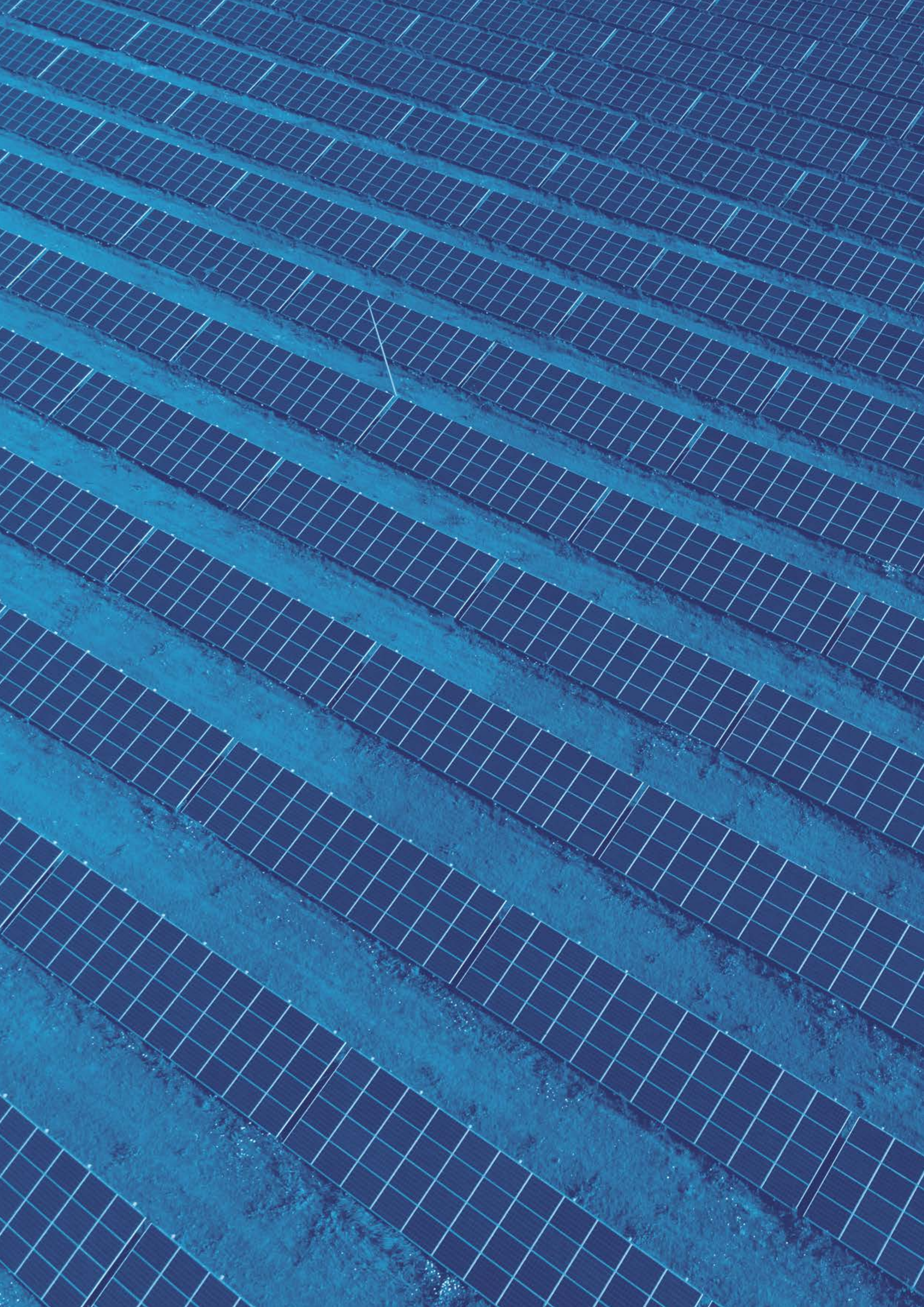
LSI FINANCIAL SERVICES

The Indian Solar Power Landscape

Aiding the energy push towards net zero



Executive Summary

Majority of primary energy embodies fossil fuel which posits intergenerational injustice and hence the adoption of renewable energy is ineluctable to reach the Sustainable Development Goals.

Countries across continents have equivalent growth rate in the production and consumption of Renewable energy. USA being the second highest polluter of Carbon is pioneering in the production of renewable energy. Sweden's transition to low carbon economy is remarkable. Among African and Asian countries, South Africa and China top the list. **India is the second largest producer of renewable energy followed by Japan.**

Government of India is targeting a transition from traditional to electronic vehicles by 2025 which will lead to the unavoidable consequence of electricity generation through thermal sources. Hence, adoption of renewable energy in electricity generation is imperative.

As of 2022, amongst all the installed capacities of renewable energy sources in India, solar power has the most potential followed by Wind and Large Hydro. But the consumption from hydro has been perpetually high.

In Paris COP, 2015, India has pledged a target of installing 175 GW of renewable energy of which 100 GW is targeted from solar energy by 2022. In spite of having a target deficit of 35.62 GW of solar capacity, the country has set a new target of installing 500 GW of renewable energy capacity of which 270 GW will be sourced from Solar energy.

The various types of solar power technology are Low temperature solar thermal, solar electric or photovoltaic and high temperature solar thermal. Concentrating Solar Power (CSP) Technology provides consistent supply of electricity with least carbon emission than Solar Photovoltaic (SPV) technology but CSP industry faces certain restrictions in terms of capital investment and operational cost.

An empirical analysis through Multiple Linear Regression Model has been conducted to understand how the institutional, infrastructural and financial indicators influence the deployment of solar capacities in India both at large scale and distributed scale.

NSDP, solar potential, structural policy variables like SPC, RPO and REC, population growth, Annual Per Capita Consumption of Electricity (APCE), Ease of Doing Business Index (EODBI) and Share of Renewable Energy in Electricity Generation (SRGE) are found to influence Large-Scale Solar Deployment positively. While Share of Transmission and Distribution Loss in Gross Electricity Generated (STDLGE) and Electricity tariff are causing negative effect on large scale deployment.

NSDP, Power Requirement, Share of Renewable in Electricity Generation (SRGE), Solar Potential, policy variable RPO, APCE, Average Electricity Tariff, Population growth and TDL have positive relation with Distributed-Scale solar deployment. While, number of REC purchased, power availability and Ease of Doing Business are negatively affecting deployment of Distributed-Scale solar.

The State wise performance analysis of large-scale solar deployment depicted that Rajasthan is outperforming in deployment with 34.8% above the National Predicted Average (NPA) followed by Karnataka and Gujarat. Among the bottom performing states, Meghalaya has maximum negative deviation of -56.1 % from NPA followed by Nagaland, Mizoram and other North-eastern States.

An in-depth analysis through Random Forest Model has been executed to understand the fundamentals of top five and bottom five states based on the above-mentioned indicators.

Growth and productivity dynamics of solar power in India have been shown through various graphs.

The long run behaviour of carbon emission during 1966-2020 is observed and forecasted period till 2030 has been studied incorporating the impact of solar power. Compounded Annual Growth Rate (CAGR) of the forecasted growth rate of carbon emission excluding the impact of solar power is accelerating while CAGR of the forecasted growth rate of carbon emission including the impact of solar power is found to be decelerating.

Climate change is an important factor which affects the investment portfolio and calls for capital flow towards green projects and away from brown industries. Climate risk is well assessed by ESG (Environmental, Social and Governance) scores, which identifies how well companies manage environmental risks.

A correlation analysis has been conducted based on ESG scores of different Renewable power manufacturers and their investment amounts. The result suggests negative association between the two because companies with high ESG scores are more exposed to ESG risks and any amount of their investment level is not considered as responsible investment behaviour.

Climate finance approach in India moves in three priority zones-Resilient cities, Energy and Agriculture. The country's climate finance roadmap to 2030 suggests key areas of investment like Renewable energy, Sustainable Food, Resilient Cities, Generation Efficiency, Demand Efficiency and Electric Transport.

Solar power is supposed to be the biggest game in climate town in India. By 2030, 280 GW of solar energy capacity is expected which is 7 times greater than the current level.

Currently **share of renewable energy in primary energy supply is 2.08% in India.**

In India, as of 2021 **share of solar power in the electricity grid capacity is 12.43% and share of solar power in electricity generation is 3%.**

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Chapter 1

Solar Energy- Overview & Market Scenario in India

About Solar Energy

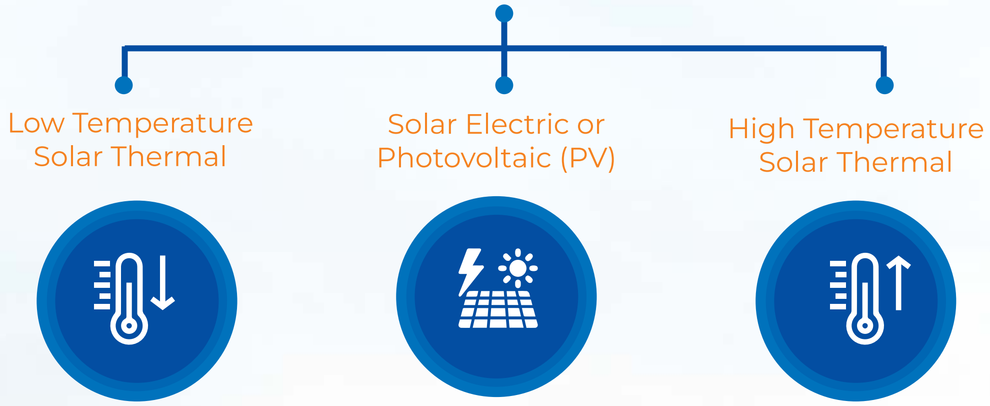
Global economy is currently facing the twofold challenge of fulfilling the growing energy demand and, reducing the green-house gas emission and improve energy efficiency. The singular approach to make the situation conducive and meet both the ends is usage of renewable energy. One of the ways to reduce the carbon emission and improve efficiency of the energy system is by increasing the share of renewable energy in generating electricity.

Taking into consideration the twofold objectives of sustainable future and reducing serious impacts of climate change, especially global warming, developing countries are urgently shifting from traditional energy sources to renewable energies. One of the most competitive choices of all the form of RE is ***"The Solar Energy"***, it is abundant, free and non-polluting.

Solar energy is the primitive most energy on the planet earth is being derived from Sunlight. Most of the renewable energy on earth are derivatives of solar energy, to mention, hydropower comes from falling water, which occurs because solar energy evaporates water at low elevations that later rains on high elevations. The sun also creates wind through differential heating of the earth's surface. Biomass energy comes from plant matter, produced in photosynthesis driven by the sun.

Solar energy can be directly used for heating purposes and generating electricity

Solar energy comes in three different forms



1. Application of Low Temperature Solar Thermal:

Comprising of **solar water heating and solar space heating**, works when sunrays strike the surface, usually black in colour for the purpose of maximum solar absorption which in turn will heat the air or water. The absorbing surface usually are coated with a shiny protective layer, is of the use to retain the heat. High-mass materials like water or stone are used for the storage of solar heat. Low temperature solar energy typically uses simple and proven technologies.

Both solar water heating and space heating is financially competitive with fossil fuels. But a demand-supply challenge is faced with solar space heating, because the direction of demand and supply are in opposite direction i.e., the demand gets generated in the winter season when the supply of sunlight is low and during summers when supply is more there is very less demand for solar space heating, excepting in few regions where summers are not that warm. ***In practice this means that solar space heating systems almost always require some supplemental heat source, since the marginal cost of gathering solar energy in the depths of winter is extremely high.*** Supplemental heating adds to the cost of solar heating systems.

2. Application of Solar Electric or Photovoltaic (PV):

Another usage of solar energy is producing electricity. When sunlight strikes **Photovoltaic (PV)** cells, semiconductor materials are employed to generate flow of electricity. The respective technology is well developed and reliable, but it comes at a very high relative cost compared to the existing fossil fuel sources for generating electricity. But currently the cost of PV is falling compared to the past and is projected to fall further. To make the price competitive with respect to the existing fossil sources government and respective institutions have to design appropriate pro market policies.

