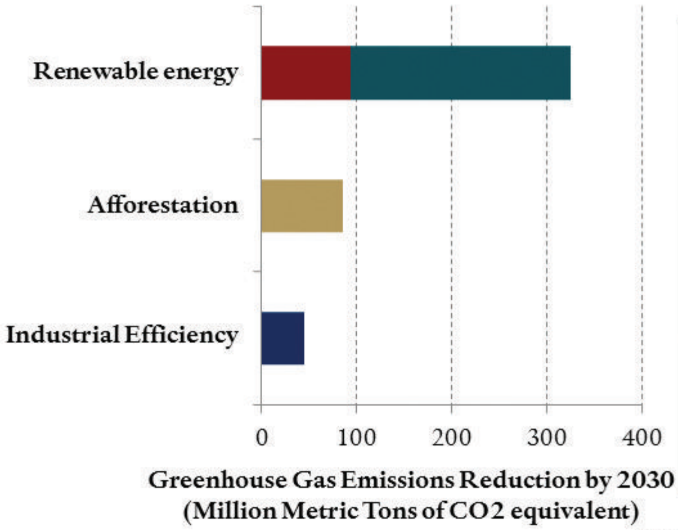
Because the Modi administration's informal target is for solar to compose 250 GW of its total 350 GW goal by 2030, solar is by far India's largest climate commitment

power plants. Therefore, getting to the goal of 40 percent non-fossil fuel power by 2030 will require wind and solar capacity to reach roughly 350 GW, or four times today's level of non-fossil fuel power capacity.[47] India's 100 GW target for solar by 2022 is a major down-payment on that 2030 commitment.

Figure 2 disaggregates the GHG reductions from new renewable energy deployment from the other major initiative in the INDC, known as the "Perform Achieve Trade" scheme that is aimed at improving industrial energy efficiency. In the resulting comparison, India's 2030 renewable energy goal leads to emission cuts nearly double those of both the industrial energy efficiency and afforestation goals combined. And because the Modi administration's informal target is for solar to compose 250 GW of its total 350 GW goal by 2030, solar is by far India's largest climate commitment.[48] Even so, India's INDC does not imply that its aggregate emissions will stop growing. To the contrary, the country's emissions are likely to more than double by 2030 compared with current levels.[49] This irony—that even with potentially unprecedented advances in renewable energy deployment, coal power will continue to dominate the Indian electricity mix—is the crucial insight for assessing solar's central role in India's climate policy. The Modi administration has major plans for coal, including a target to double current domestic coal production. As the largest source of India's emissions, the future of coal will largely determine India's emission trajectory **(Figure 3).**

Figure 2: Solar is India's most significant climate commitment

Projected impact of India's INDC mitigation commitments



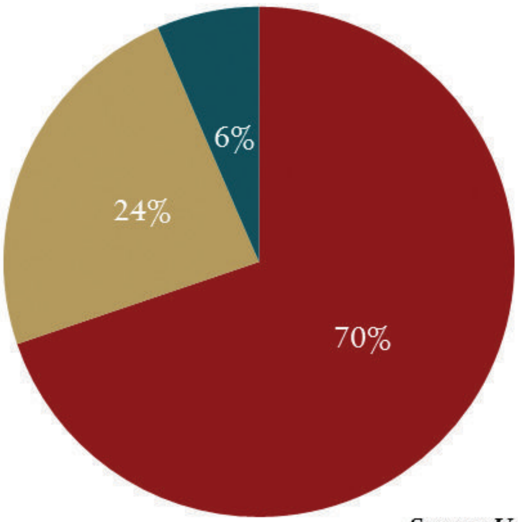
Reduction in Annual Emissions (million metric tons in 2030)	
220-240	Solar
90-100	Other renewables
70-100	Afforestation
30-60	Industrial Efficiency
410-500	**Total**

Source: World Resources Institute

Stanford | Steyer-Taylor Center for Energy Policy and Finance | 2

Figure 3: Coal accounts for a large majority of India's energy-related greenhouse gas emissions

India's Emissions by Primary Energy Source, 2012



Annual Emissions (million metric tons)	
1,280	Coal
435	Petroleum
119	Natural Gas
1,834	**Total**

Source: U.S. Energy Information Administration

Stanford | Steyer-Taylor Center for Energy Policy and Finance | 3

Importantly, one of the key factors in this assessment is the low "capacity factor" of solar (and wind) compared with that of coal. Thus, given two 500 MW power plants, one running on coal and the other on solar, the coal plant will typically generate over twice as much electricity (measured in megawatt-hours) because it is not tied to an intermittent resource and therefore can operate more consistently across a day or month or year. This explains why renewables produce a disproportionately smaller fraction of India's electricity, despite their larger share of generating capacity **(Figure 4).**

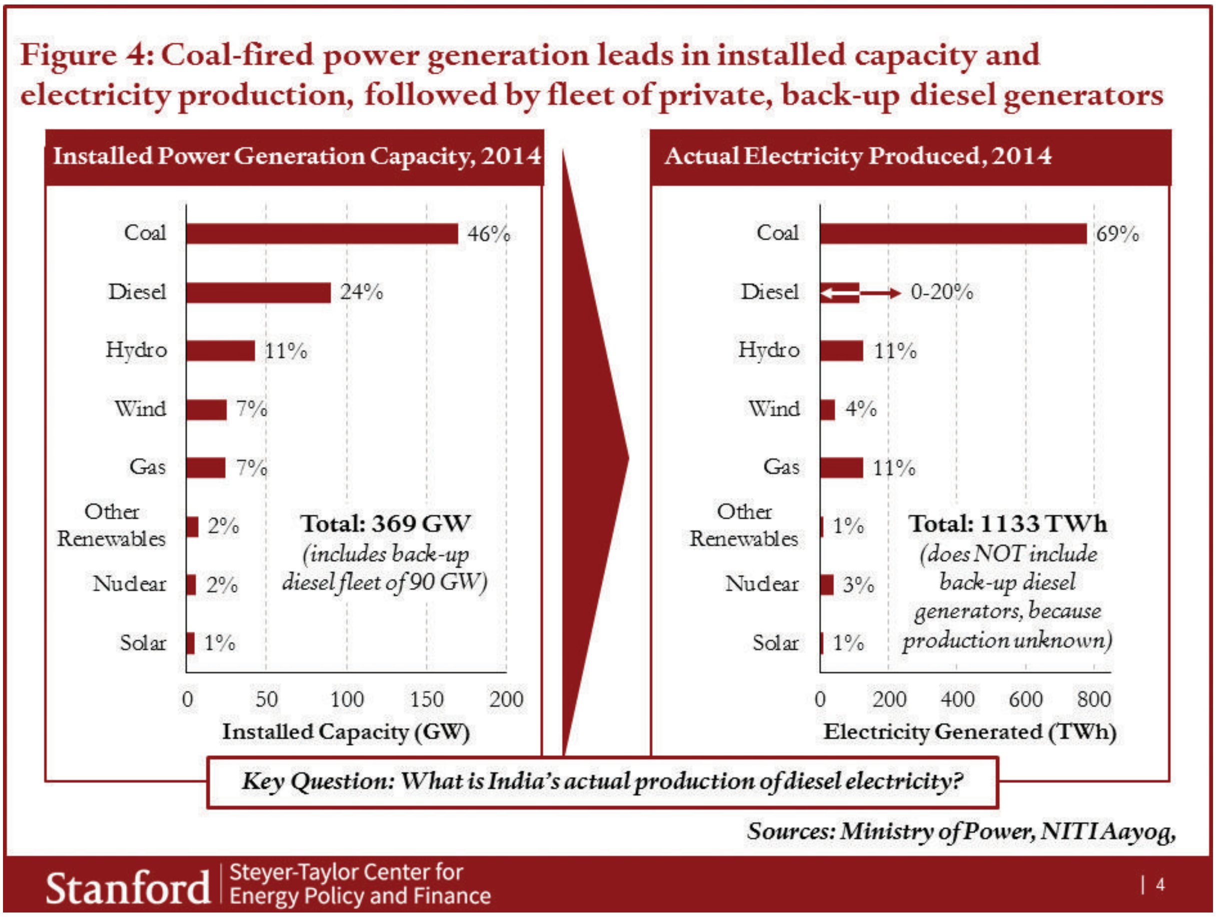


Figure 4: Coal-fired power generation leads in installed capacity and electricity production, followed by fleet of private, back-up diesel generators

This irony—that even with potentially unprecedented advances in renewable energy deployment, coal power will continue to dominate the Indian electricity mix—is the crucial insight for assessing solar's central role in India's climate policy

As the largest source of India's emissions, the future of coal will largely determine India's emission trajectory

Solar power's largest climate impact could actually come from discouraging construction of new coal plants, particularly those not equipped with carbon capture and storage technology. The threat of solar's rise is already giving investors second thoughts about the long-term profitability of new coal-fired power plants.[50,51] And if solar deployment accelerates according to plan, and prices continue to drop, the investment case for new coal could further deteriorate. Furthermore, if large-scale electricity storage becomes an economic reality, then solar's intermittency challenge relative to coal could be somewhat mitigated.

All of this comes on top of other obstacles that proposed coal power plant projects, as well as the Modi administration's plans to increase domestic coal production, already face. At present, many rail lines to carry coal to prospective coal plant sites have not yet been built. Additionally, existing coal plants are suffering financially because embattled utilities are not purchasing as much power as the plants can generate. This helps explain why coal plants are now running at 60–70 percent "utilization", i.e., they remain idle about a third of the time.[52]

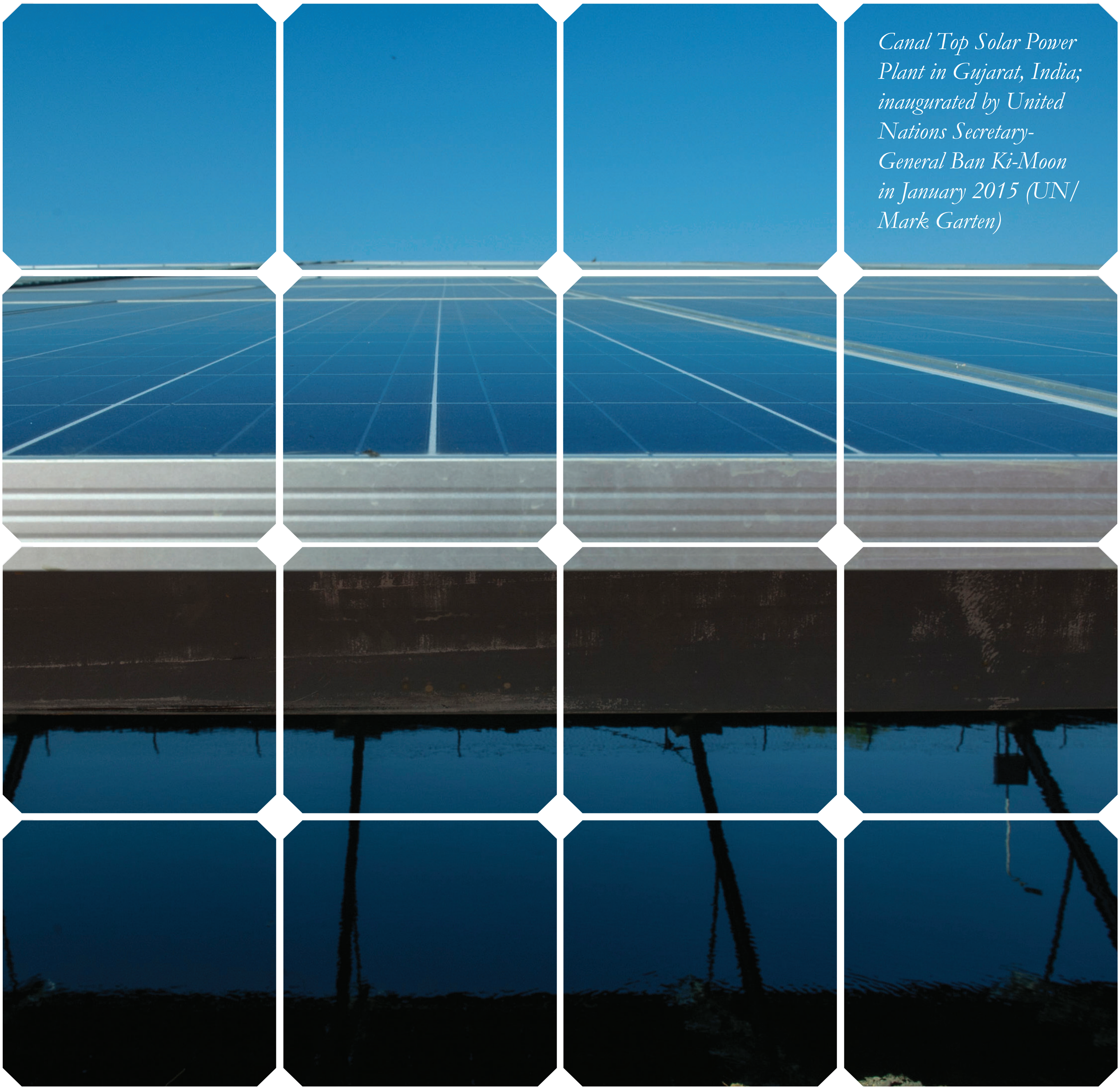
Despite its emission trajectory, India is heading into the Paris summit more willing to act on climate than at any point in its history. Its commitment to solar and renewable energy broadly is commendable and could earn India a leading role in determining the outcome of the summit. The ideal outcome in Paris will be a constructive accord that holds countries to their commitments but also facilitates significant capital flows—public and private—from wealthier nations and major investors to help developing countries like India accomplish their climate ambitions.

Despite its emission trajectory, India is heading into the Paris summit more willing to act on climate than at any point in its history

Its commitment to solar and renewable energy broadly is commendable and could earn India a leading role in determining the outcome of the summit

2.2 Solar Deployment Progress to Date and Lessons Learned

Meeting Prime Minister Modi's 100GW solar target would be a tall order in any country, but it is particularly difficult in India, given stalled infrastructure projects, insolvent utilities, and political obstacles to decisive reforms. Nevertheless, India has made surprisingly good progress to date on ramping up utility-scale solar. The installed cost of completed Indian solar projects has plunged, and developers in some regions have recently made bids to construct new projects that would be among the cheapest in the world. While not all bids turn into reality, India has learned from its recent experience, positioning policymakers to enact critical reforms as India ramps up solar.



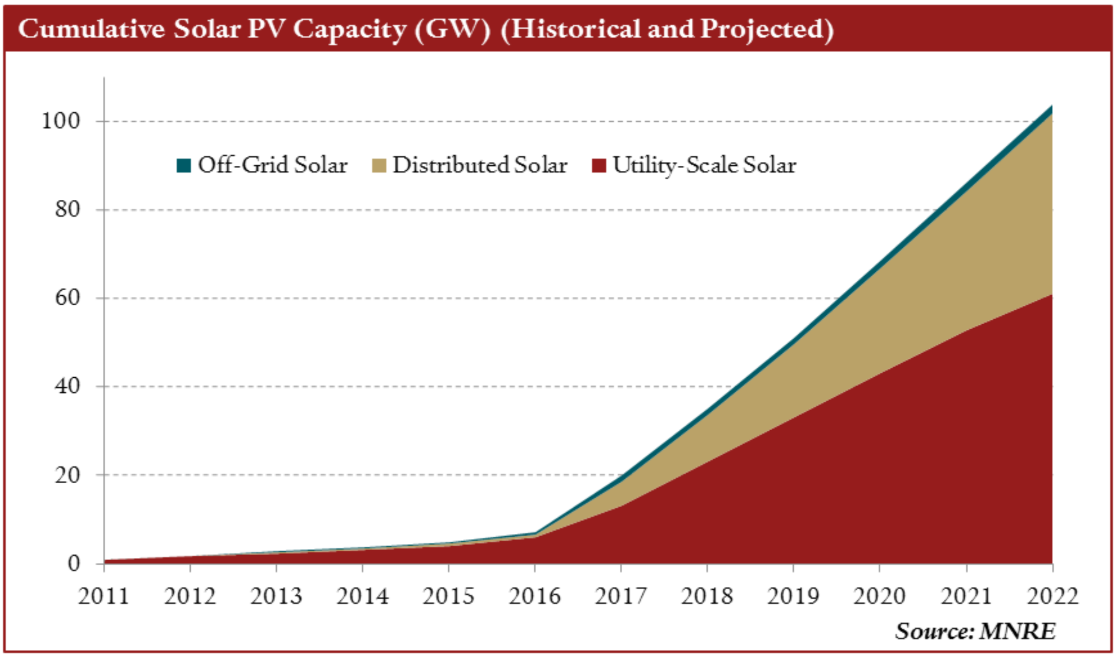
Canal Top Solar Power Plant in Gujarat, India; inaugurated by United Nations Secretary-General Ban Ki-Moon in January 2015 (UN/ Mark Garten)

Over the last five years, India has made considerable progress in deploying utility-scale solar. In 2010, the previous Indian federal administration took a big step toward large-scale solar deployment in India with the Jawaharlal Nehru National Solar Mission (JNNSM).[54] Originally, this program set a target of 20GW of federally installed solar by 2022, and it divided progress toward that goal into three phases.[55] In the first phase, from 2010–2013, the federal government deployed 500 MW of projects, largely through national-level procurement of utility-scale solar. When Prime Minister Modi came to power in 2014, his administration revised the JNNSM targets upward. Under the revised schedule, India is now in phase two of the JNNSM, with a target of 14 GW by 2017. By 2022, JNNSM phase three is intended to culminate in 100 GW of installed solar capacity that is tied to the grid (Figure 5).[56] Importantly, in both phases two and three, the revised JNNSM envisions a much larger role for state governments in deploying solar.

Under the JNNSM, the federal government has used a range of incentives to encourage adoption of solar power. For projects procured centrally, the federal government offers a 25-year power purchase agreement (PPA) that eliminates the risk of electricity market price volatility to solar owners. The government also provides preferential tax treatment for solar assets, allowing owners to accelerate the depreciation schedule to more rapidly realize tax benefits. These JNNSM policies build on the federal government's prior directive that each state enact a renewable portfolio obligation (RPO) that sets out the percentage of its power that should come from solar energy, with the ability to trade renewable energy certificates (RECs) for excess power to other states.

