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India's Solar Energy Boom: Hits and Misses

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SYNOPSIS

India has made firm pledges to reduce its greenhouse gas emissions by 2030 and achieve net zero by 2070. Among a potpourri of strategies, the mass deployment of renewable energy will have an impact across sectors. Solar energy is one of the most feasible options due to the abundant availability of resources, market acceptance, strong manufacturing capacity, and robust policy tools that encourage adoption. Many states in India have seen success in solar for decades, and India's solar energy sector is scaling borders towards international success. However, several challenges show that solar energy may not be India's Holy Grail for decarbonisation.

KEY POINTS

- Renewable purchase obligation, subsidies and free maintenance for rooftop solar PV, and price decline encouraged the deployment of solar PV in India.
- Transmission development lags behind renewable energy deployment, causing disruptions in renewable electricity supply.
- Institutional and political instabilities prevent solar energy from attaining fruition at a national level, and economic priorities result in demand and supply challenges affecting local uptake.

INTRODUCTION

In the early 2000s, a sense of energy insecurity ensued as India's reliance on imported energy sources, especially oil, increased. India began diversifying its energy sources, and the government encouraged using solar energy as an alternative source. The National Solar Mission (NSM) was launched in 2010 by the Manmohan Singh government, and this trickled down to state-level policies that pushed for on-ground implementation. The NSM target was set to 20 GW by 2022, but in 2014, the subsequent Narendra Modi government expanded this target to 100 GW by 2022. The NSM resulted in diverse policies that advanced on-grid and off-grid solar at a mass scale. Over the years, the price of solar has dropped lower than that of fossil fuels, and urban and rural populations have embraced access to affordable electricity. This sowed the seeds of a booming manufacturing sector for solar infrastructure and components.

However, different state machinery, geographical contexts, and market acceptance levels have led to uneven uptake of solar in each state. To address this issue and facilitate nationwide solar deployment, India needs more robust and integrated policies to tie up loose ends and scale impact. More state collaboration, integration of allied policies, and responses to market needs are imminent.

ANALYSIS

Large-Scale Solar Implementation

The power sector distributes electricity to end-users through private or public utilities, known as Distribution Companies (DISCOMs). The National Tariff Policy tapped into this network for the penetration of solar energy into the power sector. It established Renewable Purchase Obligation (RPO), under which DISCOMs are mandated to purchase a minimum percentage (10.5% as of 2021) of solar in their distribution mix. DISCOMs facing difficulty meeting the RPO target by procuring renewable electricity are allowed to purchase Renewable Energy Certificates (RECs) to cover deficits. State Electricity Regulatory Commissions (SERCs) issue the RECs and can

incentivise or penalise a distribution licensee on their renewable energy (RE) purchase performance. SERCs can also provide cheaper RECs to DISCOMs that experiment with new or innovative technologies while charging higher to those that use out-of-date technologies. The RPO scheme has far-reaching impacts, as it influences the procurement behaviour of DISCOMs across sectors, including residential, commercial, industrial, and transport, by mandating a renewable energy purchase mix among distributors.

However, the Indian RPO scheme has been criticised for not being ambitious enough. The targets set at the state level are often low, and DISCOMs simply purchase RECs to meet targets. The REC prices set by SERCs are low due to an oversupply of RECs. Despite these favourable conditions for DISCOMs, many states are still non-compliant with the 10.5% target. DISCOMs take a 'wait and see' approach due to concerns over price volatilities, intermittency of RE, and the need for infrastructure upgrades. Therefore, the RPO scheme has not pushed DISCOMs to go beyond. DISCOMs are financially weak and are often unable to decarbonise as they are stuck in a cycle of debt. For example, the Maharashtra State Electricity Distribution Company Limited (MSEDCL) entered into long-term Power Purchase Agreements (PPAs) with the Maharashtra State Power Generation Co. Ltd., which still operates inefficient and obsolete thermal equipment at high variable costs. Despite the cost of this thermal energy being higher than solar energy in Maharashtra, MSEDCL is forced to honour the PPA and is unable to diversify due to its poor financial situation.