The space required for solar PV is significant. Solar cells are typically mounted in modular panels, which are installed in arrays that can be ground, pole, or roof mounted. Arrays range in size from a few panels on a rooftop, to a roof made entirely of solar panels, to a field of many acres covered by panels. Supplying much of society's electricity from solar PV would require a considerable, though not insurmountable, amount of space.

3. Application of High Temperature Solar Thermal:

High Temperature Solar Thermal is used to generate electricity or to provide process heat to industrial application. The installation has a mirrored surface on which the sun rays are concentrated. The concentrated sunlight is directed to a point where the energy is absorbed and passed to a transfer medium such as oil. High temperature oil then makes steam to generate electricity in conventional turbines. Though such systems are more complex than solar PV, with many moving parts, on a large scale they may produce electricity less expensively than PV in some locations. Long run cost of this method of generating electricity is not in widespread use and so prediction about the long run cost is ambiguous.

Solar Power Generation Technology and Process

Solar Power is the generation of electricity from sunlight. The technology of solar power generation can be classified into:

- Solar Photovoltaic Plant (SVP)
- Solar Thermal Power Plants or Concentrating Solar Power (CSP)

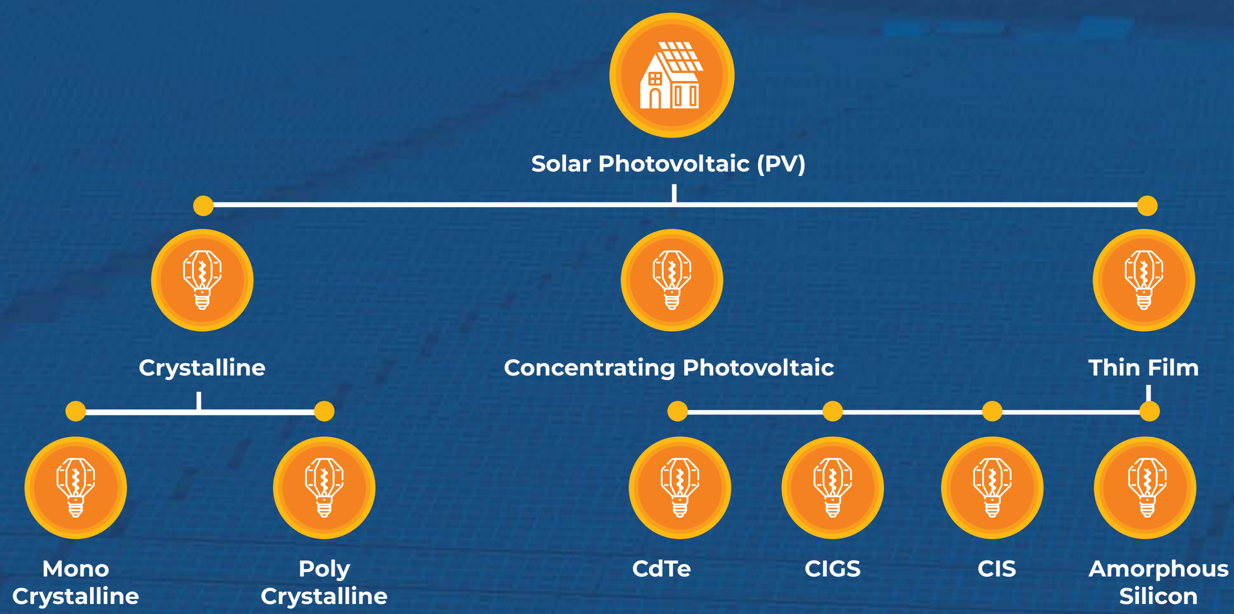
i) Overview of Solar Photovoltaic (PV)

A solar photovoltaic cell is a solid-state device that receives the solar radiation and convert it into electric current using the photo electric effect. The device is composed of thin layers of semiconductor material which produces electric current when it receives sun-light. Power generation happens through solar panels which contains photovoltaic materials. Materials presently used for photovoltaic include mono-crystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium selenide/sulphide. Due to the growing demand for renewable energy sources, the manufacture of solar cells and photovoltaic arrays has advanced considerably in recent years.

Another method of generating power from sun is concentrating photovoltaics (CPV). Electricity is generated in CPV systems by employing sunlight concentrated onto photovoltaic surfaces.

Solar concentrators of all varieties may be used, which are often mounted on a solar tracker in order to keep the focal point upon the cell as the sun moves across the sky. Tracking can increase flat panel photovoltaic output by 20% in winter, and by 50% in summer. There are many competing technologies, including at least fourteen types of photovoltaic cells, such as thin film, mono-crystalline silicon, polycrystalline silicon, and amorphous cells, as well as multiple types of concentrating solar power. Single cells are connected in groups to form a module, and modules are grouped to form an array. The voltage and the current output from the array depend upon how the system is configured.

The solar PV energy technology can be broadly classified into:



Monocrystalline silicon (c-Si)

It is single crystal wafer cell and tends to be expensive. Since modules are cut from cylindrical ingots, they do not completely cover a square solar cell module without substantial waste of refined silicon. Hence, most c-Si panels have uncovered gaps at the four corners of the cells. However, c-Si remains the preferred choice because of efficiency, longevity, lower installation cost and various other advantages.

Polycrystalline silicon or multi-crystalline silicon (poly-Si or mc-Si)

It is made from cast square ingots like large blocks of molten silicon carefully cooled and solidified. Poly-Si cells are less expensive to produce than single crystal silicon cells, but are less efficient as well.

Amorphous or Thin film

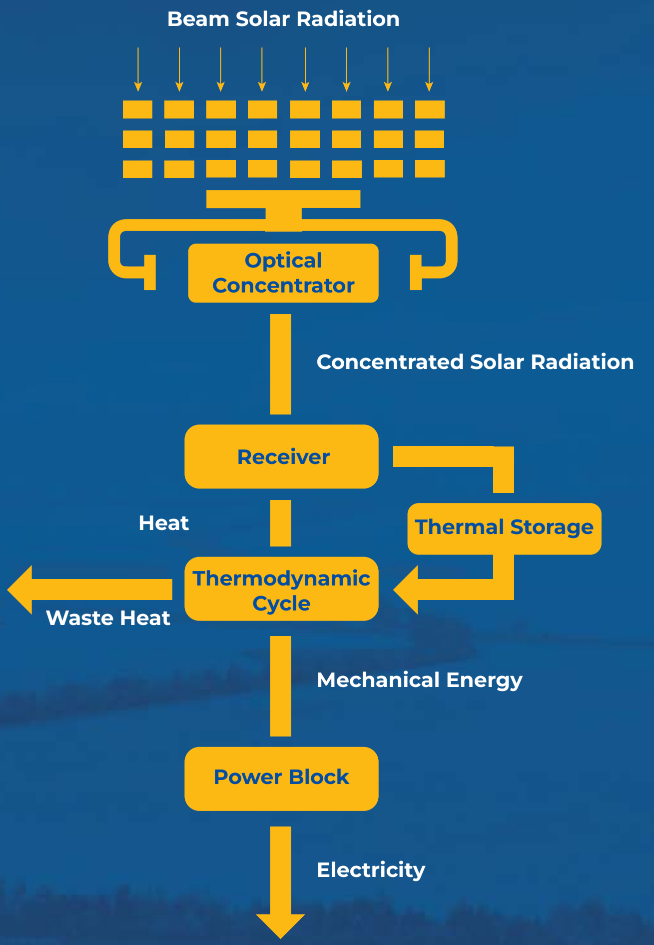
A thin film solar cell also called a thin film photovoltaic cell is a solar cell that is made by depositing one or more thin layers of photovoltaic material on a substrate. The thickness range of such a layer is wide and varies from a few nano-meters to tens of micro-meters. Thin-film technology reduces the amount of material required in creating the active material of solar cell. Most thin film solar cells are sandwiched between two panes of glass to make a module. Since silicon solar panels only use one pane of glass, thin film panels are approximately twice as heavy as crystalline silicon panels. The majority of film panels have significantly lower conversion efficiencies and lag silicon by 2-3%. Thin-film solar technologies have enjoyed large investment due to lower cost and flexibility compared to wafer silicon cells, but they have not become mainstream solar products due to their lower efficiency and corresponding larger area consumption per watt of production.

ii) Overview of Concentrating Solar Power (CSP)

Concentrating solar power systems employs lenses or mirrors and tracking systems to focus a large area of solar radiation into a small beam. Concentrated heat is then used to generate power.

The working methodology of CSP for generation of electricity is presented in Exhibit 1.1. Beam solar radiations are coming to the plate of optical concentrator, these joined together and become concentrated solar radiation, then move to the receiver. Now from this the receiver absorb the thermal energy of the solar radiation and then the absorbed thermal energy is being transferred by the working fluid which run the turbine-generator system. This will lead to the generation of the electricity.

Exhibit 1.1: Schematic Diagram of CSP



Concentrating solar power (CSP) is a large-scale, commercial way to generate electricity through solar energy. These technologies are appropriate for the areas where direct solar radiation and number of clear sunny days in the year are high. CSP systems produce heat or electricity using hundreds of mirrors/reflectors to concentrate the solar radiation to a temperature typically between 400 and 1000 1C. This thermal power triggers Rankine, Brayton or Sterling cycles and finally mechanical energy is converted in to electricity through an electric generator which is further injected in to the transmission grid. The major systems of CSP are concentrators/reflectors, receivers, power conversion system, thermal storage system (optional) and hybrid system (optional). Concentrator is the element which concentrates (concentration ratio 20–2000 times) incident direct solar radiation on a small area absorber. Its performance is measured by optical efficiency which depends on transmission, interception, absorption and shadowing in the path of direct solar radiation. The receiver or absorber tube generates thermal energy from collected direct solar radiation by the concentrators. The heat transfer fluid (HTF) flows through the solar receivers; which might be water, molten salts, synthetic oil, air, helium, nitrogen etc.

Different classes of CSP system:

Concentrating Solar Power (CSP)

- Parabolic Trough System
- Solar Power Tower
- Parabolic Dish System
- Linear Fresnel Reflector

Reciver Type	Description	Focus Type	
		Line Focus	Point Focus
Fixed	Fixed receivers are stationary devices that remain independent of the plant's focusing device. This eases the transport of collected heat to the power block.	Linear Fresnel Reflectors	Central Receiver System
Mobile	Mobile receivers move together with the focusing device. In both line focus and point focus designs, mobile receivers collect more energy.	Parabolic Trough Collectors	Parabolic Dishes

Concentrated Solar Power plant based on: Parabolic Trough; Solar Tower; Parabolic Dish; and Linear Fresnel Reflectors, all are discussed below respectively.