The progress from 2010, when installed solar capacity in India was a mere 18 MW, to 2015, when installed capacity is around 4.5 GW (as of August 2015) and growing, has demonstrated the viability of India as a major solar market.[57] As India's installed solar capacity has grown, the cost of solar has plummeted, falling on average by 10 percent each year over the past five years, from approximately 30 cents per kWh in 2010 to roughly 11 cents per kWh for projects that were bid in 2014 and are now operating.[58] In 2015, developers of utility-scale solar have placed bids as low as 8 cents per kWh, below the global average solar cost in 2014 of 10 cents per kWh.[59,60,61] Some of this improvement in cost has come from the plummeting cost of solar panels, largely manufactured in China. However, on top of cheaper panels, the "balance of systems" cost of solar, which encompasses the permitting, land acquisition, installation, and financing of a solar project, has also declined sharply in India as solar players gain project development experience.[62]

Figure 5: The Modi administration has set an overall target of 100 GW for solar deployment by 2022, composed of three types of solar



The past five years have also enabled India to discover, via trial and error, which policies do and do not work. Initially the JNNSM specified strict "domestic content" requirements, prohibiting imports of crystalline silicon solar panels (the dominant variety in the solar market and predominantly manufactured by Chinese producers) in a bid to encourage domestic manufacturing. However, instead of catalyzing domestic manufacturing of crystalline silicon solar panels, this policy mostly enabled U.S. firms that use alternative "thin-film" solar materials to corner the Indian market.[63] Recently, the federal government reduced the domestic content restrictions, allowing imports of all types of solar panels except for a small carve-out of 12.5 percent reserved for domestically produced panels.[64] This effectively removed a major barrier to rapid deployment of solar, since an integral element of the falling cost of solar has been the availability of cheaper foreign panels.

Another useful lesson learned from India's solar experience to date is the difference between commitments made and solar actually deployed. Early on, some state programs experienced low conversion rates from an initial memorandum of understanding between a solar developer and the state to a completed project.[65] Developers would often provide winning bids for reverse auctions but fail to secure financing to move forward with their projects. For example, in 2011, the state of Karnataka had to cancel 18 projects totaling 120 MW owing to lack of financing.[66]

In many cases, state inexperience with running effective auction schemes has contributed to these problems.[67] Some have alleged that state programs have fallen victim to graft, corruption, and money laundering schemes.[68] Given the steep ramp-up of solar deployment targets, in which state procurement will have to account for the majority of installed capacity, closing the gap between initial commitments to solar projects and actual deployment is essential. Some states have begun to reform their procurement processes accordingly. For example, Karnataka has recently adopted a straightforward reverse auction system which awards a predetermined amount of capacity to the lowest-bidding developers, who can then sign PPAs at the rate that they bid. This has improved the rate of project completion compared with less successful schemes that neighboring states have tried, which force any bidder to accept the tariff of the lowest bidder in the auction in order to conclude a PPA with the state.[69]

Closing the gap between initial commitments to solar projects and actual deployment is essential

By contrast, federal solar procurement has been reasonably effective in translating commitments into installed capacity in a cost-effective manner.[70] This is because federal procurement is centrally administered by credit-worthy national power companies—the National Thermal Power Corporation (NTPC), its subsidiary Vidyut Vyapar Nigam Limited (NVVN), and the Solar Energy Corporation of India (SECI)—that enforce stricter timelines for project completion and penalize reneging developers, attracting more credible bids.[71]

2.3 Four Building Blocks for Solar to Succeed in India

Although recent progress is promising, solar remains a marginal contributor to India's electricity mix, and utility-scale solar has dominated deployment to date. The ramp-up necessary to meet the Modi administration's 100 GW target will require a well-coordinated effort to deploy solar as a mainstream power source. To meet the target and make progress on deploying all three segments of solar, Indian policymakers, with help from governments and institutions around the world, should pursue four key building blocks of a winning solar strategy.

Tangled wires that are part of an Indian distribution grid (Source: Flickr)

Deploying all three segments of solar at a scale matching the Modi administration's ambition is a tall order. Fortunately, Indian policymakers at both the federal and state levels are poised to act in an unprecedented fashion. First, a confluence of new revenue sources over the past year has left the Indian government with a fiscal windfall that can do much to advance the massive solar target. This includes $2 billion in savings from new taxes on coal, over $5 billion from the Modi administration's reform of diesel subsidies, and over $60 billion from successful coal and telecom spectrum auctions.[72,73,74] Second, Prime Minister Modi has demonstrated early success in attracting the attention of international investors—who have made promising but still largely unfulfilled financial pledges—and launching partnerships with countries like the United States and institutions like the World Bank to enable massive solar deployment.[75]

A confluence of new revenue sources over the past year has left the Indian government with a fiscal windfall

With all this momentum and fiscal headroom, now is the time for India to deliver on its solar ambition. The task ahead—to ramp solar to over 100 GW in seven years and achieve a diverse mix of the three different solar segments—is substantially different from the progress it has already achieved over the last five years, ramping from virtually zero to nearly 5 GW of largely utility-scale solar. Indian federal and state governments, supported by international actors, should embark on a wide-ranging solar strategy to tackle this new task. The four building blocks that compose such a strategy are introduced below, particularly in the context of the barriers that must be surmounted for solar to succeed. Later, in Chapter 3, these building blocks are applied to each of the three solar segments to derive specific recommendations.

Building Block 1: Reform the utility sector

The effectiveness of solar at scale is limited by the health of the Indian power grid and the utilities that run it. Today, in many states, utilities operate a grid beset with many problems that discourage solar investment.[76] There are near-term solutions to help all three segments of solar surmount some of the obstacles posed by an embattled state utility sector. Over the long run, India will need to pursue a transformation of its utility sector to increase renewable generation while also keeping power affordable and reliable. Further research and international assistance is needed to guide such a transformation.

For over a decade, utility reform has been a policy priority in India. Under the 2003 Electricity Act, the federal government attempted to liberalize the power sector through "unbundling"—splitting up electricity generation, transmission, and distribution functions into different entities—and weakening the political influence of the state over utility operations.[77] State utilities exist in various stages of unbundling—some states retain bundled utilities, or vertically integrated State Electricity Boards (SEBs), whereas other states have replaced SEBs by creating separate distribution companies (Discoms) that are formally distinct from power generation and transmission companies and in theory operate at arm's length from the state.[78,79]

In many Indian states, however, electricity sector liberalization has not delivered the expected improvements in independent and efficient operations, regardless of whether unbundling has happened or not on paper. Often, Discoms operate poorly managed and maintained power delivery infrastructure.[80] As a result, the average Indian utility loses 26 percent of its electricity to "Aggregate Technical and Commercial" (AT&C) losses, which include power theft.[81] These kinds of losses are negligible in the developed world.[82] Moreover, in some cases, political involvement in the nominally independent Discom regulatory process has preserved heavily subsidized rates for some customers, for example in the agricultural and residential sectors.[83] In 2014, after roughly three quarters of generated power actually made it to customers, heavily subsidized rates resulted in aggregate state utility losses of over $45 billion.[84] These ongoing losses can trap Discoms in a vicious cycle of financing operational losses by issuing debt and then suffering under the burden of servicing their ballooning debt, which now exceeds $65 billion in total.

This is not to say that all state utilities are facing these challenges. .Five states—including Prime Minister Modi's home state Gujarat— have recently recorded net profits for their utility sectors. However, the troubles faced by the majority of the state utilities present serious counterparty risks for prospective investors, especially international ones.

Further complicating matters, many utilities need to construct new transmission lines to interconnect remotely sited solar installations. And if solar does achieve substantial penetration on the electricity grid, state utilities will have to contend with the challenges of intermittent solar (and wind) production which aging grid infrastructure could worsen.[88] Because India lacks a robust market for "ancillary services"—resources that help maintain the quality of power on the grid—and there are few quick-ramping "peaker" natural gas power plants that can buffer the variability of wind and solar, increasing the amount of renewable energy on the grid could increase existing power quality and reliability challenges.[89]

The effectiveness of solar at scale is limited by the health of the Indian power grid and the utilities that run it

Building Block 2: Harmonize federal and state policies

The structure of Indian federalism enables flexibility in sharing responsibility between the federal and state governments. Under the Indian Constitution, federal and state governments share "concurrent" jurisdiction over several spheres of policy. The fulfillment of the Modi administration's solar targets are an example of such shared responsibility.[90] For example, in the first phase of the JNNSM, the government focused on federal procurement of solar. As such, not much policy coordination was necessary between the federal and state governments. However, to ramp up solar, India will now need to implement an efficient division of labor between the federal government, which sets overall targets, and state governments, that implement the targets and oversee most of the deployment of the targeted capacity. Therefore, it is essential that federal and state governments coordinate their policies to ramp up all three types of solar.[91]

A prominent example of the federal/state policy model breaking down is the ineffectiveness of the linked Renewable Portfolio Obligation (RPO) and Renewable Energy Credit (REC) programs.[92] Under the 2003 Electricity Act, the federal government delegated to state governments the authority to set an RPO target for the percentage of power to be sourced from renewable generators and, in particular, for solar power. States set different targets based on the financial health of their utilities and the technical potential for renewable energy within their borders. For example, Rajasthan has plentiful sunlight but inadequate transmission infrastructure to export solar power to other states.[93] To increase the ambition of states and leverage the untapped renewable resources in some states, the federal government created the REC program in 2011 to enable states to trade renewable energy credits and achieve RPO compliance.[94] In the case of Rajasthan, the arrival of the REC market led the state to increase its RPO target from 7.5 to 9.5 percent, anticipating compensation from the sale of RECs to other states.[95]

However, to date this trading program has not been very successful as a result of both state and federal implementation problems. State governments have failed to enforce RPOs that would create demand for tradable credits. And although some states like Rajasthan increased their RPOs in anticipation of the REC market, other states have lowered RPOs. For example, Madhya Pradesh's RPO fell from 11 percent to 0.8 percent in 2010.[96] Finally, the federal government's design of the marketplace, including choices of the floor price of credits and the length of time that credits can be banked, is often ill-suited to support a REC price high enough to stimulate substantial investment in renewable energy and credit trading across state borders.[97]

The federal-state coordination challenge exemplified by the RPO/REC issue extends to a broader constellation of problems. These include limited standardization of state-level solar auctions, uneven land and permitting policies, and inconsistent compensation for distributed solar.[98,99,100]

Building Block 3: Secure substantial and cost-effective financing

Looking ahead, India will have to close the gap between initial development commitments and deployed capital to rapidly ramp up installed solar capacity at utility scale. And the distributed and off-grid solar segments start from an even less mature stage. To ensure that sufficient financing, on attractive terms, exists to meet the Modi administration's target, India will have to improve the viability of domestic financing and also mitigate risks confronting foreign investors. Federal financial incentives, innovative state and local schemes, and the support of the international community—both public and private—can all improve the financial viability of solar in all three segments in India.

India expects over $160 billion of investment inflows from international developers and banks to finance renewable energy over the next five years.[101] Japan's Softbank, for example, announced a joint venture with Taiwan's Foxconn and India's Bharti Enterprises to invest $20 billion in 20GW worth of solar capacity. U.S. solar developer SunEdison committed in early 2015 to a $4 billion venture with India's Adani Power to manufacture and deploy solar panels in India (recent press reports, however, suggest that the deal may be unraveling).[102,103,104]

To ensure that sufficient financing, on attractive terms, exists to meet the Modi administration's target, India will have to improve the viability of domestic financing and also mitigate risks confronting foreign investors

These and other commitments are for the most part not yet reality, and expectations of foreign investment must not lead to complacency at home. India suffers from a dearth of domestic debt capital available to finance infrastructure, and so long as India's banking sector remains largely unable and unwilling to support solar deployment, foreign investors will hesitate before locking their capital in a country whose own banks do not participate.[105] Domestic debt in India is primarily provided by banks, due to shallow bond markets.[106] But the domestic banking sector's woes are profound. Bank balance sheets are weighed down by an estimated $100 billion in loans to just ten large power and infrastructure firms.[107] Indian infrastructure projects are plagued by low completion rates and significant delays, preventing many project developers from repaying their loans. This fuels a vicious cycle of debt extensions and repayment schedule slippage. Indeed, in 2015 alone, aggregate debt in the power sector grew by 10 percent.[108]

Further compounding the problem is that the cost of domestic debt capital is high. Banks like the State Bank of India offer debt at interest rates between 11 and 13 percent, roughly double the cost of project debt in the United States or Europe.[109,110] These rates largely result from macroeconomic issues, such as high inflation and high government borrowing. And as a result of these challenges, typical debt tenors are relatively short (around 10 years), and debt tends to have a variable interest rate rather than a fixed one, increasing risk to the borrower. The higher cost of capital erodes the natural advantage that solar should have in India, adding about 30 percent to the price tag of a solar installation. Absent this burden of higher-cost debt, solar in India could be far cheaper than in the United States or Europe (at present solar is still cheaper in India, but only by a small margin) because of India's comparatively plentiful sunlight and low labor and installation costs.[111]

For this reason, Indian policymakers correctly recognize that foreign capital, which often comes with more attractive financing terms, is crucial to supplement inadequate domestic capital. But what has worked in the past may not work at the scale of solar deployment that India is targeting for the near future. Whereas in the past U.S. export and development finance institutions have supported hundreds of millions of dollars in project finance for U.S. firms to deploy solar in India, the $100 *billion* or more in future capital called for by the Modi administration to meet India's 2022 target far exceeds the investment capacity of development banks.[112] Despite existing pledges of $1 billion each from the German development bank KfW, the Asian Development Bank, and the U.S. Export-Import Bank (which has since shut down pending Congressional reauthorization), the vast majority of the capital for Indian solar deployment will have to come from private investors.[113]

Foreign investors, however, are wary of investing in India due to substantial off-take and currency

Foreign investors, however, are wary of investing in India due to substantial off-take and currency risk in financing Indian infrastructure

risk in financing Indian infrastructure. The off-take risk refers to the risk that a utility, which has contracted to purchase power from a solar developer, fails to honor that contract and pay for the generated power. The currency risk is associated with changes in the exchange rate between the rupee, in which PPAs are denominated, and the international investor's home currency. Hedging this risk can be expensive—typically adding over seven percentage points to the cost of capital—and can make the hedged foreign debt as expensive as domestic debt.[114]

Building Block 4: Foster diffusion of technology and standards from abroad

Finally, as India ramps up solar, it may want to examine its reliance on foreign technology and modest domestic technical know-how in the solar area to adapt and deploy these technologies in the Indian context. Governments and institutions around the world are well placed to undertake collaborations with India to ensure access to foreign products, modify technologies for use in the Indian climate, and train a workforce capable of deploying reliable installations.

India lacks enterprises developing advanced batteries to store excess energy from grid-connected or off-grid solar, and power electronics to strengthen the grid's ability to integrate renewable energy.[115] Moreover, although some Indian state utilities have made progress in deploying remote control and monitoring systems that provide real-time information about the health of the grid, further technology can enable a smarter grid. For example, developed countries like the United States are deploying more powerful software and monitoring devices like "synchrophasors" that provide detailed measurements to more effectively manage the unpredictability of high penetrations of solar on the grid.[116] In the medium and long-term, such technologies could especially help India ramp up solar.

> **Respect for IPR actually encourages the diffusion of low-carbon technology from developed countries**

India also needs to develop technical standards to deploy solar safely and reliably, and leverage robust standards used by early solar adopter countries like Germany and the United States. Especially for distributed solar, India needs to promulgate standards for the specification, installation, maintenance, and interconnection of grid-tied systems to ensure that the systems are safe, reliable, and high-quality.[117] Although some aspects of the standards need to be customized to the Indian context—for example, to account for frequent usage of distributed systems for back-up power when the power grid goes down—India can make substantial progress in standards development by collaborating with international standards bodies that have already grappled with these technical challenges.[118]

A potential roadblock to technology diffusion is the tension between the Indian government's aspiration for affordable technology access and potential costs arising from intellectual property rights (IPR) held by foreign companies. India's climate INDC for the Paris talks emphasizes "technology transfer" as a condition of its climate commitments. Specifically, discussing clean technologies, the Modi administration advocates "enabling their transfer, free of Intellectual Property Rights (IPR) costs, to developing countries."[119]

The appeal in India's INDC to transfer clean energy technology free of IPR costs echoes India's position on making pharmaceuticals widely available to its population, which has led to trade disagreements with the United States.[120] However, India's recent experiences with clean energy technology IPR have been largely positive and lay the groundwork for a collaborative licensing model for technology diffusion. For example, to encourage adoption of energy-efficient lighting, the Indian government has pursued bulk procurement programs for LEDs. In doing so, the government has been able to encourage international LED manufacturers like Philips to pursue joint ventures with Indian companies and license patents for their technology for indigenous production of products that are suited for operation in the Indian context.[121] Indeed, recent analysis demonstrates that respect for IPR actually encourages the diffusion of low-carbon technology from developed countries via credible commercial ventures, often to manufacture

> **If India can demonstrate that it is a safe investment destination for companies that value intellectual property and an eager partner in technical collaboration, the country can accelerate incoming technology diffusion**

technology locally. This diffusion can also lead to flourishing domestic innovation in a virtuous feedback cycle.[122]

Around the world, countries, multilateral institutions, technical bodies, and companies have developed solutions to accommodate large amounts of solar on the electricity grid, standardize the configuration of distributed solar assets, deploy self-sufficient microgrids, and develop new storage technologies. If India can demonstrate that it is a safe investment destination for companies that value intellectual property and an eager partner in technical collaboration, the country can accelerate incoming technology diffusion.