Another programme that accelerated solar deployment is the Rooftop Solar (RTS) programme under the Electricity (Rights of Consumer) Rules. Through net-metering options, households and building owners can function as 'prosumers' producing their electricity while interacting with the public grid to send or buy electricity based on availability and needs. Potential prosumers can apply for a subsidy or central financial assistance to set up solar panels on their rooftops and avail of free maintenance services for several years. The RTS programme is a clear example of how policy initiatives can have different outcomes in different states. Excitement from the market and greater involvement from the public resulted in the programme flourishing in Gujarat to the extent that it houses India's first village that operates on ground-mounted solar and RTS during the day and uses battery energy storage at night. By contrast, the state of Tamil Nadu, with similar solar irradiance and enabling policies, did not receive as much traction for RTS. This was largely due to the public's financial conservatism, as they were hesitant to invest in new technologies that require long periods to yield profits.

The fall in solar prices has aided DISCOMs and end-users in purchasing more solar energy. In addition to the usual feed-in tariff, the National Tariff Plan introduced competitive bidding to encourage utilities to provide consumers with RE at affordable prices. To ensure a stable supply of energy and foster trust among utilities, PPAs have been set up between the Solar Energy Corporation of India and solar energy generators for 25 years. Over the years, the solar energy market in India flourished, with greater private investments and a robust supply chain. The falling costs of solar photovoltaic technology and supportive policies that subsidise capital costs created a greater economy of scale in India. As a result, the levelised cost of energy (LCOE) of solar declined even below that of coal. In the amendment of the Electricity (Rights of Consumer) Rules, Time of Day (ToD) tariffs were included, wherein the electricity price is lower by at least 20% during solar hours. This applies to all end-users, from residential to industrial consumers, and maximises the use of solar energy. This also encourages and enables DISCOMs to meet their RPO targets.

Global Leadership in Solar

Energy security is a critical component of India's decarbonisation goals. To mass solarise the country, India needs to ramp up local capacity. India has historically been a manufacturing-based economy, and through governmental push, manufacturers benefitted from setting up industrial production of solar modules. India has made significant strides towards self-reliance in solar module manufacturing, but it is still highly dependent on imports for components, including ingots, wafers, and cells. The Product Linked Incentive

scheme for high-efficiency solar PV modules grants subsidies for setting up local manufacturing capacity for solar components and modules. Furthermore, in 2022, India imposed a basic customs duty of 40% on the import of solar modules and 25% on solar cells. Such import duties enable greater demand for locally produced modules. In 2024, Adani New Industries Limited became the first company to begin commercial manufacture and sale of solar components including ingots and wafers of 2 GW. In addition to reducing import dependence, these taxes enable Indian manufacturers to bolster production and compete with global markets. Especially with global geopolitical tensions such as the United States' sanctions on Chinese solar imports, India can emerge as an alternative market. Indeed, exports to the United States and Europe are increasing as importers in these countries also get better and competitive prices for their sales. While catering to export demands presents an immense potential for economic growth, India also needs to ramp up production and strengthen its supply to meet local needs. Currently, India suffers a significant shortage in the availability of solar modules as demand exceeds supply.

Social Development Through Solar

Not every household in India has access to an uninterrupted, stable supply of electricity. Grid integration in remote, mountainous areas has been challenging due to economic and logistical difficulties in laying and maintaining infrastructure. Solar energy was a realistic response to address energy poverty in India. The NSM launched the Off-grid and Decentralised Solar PV Applications Programme to advance off-grid solar technologies in homes and public places. Households got access to home lighting systems such as solar lanterns and lamps, and battery-backed solar street lights and light trees were set up to illuminate public spaces at night. Off-grid solar parks were established at public institutions like schools and police stations. Women and children living in rural villages experienced greater safety at night, and neighbours could sit together and interact as a community around solar trees during outages. Under the Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) scheme, rural households in hard-to-reach areas were provided with solar power packs consisting of LED lights, battery storage, DC fans, and power plugs. Solar micro grids within smaller geographical areas have provided access to greater stability in power supply and enabled critical everyday activities to carry on without disruption, even after dark. It has contributed to better health, education, and quality of life.