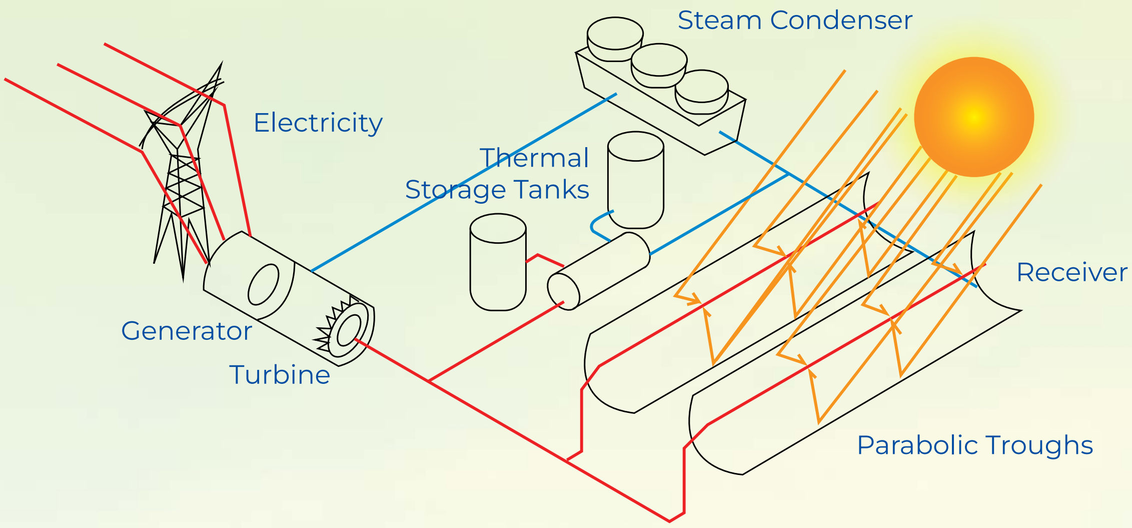
Parabolic Trough System

Parabolic Trough System (PTS) is comprised of parallel rows of mirrors (reflectors) curved in one dimension to focus the direct incidence of sun rays. The reflector is made to follow the Sun during the daylight hours by tracking along a single axis The mirror arrays can be more than 100 m long with the curved surface 5 to 6 m across. Stainless steel pipes (absorber tubes) with a selective coating serve as the heat collectors. The coating is designed to allow pipes to absorb high levels of solar radiation while emitting very little infra-red radiation. The pipes are insulated in an evacuated glass envelope. The reflectors and the absorber tubes move

in tandem with the sun as it crosses the sky. All parabolic trough plants currently in commercial operation rely on synthetic oil as the fluid that transfers heat (the HTF) from collector pipes to heat exchangers, where water is preheated, evaporated and then superheated. Alternatively mineral oil, water or molten salt can be used as HTF. The temperature of concentrated heat reaches to 400°C in case of synthetic thermal oil, 550°C in case of molten salt or 500 °C in case of pressurized water. The superheated steam runs a turbine, which drives a generator to produce electricity. After being cooled and condensed, the water returns to the heat exchangers.

Parabolic trough systems provide the best land-use factor of any solar technology. Parabolic trough systems are currently the most proven CSP technology and dominate the global market, being installed in 78% of the CSP plants in operation and under construction.

Exhibit. 1.2: Schematic diagram of parabolic trough system



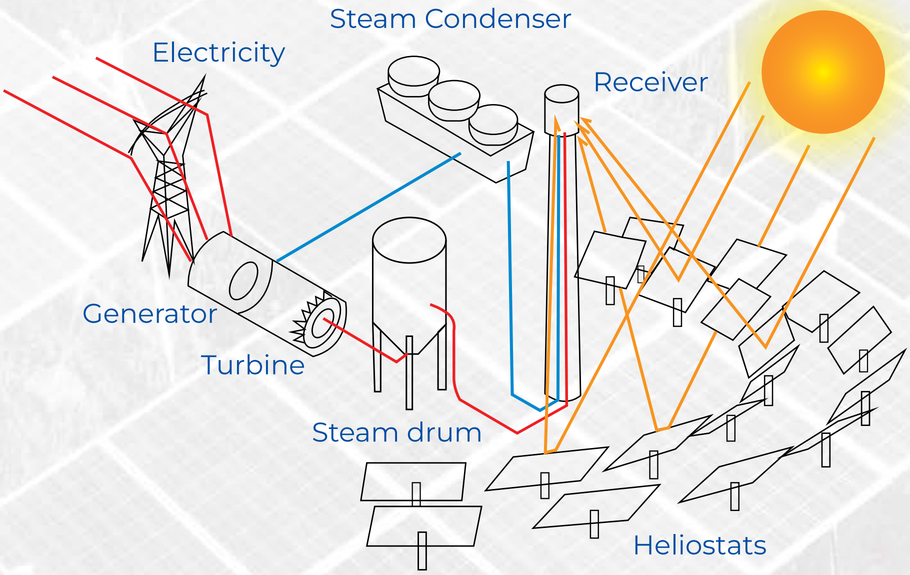
Source: Adapted from http://stem-works.com/external/cool_job/23

Solar Tower

Solar Tower also known as the Central Receiver System (CRS), consist of many reflectors/mirrors which are called heliostats. These heliostats are employed to concentrate the sun rays on a central receiver placed atop a fixed tower. Each heliostat has its own tracking mechanism to keep it focused on the tower to heat the transfer fluid, which is then used to run a turbine. Solar Tower plant uses Direct steam Generation (DSG) or molten salts as both the heat transfer fluid and storage medium. The HTF medium in this central receiver absorbs the highly concentrated radiation reflected by the heliostats and converts it into thermal energy, which is used to generate superheated steam for the turbine. The concentrating power of the tower concept achieves very high temperatures, thereby increasing the efficiency at which heat is converted into electricity and reducing the cost of thermal storage. If pressurized gas or air is used at very high temperatures of about 1000°C or more as the heat transfer medium, it can even be used to directly replace natural gas in a gas turbine, making use of the excellent efficiency (≥60%) of modern gas and steam combined cycles. In addition, the concept is highly flexible; designers can choose from a wide variety of heliostats, receivers, transfer fluids and power blocks.

The prime advantage of using this system is the opportunity to use thermal energy storage to raise capacity factors and allow a flexible generation strategy to maximise the value of the electricity generated, as well as to achieve higher efficiency levels. After Parabolic Trough system CRS is the most dominant class in CSP. The technology is cost effective and provides better storage capacity among the other CSP technology options. The key application of the solar power tower is to produce electricity, but it finds its place in providing process heat for several industrial applications.

Exhibit 1.3 Schematic diagram of solar tower or central receiver system



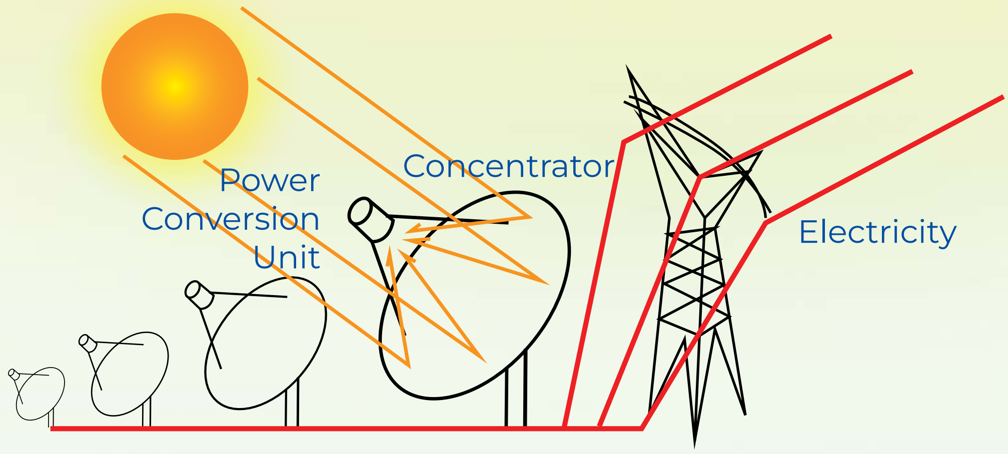
Source: Adapted from http://stem-works.com/external/cool_job/23

Parabolic Dish System

Parabolic mirrors are employed by a parabolic dish system (PDS). Parabolic mirrors are used to focus on incoming solar radiation on a receiver anchored above the dish at its focal point. The entire apparatus tracks the sun, with the dish and receiver moving in tandem. Most dishes have an independent engine/generator (such as a Stirling machine or a micro-turbine) at the focal point. The working fluid in the receiver is heated to 250–700°C and then used by a Stirling engine to generate power. This design eliminates the need for a heat transfer fluid and for cooling water. Dishes offer the highest solar-to-electric conversion performance of any CSP system.

The advantages of Stirling solar over photovoltaic cells are higher efficiency of converting sunlight into electricity and longer lifetime. Several features – the compact size, absence of cooling water, and low compatibility with thermal storage and hybridisation – put parabolic dishes in competition with PV modules, especially concentrating photovoltaics (CPV), as much as with other CSP technologies. Very large dishes, which have been proven compatible to thermal storage and fuel backup, are the exception. Promoters claim that mass production will allow dishes to compete with larger solar thermal systems. Parabolic dishes are limited in size (typically tens of kW or smaller) and each produces electricity independently, which means that hundreds or thousands of them would need to be co-located to create a large-scale plant. By contrast, other CSP designs can have capacities covering a very wide range, starting as low as 1 MW. The optimal size of troughs, LFR and towers, typically from 100 to 250 MW, depends on the efficiency of the power block.

Exhibit 1.4: Schematic diagram of parabolic dishes system



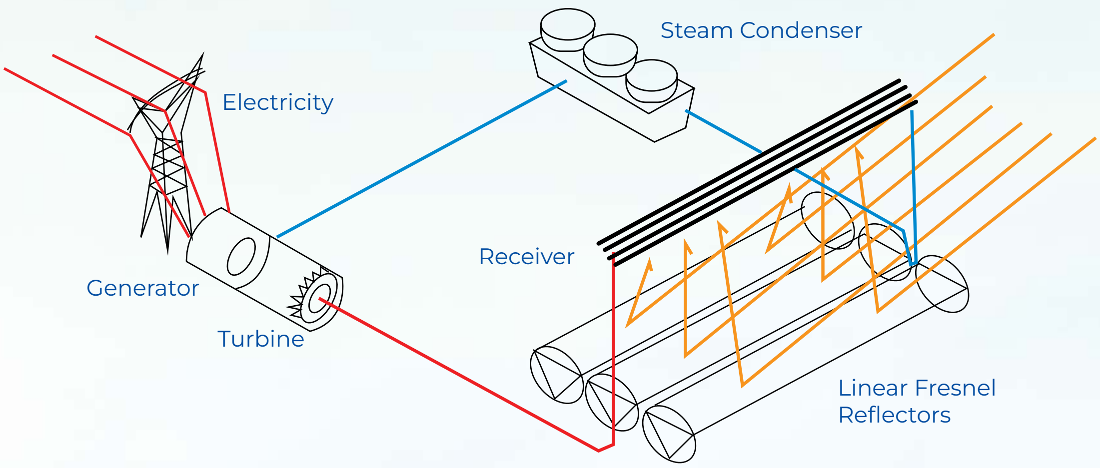
Source: Adapted from http://stem-works.com/external/cool_job/23

Linear Fresnel Reflectors

Linear Fresnel Reflector (LFR) system one axis tracking technology consists of fixed collector and elevated inverted linear fixed receivers. LFR approximate the parabolic shape of trough systems. The radiation is reflected and concentrated onto the fixed linear receivers propped over the long rows of flat or slightly curved mirrors. A more recent design, known as compact linear Fresnel reflectors (LFRs), uses two parallel receivers for each row of mirrors and thus needs less land than parabolic troughs to produce a given output.