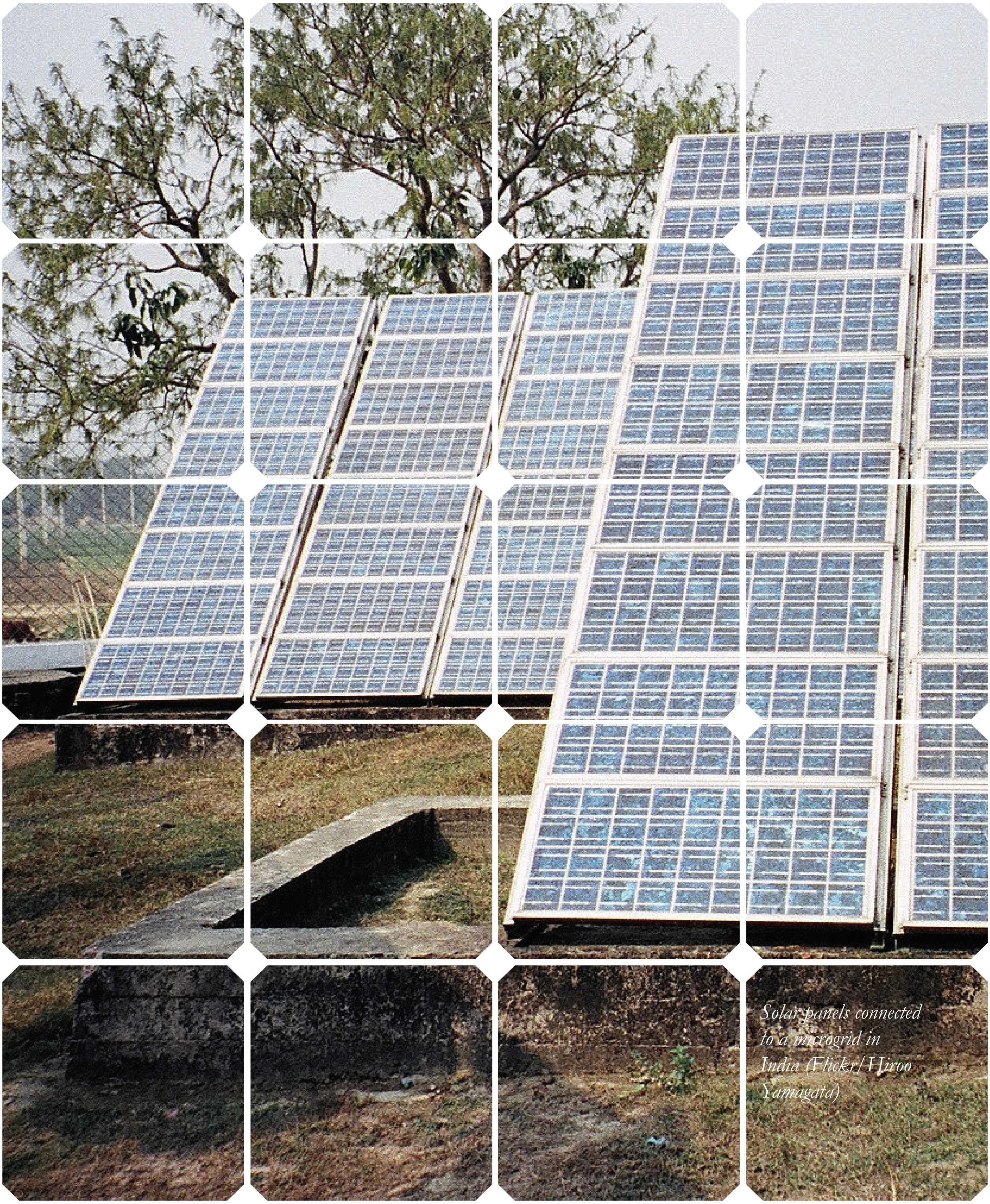
The Paris summit presents an ideal opportunity for national governments, international institutions, and civil society actors to offer their support to India

The Paris summit presents an ideal opportunity for national governments, international institutions, and civil society actors to offer their support to India as it begins to pursue ambitious renewable energy targets and execute against the four building blocks we describe above. Achieving even a substantial fraction of India's solar goal will be a daunting challenge, but the planet's third largest carbon emitter should not have to tackle it alone. If Indian negotiators in Paris encounter international support to achieve the nation's commitments rather than criticism of its climate plan, India is much more likely to make progress on renewable energy and engage constructively in future international climate discussions.

Achieving even a substantial fraction of India's solar goal will be a daunting challenge, but the planet's third largest carbon emitter should not have to tackle it alone

3

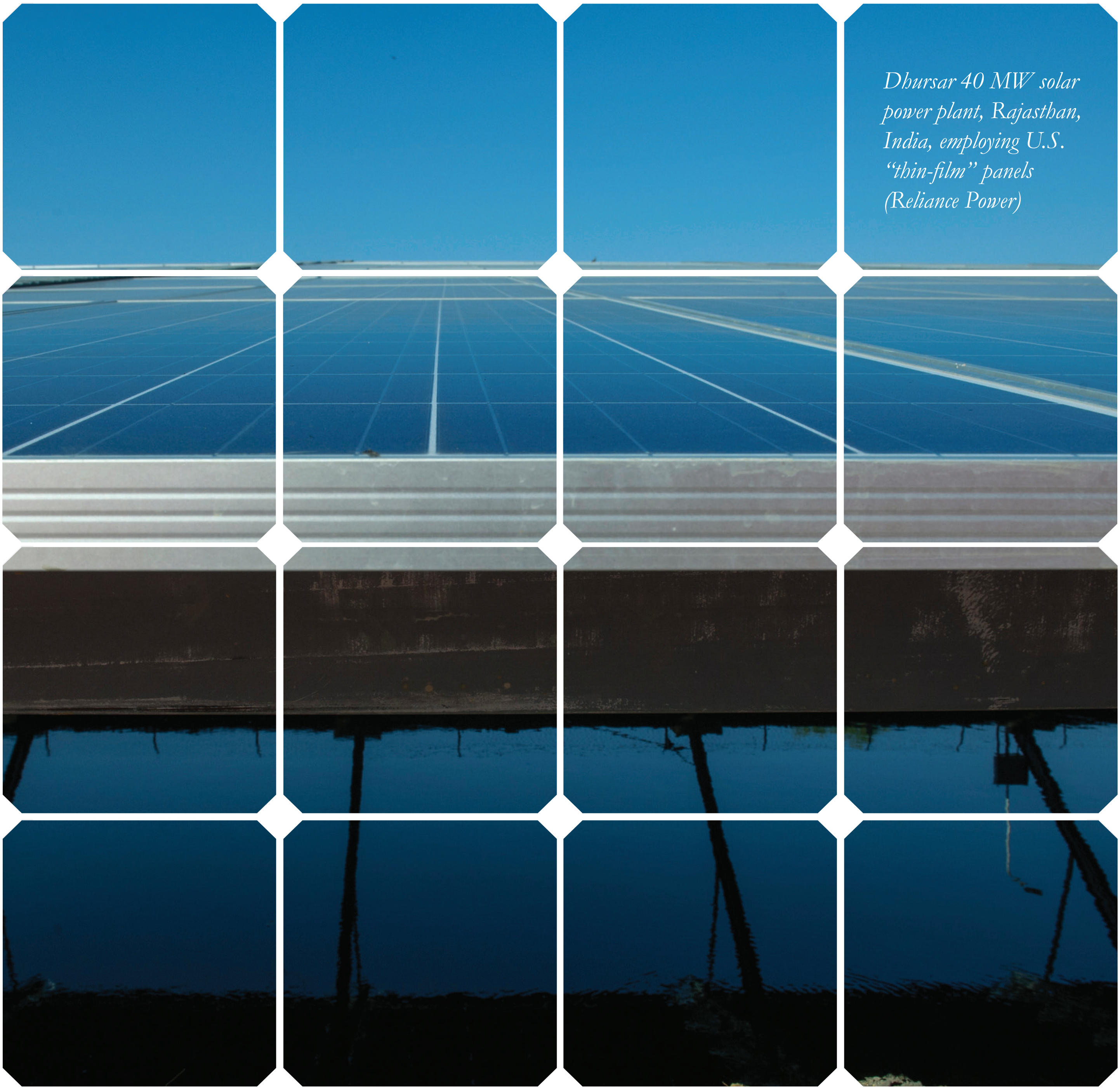
The Path Forward: Achieving Success in Three Segments of Solar



Solar panels connected to a microgrid in India (Flickr/Hiroo Yamagata)

3.1 Utility-Scale Solar

Utility-scale solar is the largest piece of the Modi administration's solar target, accounting for 60 GW of the 100 GW target for grid-tied solar, and it already composes the vast proportion of installed solar capacity.[123] Thanks to economies of scale, utility-scale solar is the cheapest of the three segments of solar and holds the greatest potential to compete in bulk with coal-fired power plants, the biggest source of India's emissions. Indeed, if India's federal and state policies can quickly accelerate the ramp-up utility-scale deployment, it may reduce construction of new coal-fired power plants without carbon capture and storage technology that would lock in decades of rising emissions.



Dhursar 40 MW solar power plant, Rajasthan, India, employing U.S. "thin-film" panels (Reliance Power)

In many cases, the cost of utility-scale solar power is already below that of electricity generated from *imported* coal, the marginal power source that solar is likely to replace first. Moreover, projections vary, but some contend that utility-scale solar power could become cheaper than power from domestic coal in the next five years.[124,125] For those projections to come to fruition, India must continue to construct new utility-scale solar plants.

Some of the cost decreases will arrive exogenously thanks to global price declines of imported panels, but the costs associated with permitting, construction, land acquisition, and financing will only decline with strong domestic efforts and increasing scale of Indian deployment. Therefore, continuing to advance federal and state utility-scale deployment is important to improving solar's competitiveness with coal.

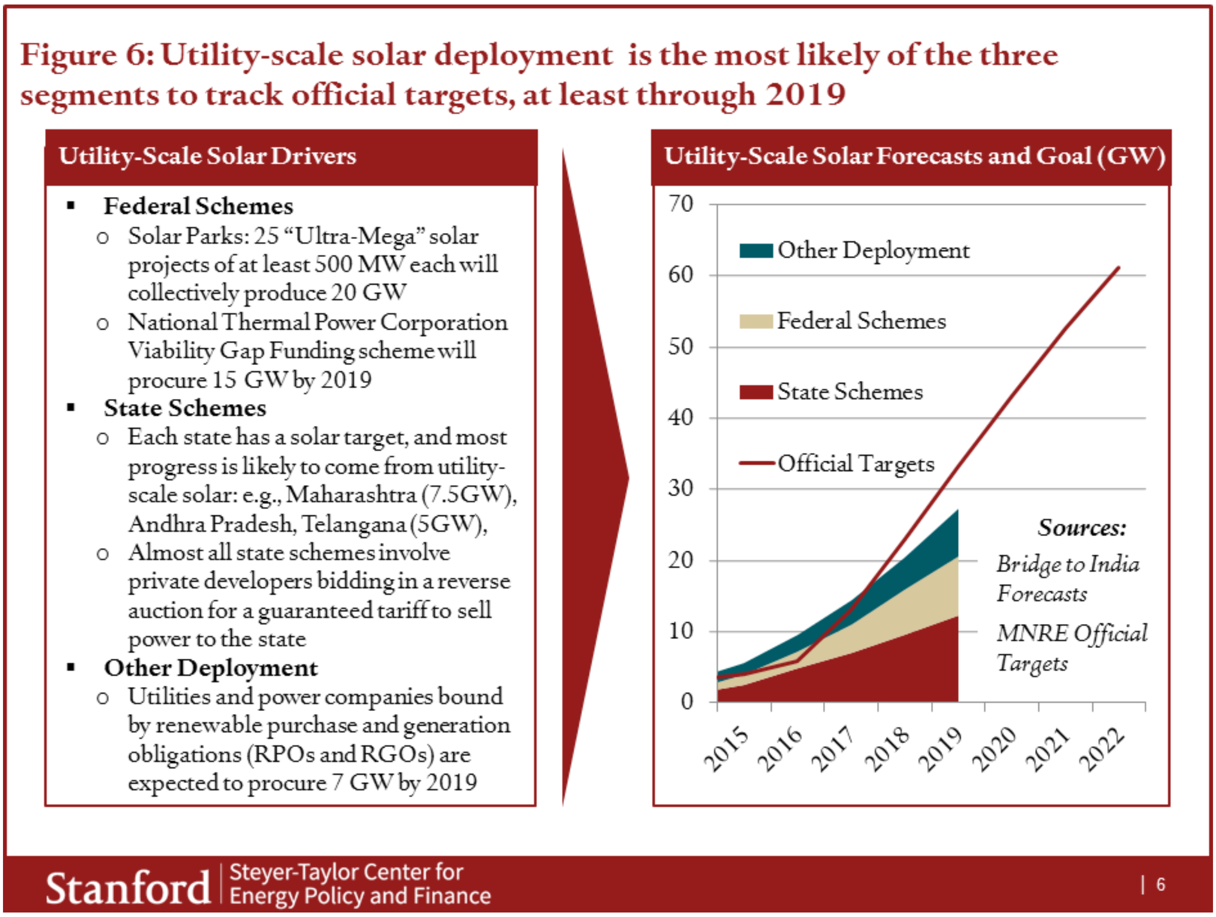


Figure 6: Utility-scale solar deployment is the most likely of the three segments to track official targets, at least through 2019

If utility-scale solar can remain on its current trajectory of cost declines, it will exert pressure on existing coal power plants and may slow construction of new ones, especially those without carbon capture and storage

If utility-scale solar can remain on its current trajectory of cost declines, it will exert pressure on existing coal power plants and may slow construction of new ones, especially those without carbon capture and storage. As the cost of solar declines, existing fossil fuel plants will face competition in power auctions, and developers with prospective plants in the pipeline may reevaluate their profitability. Aging plants may also shut down, unable to compete with solar in a race to reduce power tariffs, especially where solar intermittency issues can be cost-effectively addressed.

The prospect of utility-scale solar confronting India's largest source of emissions head-on will only develop if utility-scale solar can surmount serious challenges. As discussed in **Section 2.3** above, domestic financing for projects is scarce, and international investors are skittish about the various risks involved in investing in capital projects in India and selling power to utilities that may not be able to honor long-term contracts. Additionally, there are other challenges that only utility-scale solar faces by virtue of its size and remoteness.

First, developers of large-scale solar projects face challenges known as "completion risks." Among these, land acquisition will become increasingly difficult, hampered not only by existing regulatory challenges but also because prime territory near grid substations will no longer be available as more utility-solar is installed.[126] A 20 MW project in India that requires 100 acres may require a developer to consolidate land currently owned by tens of farmers, which can be costly and time-intensive.[127,128] A recent land acquisition bill proposed by the Modi administration would speed the process, but thorny politics have so far prevented its enactment.[129]

In addition to land acquisition, other project completion risks include permitting and interconnection uncertainties. Difficulties in obtaining regulatory permits and delays in transmission line construction to connect solar to the grid can lead to cost overruns for utility-scale solar projects and sometimes prevent their completion.[130] Indeed, although the cost of utility-scale solar at the point of generation has fallen rapidly, as more projects are built farther away from existing grid infrastructure the cost of transmission lines—currently estimated at nearly a quarter of a million dollars per MW—to connect solar to the grid could undermine its economic competitiveness with coal.[131] To head off this problem, the federal government, with financial pledges from the U.S. and German governments, has announced a $6 billion "Green Corridor" project to build transmission capacity from states rich in solar potential—like Madhya Pradesh and Rajasthan—to major consumption centers, like Delhi and Maharashtra.[132]

Second, the disparity between federal and state efficacy at commissioning utility-scale solar threatens to limit solar deployment. The federal government has flirted with increasing the renewable purchase obligations of states to a uniform 8 percent across the country, but analysts warn that if state regulatory boards do not enforce the regulations, then states could fall behind their targets.[133]

To surmount these obstacles to utility-scale solar, India will need to make progress on each of the four building blocks of a winning strategy for solar described above, via actions by both federal and state governments, with international actors providing much needed support:

1) Reform the utility sector

In the short-term, a solution to insulate utility-scale solar targets against the insolvency of the utilities could be a payment security mechanism (PSM) along the lines of one offered under Phase 1 of JNNSM.[134] This PSM, created as a standalone fund, would be provided to a federal procurement agency, such as the NVVN or the SECI, which would buy power from developers and sell to distribution companies. The main idea would be to cover the pooled credit risk of distribution companies by offering to pay generators in case of payment default by one (or more) of the distribution companies.[135]

Over the longer term, the Indian state utility sector must also undergo broad reform to enable renewable energy to achieve an even higher share of power generation and facilitate a transition to a low-carbon, affordable, reliable power system. The Indian federal government has previously tried to help reform state utilities but despite some incremental successes, these schemes have largely failed to achieve major change. To improve financial efficiencies, the recent Chaturvedi report outlined a plan to restructure the current utility debt burden with federal and state support.[136] However, while eight states, representing 80 percent of accumulated Discom debt, signed up for the program, so far none of them have met the prerequisites for securing federal debt relief, such as reducing subsidies and grid power losses.[137] Similarly, to improve operational efficiencies, the federal government launched the Accelerated Power Development and Reform Program (APDRP) scheme in 2002, but the scheme has yet to show results.[138] In light of these challenges, the Modi administration acknowledges the importance of reforming the power sector, and the Power Minister has described utility reform as a top priority.[139] Further research is needed to provide fresh recommendations to reform utilities.

2) Harmonize federal and state policies

This building block will require action by both the federal and state governments. At present, federal procurement of utility-scale solar is more efficient and effective than state programs, largely because of the diversity of state approaches. Whereas some policies benefit from customization to a state's particular context, best practices for utility-scale contracting should be reasonably consistent across state boundaries, because of the similarities among utility-scale projects.[140]

Some states, like Tamil Nadu, have begun to follow the federal government's lead in penalizing developers for incomplete projects and increasing the size of utility-scale projects to 10 MW or greater, deterring less credible developers from competing in auctions.[141] The remaining states will need to follow suit if they are to meet their targets, but fortunately both the federal government and states like Karnataka have already demonstrated an effective auction mechanism that reveals the most competitive prices and ensures project completion when the auction is well designed.[142]

The federal government can do its part to streamline state efforts to support utility-scale solar by facilitating uniform permitting and land acquisition policies across state boundaries and providing payment guarantees to offset regulatory risks. And national transmission system planning, if coordinated with state-level solar auctions, can ensure that winning project bids are only awarded for areas on track to receive access to the power grid.