However, after the first few years, communities have experienced erratic power supply, frequent shutdowns, and defunct micro grid systems. This pattern is common across policy implementation in India, wherein initiatives are undertaken to appease communities without strong follow-ups and monitoring mechanisms. Due to the lack of maintenance, poor response from authorities, and bureaucracy, communities often switch back to diesel generators for electricity.

Transmission and Evacuation Systems

The Green Energy Corridor (GEC) Programme began in 2012 to establish transmission networks connecting RE-rich regions with the national grid. So far, the national grid has been synchronised into a single AC grid and operates on the same frequency. At the interstate level, HVDC transmission lines are needed to evacuate large amounts of power over long distances. Commissioning these projects takes 3-5 years, while RE projects take only about 1-2 years. There are severe delays in the GEC programme due to challenges such as land acquisition and right of way. These land-related issues include topographical challenges such as forests, water bodies, and highway and railway crossings in the chosen locations. The Leh-Kaithal interstate GEC has already begun planning, but the project itself will start work only in 2026. Such a high-altitude mega-project across the Himalayan Mountain region requires extensive HVDC transmission lines and HVDC terminals for synchronisation. It necessitates substantial engineering studies and planning, and perhaps a longer time for implementation. Meanwhile, under the Electricity Act 2003, the utility is required to pay compensation to private landowners for disruptions caused to their land for laying transmission lines as well as operations and maintenance. It also needs to convince and compensate farmers to cooperate and sometimes choose shorter crops that do not disrupt overhead electrical lines. Navigating these challenges with

multitudes of people, authorities, and stakeholders, obtaining permissions, and clearing paperwork is highly time-consuming and cumbersome.

As the pace of grid strengthening is not happening at the pace of RE deployment, there have been several delays and disruptions in RE projects. Additionally, the grid itself cannot promise stability with the pace at which India is expanding its RE capacity. While the centre needs to strengthen its planning to match the pace of RE expansion, state utilities also need to cooperate and meet the timelines set for establishing transmission lines.

Learnings for Singapore

India's solar experience highlights key lessons for Singapore. First, its success with rooftop solar shows the importance of strong financial incentives, public engagement, and streamlined regulations. Singapore can apply these factors to enhance and accelerate RTS adoption. Second, India's solar manufacturing push through subsidies and tariffs strengthened energy diversification and created a strong market. While large-scale production is not feasible in Singapore, investing in high-value areas like energy storage and smart grids can strengthen supply chains. Singapore can also invest in research and development on advanced solar technologies, localised to Singapore's context to lower costs and achieve feasibility at scale. Third, India's delays in transmission infrastructure development have slowed RE integration. Singapore should ensure that its grid is prepared for higher solar penetration, leveraging smart grid technologies to prevent inefficiencies. Fourth, India's policy gaps reveal that integrated planning across government agencies is critical. Singapore can refine policies by aligning solar initiatives with urban planning, transport electrification, and regional energy collaboration to maximise impact. Finally, Singapore may position as a clean energy hub for ASEAN by focusing on technology innovation, energy financing, and regional project development. It is important to strengthen clean energy diplomacy through initiatives like the Green Economy Agreement with regional partners.

CONCLUSION

Through large-scale solar implementation, India has achieved a multitude of positive impacts, such as social development, economic growth, and global trade leadership. This puts the country at a strategic advantage for the accelerated development of solar generation and industry. But, for its solar policies to fully attain fruition, a systemic rewiring of the institutional and political machinery is critical. Monitoring systems are needed to ensure accountability of policy delivery. Policy design requires an all-encompassing view of other policies already in place, risks of implementation, and challenges in delivery at local levels. Currently, national policies function in silos without much communication with other relevant policies and on-ground realities. More significant synergies within the institutional system, public consultations, and innovative monitoring systems like appointing ombudspersons, would tie up loose ends and make India's efforts towards solar deployment more realistic and impactful.

WHAT TO LOOK OUT FOR

- India's greater manufacturing capacity for solar cell components and increasing participation in the export market.
- Increase in attractive state policies that push for the uptake of rooftop solar, especially in solar-rich states.
- Entry/growth of heavily invested private distribution companies that distribute more renewable energy, especially solar.

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