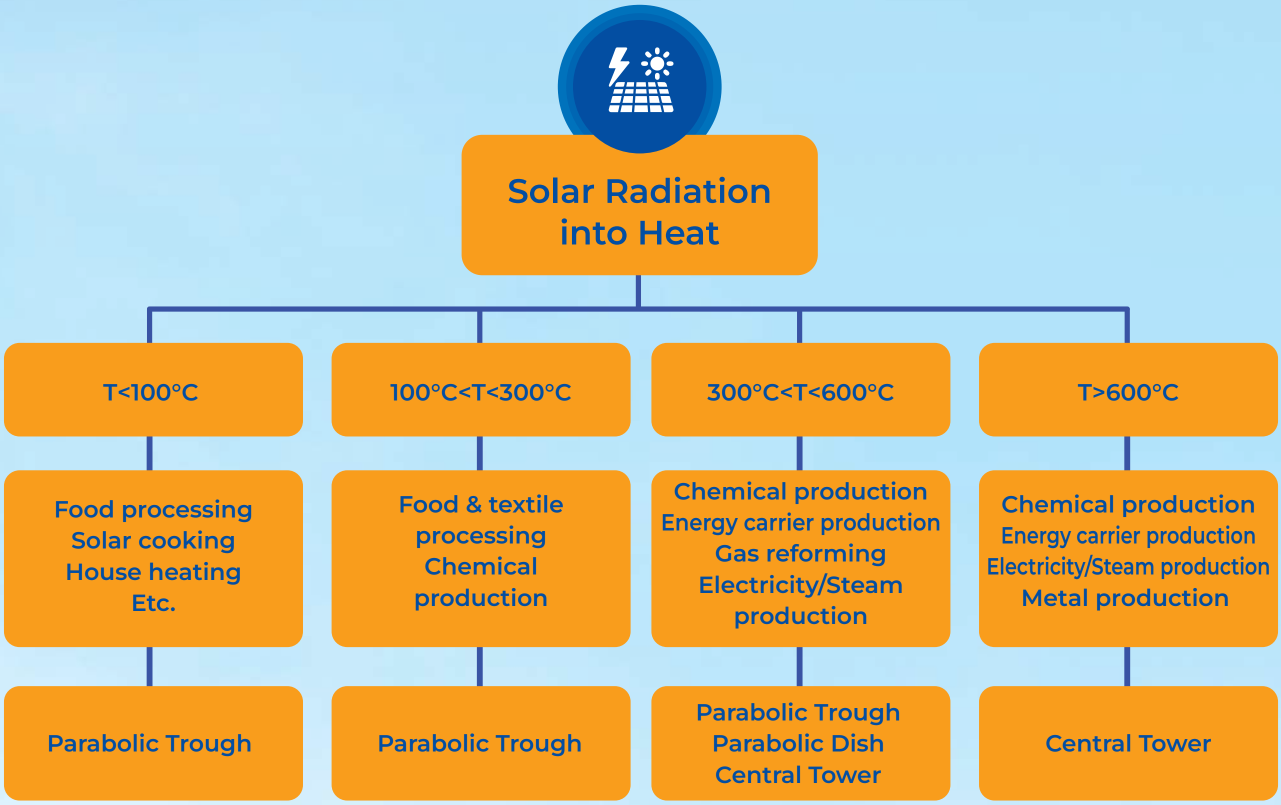
The key advantage of using LFR technology is the ability to use low-cost components arising out of simple design of flexibly bent mirrors and fixed receivers. The system enables direct steam generation and eliminates the requirement of heat transfer fluids and heat exchangers and saving cost there too.

Exhibit 1.5: Schematic Diagram of Linear Fresnel Reflector Power Plant



Source: Adapted from http://stem-works.com/external/cool_job/23

Exhibit 1.6: Applications of CSP technologies



Market Scenario of CSP and SPV

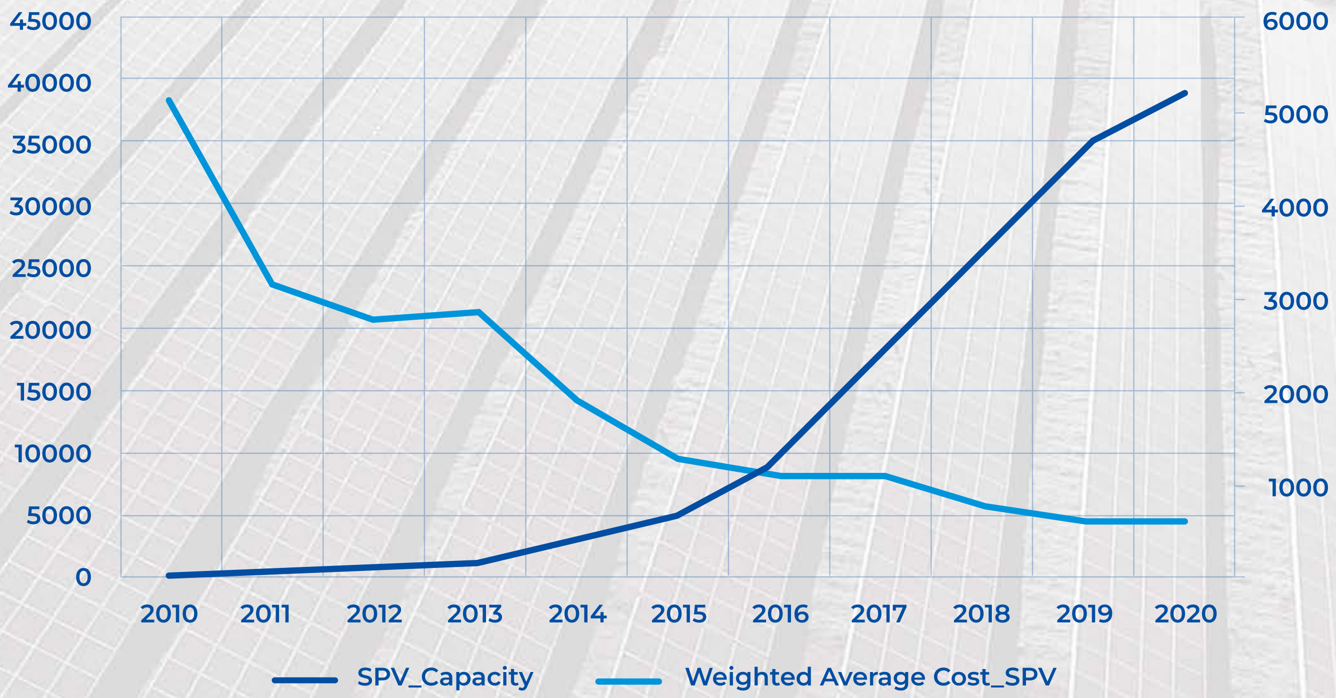
As per National Solar Mission in 2010, followed by Jawaharlal Nehru National Solar Mission (JNNSM) by Ministry of New and Renewable Energy (MNRE), Government of India has drafted a progressive long-term plan to attain an installed solar power generation capacity of 20,000 MW by the year 2020, which would be increased to 100,000 MW by the year 2030 and further to 200,000 MW by the year 2050. According to Paris Agreement in 2015, Government of India is striving hard to bring parity in solar power production

and thermal power generation by 2030. National Solar Mission also has the plan to gradually lower down the cost of solar power generation. Market incentives are provided in terms of solar power production and policy intervention with respect to infrastructure building has been initiated for solar power generation. Government is focussed on both the technology solar photovoltaic (SPV) and concentrated solar power (CSP).

Solar PV in context to India

Solar PV industry is changing briskly in tandem with the technology and policy changes happening in the global sphere. India too is adept in adapting the technology given the focus on environmental and sustainability goals on high priority in the policy agenda. Supply of energy to the industrial units and households is being continuously in realignment with the green energy where solar PV has a great potential with 300 sunny days. Capital cost associated with the installation of solar PV is very high and act as a deterrent in flourishing of the industry. But the operational cost of SPV is lowest amongst all renewables due to low maintenance and less repair needs. To have the highest market penetration, it is very much imperative to bring down the capital cost of SPV. The raw materials for building SPV are mostly imported, and off let government is trying to reduce down the import cost by encouraging domestic production of SPV inputs; raw materials and components.

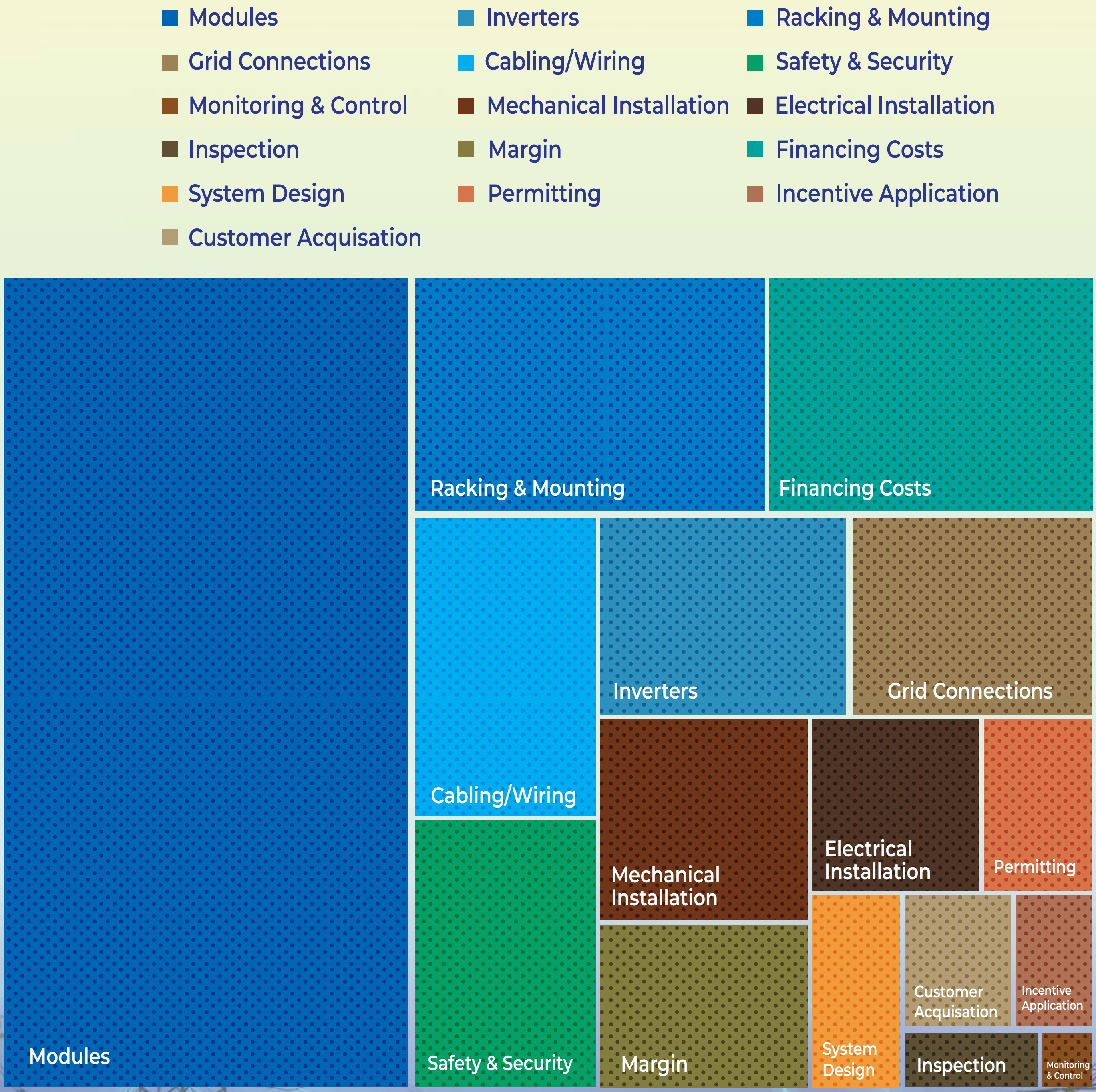
Exhibit 1.7: Dynamic Relation of Solar PV Capacity and Solar PV cost in India