Finally, fixing the problematic RPO/REC system, as introduced in **Section 2.3** above, is an exceptionally important priority. To achieve reform, the federal government and state governments need to first coordinate to strictly enforce RPO obligations and signal to markets that RECs are here to stay for the long-term. This will improve the bankability of RECs in private markets and increase the value of credits. The federal government can condition the financial incentives introduced below in the financing building block to incentivize states to enforce RPOs. Finally, voluntary credit set-asides are a design feature of REC markets elsewhere that support additional clean energy deployment by private entities. Such a scheme could succeed in India as well.[143] International experts with experience in renewable energy credit systems, like European countries or U.S. states, can offer technical assistance to India to fix the RPO and REC systems.[144]

3) Secure substantial and cost-effective financing

Thanks to the recent fiscal windfall from fuel subsidy reform, coal and telecom auctions, and new coal taxes, as described in **Section 2.3** above, the Indian federal government has some of the resources to provide financing support to unlock domestic capital as well as motivate international capital inflows. Currently, federal support for utility-scale solar projects includes two incentives. First, a project developer can receive "viability-gap funding," under which the federal government uses a reverse auction to award a capital grant of up to 30% of the project cost to a winning project.[145] Second, the owner of a solar project can apply an "accelerated depreciation" rate of 80% in the first year of operation to the project to increase near-term tax benefits.[146]

However, these existing policies are not the optimal way for the federal government to incentivize utility-scale solar deployment. A more cost-effective policy would be to directly provide reduced-cost, longer tenor debt for projects.[147] The federal government can leverage its creditworthiness to mobilize funds to provide loans to project developers at lower interest rates and for longer maturities than the domestic banking sector can offer. Over the long run, the government would recover much of its subsidy compared with existing policies—mobilizing low-cost debt could cost the government far less than disbursing capital subsidies or providing tax write-offs—lowering the total subsidy cost by up to 75 percent.[148]

However, directly providing low-cost long-term loans, due to their high capital outlay requirements in the short-term, may pose challenges given the government's competing fiscal priorities.[149] Therefore, they should be paired with a short-term financing strategy of subsidizing the interest rates of commercial loans, where the government would reduce the effective interest rate by paying part of the interest payments. For example, compared with viability-gap funding, a comparable interest subsidy would reduce the required subsidy outlay by more than 10 percent and would support 30 percent more solar deployment. Together, the federal government could leverage both strategies—providing interest subsidies in the short-term and low-cost, longer tenor debt in the long-term—to reduce its subsidy bill while accelerating solar deployment.[150]

Beyond directly providing or subsidizing loans, the government could adopt regulations that make it easier for both domestic and foreign investors to provide cheaper debt capital, and thus act as a facilitator as opposed to a provider. To mobilize attractive *domestic* capital, the federal government should encourage the development of partial credit guarantees (PCGs) for project bonds as well as infrastructure debt funds (IDFs).[151] PCGs are provided by a highly credit worthy guarantor to back the cash flows in case of default. IDFs, on the other hand, are pooled instruments that combine multiple cash flows. Both of these have the ability to improve credit ratings of underlying renewable projects, so as to attract domestic institutional investors and, in the process, improve the cost of debt by up to 3 percentage points and increase tenors by up to 5 years. To better enable the private banking sector to utilize such instruments, the federal government can modify existing regulations, for example to raise the 10 percent ceiling limiting any individual investor's contribution to fund a renewable energy bond offering.[152]

To mobilize *foreign* capital, the federal government can offer a foreign-exchange hedging facility that reduces currency risk from movements in the exchange rate between rupees and dollars (in addition to the Payment Security Mechanism, described above).[153] The government has already begun exploring such a policy, and by correctly designing a hedging facility, it can pass on the expected hedging costs as a fee to developers. Even with the fee, developers who once faced a 7 percentage point increase in the cost of capital from currency risk would now face a net 3.5 percentage point increase, reducing both the cost of the utility-scale solar project as well as the cost of government support.[154] International financial institutions with extensive experience designing currency hedges, like the International Finance Corporation, can provide technical assistance to accelerate India's development of a sound currency hedging facility to support inflows of international capital to solar projects.[155]

4) Foster diffusion of technology and standards from abroad

International actors can support utility-scale solar in India by focusing on this fourth building block. India needs to upgrade its electricity grid to transmit and host large amounts of intermittent solar energy. Developed countries can provide technical assistance to India to install advanced transmission infrastructure, like high-voltage direct-current (HVDC) lines that could compose the backbone of India's Green Corridors. Such HVDC lines are found across Europe, North America and China and are used to transmit current over very long distances for which normal alternating current (AC) transmission lines are less well suited because of high transmission losses. India is seeking to install similar lines to move surplus solar energy from sunny states like Rajasthan to electricity demand centers elsewhere in the country.[156]

Second, for solar (and other renewable) energy to become a significant contributor in terms of generation, key supporting technologies will be needed to buffer solar's intermittency. In the developed world, natural gas "peaker" power plants can quickly change their output to offset the variability of renewable generators, and equipment such as "capacitor banks" can help integrate power flows from large solar plants into the rest of the grid. In the Indian context, such equipment is less necessary in the near-term. However, as India prepares for a grid with a higher penetration of solar, it will need to invest in a power grid that can handle solar (and wind) variability. To help India prepare, developed countries with experience in integrating large-scale renewables can offer technical assistance to Indian electricity system planners to integrate storage and smart grid solutions, as discussed in **Section 2.3** above.

To mobilize foreign capital, the federal government can offer a foreign-exchange hedging facility that reduces currency risk from movements in the exchange rate between rupees and dollars

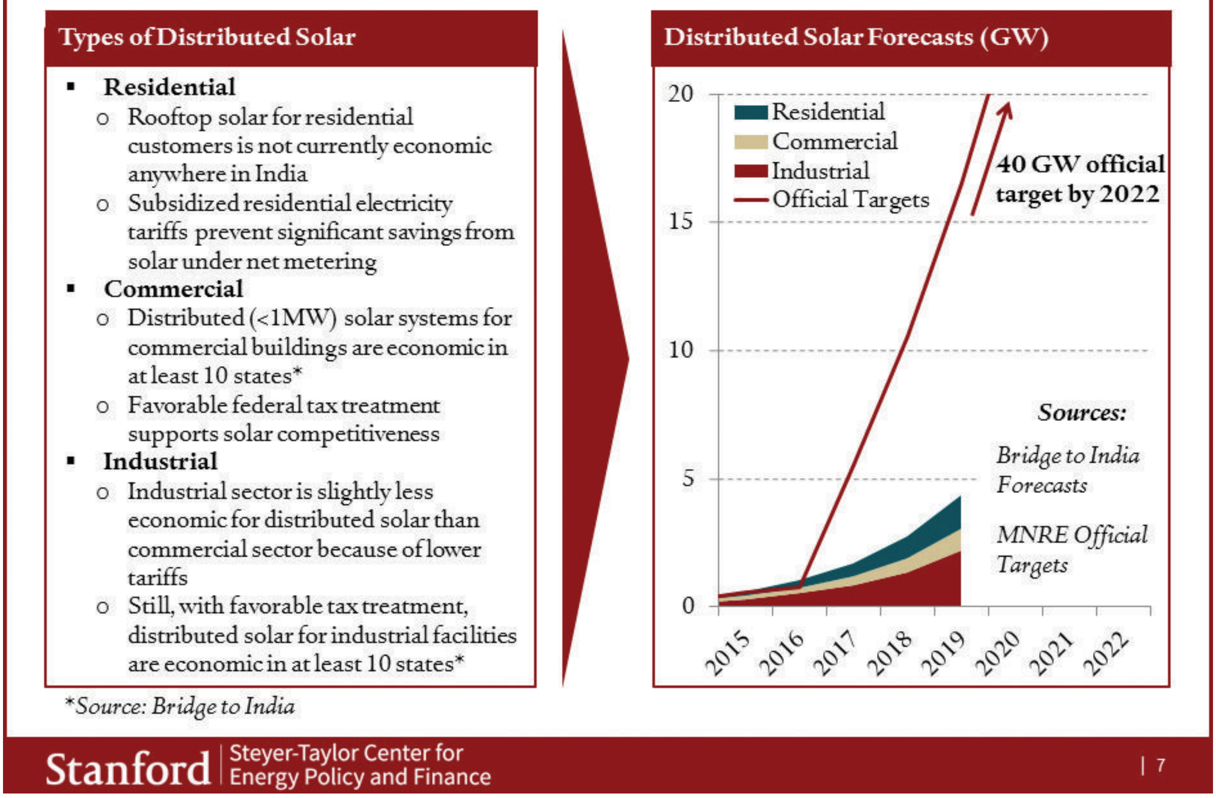
3.2 Distributed Solar

Whereas utility-scale solar has received the most attention from domestic policymakers and international investors, distributed solar must also succeed for India to fully capture the domestic benefits of solar. Decentralization brings trade-offs. By bypassing the problematic grid, distributed solar in India can improve access to and reliability of power. However, it is not amenable to massive economies of scale and central planning the same way utility-scale solar is. Still, the same four building blocks anchor the policy prescriptions for success in distributed solar.

5 kW solar rooftop project in Chennai (Consul Neowatt)

Distributed solar offers fewer direct climate benefits, compared with utility-scale solar, for two reasons. First, the government's 40 GW rooftop solar target by 2022 is extremely ambitious, requiring annualized growth of roughly 100 percent, so deployment of distributed solar is very likely to lag that of utility-scale solar in terms of bulk energy generation (**Figure 7**). Second, although distributed solar can help displace emissions from diesel, which powers small generators used for back-up power, distributed solar will continue to supplement, rather than fully replace, back-up fossil fuel generation until cost-effective energy storage is available.[157]

Figure 7: Distributed Solar Deployment is Projected to Dramatically Lag Official Targets



Still, widespread deployment of distributed solar could offer a badly needed alternative to problematic state grids. Viable markets are numerous—indeed, a recent model suggests that there is potential for 22 GW of rooftop solar by 2022 *if* policy support is ramped up.[158] Sensitive facilities for which reliable power is especially valuable, like hospitals, offices, data centers, and factories, would benefit from solar microgrids-self-contained electricity grids powered by solar and batteries that can supply power even when the central grid fails. Other customers, across residential, commercial, and industrial sectors, could benefit from just the solar panels without the microgrid to improve reliability during the daytime.

In fact, these are not new distributed generation markets. The Indian federal electricity regulator estimates that non-utility diesel generator capacity amounts to about one-third of the central power plant fleet's capacity (**Figure 4**). Many of these back-up systems are already equipped with the associated electrical equipment needed for solar to supplement diesel power.[159] On paper, the economics vastly favor solar over diesel. Diesel generators produce power that costs roughly $0.27 per kWh, more than double the cost of solar in many locations in India.[160] However, the difference is that solar's costs are frontloaded—that is, nearly all of the costs of solar are an initial capital outlay, followed by decades of zero fuel-cost operation. By contrast, diesel generators themselves are relatively cheap, but ongoing fuel costs are high. Because of the low domestic availability of capital, especially for residential consumers, to finance solar systems, distributed solar has yet to take off to a significant extent. But the opportunity clearly exists for consumers to realize substantial savings if offered a route to repackaging their existing expenditures on diesel to finance solar.[161]

Distributed solar offers other domestic co-benefits that could help sustain public support for aggressive renewable energy targets. Even though displacing diesel generators used for back-up power may have limited climate benefits, diesel generators are contributors to urban air pollution, which distributed solar could ameliorate.[162] Moreover, compared with utility-scale solar, distributed solar can support over double the number of short-term construction jobs and its long-term job creation potential is one third greater per MW of installed capacity.[163] As a highly visible manifestation of solar, compared with remote utility-scale installations, distributed solar can be much better at winning over public opinion to back further efforts in support of renewable energy, especially with tangible economic and environmental benefits.

Non-utility diesel generator capacity amounts to about one-third of the central power plant fleet's capacity

At present, distributed solar makes the most sense for industrial and commercial customers.[164] These customers, especially large industrial buildings, often have underutilized roof space available for solar, sidestepping the land problem facing utility-scale solar deployment. For example, in Delhi, 40 percent of industrial rooftops are sturdy enough to host solar versus only 20 percent of residential rooftops.[165] Additionally, these customers face electricity rates from the utility of $0.12–0.18 per kWh, higher than the "levelized cost" of solar power, a metric that spreads out the up-front capital cost of solar over several years of asset use to enable a per-kWh comparison with other sources of power.[166]

However, because of inconsistent public policy support for distributed solar, progress has been limited in most states. Of the 350 MW of distributed solar capacity installed so far (less than one-tenth the deployment of utility-scale solar), over 30 percent is concentrated in just three of India's twenty-nine states: Maharashtra, Tamil Nadu, and Gujarat. Federal capital subsidies have proven unsuccessful at stimulating distributed solar deployment across India, in part because of erratic delivery of subsidy payments. Moreover, not all states offer "net metering," under which customers can use self-generated solar power to offset purchases of energy from the grid and receive compensation for excess solar energy sold back to the grid. And some states that do offer net metering cap the penetration of solar that is allowed to interconnect to the grid and further restrict the number of solar systems eligible for compensation. Finally, across India, utilities offer subsidized electricity rates for residential and agricultural customers, reducing the savings that distributed solar can offer for those customer segments. As a result of these barriers, the Bridge to India consultancy projects that, absent policy changes, only 4 GW of rooftop solar will be installed between 2015 and 2019, compared with 24 GW of utility-scale solar.[167]

Technical challenges also obstruct progress in deploying distributed solar. For example, because of safety features built into foreign-made inverters, which serve as the interface between the solar panels and the grid, minor fluctuations in the quality of grid power can force the solar system to shut down.[168] As a result, when the grid goes offline, the solar system will not work as a backup power source, and often even a flicker in the quality of grid power will also trip off the solar system. Although such inverter behavior makes sense on safety grounds in developed countries, for which the inverters were designed and where blackouts are rare, in India these features erode the usefulness of distributed solar. India lacks inverters with customized operating standards that still ensure safety but also enable the equipment to continue operating despite poor grid power quality. Moreover, distribution utilities often have not installed adequate infrastructure to handle the bidirectional power flow that occurs when distributed solar provides excess power to the grid.[169] This lack of infrastructure can make it difficult to integrate substantial amounts of solar and maintain the reliability of Indian distribution grids.

The opportunity clearly exists for consumers to realize substantial savings if offered a route to repackaging their existing expenditures on diesel to finance solar

Finally, since the distributed solar industry is still nascent, financing and business challenges abound. Although federal capital subsidies offer support in theory, they have not been sufficiently funded or disbursed.[170] Commercial banks are hesitant to finance projects, especially for residential customers, resulting in a high cost of debt. Unlike in developed countries, where established distributed solar players offer third-party financing to help customers avoid up-front capital investments, the Indian distributed solar industry is new and fragmented, and third-party financing is rare.[171] However, recent policy developments are promising. For example, the federal government has announced a scheme to work with international development banks to offer reduced interest rate loans for distributed solar.[172]

Only 4 GW of rooftop solar will be installed between 2015 and 2019, compared with 24 GW of utility-scale solar

To enable distributed solar to succeed, Indian policymakers and the international community can collaborate in advancing the four building blocks of a winning Indian solar strategy.

1) Reform the utility sector

There are two important utility reforms that Indian states can undertake, with the help of the federal government. First, if states reduce subsidies on electricity rates, they will improve the fiscal health of utilities, which can collect payment more closely related to the cost of electricity service. And reducing subsidies will improve the economics of distributed solar under net metering, especially for residential customers, by increasing the rate at which distributed solar systems are compensated for delivering power to the grid. These subsidies are substantial and result in residential rates for grid power that, depending on the state, are between one third and two thirds of the levelized cost of solar, artificially making distributed solar uncompetitive.[173] Importantly, however, subsidies are a politically sensitive issue, so further research may be needed to suggest innovative mechanisms for subsidy reforms that address the energy needs of a developing country.

Second, if state regulators push utilities to invest in distribution grid infrastructure, utilities will be able to host more grid-connected distributed solar. The federal government has already demonstrated its willingness to fund such infrastructure, including a $4 billion smart meter initiative.[174] Further funding can be conditioned upon state utility reform to support distributed solar. This would weaken the justification for existing utility practices in many states that limit grid access and net metering compensation for rooftop solar.

2) Harmonize federal and state policies

For distributed solar to take off across India, policy support at both the federal and state levels is necessary. At present, policies are inconsistent on a state-by-state basis, and federal policies tend to ignore distributed solar instead of helping to level the uneven state playing field.

Net metering policies, which are determined at the state level, are crucial for the economics of distributed solar, because compensation for power exports to the grid can provide steady revenue to finance the installations. However, compensation schemes for distributed solar differ across state boundaries. Although 25 states have announced some form of net metering policy, each state differs on the eligibility criteria, penetration limit of distributed solar on the grid, allowed quantity of electricity exports, and most importantly, the level of the electricity tariff.[175]

Subsidies are a politically sensitive issue, so further research may be needed to suggest innovative mechanisms for subsidy reforms that address the energy needs of a developing country

This heterogeneity has contributed to vastly different rates of deployment of distributed solar across state lines. However, swinging to the other extreme—strict uniformity of solar compensation policies—is not the solution either. The prudent solution would be for all states in India to adopt basic guidelines for integrating distributed solar on the grid, enabling each state to tailor further ambition to its local context. The Forum of Regulators, an organization that combines federal and state regulators in India, is ideally poised to harmonize baseline solar compensation regulations and has already issued some guidance to standardize state policy.[176]

A nuanced approach to designing net metering policies is necessary to both support solar deployment and also to avoid imposing further financial strain on utilities. In the United States, net metering has come under fire from utilities, which contend that it poorly reflects the cost of service for solar customers who take advantage of net metering to underpay for grid services.[177] Applied to India, this argument might carry extra weight because utilities are already so cash-strapped that a further revenue blow via net metering might preclude badly needed grid investments. Therefore, Indian regulators, guided by coordinating bodies like the Forum of Regulators, need to carefully design compensation mechanisms that encourage distributed solar but do not cause utilities further financial distress, especially as many commercial and industrial Indian utility consumers consider switching to solar. In some parts of the United States, utility rates for commercial and industrial customers are tuned so that the utility is largely indifferent whether a customer chooses to generate power on-site or draw power from the grid. The United States can share this experience with rate design so that Indian regulators can accomplish the same goals.[178]

3) Secure substantial and cost-effective financing

Across developed countries, financing costs for distributed solar have fallen as the industry matures and gains experience. In India, similar cost reductions should occur with time as the presently nascent and fragmented industry consolidates and the business models evolve. However there are some policy interventions by the Indian federal and state governments that can accelerate this process.

First, federal policy reform can help accelerate third-party financing, which has advanced the deployment of distributed solar across much of the developed world. Existing tax incentives, like accelerated depreciation for solar systems, in many cases do not pass through to third party investors who might finance the high capital costs that put distributed solar out of reach for many consumers.[179] Rewriting federal tax incentives could enable companies to structure financing models that attract third-party tax equity investors, a model that has proven successful in the United States despite some challenges, including a limited number of tax equity investors.[180] Moreover, third party investors fear default risks if their property rights to solar systems leased to consumers are not clear.[181] Therefore, increasing the reach of federal tax incentives and enhancing federally enforced property protections could offer third party investors a more attractive route to finance and lease distributed solar systems.