Source: LSI Research calculations based on IRENA data

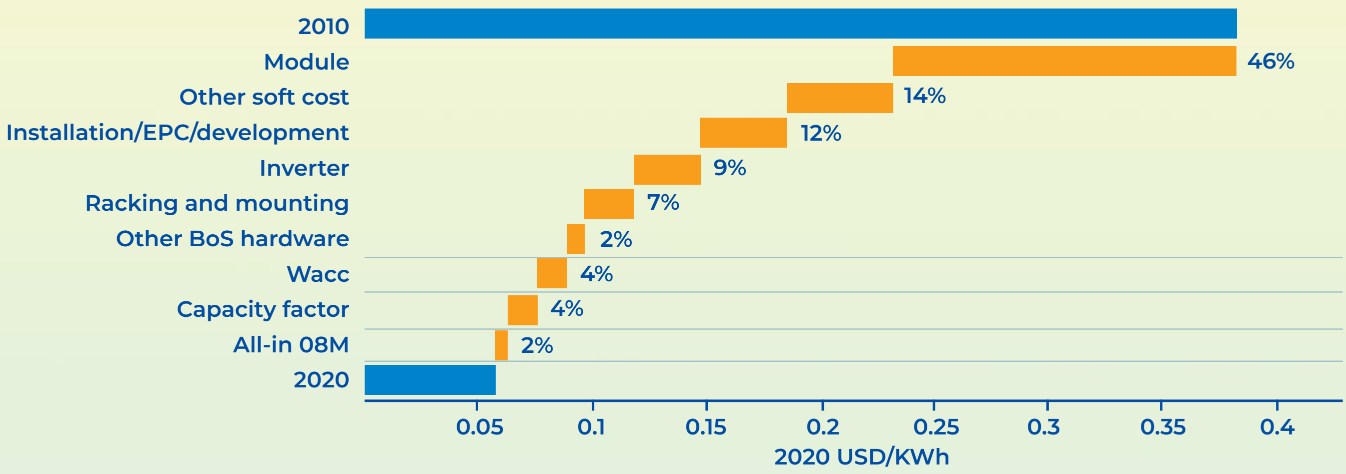
Market scenario of SPV has changed in recent past with the demand for clean energy and industries starved of with energy, many companies are coming up domestically to cater to this energy space. After 2010, with the gradually declining cost of solar PV (up to 88%), and along with pro-active policies of government and interest of industries at large, the solar PV capacity addition has increased exponentially. Notably, the capacity addition of SPV has been much more rapid and smooth compare to the decline in the weighted average cost of SPV. From Exhibit 2.7, it is observed that after 2015 Paris Agreement, there has been a trajectory change in SPV capacity addition. Initially the cost of light to electricity ranges from Rs 12 to Rs 20 per kwh when the National solar mission was launched but now the LCOE has declined to Rs 2.44. **The emerging market scenario of solar PV seems to be astounding, solar PV technologies have achieved an efficiency of 20% since its days of inception. Till 2022 cumulative SPV capacity addition stands at 64,037 MW with a CAGR of 48.11%.**

Exhibit 1.8: Detail breakdown of installed cost of utility-scale SPV in India in 2020



Source: LSI Research calculations based on IRENA data

Exhibit 1.9: Decomposition of declining cost of SPV from 2010 to 2020



Source: LSI Research, IRENA

Concentrating Solar Power (CSP) in context to India

The entire world is facing the challenge of climate challenge and high crude oil consumption with the advent of 21st century. India with no exception is equally struggling hard to overcome the same challenge with multiple constraints on board. **Crude oil gives 40–43% of world's energy. The 40% of global warming is only because of fossil fuels (coal and oil). Given this backdrop, CSP technology holds a tremendous potential to be a prudent supplier of electricity by converting large scale solar energy.** CSP has a competitive edge over SPV in terms of producing electricity, because unlike SPV it does not generate electricity via diffuse solar radiation, rather it uses only solar beam radiation. **CSP technology has the edge over SPV in terms of integrating cost effective storage systems directly into the plant environment.** CSP technology scores over other RE in terms of constant supply of electricity. The plant size ranges from kW to MW. Globally CSP should get a prime importance to be established as key source to supply non-conventional source of energy. Sometimes it becomes difficult for the countries to establish CSP plant given the geographical region they are lying, since solar radiation gets obstructed by fogs and in process minimizes the annual generation of electricity from CSP plants to certain a range that it possibly will never become economically reasonable. Countries like Japan, South Korea, Canada, some parts of USA and Russia, and some European countries does not hold the potential to establish CSP plant. But countries lying in the tropical zone like India has enough potential in regard to CSP plants.

India being a tropical country, is equipped with 300 sunny days approximately and solar radiation strength of 200 MW/km2, and thus has the robust prospect from establishing CSP as a source of generating electricity. States like, Madhya Pradesh, Gujarat, Ladakh, Andhra Pradesh, Maharashtra, and Rajasthan has requisite quantity of solar radiations available, and can be optimal locations for setting up CSP plants. Currently maximum number of CSP plants are established in North-Western part of India.

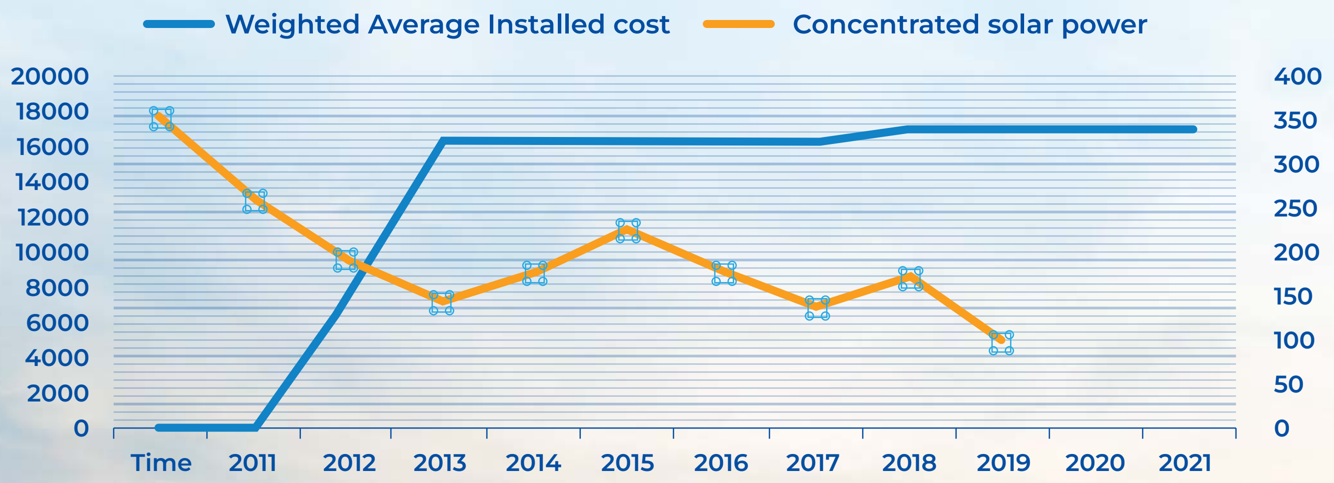
Exhibit 1.10: Details of CSP plant In India

Power Station	Location	Owners	Technology	Nominal Capacity	Status	Start Year
ACME Solar Tower	Rajasthan	ACME Group	Power Tower	2.5 MW	Operational	2011
Dadri ISCC Plant	Uttar Pradesh India	NTCP	Hybrid Linear Fresnel	14 MW	Operational	2019
Dhursar	Rajasthan	Reliance power	Linear Fresnel	125 MW	Operational	2014
Godawari Solar Project	Rajasthan	Godawari Green Energy	Parabolic Trough	50 MW	Operational	2013
KVK Energy Solar Project	Rajasthan	KVK Energy Ventures Ltd, Lanco	Parabolic Trough	100 MW	Currently Non-Operational	2013
Megha Solar Plant	Andhra Pradesh	Megha Engineering and Infrastructure	Parabolic Trough	50 MW	Operational	2014
National Solar Thermal Power Facility	Gurgaon	IIT Bombay	Parabolic Trough	1 MW	Operational	2012

Source: LSI Research, NREL

According to Govt of India's JNNSM, the plan was to emphasise equally on SPV and CSP to in the first phase (2010-2013) to bring parity in grid with the thermal generated electricity. Therefore, 500 MW each was allocated to solar PV as well as CSP technologies in Phase-I. For CSP, 7 projects (470 MW) were awarded out of which only 225 MW capacities is implemented by end 2015. In later stages three projects of 10 MW capacities each were awarded through migration scheme of the Indian Ministry of New and Renewable Energy (MNRE) out of which only 2.5 MW capacity is implemented.

Exhibit 1.11: Dynamic Relation of CSP Capacity and World CSP Install Cost in India



Source: LSI Research calculations based on IRENA data

In exhibit 1.11 relationship of CSP capacity addition in India against the world weighted average CSP install cost is explored (due to unavailability of data on India's CSP install cost, world weighted average cost is used as the nearest proxy). Overall, a declining trend in the World average install cost of CSP is observed in the period of 2011-2020, and correspondingly the addition in CSP capacity is found to be increasing since 2011 to 2013, but after that the capacity addition have remained uniformed till the entire period.

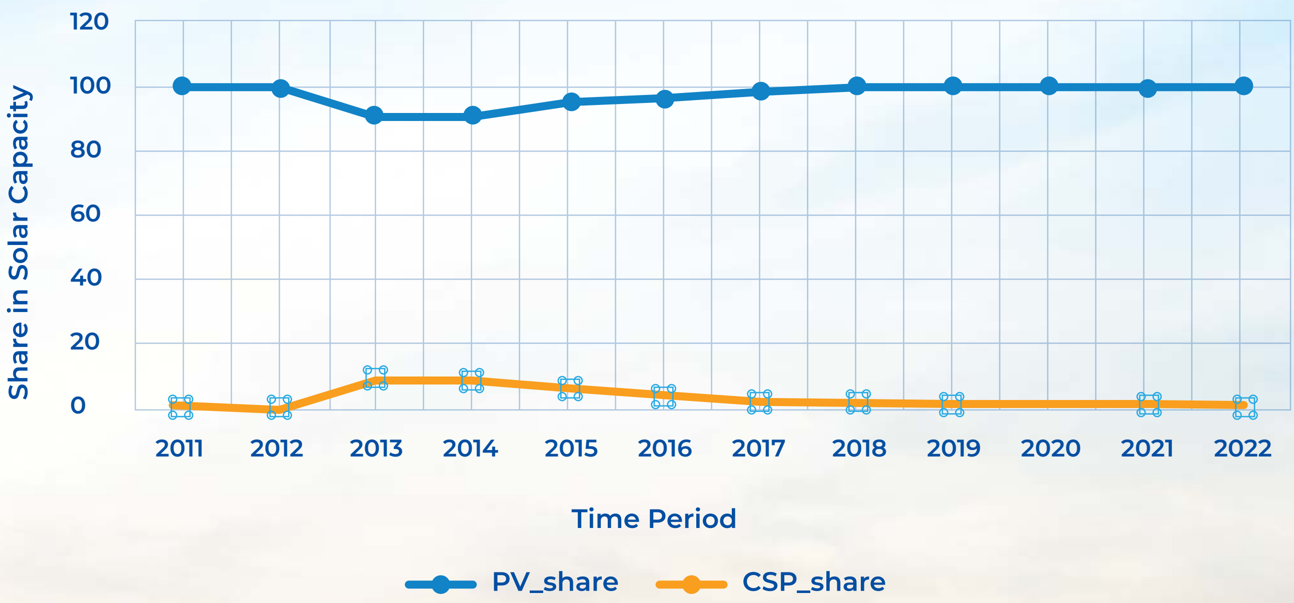
CSP generates large amount of electricity with least carbon emission through the entire production process and long-term solar plan with consistent supply of electricity is only possible to achieve by means CSP technology. But the expansion of CSP industry faces certain obstruction in terms of huge amount of capital investment and operating cost associated with it.

- Cost comparison of CSP and SPV nowhere can be brought to same scale: Expenditure of SPV system installation is around 5.87 crore per MW, and CSP is 12 crores per MW.
- Additional difficulties faced by the CSP implementation are of meteorological nature-water availability, grid loading, and wasteland availability and acquisition.