Second, municipalities and state governments can issue bonds to provide lower-cost loans to customers to install distributed solar, leveraging experience from abroad. In developed economies, local governments have devised several innovative approaches to financing clean energy. For example, across the United States, states and municipalities are ramping up Property-Assessed Clean Energy (PACE) financing schemes, under which property owners, especially on the commercial side, can pay for renewable energy and energy efficiency via an assessment on their property tax bills. The additional tax assessment is secured by a senior lien on the property, which confers strong debt collateral. The property owner often does not have to make any down payment and immediately sees monthly savings from lower energy bills.[182,183,184]

Foreign and domestic nonprofit organizations can also improve the availability of attractive financing by increasing the quantity and availability of data. Accelerating deployment of solar around the world is helped by greater investor confidence in assets that are well understood. Increasing amounts of data are available quantifying the performance of solar installations over multiple years and sometime decades of operation. In India, more data is needed, especially for distributed and off-grid solar, to increase investor confidence and drive down the cost of capital. Nonprofit organizations supporting solar deployment in India can help state and federal governments set up robust databases to capture the performance data of solar systems within each segment. The availability of such data will be a key enabler of innovative financing approaches like issuing asset-backed securities, which are financial instruments comprising several renewable energy assets that can then be traded on financial markets, increasing the potential pool of investors and lowering the cost of capital. In developed countries like the United States, this strategy is increasingly popular in financing distributed solar.[185] But in a country like India, a proven track record of performance from carefully collected data is essential to enable investors to correctly value and invest in solar.[186]

4) Foster diffusion of technology and standards from abroad

International actors can offer assistance not just in improving the availability of financing, but also in sharing technical expertise on designing and deploying distributed solar systems. Local developers and installers have not coalesced around a standard system design, set of installation equipment, or interconnection standards. Solar installers often lack requisite training to ensure project quality. And there are no standard protocols for designing and installing microgrids to serve sensitive loads.[187]

Moreover, the industry needs guidance on how to customize distributed solar installations to the Indian context. For example, inverters need to be configured to continue operating even if the grid flickers, assuming an adequate safety margin can be maintained. Additionally, many inverters can actually be used to bolster the grid (e.g., reactive power support), adding further value to distributed solar, especially in the context of a struggling grid.[188]

International technical bodies, like the U.S. IEEE (Institute of Electrical and Electronics Engineers), should work with Indian standard-setting bodies to develop guidelines for interconnection, islanding operation (when a solar installation or microgrid supplies power even when the grid goes down), low-voltage ride-through (the ability to keep working during episodes of grid instability), and provision of voltage and frequency regulation support (which helps the grid deliver reliable and high-quality power).[189] International distributed solar developers and research laboratories (like the U.S. National Renewable Energy Laboratory) can help specify standard system designs for use across India. By supporting the adoption of technology and standards in India, international actors can help India ramp up its young but promising distributed solar sector.

3.3 Off-Grid Solar

The 3 GW target for off-grid solar contrasts with the multibillion dollar investment push for utility-scale solar, and the ambitious ramp-up that the Modi administration plans for distributed solar. But even though off-grid solar cannot compete with the other two segments of solar on a megawatt basis, achieving the Modi administration goal will reach tens of millions of homes and raise the profile of solar power by helping increase energy access for a substantial segment of India's population.

Electric lamps powered by a solar microgrid enable rural Orissa children to read at night (UK Department for International Development)

Off-grid solar refers to solar power systems that serve customers without a utility electricity grid connection. Broadly, there are two categories of off-grid solar. First, some vendors offer solar home systems (SHS), which generally include solar panels and a battery to power a limited number of appliances (e.g., lighting and a cell phone charger) in a single home. The second business model for off-grid solar is to build a microgrid (also known as a decentralized renewable energy system or DRE) that serves multiple customers.[190]

Because of its ability to change an underserved customer's life, off-grid solar is an ideal tool to elevate the profile of the Modi administration's solar plans among a large and politically significant segment of the population. In India, over 360 million people have no access to the grid, and a further 95 million are severely underserved by the grid, receiving fewer than four hours of electricity service per day. These figures are the highest of any country in the world in absolute terms.[191]

Nevertheless, the Modi administration has not paid adequate attention to this solar segment, and its 2022 target for off-grid solar is only 3 GW. Progress has been halting, with only 234 MW of off-grid solar capacity installed to date.[192] Federal support for off-grid solar dates back to the Electricity Act of 2003, which set a goal of electrifying every village and household by 2012. Although the government reports having electrified over 90 percent of villages, that official statistic likely overstates gains in energy access, conflating construction progress on building distribution outposts with rural consumers actually connecting to the grid.[193] A more telling statistic is that just over half of rural households have access to electricity, whereas the remaining households use kerosene for lighting and heat.[194,195]

In specific cases, both the government and private enterprises can point to successes. Where successfully implemented, federal capital subsidies of up to 90 percent and loan refinancing assistance through the Ministry of New and Renewable Energy's investment arm have funded off-grid solar projects, notably in Karnataka and Uttar Pradesh.[196] And private entities, both homegrown and foreign, have devised innovative ways to make off-grid solar a financially sustainable proposition, as described in a 2015 Goldman Sachs review of the diversity of off-grid business models.[197] Some vendors—like Simpa Networks—have successfully monetized latent demand for electricity through pay-as-you-go models, in which customers use a cellphone to view their remaining electricity balance and purchase more power via text message for a remotely controlled SHS or DRE power source.[198] Similarly, Selco helps households obtain loans from rural banks to finance SHS systems, which can include a diverse range of energy services and products, like electric sewing machines, developed by Selco's innovation lab. Others—like Mera Gao power—have harnessed the power of microfinance to enable community ownership of solar systems. Finally, some DRE enterprises—like OMC Power—have built a microgrid around an anchor client, like a cell tower, which guarantees the majority of the revenue segment and enables the vendor to serve nearby village customers who also purchase power from the solar system. Given the low penetration of off-grid solar and the vast potential market, the various business models for off-grid solar could collectively drive 60 percent annual market growth (**Figure 8**).[199]

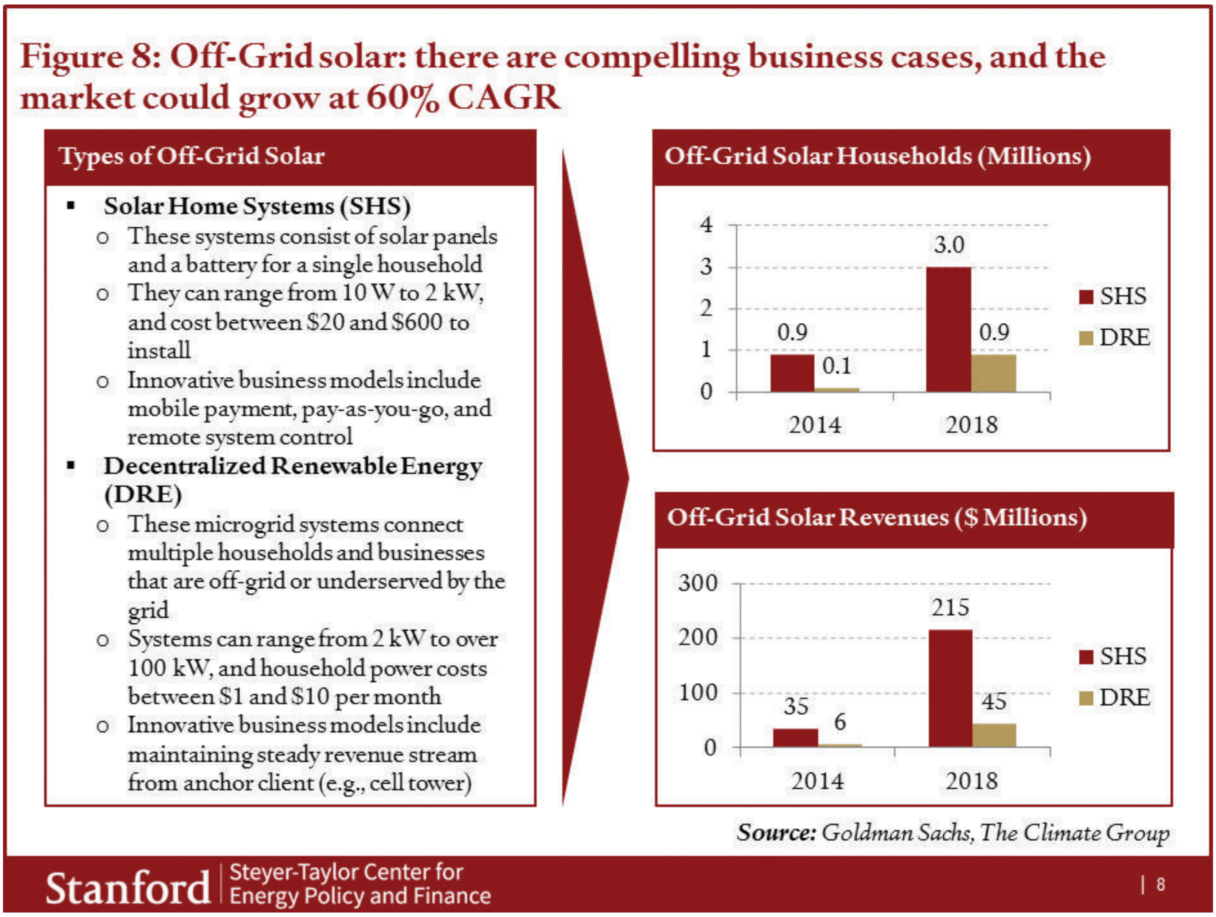


Figure 8: Off-Grid solar: there are compelling business cases, and the market could grow at 60% CAGR

Still, despite individual successes, off-grid solar overall faces several challenges for the government to meet its 3 GW deployment target to say nothing of larger-scale deployment. Financing is the main challenge, for three reasons: the lack of availability of domestic capital; kerosene fuel subsidies that artificially alter its competitiveness with solar; and the diversity of actors seeking financing for off-grid projects. Commercial banks, often unfamiliar with off-grid projects, are unwilling to lend capital to construct them.[200] Although federal subsidies are generous on paper, they are disbursed unpredictably and often exclude smaller, entrepreneurial vendors.[201] And the customers who seek off-grid solar often cannot afford the capital costs of even a $100 SHS setup, which also come with equipment maintenance and replacement costs.[202]

Moreover, off-grid solar faces a range of technical challenges. Reliably earning revenue from rural customers entails considerable collection costs. Despite some cases where vendors have successfully deployed remote mobile payment systems, most vendors have relied on door-to-door collection. One reason is that Indian federal regulation requires mobile network operators to partner with banks to offer mobile money services, and banks are often unwilling to extend their services to remote areas.[203]

Similar to the obstacles facing distributed solar, off-grid solar also suffers a lack of trained technicians to install the solar systems.[204] Since there are several competing configurations for SHS and DRE setups, the lack of standardization results in widely differing reliability outcomes. And solar equipment is often not customized to India's context, which involves high temperatures, humidity, dust, and low precipitation, further reducing equipment reliability.[205]

It is imperative that the Modi administration, with the support of international actors, overcomes the challenges facing off-grid solar in order to advance it as an energy solution for all. Again, the four building blocks can facilitate such success:

1) Reform the utility sector

Although off-grid solar is, by definition, not connected to the grid operated by state utilities, modifications to the state utility model can alleviate serious risks impeding widespread off-grid solar deployment. At present, state plans for extending the grid threaten the long-term viability of a significant number of off-grid SHS and DRE models. Even though extension of the power grid is an important national priority, off-grid solar developers are afraid to build systems that may become obsolete if the grid arrives, often offering subsidized power, and puts them out of business.[206]

There is a way to coordinate efforts to extend the grid and to deploy off-grid solar, so that both approaches can constructively advance the goal of energy access rather than impede each other. State utilities can treat off-grid developers as "franchisees," offering the developers a guaranteed 10-year contract to collect power revenues from designated off-grid areas without the risk of competing with the grid.[207]

This approach has worked elsewhere, for example in Tanzania, and the Forum of Regulators has proposed federal legislation to expand this approach across India.[208,209] If a grid extension project were to intrude on an off-grid solar developer's service territory, under the new legislation the franchisee would be entitled to remedies, including the possibility of operating the new distribution grid to continue providing power within the service territory. Such legislation could enable off-grid solar microgrid business models, which are increasingly attractive across the developing world, to attract capital from investors who need not fear competition from the grid.

Private entities, both homegrown and foreign, have devised innovative ways to make off-grid solar a financially sustainable proposition

2) Harmonize federal and state policies

Federal and state policy coordination could advance off-grid solar deployment by phasing out kerosene subsidies that make off-grid solar uncompetitive. Indeed, nonprofit groups that operate off-grid solar microgrids across the developing world report that customers in India are only willing to pay one fourth the price paid by Haitian off-grid solar customers, because in India subsidized kerosene provides an artificially cheap alternative to electricity. At a deregulated price, the cost of kerosene far exceeds that of off-grid solar, even before accounting for other benefits of solar like avoided air pollution.[210] The Modi administration has already expressed its willingness to tackle consumer fuel subsidies, deregulating the price of diesel last year.[211] However, kerosene subsidies are an even more politically inflammatory subject, so a nationwide reform to the subsidies is likely a political non-starter for the administration. But targeted subsidy reform to enable off-grid solar to displace kerosene in selected areas can provide a beachhead of reform for the Modi administration to build on.

Such a targeted scheme would require careful coordination between the federal and state governments. The federal government sets the level of kerosene subsidy at a nationwide level. Then state governments are responsible for allocating the subsidized kerosene to local districts.[212] To set up a subsidy reform demonstration project, a state government could select one or more off-grid villages and decrease the allocation of subsidized kerosene to the demonstration area. The federal government could repurpose the savings from subsidy payments to financial incentives for off-grid solar developers to set up microgrid projects to electrify the target rural area.[213] Replicated across different states, such demonstration projects could help build momentum to roll back one of India's most intractable subsidy programs. Nevertheless, such a program must be carefully staged to ensure that subsidized kerosene does not disappear before an operational off-grid solar system can be deployed, among other design considerations. Indeed, the politically sensitive nature of subsidy reform suggests that further research is necessary to design and implement a revenue-neutral, politically palatable scheme to wean rural residents off subsidized kerosene.

3) Secure substantial and cost-effective effective financing

The fundamental business case for off-grid solar exists, but it will take tailored policy support to create a self-sustaining ecosystem of suppliers, distributors, and customers. Current federal policy may offer generous financial support on paper, but the policies are not customized to the specific difficulties that off-grid solar faces. For example, rather than only provide capital subsidies for up front construction costs, federal generation incentives would encourage vendors to ensure that the solar systems continue generating electricity.

The various business models for off-grid solar could collectively drive 60 percent annual market growth

This could address the current challenge of developers using substandard equipment to seek capital subsidies for solar systems that fail soon after deployment.[214]

Additionally, the federal government can step in to guarantee loans to off-grid entrepreneurs and other emerging developers that commercial banks are presently unwilling to back.[215] This would help alleviate the shortage of working capital and low-cost debt finance to deploy off-grid systems. There are existing energy access funds supported by international institutions like the World Bank and corporate foundations like the Shell Foundation that already aim to provide working capital for off-grid solar developers in Asia.[216] The Indian government should welcome these efforts and can accelerate them by contributing risk capital to these funds. And, if the federal government can partner with off-grid developers to route power payments through bank accounts linked to the government's new national identification system (*Aadhar*), this can alleviate investor fears about collection risks and unlock private capital to own and operate off-grid solar systems.[217]

International actors can also help. For example, the United Nations Environment Program Solar Loan Initiative, launched in 2003, has subsidized interest payments and coordinated market entry of international microfinance investors.[218] Expanding these kinds of initiatives outside of the few states that have received such support can expand the reach of off-grid solar. And as was the case for distributed solar, international nonprofit organizations can help compile and disseminate data on off-grid solar performance to further de-risk investments in this segment.

4) Foster diffusion of technology and standards from abroad

Off-grid solar is still a nascent market in India, and there is a pressing need to standardize equipment, configurations, and business models to achieve widespread deployment. International collaborations between U.S. and Indian research laboratories, like the Solar Energy Research Institute for India and the United States (SERIIUS), can investigate new solar materials and equipment modifications to enable long-lived deployments in the Indian climate.[219] And similar to the distributed solar sector, the off-grid solar sector would benefit from the transfer of technical standards from international standards bodies, for example for the operation of micro-grids.[220]

Finally, low-voltage direct-current (DC) microgrids that leverage off-grid solar are increasingly popular as a potential cost-effective solution to achieve widespread energy access, but they require greater availability of associated DC appliances to realize their cost-saving potential.[221] DC microgrids avoid the losses that would otherwise result from converting solar power (which is DC) into alternating current (AC). For some applications, like mobile charging, there are further losses in another conversion back into DC. Moreover, many DC appliances use less energy than AC appliances.[222] To date, some private companies have demonstrated successful pilot programs in Bihar and Uttar Pradesh to deploy DC microgrids along with efficient DC appliances.[223,224] To help these and other companies achieve scale, the Indian government can partner with foreign multinational firms to pursue bulk procurement of energy-efficient DC appliances, like televisions and fans.[225] Indeed, India has already had success in bulk procurement of light-emitting diodes (LEDs), another energy-efficient DC appliance, through which it was able to encourage licensing deals and joint ventures with foreign multinationals like Philips to develop domestic manufacturing.[226] A similar strategy can help create a thriving ecosystem of DC appliances to encourage the development of off-grid DC microgrids.

Low-voltage direct current microgrids that leverage off-grid solar can provide cost-effective and energy-efficient access to power

4

Conclusion and Future Research Priorities

Woman trains to install off-grid solar microgrids at Barefoot College, Rajasthan (Knut-Erik Helle)

From a climate perspective, India's solar ambition is the bright spot in an energy landscape that will likely be dominated by carbon-heavy fuels for the foreseeable future. But to play a meaningful role in curbing the projected rise in India's

India's solar ambition is the bright spot in an energy landscape that will likely be dominated by carbon-heavy fuels for the foreseeable future

GHG emissions, solar must attract broad and durable political support. A range of co-benefits-improving power reliability, expanding access to energy, reducing air pollution-could help in this regard. India has long opposed reducing emissions for climate reasons alone, but emission reduction could be a happy collateral outcome of a solar strategy aimed at solving an array of domestic problems. However, the overwhelming focus of the Indian government to date on utility-scale solar projects cannot produce the diverse range of benefits that solar must deliver. Attention from the Modi Administration and international support are badly needed to accelerate deployment of the two other solar segments-distributed and off-grid solar.

Four building blocks-reforming the utility sector harmonizing state and federal policy, securing substantial and cost-effective financing, and fostering the diffusion of technology and standards from abroad-compose a winning strategy that state and federal governments, along with public and private players from abroad can pursue in each of the three segments of solar.

Further analytical work by academics, consultants, NGOs, government researchers, etc. can also support India's solar progress by investigating five unresolved questions. The answers to these questions could guide policymakers to further refine their approach thereby accelerating solar deployment in India:

How do the three segments of solar compare with respect to their climate benefits and domestic co-benefits? This study provides a coarse rank-ordering of the three segments and their respective strengths (**Figure 1**), but further quantitative study can better guide the relative weight that each segment deserves. The Modi administration's target of over 100 GW is highly ambitious and perhaps at this point only aspirational. Armed with better knowledge of the marginal benefits of each GW from the three segments of solar, the administration can more accurately prioritize its resources as it pursues its challenging solar goals.

What are the right performance metrics to track the progress of each segment of solar? Measuring progress is as important as setting appropriate targets. This study has compiled a variety of secondary research to take a snapshot of each of the three segments of solar but the data is limited in content and availability. What if policymakers in India could automatically update a dashboard of performance metrics from regularly collected data, transforming such snapshots into a moving picture illustrating India's trajectory and the course corrections required? Further research to inform such an effort could be very useful.