Disproportionate addition of SPV against CSP in India

MNRE in JNNSM-Phase-I planned to achieve solar grid parity with thermal by the year 2022, by equally emphasising on SPV and CSP, and if not equally then at least in the ratio of 60:40. But in Phase-II of JNNSM the share of CSP was reduced to 30% and states were asked to fulfil the 60% of the target at least. The 100GW target up to 2022 was decomposed as: 40 GW of rooftop solar will entirely be based on SPV technologies and there is no clarity on whether the proposed scheme of 60 GW of Solar Parks and Ultra Mega Solar Power Projects would be based on CSP or SPV technology.

Exhibit 1.12: Share of SPV and CSP in Total Solar Capacity addition in India



Source: LSI Research calculations based on IRENA data

From 2011 to 2022 CAGR of CSP addition is found to be 50.68% is slightly more than the CAGR of SPV which is 48.11%, but the relative share of SPV is way beyond the CSP. SPV plants unlike the conventional source of electricity cannot provide uninterrupted supply of electricity. Moreover, to maintain grid frequency, grid operator must predict the sunshine with best precision, but prediction of exact sunshine every time in practically not possible. A small error in judgment will trigger frequency fluctuations and, thereby, instability in the grid. India needs backup power facility to balance between base and peak load, and CSP has the feature of storage of power within the system and make the power supply continuous. Hence, India needs to focus more on the expansion of CSP plants to achieve a sustainable and consistent power supply as a long-term plan.

Exhibit 1.13: Comparison Between CSP Technologies

Technical Parameters	Units	PTS	CRS	LFR	PDS
Capacity	MW	1–250	1–400	1–125	0.01–10
Tracking	---	Single-axis	Two-axis	Single-axis	Two-axis
Concentration ratio	---	50–90	>1000	50–70	>1300
Operating temperature	°C	393 (therminol), 550 (molten salt)	"250–500 (water), 550 (molten salt), 680 (air)"	250–400 (Water)	250–700 (Hydrogen or helium)
Peak solar-to-electric efficiency	%	23–27	20–27	18–22	29–32
Annual solar to electric efficiency	%	10–16	10–20	8–12	16–29
Relative capital cost	---	Low	High	Low	Very High
Technology development risk	---	Low	Medium	Medium	Medium
Power-generating cycle	---	Steam Rankine, organic Rankine	Steam Rankine, Brayton	Steam Rankine, organic Rankine	Steam Rankine, Brayton, Stirling
Water consumption	m3/MWh	3 (Wet cooling) 0.3 (dry cooling)	2–3 (Wet cooling) 0.25 (dry cooling)	3 (Wet cooling) 0.2 (dry cooling)	0.05–0.1 (for mirror washing only in dish Stirling system)
Storage system	---	Indirect two-tank molten salt or direct two-tank molten salt	Direct two-tank molten salt	Short-term pressurized steam storage in DSG systems	No storage for dish-Stirling system

Exhibit 1.13: Comparison Between CSP Technologies

Barriers	PV	CSP
Technical barriers	• The efficiency constraint: 4–12% (for thin film) and under 22% (for crystalline) in the current market. • Performance limitations of balance of system (BOS) components such as batteries, inverters and other power conditioning equipments. • Silicon supply has to be robust to support the strong demand for PV. Otherwise if demand outpaces the supply then the growth of solar sector will be stalled. • Cadmium and tellurium supply for certain thin film cells: these two components are by-products from respectively the zinc mining and copper processing and their availability depends on the evolution of these industries. • Lack of adequate infrastructure to interconnect for hassle-free metering and billing.	• Heat carrying capacity of heat transfer fluids. • Thermal losses and energy storage system issues with CSPs. • Supply orientation in the design of solar water heaters when product diversity is needed to match diverse consumer demand profiles. • For solar water heating, lack of integration with typical building materials, existing appliances and infrastructure, designs, codes, and standards has hampered widespread application. • In case of central receiver systems, the promising technologies such as the molten salt-in-tube receiver technology and the volumetric air receiver technology, both with energy storage system needs more experience to be put for large-scale application.
Economic barriers	• High initial cost and lack of easy and consistent financing options forms one of the biggest barriers primarily in developing countries. • Unusually high risks while assessed in creditworthiness determined by finance institutions because of their lack of experience with projects. • Cost of BOS is not declining proportional to the decline in module price. • Bias against distributed technology platforms among conventional energy agencies and utilities.	• High upfront cost coupled with lengthy payback periods and small revenue streams raises creditworthiness risks. • The financial viability of domestic water heating system is low. • Backup heater required in water heating systems to provide reliable heat adds to the cost. • Increasing cost of essential materials like copper make water heating and distribution costly. • Limited rooftop area and lack of building integrated systems limit widespread application.

Chapter 2

State-Wise Assessment of Solar Power Deployment & Gap Analysis

In the Indian power sector nouveau arrival of the Solar Energy is a perfect fit and solution to many persistent problems faced by the sector and the sustainable growth mitigating the climate change. Government and other stake holders in the sector are touting solar power over the years for a range of reasons: A clean, abundant, decentralization-capable, and nationally self-reliant source of power, and solar power has assured in principle, alleviation from chronic power shortages as well as the strategic handicaps of imported fuel dependence, while also promising other socio-economic advantages.

Endowments for developing Solar Power in India:

In this section we will discuss the factors responsible for impetus to the growth and development of solar power sector in India. The highlighted factors are key enablers of bringing domestic, as well as foreign investment, in the solar power sector of India.

1. Availability of Solar Energy

Geographically India is situated at the equator sun belt and lies between 8°4′ to 37°6′ north latitude and 68°7′ to 97°25′ east longitude and it is the 7th largest country in the world, having landmass of 3.287 million Km2 and, therefore solar radiation received is in enormity. The average number of sunny days in India is 250-300 with mean solar radiation of 200 MW/km2. Total solar power reception of India is anticipated as more than 5000 trillion kWh per year, which puts India in the top five countries producing solar energy in the world, and capable enough to meet the total annual consumption.

2. Availability of Land

Large landmass of India acts as the favourable geographical conditions for setting up solar installations. An important parameter for power generation is solar land use energy intensity- defined as environmental impact and capital cost the amount of land area required for a particular amount of utility scale power generation. A solar utility scale solar power plant has large land use energy intensity as compared to fossil-based power plant. Land area required for setting up a solar plant of 20MW capacity is around 7.9 Acres/MW. Profuse amount of waste land is available in India and can be used for installation and development of utility scale solar power plant. Developing a utility scale solar power plant on wasteland doesn't create any environmental pressure on agricultural systems because wasteland is neither fit for residential purpose nor for any type of agriculture purpose. Whereas in many Mediterranean countries there is dearth of wasteland and are facing excessive environmental pressure on their cropping system due to ground mounted photovoltaic installations. So relative opportunity cost of producing solar power in India is less with respect to the global scenario. It is estimated that to fulfil the electricity needs of

India till 2031, only 1% of land area is sufficient, even with the present efficiency levels of solar PV modules, and The National Remote Sensing Centre has prepared a wasteland atlas of India and by analysing that atlas it has been found that around 46.7 million hectares of wasteland are available in India.

3. Minimum Dependency of Solar Installations on External Cost

Solar power developers in India can get the advantage of setting up a large utility scale solar power plant in terms of minimum external cost (installation time, fuel supply risk, water consumption, pollution and currency exchange rate), as compared to conventional power sources. Some forms of power generation have very significant external costs to the community and the economy but solar power has more merits in comparison to other sources of power.

Exhibit 2.1 Cost Comparison of Wholesale Electricity in India

Fuel source	Capital cost (US$ m/MW)	Install time (in Years)	Fuel supply risk	Wholesale price INR/ KWh	Air pollution	Inflationary impact
Coal fired domestic	0.8-0.9	4.5	Medium	3.5	Extreme	Low
Coal fired Imported	0.8 - 1.0	4.5	High	5.6	Extreme	Upward
Diesel fired	0.8 - 0.9	3.4	High	12.15	Extreme	Upward
Gas fired domestic	0.7	4.5	High	5	High	Low
Gas fired imported	0.7	4.5	Medium	6.8	High	Upward
Nuclear	2.3	5.1	High	N/A	Nil	Upward
Hydro large scale	1.3	5.15	Zero	3.4	Low	Down
Hydro small scale	1.2	4.5	Zero	3.5	Nil	Down
Wind	1	1.5-2	Zero	4.5	Nil	Down
Solar PV	1.0 - 1.3	1	Zero	5.6	Nil	Down

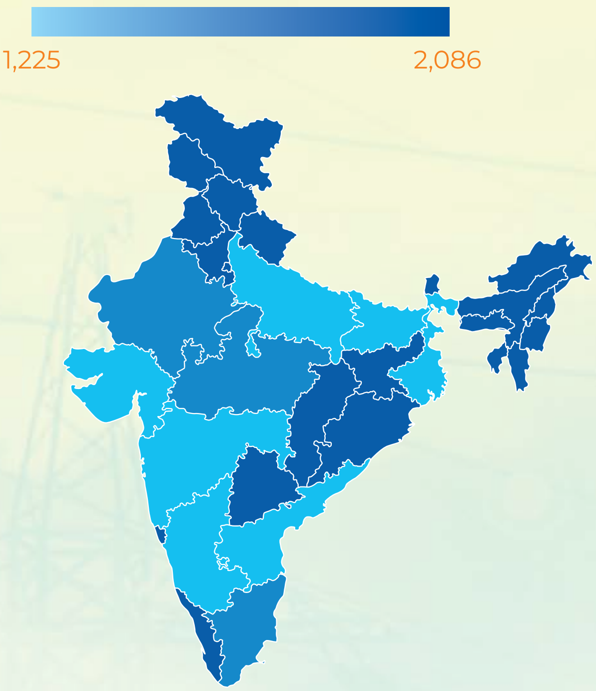
Source: Institute of Energy Economics and Financial Analysis

4. Water Availability

Unlike the other RE like solar PV and wind, solar CSP requires a considerable amount of water mainly for cooling purposes and for spinning steam turbines. Solar thermal plant requires around 3-4 M/MWh of water for the purpose of operation.

Solar Radiation Distribution

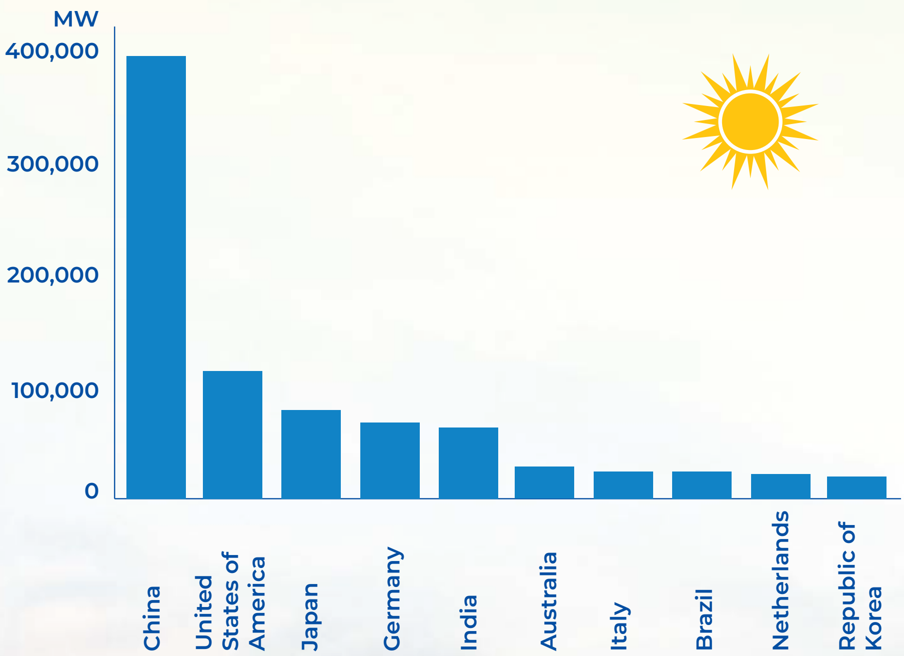
Annual Mean Direct Normal Irradiation (kWh/m²)