How can finance be mobilized on attractive terms? Another recurring theme in this report has been the lack of large quantities of low-cost capital for reaching India's renewable targets. Future scholarship should explore the development of new financial instruments that de-risk investments in solar, such as payment security mechanisms to reduce the risk of utilities failing to honor PPA contracts. Moreover, future research should analyze refinement of existing financial instruments, like partial credit guarantees and infrastructure debt funds. Since these

Emission reduction could be a happy collateral outcome of a solar strategy aimed at solving an array of domestic problems

instruments have been deployed successfully to finance assets in other sectors, a priority should be to customize their application to the solar context. In addition, other pooled financing vehicles, such as YieldCos and Infrastructure Investment Trusts (INVITs), should be explored. Together, existing and new financing tools can enable solar and other renewable energy types in India to tap into new sources of capital, both domestic and foreign.

What new business models should be developed? Beyond finance, India's unique structure and needs also require development of new business models. The solar-as-a-lease business model, though offering tremendous potential, needs to be developed and refined in the context of Indian rooftop and off-grid solar systems. Additionally, a potential path for rooftop systems could be to target large segments that already use diesel to provide electricity. And with respect to off-grid systems, new models are needed to improve revenue collection, perhaps by offering a wider range of energy services for which customers will be willing to continue paying, like electric sewing machines or lighting for storefronts.

How should the power sector in India be reformed? A major theme in this study has been the barriers to solar that exist in the Indian power sector. Insolvent state utilities present counterparty risk to utility-scale solar financiers; net metering policy uncertainty chills the distributed solar sector; and the halting progress of grid expansion leaves off-grid solar developers unsure of whether they are supplementing or competing with the grid. For solar to succeed in India, it is clear that broader power reform is necessary. Achieving broader reforms must be a priority for future research. Such research should examine the recent efforts by the Indian government to accomplish reforms and make recommendations for what to do differently. For example, the World Bank has recently proposed reforms to increase private sector participation in the distribution system, through licensing and franchising models. Future work should also investigate how foreign governments can help convey utility best practices to Indian state regulators and utilities. Utility transformations in the developed world have involved creating a set of best practices, which include risk-based capital prioritization, lean procurement practices, granular customer segmentation along with profitability analyses, effective partner management, and human capital development. To help developing countries undertake power sector transformations, the United States Agency for International Development (USAID) has created a suite of instructional materials. Institutions like USAID can spearhead exchanges in which utility planners and regulators from developed countries-where system-wide losses are often an order of magnitude smaller than in India-interact with and impart best practices to Indian counterparts.

Clearly, there are considerable challenges to deploying India's three distinct types of solar-utility, distributed and off-grid. But that should not diminish the tremendous potential that solar has in solving India's varied energy challenges. If serious progress can be made over the next several years, solar could well live up to Prime Minister Modi's conviction that India, in reaching for the sun, can find its "ultimate" energy solution.

Authors

Varun Sivaram is the Douglas Dillon fellow at the Council on Foreign Relations. He is also a strategic advisor to the office of New York Governor Andrew Cuomo on Reforming the Energy Vision (REV). Before joining the Council, he was a consultant at McKinsey & Company, where he counseled Fortune 500 companies on adapting to the modern competitive landscape in energy. Prior to this role, he served as a senior advisor for energy and water policy to the mayor of Los Angeles, Antonio Villaraigosa, and oversaw the city's Department of Water and Power.

His work has appeared in the Journal of Applied Physics, the Journal of Physical Chemistry, Nature, Nature Climate Change, Scientific American, and the World Economic Forum. A Truman and a Rhodes scholar, Dr. Sivaram holds degrees from Stanford University in engineering physics and international relations, with honors in international security. He holds a Ph.D. in condensed matter physics from St. John's College, Oxford University, where he developed third-generation solar photovoltaic coatings for building-integrated applications. He lives in Washington, DC.

Gireesh Shrimali is Director, Climate Policy Initiative (CPI), India and a Fellow at the Steyer-Taylor Center for Energy Policy and Finance at Stanford University. Previously, he taught at the Middlebury Institute of International Studies (MIIS) at Monterey and at the Indian School of Business (ISB) at Hyderabad, where he helped found the CPI-ISB Energy and Environment Program in collaboration with CPI.

His current research focus is on renewable energy policy and finance in developing countries - in particular, on analytical frameworks for identification of effective policies as well as on instruments for provision of low-cost, long-term capital. His previous work has included topics such as analysis of India's solar policies; the impact of federal and state policies on the development and deployment of renewable energy in the U.S.; and business models for off-grid energy in developing countries.

He holds a Ph.D. from Stanford University, an MS from the University of Minnesota, Minneapolis, and a BTech from the Indian Institute of Technology, New Delhi.

Dan Reicher is Executive Director of the Steyer-Taylor Center for Energy Policy and Finance at Stanford University, a joint center of the Stanford Graduate School of Business and Stanford Law School, where he also holds faculty positions. Reicher came to Stanford in 2011 from Google, where he served since 2007 as Director of Climate Change and Energy Initiatives.

Reicher has more than 25 years of experience in energy and environmental policy, finance, and technology. He has served three Presidents including in the Clinton administration as Assistant Secretary of Energy for Energy Efficiency and Renewable Energy and Department of Energy Chief of Staff, as a member of President Obama's Transition Team, and as a staff member of President Carter's Commission on the Accident at Three Mile Island.

Reicher is a member of the Secretary of Energy Advisory Board, the National Academy of Sciences Board on Energy and Environmental Systems, a senior fellow (non-resident) of the Brookings Institution, and board chair and interim President and CEO of the American Council on Renewable Energy.

In 2012 Reicher received an honorary doctorate from the State University of New York College of Environmental Science and Forestry and was also named one of the five most influential figures in U.S. clean energy by Oilprice.Com.

Before his position at Google, Reicher was President and Co-founder of New Energy Capital Corp., a private equity firm funded by the California State Teachers Retirement System and Vantage Point Venture Partners to invest in clean energy projects. He also was Executive Vice President of Northern Power Systems, one of the nation's oldest renewable energy companies and a recipient of significant venture capital investment.

Reicher holds a BA in biology from Dartmouth College and a JD from Stanford Law School. He also studied at Harvard's Kennedy School of Government and MIT.

Acknowledgements

The authors thank Annushka Shivnani of the Council on Foreign Relations for invaluable research and production support. The authors are also grateful to Ginny Clegg of Stanford Law School for organizing a roundtable discussion (participants listed below) to inform the final report. The authors thank the roundtable participants for their valuable input and also Stephen D. Comello, Atul Vijaykar, and Michael A. Levi for their written feedback on the report. The report reflects the input of all these experts although they do not necessarily endorse its contents or recommendations.

Roundtable Participants
October 23, 2015
Stanford University

Participant	Affiliation
Matt Baker	Hewlett Foundation
Ranjit Bharvirkar	Regulatory Assistance Project
Bruce Clemens	Department of Materials Science Engineering, Stanford University
Stephen D. Comello	Graduate School of Business, Stanford University
Sanjay Dani	Serra Power
Kjerstin Erickson	Packard Foundation
Charlie Gay	Greenstar Foundation
Justin Guay	Packard Foundation
Himanshu Gupta	Graduate School of Business, Stanford University
Vikas Gupta	First Solar
Anjali Jaiswal	Natural Resources Defense Council
Gillian Lui	Packard Foundation
Sudatta Ray	Interdisciplinary Program in Environment & Resources, Stanford University
Dan Reicher	Steyer-Taylor Center, Stanford University
Dipender Saluja	Capricorn LLC
Krishna Saraswat	Department of Electrical Engineering, Stanford University
Gireesh Shrimali	Climate Policy Initiative
Siva Sivaram	Sandisk Corporation
Uttara Sivaram	Department of Public Policy, Stanford University
Varun Sivaram	Council on Foreign Relations
Mark Thurber	Program on Energy and Sustainable Development, Stanford University

References

1 Becky Beetz, "Global installed PV capacity to reach 200 GW soon, says German solar association," PV Magazine, July 2, 2015, http://www.pv-magazine.com/news/details/beitrag/global-installed-pv-capacity-to-reach-200-gw-soon--says-german-solar-association_100020060/.

2 Vishwa Mohan, "Prime Minister Modi pitches for solar energy as ultimate solution to India's energy problem," The Times of India, August 19, 2015, http://timesofindia.indiatimes.com/home/environment/developmental-issues/Prime-Minister-Modi-pitches-for-solar-energy-as-ultimate-solution-to-Indias-energy-problem/articleshow/48548062.cms.

3 M. Ramesh, "Solar power installed capacity crosses 4 GW-milestone, The Hindu Business Line, September 1, 2015, http://www.thehindubusinessline.com/economy/macro-economy/solar-installations-in-india-cross-the-4-gwmark/article7603722.ece.

4 "Huge Interest in Solar Alliance Launched by PM Narendra Modi," *Economic Times*, December 2, 2015.

5 Tim Buckley, "India's Electricity-Sector Transformation," Institute for Energy Economics and Financial Analysis, August 2015.

6 Rosemary Marandi and Kiran Sharma, "Modi looks to double coal production by 2020," Nikkei Asian Review, April 3, 2015, http://asia.nikkei.com/Politics-Economy/Policy-Politics/Modi-looks-to-double-coal-production-by-2020.

7 Chris Buckley, "China Pledges to Halt Growth of Carbon Emissions in Climate Plan," The New York Times, June 30, 2015, http://www.nytimes.com/2015/07/01/world/asia/china-carbon-emissions-climate-change.html?_r=0.

8 Bill Chappell, "U.S. Promises To Cut Greenhouse Gas Emissions Up to 28 Percent By 2025," NPR, March 31, 2015, http://www.npr.org/sections/thetwo-way/2015/03/31/396577721/u-s-promises-to-cut-greenhouse-gases-by-a-quarter-of-2005-levels.

9 Varun Sivaram and Annushka Shivnani, "India Warms Up to Climate Action," Council on Foreign Relations, November 19, 2015, http://www.cfr.org/india/india-warms-up-climate-action/p37268.

10 Adam Vaughan, "India unveils climate change plan," The Guardian, October 2, 2015, http://www.theguardian.com/world/2015/oct/02/india-pledges-40-percent-electricity-renewables-2030.

11 Coral Davenport, "Emissions from India Will Increase, Official Says," The New York Times, September 14, 2014, http://www.nytimes.com/2014/09/25/world/asia/25climate.html?_r=0.

12 Amitabh Sinha, "Here are India's INDC Objectives and how Much It will Cost," The Indian Express, October 2, 2015, http://indianexpress.com/article/india/india-news-india/here-are-indias-indc-objectives-and-how-much-it-will-cost/

13 Urmi A. Goswami, "India's INDCs for UN climate summit to be comprehensive: Prakash Javadekar, The Economic Times, August 24, 2015, http://articles.economictimes.indiatimes.com/2015-08-24/news/65808438_1_climate-change-indc-climate-summit.

14 Chandrika Srivastava, "Why India Can't Stop at 100 Gigawatts of Solar," Greentech Media, January 20, 2015, http://www.greentechmedia.com/articles/read/why-india-cant-stop-at-100-gigawatts-of-solar.

15 "Physical Progress (Achievements)," Government of India Ministry of New and Renewable Energy, 2015, http://mnre.gov.in/mission-and-vision-2/achievements/.

16 Ganesh Nagarajan, "India to Quadruple Renewable Capacity to 175 Gigawatts by 2022," Bloomberg Business, Februrary 28, 2015, http://www.bloomberg.com/news/articles/2015-02-28/india-to-quadruple-renewable-capacity-to-175-gigawatts-by-2022.

17 M. Ramesh, "Solar power installed capacity crosses 4 GW-milestone, The Hindu Business Line, September 1, 2015, http://www.thehindubusinessline.com/economy/macro-economy/solar-installations-in-india-cross-the-4-gwmark/article7603722.ece.

18 Shreya Jai, "Falling rates hit solar power players," Business Standard, November 9, 2015, http://www.business-standard.com/article/economy-policy/falling-rates-hit-solar-power-players-115110900032_1.html.

19 Krishna N. Das, "Obama backs India's solar goals, seeks support for climate talks", Reuters, January 25, 2015, http://in.reuters.com/article/2015/01/25/india-obama-climatechange-idINKBN0KY0QN20150125.

20 Ganebbsh Nagarajan, "India to Quadruple Renewable Capacity to 175 Gigawatts by 2022," Bloomberg Business, February 28, 2015, http://www.bloomberg.com/news/articles/2015-02-28/india-to-quadruple-renewable-capacity-to-175-gigawatts-by-2022.

21 Krishnan Guru-Murthy, "Will coal or solar power furl India's drive to bring electricity to its villages," The Guardian, October 30, 2014, http://www.theguardian.com/world/2014/oct/30/coal-solar-power-india-electricity-villages-mining-narendra-modi.

22 Brad Plumer, "India's air pollution is so bad it's reducing life expectancy by 3.2 years, Vox, February 24, 2015, http://www.vox.com/2015/2/24/8094597/india-air-pollution-deaths.

23 "Indian Power Failure Shocks Growing Political Gridlock," Bloomberg View, August 2, 2012, http://www.bloombergview.com/articles/2012-08-02/indian-power-failure-highlights-growing-political-gridlock-view.

24 Gopal Ritolia, "Initiation of Coverage: India Power Utilities," UBS, March 19, 2015.

25 "Energy Statistics 2015," Government of India Ministry of Statistics and Program Implementation, 2015, http://mospi.nic.in/Mospi_New/upload/Energy_stats_2015_26mar15.pdf.

26 Anil Kumar, "State wise Estimated Solar Power Potential in the Country," National Institute of Solar Energy, November 24, 2014.

27 Bassam Fattouh, "Energy in India," Oxford Institute for Energy Studies, no.99, February 2015.

28 See http://www.nytimes.com/2014/09/25/world/asia/25climate.html?_r=0.

29 Sudhakar Sundaray, Lovedeep Mann, Ujjwal Bhattacharjee, Shirish Garud, and Arun K Tripathi,"Reaching the sun with rooftop solar," The Energy and Resources Institute, 2014.

30 Fracesco Meneguzzo, Rosaria Ciriminna, Lorenzo Albanese and Maria Pagliaro, "The great solar boom: a global perspective into the far reaching impact of an unexpected energy revolution," Energy Science and Engineering, September 3, 2015.

31 "India Solar Handbook," Bridge to India, June 2015, http://www.bridgetoindia.com/?p=3364.

32 Christian Roselund, "India surpasses 4 GW of installed solar PV," PV Magazine, September 4, 2015, http://www.pv-magazine.com/news/details/beitrag/india-surpasses-4-gw-of-installed-solar-pv_100020939/.

33 "Millions of people in India have no electricity," The Economic Times, http://economictimes.indiatimes.com/new-sections/energy/millions-of-people-in-india-have-no-electricity/lifenologyshow/41089385.cms.

34 "Coal power: air pollution," Union of Concerned Scientists, http://www.ucsusa.org/clean_energy/coalvswind/c02c.html#.VjEB8LerS71.

35 "Health Effects of Diesel Exhaust," Cal/EPA's Office of Environmental Health Hazard Assessment and The American Lung Association of California, http://oehha.ca.gov/public_info/facts/dieselfacts.html.

36 Nicholas L. Lam, Kirk R. Smith, Allison Gauthier, and Micheal N. Bates, "Kerosene: A Review of Household Uses and Their Hazards in Low- and Middle- Income Countries," NIH Public Access, May 25, 2013.

37 Hunt Allcott, Allan Collard-Wexler, and Stephen D. O'Connell, "How Do Electricity Shortages A!ect Productivity? Evidence from India," National Bureau of Economic Research, March 23, 2014, http://pages.stern.nyu.edu/~acollard/ACO_Electricity_Shortages_in_India.pdf.

38 Gopal Ritolia, "Initiation of Coverage: India Power Utilities," UBS, March 19, 2015.

39 Hunt Allcott, Allan Collard-Wexler, and Stephen D. O'Connell, "How Do Electricity Shortages A!ect Productivity? Evidence from India," National Bureau of Economic Research, March 23, 2014, http://pages.stern.nyu.edu/~acollard/ACO_Electricity_Shortages_in_India.pdf.

40 "Beehives or elephants? How should India drive its solar transformation?," Bridge to India, Tata Solar Power, September 2014.

41 Council on Energy, Environment and Water, "Solar Power Jobs: Exploring the Employment Potential in India's Grid-Connected Solar Market," August 2014.

42 Ministry of Environment & Forests, "India and UNFCCC," http://envfor.nic.in/sites/default/files/cc/india_unfccc.htm.

43 Tuula Honkonen, "The Common but Differentiated Responsibility Principle in Multilateral Environmental Agreements," Kluwer Law International, 2009.

44 John Vogler, Climate Change in World Politics, (New York: Palgrave Macmillan, 2015).

45 Damandeep Singh, "India's INDC ignites hope for a green future," The Times of India, October 5, 2015, http://timesofindia.indiatimes.com/home/environment/developmental-issues/Indias-INDC-ignites-hope-for-a-green-future/articleshow/49226076.cms.

46 "India's Intended Nationally Determined Contribution," UNFCC, October 2015.

47 Anurabha Ghosh and Kanika Chawla, "Decoding India's INDCs," Council on Energy, Environment and Water, blog, October 2, 2015, http://ceew.in/blog/?p=427.

48 Nitin Sethi, "India's energy mix to have 40% renewable sources by 2030," Business Standard, September 22, 2015, http://www.business-standard.com/article/economy-policy/india-s-energy-mix-to-have-40-renewable-sources-by-2030-115092200057_1.html.

49 "How Ambitious Are the Post-2020 Targets?" Bloomberg New Energy Finance, October 2, 2015. http://about.bnef.com/content/uploads/sites/4/2015/10/2015-10-02-How-ambitious-are-the-post-2020-targets-UPDATE-2-Oct.pdf.

50 Tim Buckley, "India's Electricity-Sector Transformation," Institute for Energy Economics and Financial Analysis, August 2015.

51 Siddharth Saikia, "Private equity steps down funding for power projects," The Hindu Business Line, March 13, 2013, http://www.thehindubusinessline.com/companies/private-equity-steps-down-funding-for-power-projects/article4505507.ece.

52 Anupam Srivastava, "India's first-ever environmental rating of coal-based power plants finds the sector's performance to be way below global benchmarks," Centre for Science and Environment, February 21, 2015, http://cseindia.org/content/india%E2%80%99s-first-ever-environmental-rating-coal-based-power-plants-finds-sector%E2%80%99s-performance.

53 Chetan Chauhan, "World's cheapest solar power in Madhya Pradesh at Rs 5 per unit," Hindustan Times, August 10, 2015, http://www.hindustantimes.com/india/world-s-cheapest-solar-power-in-madhya-pradesh-at-rs-5-per-unit/story-u233ML3vD5YBBY6gtw4KxN.html.

54 In this paper, we have mostly focused on JNNSM and similar state-level programs that use auctions to procure solar power. The only exception is the state of Gujarat which started its solar policy in 2010, with a cumulative capacity of approx. 1GW under a feed-in tariff regime. This feed-in tariff regime, though apparently successful in the beginning, has recently come under attack for being too expensive, asking for retroactive tariff cuts.

55 Jawaharlal Nehru National Solar Mission, "Guidelines for Off-grid and Decentralized Solar Applications and Other Small Solar Power Plants," June 16, 2010.

56 Jawaharlal Nehru National Solar Mission, July 23, 2015, http://pib.nic.in/newsite/PrintRelease.aspx?relid=123607.

57 Tom Kenning, "Mercom: India's 2015 Solar Forecast Up to 2.5 GW," PV Tech, August 20, 2015, http://www.pv-tech.org/news/mercom_india_2015_forecast_revised_up_to_2.5gw.

58 "State implementation of various schemes to achieve 100,000 MW solar plan," Government of India Ministry of New and Renewable Energy, 2015, http://mnre.gov.in/file-manager/UserFiles/GW-Solar-Plan. pdf.

59 Anindya Upadhyay, "India's Largest Solar Power Auction Brings Further Drop in Costs," Bloomberg Business, August 4, 2015, http://www.bloomberg.com/news/articles/2015-08-04/india-s-largest-solar-power-auction-brings-further-drop-in-costs.

60 Saurabh Mahapatra, "Solar Power Bids Fall By Over 50% In 5 Years in India," Clean Technica, October 15, 2015, http://cleantechnica.com/2015/10/15/solar-power-bids-fall-50-5-years-india/.

61 Chetan Chauhan, "World's cheapest solar power in Madhya Pradesh at Rs 5 per unit," Hindustan Times, August 10, 2015, http://www.hindustantimes.com/india/world-s-cheapest-solar-power-in-madhya-pradesh-at-rs-5-per-unit/story-u233ML3vD5YBBY6gtw4KxN.html.

62 "Renewable Power Generation Costs, in 2014," International Renewable Energy Agency, 2015, http://www.irena.org/documentdownloads/publications/irena_re_power_costs_2014_report.pdf.

63 Gireesh Shrimali and Anshuman Sahoo, "Has India's

Solar Mission Increased the Deployment of Domestically Produced Solar Modules?" Energy Policy, 2014.

64 Ministry of New and Renewable Energy, "Guidelines for Implementation of Scheme for Setting up of 2000 MW Grid-connected Solar PV Power Projects under Batch-III," August 2015.

65 Kapil Dave and Kalpesh Damor, "61% of Vibrant projects are on: Gujurat," The Times of India, January 16, 2015, http://timesofindia.indiatimes.com/india/61-of-Vibrant-projects-are-on-Gujarat/articleshow/45903966.cms.

66 "Exclusive India update: Solar projects without financing will be cancelled," PV Magazine, July 12, 2011, http://www.pv-magazine.com/news/details/beitrag/exclusive-india-update--solar-projects-without-financing-will-be-cancelled_100003641/#axzz3s07xYnYK.

67 Gireesh Shrimali, Charith Konda, Arsalan Farooquee, David Nelson, "Reaching India's Renewable Targets Cost-effectively: Effective Project Allocation Mechanisms," Climate Policy Initiative, May 2015.

68 Tilman Altenburg, Oliver Johnson and Tobias Engelmeier, "Rent management and policy learning in green technology development: the case of solar energy in India," in Anna Pegels, ed., Green Industrial Policy in Emerging Countries (New York: Routledge, 2014), pp. 104-125.

69 Gireesh Shrimali, Charith Konda, Arsalan Farooquee, David Nelson, May 2015.

70 Gireesh Shrimali and Vijay Nekkalapudi, "How Effective Has India's Solar Mission in Reaching its Deployment Targets?" Economic and Political Weekly, 2014.

71 Jasmeet Khurana, "Understanding India's Solar Transition Under the New Government," PV Magazine, October 15, 2014, http://www.pv-magazine.com/opinion-analysis/blogdetails/beitrag/understanding-indias-solar-transition-under-the-new-government_100016813/#axzz3scBakQD7.

72 Chaturvedi, Saurabh and Sahu, Prasanta, "India Frees Diesel Prices from Government Control," Wall Street Journal, October 20, 2014, http://www.wsj.com/articles/india-frees-diesel-prices-from-government-control-1413648469.

73 "Coal cess to boost clean energy, say CEOs," Business Standard, March 3, 2015, http://www.business-standard.com/budget/article/coal-cess-to-boost-clean-energy-say-ceos-115030200936_1.html.

74 "Government makes over 3-lakh crore from spectrum sale," NDTV, March 10, 2015. http://www.ndtv.com/india-news/government-makes-over-3-lakh-crore-from-coal-and-spectrum-sale-government-auditors-estimates-surpass-745355.

75 Anindya Upadhyay, "$100 billion investment likely in renewable energy in 5 years: Piyush Goyal, Power and coal minister," Economic Times, September 19, 2014, http://articles.economictimes.indiatimes.com/2014-09-19/news/54108858_1_piyush-goyal-renewable-energy-energy-minister.

76 David Line, "India's uncertain energy future," The Economist, October 15, 2012, http://www.economistinsights.com/energy/opinion/india%E2%80%99s-uncertain-energy-future.

77 Electricity Act 2003, http://powermin.nic.in/Electricity-Act-2003.

78 Sheoli Pargal and Kristy Mayer, "Governance of Indian State Power Utilities: An Ongoing Journey," World Bank, 2014, http://elibrary.worldbank.org/doi/book/10.1596/978-1-4648-0303-1#.

79 Ashish Gupta, "Did Unbundling Really Reform Our SEBs?" Observer Research Foundation, December 24, 2012, http://www.orfonline.org/cms/sites/orfonline/e_water/ashish121224.pdf.

80 "Cabinet clears $7-billion reform package to boost discoms," The Economic Times, November 6, 2015, http://articles.economictimes.indiatimes.com/2015-11-06/news/68071708_1_discoms-distribution-companies-private-power-producers.

81 "Executive Summary Power Sector," Central Energy Authority, January 2014.

82 U.S. Energy Information Administration, "How much electricity is lost in transmission and distribution in the United States?," July 10, 2015, http://www.eia.gov/tools/faqs/faq.cfm?id=105&t=3.

83 Karthik Sashidhar, "It's time discoms got their financial act together," Live Mint, October 15, 2015, http://www.livemint.com/Industry/nkjthSpgY6xHwrhFBTVgcM/Its-time-discoms-got-their-financial-act-together.html.

84 "State electricity boards' losses widen to Rs 3 lakh cr: Icra," The Finanical Express, July 8, 2015, http://www.financialexpress.com/article/economy/state-electricity-boards-losses-widen-to-rs-3-lakh-cr-icra/96808/.

85 See http://articles.economictimes.indiatimes.com/2015-11-06/news/68071708_1_discoms-distribution-companies-private-power-producers.

86 Sheoli Pargal and Sudeshna Ghosh Banarjee, "More Power to India," World Bank, 2014.

87 Rajesh Kumar Singh and Rakteem Katakey, "Solar Parks on Fertile Land Are New Adversary of India's Farmers," Bloomberg, March 17, 2015, http://www.bloomberg.com/news/articles/2015-03-17/solar-parks-on-fertile-land-are-new-adversary-of-india-s-farmers.

88 "Integrating Wind and Solar Energy in India for a Smart Grid Platform," Global Energy Network Institute, 2013, http://geni15.wrsc.org/sites/default/files/integrating-wind-and-solar-energy-in-india.pdf.

89 Rahul Tongia, "Why Renewable Energy is Harder in India than in Other Countries," Brookings, blog, May 21, 2014, http://www.brookings.edu/blogs/planetpolicy/posts/2014/05/21-renewable-energy-india-tongia.

90 "Financial Restructuring of State Distribution Companies," Government of India Cabinet Committee on Economic Affairs, 2012, http://pib.nic.in/newsite/PrintRelease.aspx?relid=87950.

91 Ahindra Chakrabarti, "Overview of Energy Sector in India," Energetica India, July 2015.

92 Jasmeet Khurana, "Understanding India's Solar Transition Under the New Government," PV Magazine, October 15, 2014, http://www.pv-magazine.com/opinion-analysis/blogdetails/beitrag/understanding-indias-solar-transition-under-the-new-government_100016813/#axzz3scBakQD7.

93 Gireesh Shrimali, Sumala Tirumalachetty and David Nelson, "Falling Short: An Evaluation of the Indian Renewable Certificate Market," Climate Policy Initiative, December 2012.

94 Forum of Regulators, "Assessment of achievable potential of new and renewable energy resources in different states during 12th Plan period and determination of RPO trajectory and its impact on tariff," CRISIL Risk and Infrastructure Solutions Limited, March 2012.

95 Gireesh Shrimali and Sumala Tirumalachetty, "Renewable energy certificate markets in India – A review," Renewable and Sustainable Energy Reviews 26, July 2013, pp.702-716.

96 Gireesh Shrimali, Sumala Tirumalachetty and David Nelson, "Falling Short: An Evaluation of the Indian Renewable Certificate Market," Climate Policy Initiative, December 2012.

97 Gireesh Shrimali, Sumala Tirumalachetty and David Nelson, "Falling Short: An Evaluation of the Indian Renewable Certificate Market," Climate Policy Initiative, December 2012.

98 Akhilesh Awasthy, "REC Market in India: Issues and prospects," Indian Energy Exchange, 2015.

99 Gireesh Shrimali, Charith Konda, Arsalan Ali Farooquee, and David Nelson, "Reaching India's Renewable Energy Targets: Effective Project Allocation Mechanisms," Climate Policy Initiative, May 2015.

100 Mudit Jain, "Will land be the main hurdle for India's solar dreams?" Bridge to India, April 22, 2015, http://www.bridgetoindia.com/blog/will-land-be-the-main-hurdle-for-indias-solar-dreams/.

101 "India Solar Handbook," Bridge to India, June 2015, http://www.bridgetoindia.com/?p=3364.

102 Krishna N. Das, "India's Adani in talks with Softbank, Foxconn on $3 billion solar plan, Reuters, August 19, 2015, http://www.reuters.com/article/2015/08/19/us-india-solar-idUSKCN0QO1QA20150819.

103 David Goodman and David Holmes, "SoftBank, partners eye 20 billion investments in India solar projects, Reuters, June 22, 2015, http://www.reuters.com/article/2015/06/22/us-softbank-india-solar idUSKBN0P21B120150622.

104 Rupa Subramanya, "Is India Ready to Be a Solar Power Leader," Foreign Policy, July 1, 2015, http://foreignpolicy.com/2015/07/01/india-modi-bjp-energy-solar-softbank/.

105 Ian Clover, "GCL partners with Adani for solar PV operations in India," PV magazine, September 28, 2015, http://www.pv-magazine.com/news/details/beitrag/gcl-partners-with-adani-for-solar-pv-operations-in-india_100021259/.

106 Tim Buckley, "India's Electricity-Sector Transformation," Institute for Energy Economics and Financial Analysis, August 2015.

107 "India Bond Market Roadmap," ASIFMA, 2013, http://www.asifma.org/uploadedfiles/news/asifma%20-india%20bond%20market%20roadmap%20draft_wcover.pdf.

108 Tim Buckley, "India's Electricity-Sector Transformation," Institute for Energy Economics and Financial Analysis, August 2015.

109 Ishan Bakshi, "Infrastructure companies' debt woes worsen," Business Standard, June 13, 2015, http://www.business-standard.com/article/companies/infrastructure-companies-debt-woes-worsen-115061300808_1.html.

110 Vedant Rathi, "Barriers to Solar Financing in India," Clean Energy Leadership Institute, June 5, 2015 http://www.cleanenergyleaders.org/barriers-to-solar-financing-in-india/.

111 David Nelson and Gireesh Shrimali, "Finance Mechanisms for Lowering the Cost of Renewable Energy in Rapidly Developing Countries," Climate Policy Initiative, 2014, http://climatepolicyinitiative.org/wp-content/uploads/2014/01/Finance-Mechanisms-for-Lowering-the-Cost-of-Clean-Energy-in-Rapidly-Developing-Countries.pdf.

112 David Nelson, Gireesh Shrimali, Shobhit Goel, Charith Konda, Raj Kumar, December 2012.

113 Anindya Upadhyay, "$100 billion investment likely in renewable energy in 5 years: Piyush Goyal, Power and coal minister," Economic Times, September 19, 2014, http://articles.economictimes.indiatimes.com/2014-09-19/news/54108858_1_piyush-goyal-renewable-energy-energy-minister.

114 Shreya Jai, "Indian solar power market sees global fund flow," Business Standard, December 5, 2014, http://www.business-standard.com/article/economy-policy/indian-solar-market-witnesses-influx-of-global-investment-114120400537_1.html.

115 David Nelson, Gireesh Shrimali, Shobhit Goel, Charith Konda, Raj Kumar, December 2012.

116 S. Gomathinayagam, "Wind Power: The Way Forward in India," Proceedings of the Eighth Asia-Pacific Conference on Wind Engineering, 2013, http://iawe.org/Proceedings/8APCWE/S.%20Gomathinayagam.pdf.

117 "Integrating Wind and Solar Energy in India for a Smart Grid Platform," Global Energy Network Institute, 2013, http://geni15.wrsc.org/sites/default/files/integrating-wind-and-solar-energy-in-india.pdf.

118 Harnessing Energy From The Sun: Empowering Rooftop Owners," International Finance Corporation, 2014, http://www.ifc.org/wps/wcm/connect/8bb2a280479cb7248b0fff299ede9589/Harnessing+Energy+From+The+Sun_Final.pdf?MOD=AJPERES.

119 Akhilesh Magal, Tobias Engelmeier, and George Mathew, "Grid Integration of Distributed Solar Photovoltaics in India," Prayas Energy Group, 2014, http://www.ncpre.iitb.ac.in/uploads/PEG_grid_integration_dist%20PV_2014.pdf.

120 "India's Intended Nationally Determined Contribution," UNFCC, October 2015.

121 Aman Khanna and Hemant Singh, "India's IPR Regime: Reconciling Affordable Access with Patent Protection," Indian Council for Research on International Economic Relations, 2015. http://icrier.org/pdf/India's_IPR_Regime.pdf.

122 "Roadmap for demand aggregation of LED lighting," Pricewaterhouse Coopers, 2013. http://shaktifoundation.in/wp-content/uploads/2014/02/LED-Demand-Aggregation-Roadmap.pdf.

123 Varun Rai, Kaye Schultz, Erik Funkhauser, "International Low Carbon Technology Transfer: Do Intellectual Property Rights Matter?" Global Environment Change, 2014.

124 "India Solar Handbook," Bridge to India, June 2015, http://www.bridgetoindia.com/?p=3364.

125 Lucy Woods, "Report charts course to possible 145GW of solar in India," PV Tech, September 2, 2014, http://www.pv-tech.org/news/report_utility_solar_level_with_imported_coal_costs.

126 Gireesh Shrimali, Sandhya Srinivasan, Shobit Goel, Saurabh Trivedi, and David Nelson, "Reaching India's Renewable Energy Targets Cost-Effectively," Climate Policy Initiative, April 2015.

127 Gireesh Shrimali, Charith Konda, Arsalan Ali Farooquee, and David Nelson, "Reaching India's Renewable Energy Targets: Effective Project Allocation Mechanisms," Climate Policy Initiative, May 2015.

128 Rupa Subramanya, "Is India Ready to Be a Solar Power Leader," Foreign Policy, July 1, 2015, http://foreignpolicy.com/2015/07/01/india-modi-bjp-energy-solar-softbank/.

129 Indian Renewable Energy Development Agency, "Atlas of Potential Land for Renewable Energy," http://www.ireda.gov.in/writereaddata/AtlasPotentialLandRE/Data/Executive%20Summary.pdf.

130 Mudit Jain, "Will land be the main hurdle for India's solar dreams?" Bridge to India, April 22, 2015, http://www.bridgetoindia.com/blog/will-land-be-the-main-hurdle-for-indias-solar-dreams/.

131 Gireesh Shrimali, Charith Konda, Arsalan Ali Farooquee, and David Nelson, "Reaching India's Renewable Energy Targets: Effective Project Allocation Mechanisms," Climate Policy Initiative, May 2015.

132 Anil Sasi, "Solar Power; Sunny Side Down," Indian Express, July 8, 2015, http://indianexpress.com/article/india/india-others/solar-power-sunny-side-down/.

133 Tom Kenning, "India to build green energy corridors, PV-Tech, June 8, 2015, http://www.pv-tech.org/news/india_to_build_green_energy_corridors.

134 "Making 100 GW Solar Target a Reality," Center for Study of Science, Technology, and Policy, Energetica India, 2015, http://www.cstep.in/uploads/default/files/pressroom/stuff/8162dad1237101f9e6156f03e04b085d.pdf.

135 Ministry of New and Renewable Energy, "Implementation of a Payment Security Scheme for Grid Connected Solar Power Projects under Phase 1 of Jawaharlal Nehru National Solar Mission during Year 2011-22," June 30, 2011.

136 "Lessons from Jawaharlal Nehru Solar Mission Phase I," World Bank Energy Sector Management Assistance Project, 2013, https://openknowledge.worldbank.org/bitstream/handle/10986/17480/832660REPLACEM0X0ESM0ESMAP00PUBLIC0.txt?sequence=2.

137 "Financial Restructuring of State Distribution Companies," Government of India Cabinet Committee on Economic Affairs, 2012, http://pib.nic.in/newsite/PrintRelease.aspx?relid=87950.

138 Utpal Bhaskar, "Bailout Plan for Dicoms Fizzles Out," Live Mint, September 9, 2014, http://www.livemint.com/Politics/xnabMXKPnPSS4VFDAw07zM/Bailout-plan-for-discoms-fizzles-out.html.

139 Ambuj Lall, "Review of APDRP and R-APDRP," Working Paper, 2011.

140 "Looking for reform success, PM Narendra Modi readies electricity rescue plan," Reuters, September 18, 2015, http://economictimes.indiatimes.com/industry/energy/power/looking-for-reform-success-pm-narendra-modi-readies-electricity-rescue-plan/articleshow/49009873.cms.

141 Anna Bertona, Jan-Paul van Term, and Alexander Tamminga, "Utility Procurement Study: Solar Electricity in the Utility Market," Solar Electric Power Association, December 2008.