State Level Assessment of Solar Power Deployment: A Gap Analysis

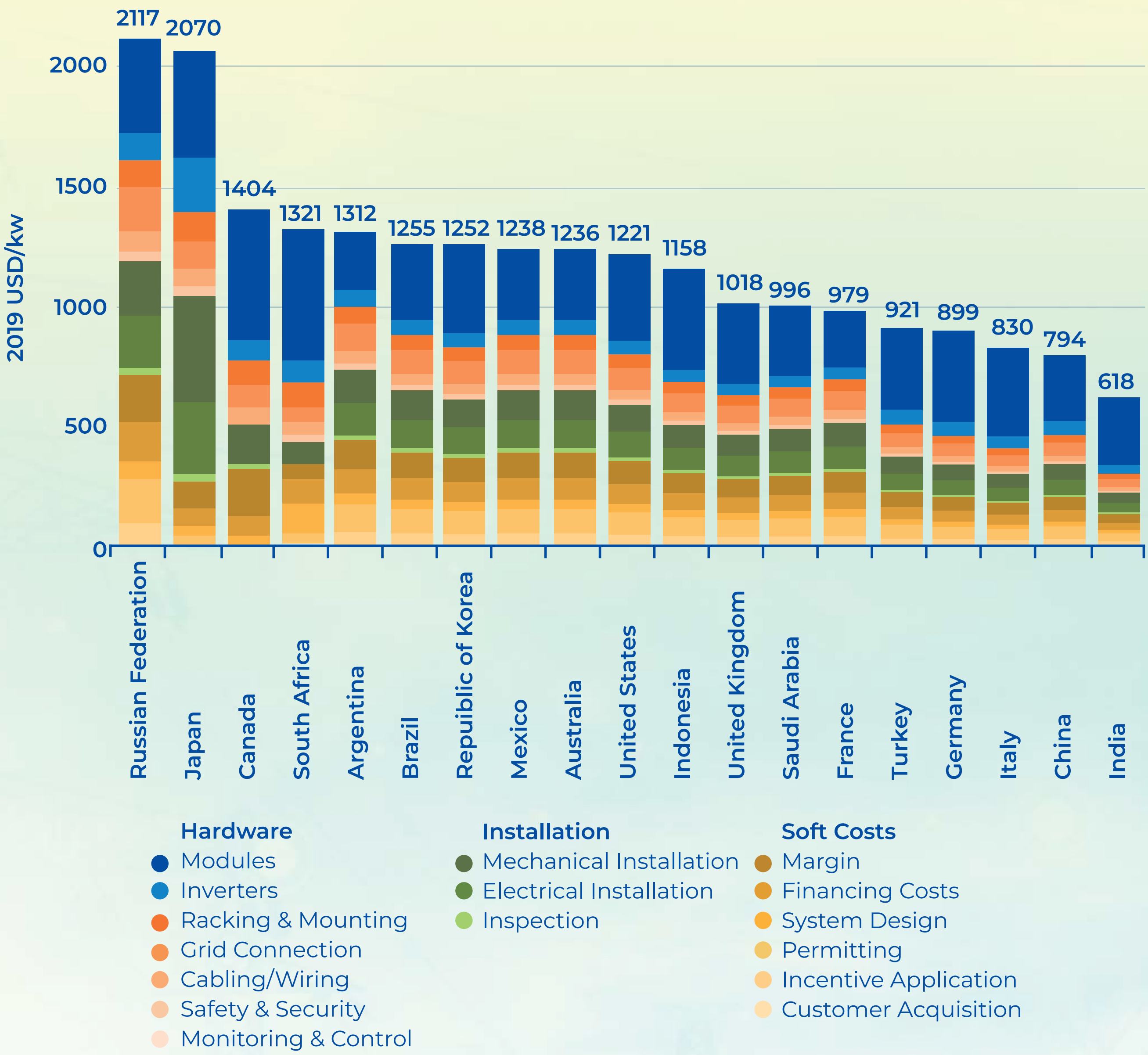
Globally solar energy has been considered as the most salient form of renewable energy to mitigate the climate change. In 2022, **World-wide cumulative deployment of total solar capacity stood at 1,05,3115 MW with a CAGR of 34.13% (during the period 2000-2022).** Given the focus on solar energy, **India's advancement in cumulative deployment of total solar capacity in the year 2022 is noteworthy with 64,380 MW and CAGR of 61.13%** (during the period 2000-2022). India ranks fifth in the world with respect to deployment of solar capacity, China holds the first position with a capacity of 393,031.8 MW and USA being the second with a cumulative capacity of 113,015 MW.

Exhibit 2.2: Top 10 Countries with Cumulative Solar Capacities



Source: IRENA

Exhibit 2.3: Detailed Breakdown of Utility Scale Solar PV Costs by Country, 2019



Source: IRENA Renewable Cost Database

At the Paris COP, 2015, India in its Nationally Determined Contribution covenanted to install 40% of its electricity capacity from renewable energy. India having prolific solar potential given the geographical position and other necessary fundamental characteristics, policymakers in the country are ambitious about meeting the target by means of solar energy. In COP, 2015 India's target to add solar capacity in grid was scaled up to 100 GW by 2022. But by 2022 only 64.38 GW of solar capacity has been installed. In-spite of having a target deficit, government of India has set the new target of installing 500 GW of electricity capacity from renewable energy sources by 2030 and among which 270 GW will be sourced from Solar energy.

Solar deployment in India has depended on multiple factors and crucially on encircling electricity policies of government. The stage was set for renewable energy to be on grid by;

- Electricity Act 2003,
- National Electricity Policy 2005, and
- National Tariff Policy 2006.

Objectives of the aforesaid policies is to make provision for optimal utilization of resources, increasing inter-state grid connectivity and sale of energy, mandating renewable purchase obligations, and supplying electricity at best possible tariff.

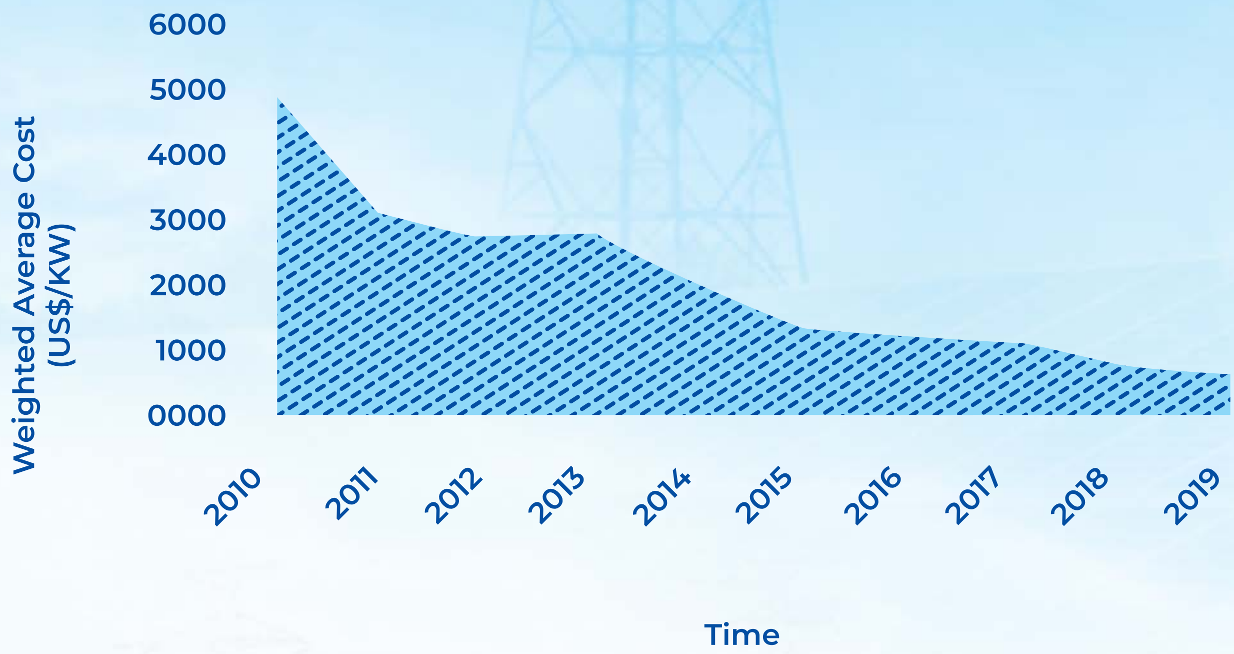
Alongside Ministry of Renewable Energy is constantly promoting solar energy and trying to cater the demand by building solar parks, mandating preferential treatments for renewable energy in public contracts; and also coordinating tax concessions to the sector and capital subsidies to individual projects. At the state level the government responsible for reducing the transmission and distribution losses.

National Solar Mission in 2010, was the most overarching policy programme initiated by the Government of India to surface solar energy extensively in power sector and an ambitious target of adding solar capacity 20GW was put forward by 2022, even though the cost of solar was very high at that time. Government took the route of reverse auction instead of feed in tariff to obtain solar power in the most cost-effective way. Upgradation of the same target to 100GW by 2022 was done after the Paris agreement in 2015.

The arduous solar mission got momentum with other complementary policies both at the national and state level:

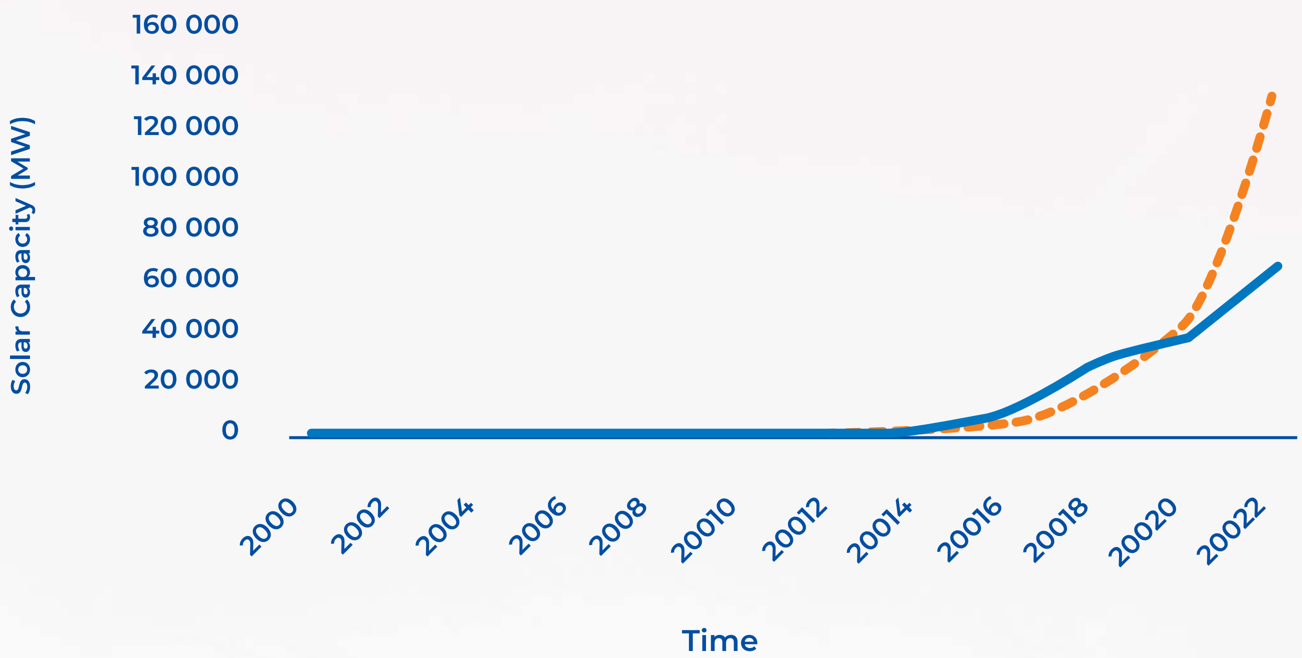
- National level policies to be mentioned are *viability gap funding, accelerated depreciation, addition of new solar park and increasing the capacity of existing solar parks.*
- Accompanying the national ones, state level policies are also formulated to support the advent of solar energy in the power sector and declared various targets and policies, including *renewable purchase obligations, net metering, banking of power, open access, etc.*

Exhibit 2.4: Weighted Average Cost of Install solar Capacity in India



Source: LSI calculations based on IRENA data

Exhibit 2.5: Cumulative Installed Capacity of Solar Power in India



Source: LSI calculations based on IRENA data

Solar deployment in India has always been into shortfall from the ambitious annual target, but the gradual increase in deployment has increased over the years. **Weighted average cost of installing solar capacity in India had a gradual decline followed by an increase in solar capacity addition. After COP, 2015 solar deployment got stimulated and there has been a sixth fold increase in the deployment of solar energy in last five years and achieved a cumulative capacity of 64.38GW till first quarter of 2023.**

- It is also visible from the above Exhibit 2.5 that the trend of solar deployment is exponentially increasing and after COP, 2015 the deployment had an overshoot and was performing above the trend. During the pandemic in 2020 the deployment slowed a bit than its recent past but gradually it is picking up pace.