142 Adam Johnson,"Indian State Tamil Nadu Opens Bids for 1GW of Solar Power," Clean Technica, December 10, 2012, http://cleantechnica.com/2012/12/10/indian-state-tamil-nadu-opens-bids-for-1gw-of-solar-power/.

143 Gireesh Shrimali, Charith Konda, Arsalan Ali Farooquee, and David Nelson, "Reaching India's Renewable Energy Targets: Effective Project Allocation Mechanisms," Climate Policy Initiative, May 2015.

144 Gireesh Shrimali and Sumala Tirumalachetty, "Renewable Energy Certificate Markets in India: A Review," Renewable and Sustainable Energy Reviews, 2013.

145 Gireesh Shrimali, Gabe Chan, Steffen Jenner, Felix Groba, Joe Indvik, "Evaluating Renewable Portfolio Standards for In-state Renewable Deployment," Steyer-Taylor Center for Energy Policy and Finance, 2015.

146 "Implementation of scheme for setting up over 2,000 MW of Grid-Connected Solar PV Power Projects with Viability Gap Funding (VGF) under Batch-Ill of Phase II of the JNNSM," Government of India Cabinet Committee on Economic Affairs, June 17, 2015, http://pib.nic.in/newsite/PrintRelease.aspx?relid=122583.

147 "Scaling Solar India Through Financing," Council on Energy, Environment, and Water, 2013, http://ceew.in/pdf/Roundtable-Issue-Brief.pdf.

148 Gireesh Shrimali, Shobhit Goel, Sandhya Srinivasan, and David Nelson, "Solving India's Renewable Energy Financing Challenge: Which Federal Policies can be Most Effective?" Climate Policy Initiative," March 2014.

149 Gireesh Shrimali, Charith Konda, and Sandhya Srinivasan, March 2014.

150 Gireesh Shrimali, Sandhya Srinivasan, Shobhit Goel, Saurabh Trivedi, and David Nelson, April 2015.

151 Gireesh Shrimali, Shobhit Goel, Sandhya Srinivasan, and David Nelson, March 2014.

152 Gireesh Shrimali, Charith Konda, and Sandhya Srinivasan, March 2014.

153 Gireesh Shrimali, "Three Ways to Attract Domestic Institutional Investment for Renewable Projects in India," Climate Policy Initiative, 2015.

154 Arsalan Ali Farooquee and Gireesh Shrimali, June 2015.

Arsalan Ali Farooquee and Gireesh Shrimali, June 2015.

155 "2003 Annual Report," International Finance Corporation, 2003.

156 Siddhartha P Saikia ahttp://www.financialexpress.com/article/economy/indias-first-hvdc-power-transmission-line-to-be-operational-on-aug-31/122405/.

157 Jasmeet Khurana, "The time for investing in renewable powered storage in India is here," PV Magazine, January 15, 2015, http://www.pv-magazine.com/opinion-analysis/blogdetails/beitrag/the-time-for-investing-in-renewable-powered-storage-in-india-is-here_100017796/#axzz3scBakQD7.

158 "Rooftop Solar Policy Coalition", Mudit Jain, Rakesh Jha, Jasmeet Khurana, Vivek Mishra, Phil Marker, Vinay Rustagi, Shilpi Samantray, and Jay C. Shiv, forthcoming.

159 Anil Sasi, "Gensets add up to under half of installed power capacity," Indian Express, August 18, 2014, http://indianexpress.com/article/india/india-others/gensets-add-up-to-under-half-of-installed-power-capacity/.

160 "Is Rooftop Solar Power Cheaper than Diesel/ Grid Power?," Solar Mango, http://www.solarmango.com/faq/1.

161 Rajabahadur Arcot, "Power from Rooftops is not a Pipe Dream," Deccan Herald, November 24, 2015, http://www.deccanherald.com/content/473993/power-rooftops-not-pipe-dream.html.

162 Dipannita Das, "Diesel generators, stone quarries, brick kilns adding to pollution level, says study," The Times of India, December 29, 2011, http://timesofindia.indiatimes.com/city/pune/Diesel-generators-stone-quarries-brick-kilns-adding-to-pollution-level-says-study/articleshow/11286683.cms.

163 Anurabha Ghosh, Shalu Agrawal, Poulami Choudhury, Kanika Chawla, Anjali Jaiswal, Meredith Connolly, Bhaskar Deol, and Nehmat Kumar,"Clean Energy Powers Lobal Job Growth in India," NRDC International: India, Center for Energy, Environment and Water, February 2015.

164 “India Solar Handbook,” Bridge to India, June 2015, http://www.bridgetoindia.com/?p=3364.

165 Tobias Engelmeier, Mohit Anand, Jasmeet Khurana, Prateek Goel, and Tanya Loond, “Rooftop Revolution: Unleashing Delhi’s Solar Potential,” Bridge to India and Greenpeace, 2013.

166 Mudit Jain, “Market projection for solar rooftop projects in India,” Market Outlook Bridge to India, blog, June 6, 2014, http://www.bridgetoindia.com/blog/market-projection-for-solar-rooftop-projects-in-india/.

167 “India Solar Handbook,” Bridge to India, June 2015, http://www.bridgetoindia.com/?p=3364.

168 Akhilesh Magal, Tobias Engelmeier, and George Mathew, “Grid Integration of Distributed Solar Photovoltaics in India,” Prayas Energy Group, 2014, http://www.ncpre.iitb.ac.in/uploads/PEG_grid_integration_dist%20PV_2014.pdf.

169 “Integrating Wind and Solar Energy in India for a Smart Grid Platform,” Global Energy Network Institute, 2013, http://geni15.wrsc.org/sites/default/files/integrating-wind-and-solar-energy-in-india.pdf.

170 “Rooftop Solar Policy Coalition”, Mudit Jain, Rakesh Jha, Jasmeet Khurana, Vivek Mishra, Phil Marker, Vinay Rustagi, Shilpi Samantray, and Jay C. Shiv, forthcoming.

171 “Rooftop Solar Policy Coalition”, Mudit Jain, Rakesh Jha, Jasmeet Khurana, Vivek Mishra, Phil Marker, Vinay Rustagi, Shilpi Samantray, and Jay C. Shiv, forthcoming.

172 M Ramesh, “India seeks $2 bn from World Bank, ADB for rooftop solar projects,” The Hindu Business Line, http://www.thehindubusinessline.com/economy/policy/india-seeks-2-bn-from-world-bank-adb-for-rooftop-solar-projects/article7395640.ece.

173 “Rooftop Solar Policy Coalition”, Mudit Jain, Rakesh Jha, Jasmeet Khurana, Vivek Mishra, Phil Marker, Vinay Rustagi, Shilpi Samantray, and Jay C. Shiv, forthcoming.

174 Northeast Group, LLC, “India To Spend $21.6 Billion On Smart Grid Infrastructure By 2025,” PR Newswire, January 20, 2015, http://www.prnewswire.com/news-releases/india-to-spend-216-billion-on-smart-grid-infrastructure-by-2025-300021970.html.

175 Gayrajan Kohli, “Net-metering is essential for India, but here is why it’s failing,” Bridge to India, blog, April 21, 2015, http://www.bridgetoindia.com/blog/net-metering-is-essential-for-india-but-here-is-why-its-failing-i/.

176 Forum of Regulators,“Evolving Net-Metering Model Regulation for rooftop based solar PV projects” August 2013.

177 Herman Trabish, “How rate design can save utilities from the solar death spiral,” Utility Dive, July 15, 2015, http://www.utilitydive.com/news/how-rate-design-can-save-utilities-from-the-solar-death-spiral/402205/.

178 Ryan Hledik, “The Top 10 Questions about Demand Charges,” The Brattle Group, May 14, 2015.

179 “Rooftop Solar Policy Coalition”, Mudit Jain, Rakesh Jha, Jasmeet Khurana, Vivek Mishra, Phil Marker, Vinay Rustagi, Shilpi Samantray, and Jay C. Shiv, forthcoming.

180 David Feldman and Travis Lowder, “Banking on Solar: An Analysis of Banking Opportunities in the U.S. Distributed Photovoltaic Market,” National Renewable Energy Laboratory, 2014, http://www.nrel.gov/docs/fy15osti/62605.pdf.

181 “Rooftop Solar Policy Coalition”, Mudit Jain, Rakesh Jha, Jasmeet Khurana, Vivek Mishra, Phil Marker, Vinay Rustagi, Shilpi Samantray, and Jay C. Shiv, forthcoming.

182 “Property Assessed Clean Energy (PACE) Financing of Renewables and Efficiency, National Renewable Energy Laboratory, 2010, http://www.nrel.gov/docs/fy10osti/47097.pdf.

183 “Property Assessed Clean Energy Financing: Update on Commercial Programs,” Lawrence Berkeley National Laboratory, 2011, https://emp.lbl.gov/sites/all/files/POLICY%20BRIEF%20pace%20financing.pdf.

184 “Commercial Property Assessed Clean Energy (PACE) Primer,” U.S. Department of Energy, 2010, http://www1.eere.energy.gov/wip/pdfs/commercial_pace_primer_revised.pdf.

185 Eric Wesoff, “AES Launches Asset-Backed Securities Based on Portfolio of Distributed Solar Generation,” Greentech Media, September 25, 2015, http://www.greentechmedia.com/articles/read/AES-Launches-Asset-Backed-Securities-Based-on-Portfolio-of-Distributed-Sola.

186 Travis Lowder and Micheal Mendelsohn, “The Potential of Securitization in Solar PV Finance,” National Renewable Energy Laboratory, December 2013.

187 Harnessing Energy From The Sun: Empowering Rooftop Owners,” International Finance Corporation, 2014, http://www.ifc.org/wps/wcm/connect/8bb2a280479cb7248b0fff299ede9589/Harnessing+Energy+From+The+Sun_Final.pdf?MOD=AJPERES.

188 Akhilesh Magal, Tobias Engelmeier, and George Mathew, “Grid Integration of Distributed Solar Photovoltaics in India,” Prayas Energy Group, 2014, http://www.ncpre.iitb.ac.in/uploads/PEG_grid_integration_dist%20PV_2014.pdf.

189 Colin Schauder, “Advanced Inverter Technology for High Penetration Levels of PV Generation in Distribution Systems,” National Renewable Energy Laboratory, 2014, http://www.nrel.gov/docs/fy14osti/60737.pdf.

190 Ankur Trehan, Brinda Ganguly, Gauri Singh, Jessica L. Long, Mark Kenber, Namita Vikas, Pankaj Agarwal, and Uday Khemka “The Business Case for Off-grid Energy in India,” Climate Group, Goldman Sachs, 2015.

191 Ankur Trehan, Brinda Ganguly, Gauri Singh, Jessica L. Long, Mark Kenber, Namita Vikas, Pankaj Agarwal, and Uday Khemka “The Business Case for Off-grid Energy in India,” Climate Group, Goldman Sachs, 2015.

192 Christian Roselund, “India surpasses 4 GW of installed solar PV,” September 4, 2015,

193 http:// www.pv-magazine.com/ news/ details beitrag /india-surpasses-4-gw-of-installed-solarpv_100020939 /#axzz3o5b7v3RU.

194 Government of India, “Progress Report of Village Electrification, May 2015.

195 Ministry of New and Renewable Energy, “Strategic Plan for New and Renewable Energy Sector for the Period 2011-2017,” February 2011.

196 “Current Status of Rural Electrification and Electricity Service Delivery in Rural Areas of India,” Vashudha Foudation, 2013.

197 “Phase I of the NSM: Has It Made Off-grid Solar Affordable?” Renewable Energy Working Group, 2014, http://www.selcofoundation.org/wp-content/uploads/2014/04/FinancingReview_NSM.pdf.

198 Ankur Trehan, Brinda Ganguly, Gauri Singh, Jessica L. Long, Mark Kenber, Namita Vikas, Pankaj Agarwal, and Uday Khemka “The Business Case for Off-grid Energy in India,” Climate Group, Goldman Sachs, 2015.

199 "Affordable Pay-As-You-Go Solar Power for India's Energy-Poor Homes," Asian Development Bank, no. 48, August 2013.

200 Ankur Trehan, Brinda Ganguly, Gauri Singh, Jessica L. Long, Mark Kenber, Namita Vikas, Pankaj Agarwal, and Uday Khemka "The Business Case for Off-grid Energy in India," Climate Group, Goldman Sachs, 2015.

201 NSM: Recommendations for nascent markets, "Ecosystem Creation for Off-grid Solar: Achieving Diffusion Across India," Renewable Energy Working Group, December 2012.

202 U.S. Agency for International Development, "Developing Effective Networks for Energy Access," August 2013.

203 "India's ambitious off-grid solar targets achievable," Business Standard, February 11, 2015, http://www.business-standard.com/article/news-ians/india-s-ambitious-off-grid-solar-targets-achievable-comment-special-to-ians-115021100165_1.html.

204 "Why mobile money has failed to take off in India," Leo Mirani, Quartz, June 19, 2014, http://qz.com/222964/why-mobile-money-has-failed-to-take-off-in-india/.

205 U.S. Agency for International Development, "Developing Effective Networks for Energy Access," August 2013, http://ceew.in/pdf/an_analysis_on_developing_effective_networks_for_energy_access.pdf.

206 Richard Martin, "India, Solar Technology, and the Monkey Problem," Energy News, August 7, 2015, http://www.technologyreview.com/news/540016/india-solar-technology-and-the-monkey-problem/.

207 Natalie Obiko Pearson, "Cheap Electricity for Poor Squeezing Out Solar in India," Bloomberg Business, November 19, 2014, http://www.bloomberg.com/news/articles/2014-11-19/cheap-electricity-for-poor-squeezing-out-solar-in-india.

208 PR Krithika and Debajit Palit, "Review of Alternative Participatory Business Models for Off-grid Electricity Services," OASYS South Asia, 28 March 2011.

209 Natalie Obiko Pearson, "Cheap Electricity for Poor Squeezing Out Solar in India," Bloomberg Business, November 19, 2014, http://www.bloomberg.com/news/articles/2014-11-19/cheap-electricity-for-poor-squeezing-out-solar-in-india.

210 Forum of Regulators, "Model Draft Guidelines for Off-Grid Distributed Generation and Supply Framework," 2012, http://www.forumofregulators.gov.in/data/homepage/5.pdf.

211 Natalie Obiko Pearson, "Cheap Electricity for Poor Squeezing Out Solar in India," Bloomberg Business, November 19, 2014, http://www.bloomberg.com/news/articles/2014-11-19/cheap-electricity-for-poor-squeezing-out-solar-in-india.

212 James Crabtree,"Modi to axe India's diesel subsides," Financial Times, October 19, 2014, http://www.ft.com/intl/cms/s/0/26de2f22-573a-11e4-a45c-00144feab7de.html.

213 "Fossil-Fuel Subsidy Reform in India: Cash transfers for PDS kerosene and domestic LPG, The Energy and Resources Institute University, August 2012.

214 Evan Mills, "Lifting the Darkness on the Price of Light," United Nations Environment Program, 2014, http://global-off-grid-lighting-association.org/wp-content/uploads/2015/01/Lifting-the-Darkness-Effects-of-Fuel-Subsidies.pdf.

215 Shuba V. Raghavan, and K. Subramanya, "Decentralized Energy Generation Extending Access at What Price, Economic and Political Review 49, no. 29, July 19, 2014.

216 U.S. Agency for International Development, "Developing Effective Networks for Energy Access," August 2013.

217 "SF and Responsibility Launch New Financial Vehicle to Scale Off-grid Energy Enterprises, Shell Foundation, 2015, http://www.shellfoundation.org/Our-News/SF-Co-creates-Energy-Access-Fund.

218 Madhavan Nampoothiri, "Policy & Regulatory Enablers for off-grid solar PV growth in India," Resolve Energy Consultants, Solarcon India, 2012, http://www.slideshare.net/re-solve/policy-regulatory-enablers-for-offgrid-solar-pv-growth-in-indiamadhavan-nampoothiri.

219 NSM: Recommendations for nascent markets, December 2012.

220 Solar Energy Research Institute for India and the United States, August 31, 2015, http://www.seriius.org/.

221 Vaishalee Dash "India's Ambitious Off-grid Solar Targets Achievable," Yahoo News India, November 2, 2015, http://www.cstep.in/uploads/default/files/pressroom/stuff/5e7aecf4d2481c7ee494b630534a01b9.pdf.

222 Debajit Palit and Sangeeta Malhotra, "Energizing rural India using micro grids: The case of solar DC micro-grids in Uttar Pradesh State, India," The Energy and Resources Institute, 2015.

223 Jim Sinopoli, "Using DC power to save energy—and end the war on currents," Greenbiz, November 15, 2012, http://www.greenbiz.com/news/2012/11/15/using-dc-power-save-energy-end-war-currents.

224 Debajit Palit and Sangeeta Malhotra, "Energizing rural India using micro grids: The case of solar DC micro-grids in Uttar Pradesh State, India," The Energy and Resources Institute, 2015.

225 "Renewable energy-based rural electrification: The mini-grid experience from India," Global Network on Energy for Sustainable Development, 2014.

226 "Identifying the gaps and building the evidence base on low carbon mini-grids," United Kingdom Department for International Development, 2013, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/278021/IED-green-min-grids-support-study1.pdf.

227 "Roadmap for demand aggregation of LED lighting," Pricewaterhouse Coopers, 2013. http://shaktifoundation.in/wp-content/uploads/2014/02/LED-Demand-Aggregation-Roadmap.pdf.

228 Sheoli Pargal and Sudeshna Ghosh Banerjee, "More Power to India: The Challenge of Electrcity Distribution," The World Bank, 2014, https://openknowledge.worldbank.org/bitstream/handle/10986/18726/889060PUB0978100Box385252B00PUBLIC0.pdf?sequence=1.

229 Matt Chambers and Roy Ellis, "Risk-based asset replacement," Ernst & Young LLP, 2012, http://www.ey.com/GL/en/Industries/Power---Utilities/Plug-in---Risk-based-asset-replacement.

230 Simon Harvey, Dale Williams, Ian de Snoo, and Nick Mountcastle, "Operational Transformation in the Power & Utilities Sector, KPMG LLP, November 2012.

231 "Energy Management: Can Utilities Seize the Opportunity?," A.T. Kearney, 2012.

232 The Regulatory Assistance Project, "Best Practices Guide: Implementing Power Sector Reform," The Energy Group Institute of International Education, 2000.

Stanford Steyer-Taylor Center for Energy Policy and Finance

Stanford Law School
Crown Quadrangle
559 Nathan Abbott Way
Stanford, CA 94305
650-723-2465
steyer-taylor@stanford.edu

steyertaylor.stanford.edu