Note: *Extant literatures and several other reports focused their studies in solar adoption, solar resources assessment and barriers faced by investors in solar power sector. There is lack of data driven research on factors affecting solar deployment. In India research in solar sector, mostly are of qualitative and descriptive in nature.*

Objective of the Study

Identifying the gaps in existing studies, this section attempts to - explore and analyse the factors influencing the deployment of solar capacities in India both at the large scale and distributed scale. The following analysis has been carried at the state level to understand how the solar capacity addition have spanned across states of India depending on multiple factors and how it has varied from the national predicted average. Keeping the focus on sustainable growth accompanied by reduced carbon emission, and compelling need of shifting to alternatives (non-fossil fuel sources) for power generation, makes the study on solar deployment of critical necessity.

Broadly, progress of solar deployment in India is the attribution of infrastructural, institutional and financial dimensions. This data driven analysis will explore the policies of the government, economic parameters and other fundamental characteristics respective to solar deployment. The study will provide key insights for all the stakeholders related to the sector: policymakers, business world and to the investors, on specific points that are responsible for stimulating solar deployment in the country.

Research Method and Data Description

This section of the report deals with the empirical analysis of the factors affecting the **solar capacity deployment-large-scale and distributed scale**, in India at the state level. This is a cross section analysis for the period of 2021-22. The objective is to find the estimates by how much the aforementioned factors (infrastructural, institutional and financial), affects the in-state solar deployment by means of **Multiple Linear Regression Model (MLRM)** - an **Econometric Modelling** approach.

Note: *Regression is a method of empirical verification of theory. It is concerned with describing and evaluating the functional relationship among variables. MLRM is applied in case of "one Dependent variable" and "more than one Independent variable". In our case dependent/target variable is solar grid capacity, which is getting influenced by many independent variables both in large scale and distributed scale*

Exhibit 2.6: Identification of the variables from influencing dimensions of solar deployment: Large Scale

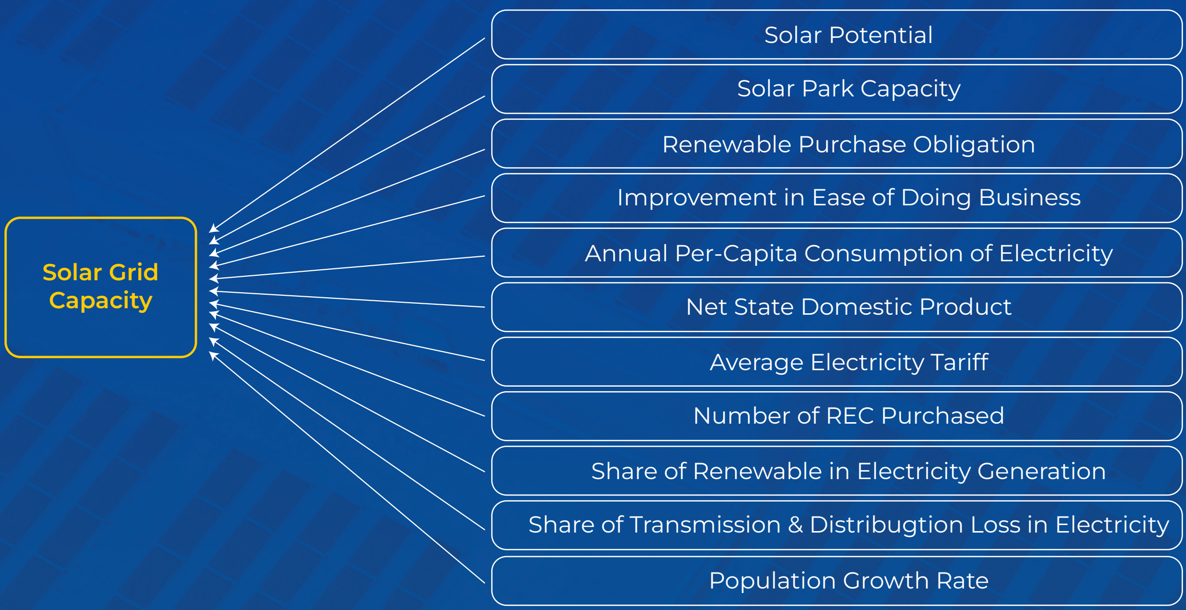
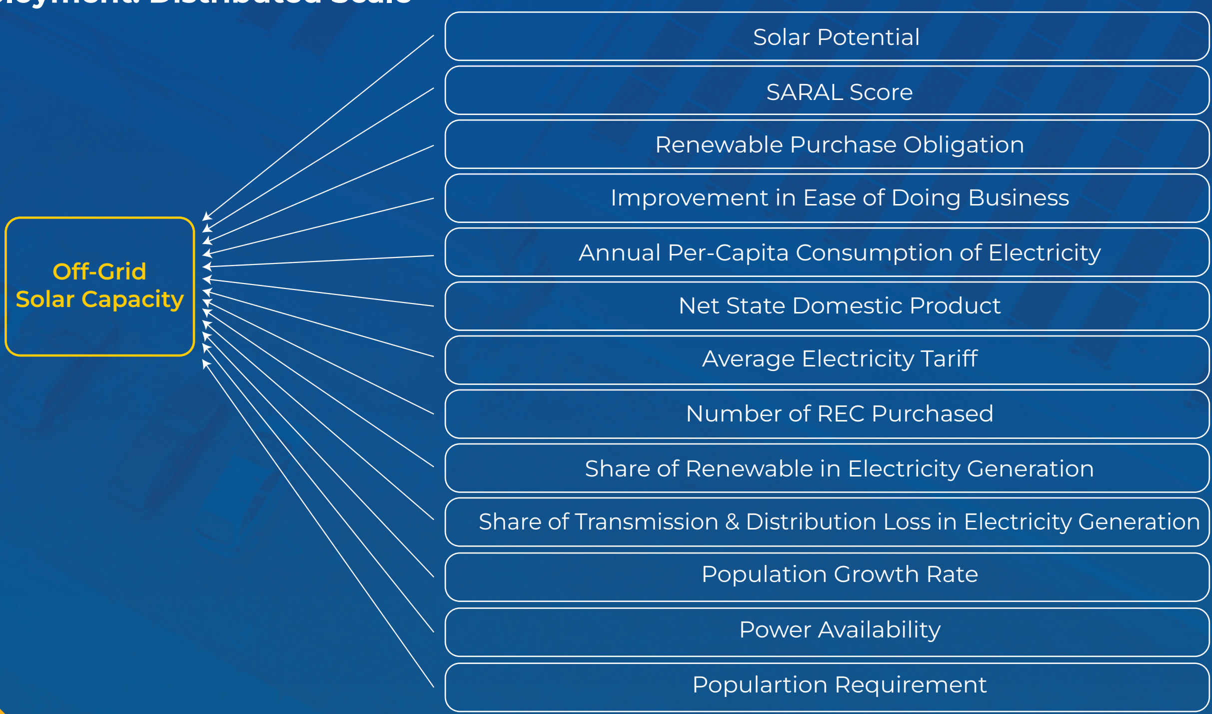


Exhibit 2.7: Identification of the variables from influencing dimensions of solar deployment: Distributed Scale



Description of Data

The data set for solar deployment analysis is taken for the period 2021-22. Initially the data set comprised of all the states and union territories of India, but due to lack of data availability, we ended up working with 31 states. The empirical analysis in the current study is unique of its own kind and so the initial challenge was to have a comprehensive data set for the analysis. So, following the conceptual framework of the study, the final dataset has been prepared by assimilating the indicators from multiple relevant sources and brought to similar scale where ever required for the analysis purpose. The dataset has been made as much exhaustive as possible.

The current study is consisting of two-fold analysis. Two different dependent variables have been used to make the objective of the study extensive:

- first being the large-scale deployment of solar capacity, typically greater than 5 MW plant capacities;
- and second is the distributed scale of solar capacity typically less than 1 MW plant capacities.

Former is used to understand the nature of ***utility-scale deployment***, completely involved in installing independent power plant supplying electricity to utilities, and the later one is for understanding of ***smaller scale deployment***, typically generating electricity for self-use purposes- industrial, commercial and residential.

Many of the independent variables used in the study to explain the behaviour of both the dependent variables are common. Independent variable set is comprised of policy, macroeconomic, infrastructural, institutional and financials. Policy variables are used in the model to discover the impact of the government policies related to the solar energy and power sector at large on the solar deployment. Policy variables are common in large scale deployment and distributed scale are renewable purchase obligation (RPO) and renewable energy certificate purchase (REC). RPO is a state-level policy that mandates that a percent of electricity generation be procured from renewable sources by a certain year. REC is a market-based instrument which entails that the bearer of the certificate will have to produce at least 1MWh of electricity from renewable energy. And the certificate can be sold in the market after the electricity is fed into the grid. Another variable solar park capacity is directly focussing on large scale solar deployment. Government guarantees land availability and other electricity infrastructural support like transmission interconnection by means of solar park capacity. Some of the other infrastructural support, institutional factors, and financial support such as banking access can be captured by means of two most important indicators, one is improvement in ease of doing business measurement (EODBI) and the second one is state rooftop solar attractive index (SARAL). EODBI is going to encompass several important dimensions: Dealing with Construction Permits, Trading Across Borders, Enforcing Contracts, Getting Credit, Getting Electricity, Registering Property, Resolving Insolvency, Paying Taxes, Labour Regulation-Enablers, Land availability and allotment, administration and Transfer of Land and Property, Environment Registration Enablers. EODBI is the indicator involved with both the large scale and distributed scale deployment of solar. Whereas SARAL is a composite indicator developed by Ministry of Renewable Energy, Govt of India, specific to the distributed scale only. SARAL index assesses the states of India on the basis of preparedness to support rooftop solar on the basis of following dimension: robustness of policy framework, effectiveness of policy support/implementation environment, consumer experience, investment climate for rooftop solar sector, business ecosystem.

Solar potential is an important variable used in both large scale and distributed scale of solar deployment. Solar energy differs from one geographical location to another depending majorly on solar radiation and on land & water availability. In this study two structural variables are considered- one is share of renewable energy in gross electricity generated (SRGE) and the other is the share of transmission and distribution loss in gross electricity generated (STDLGE). Two specific variables namely power requirement (PRT) and availability of power (APR) have been incorporated in the analysis of distributed scale. These variables are very crucial in understanding the demand and supply situation of power in existing scenario at the state level. Another essential variable annual per-capita consumption of electricity (APCE) has been used in the model for understanding the demand of electricity at the micro level.

The study has used the economic variable Net State Domestic Product (NSDP), representing the wealth of a particular state which is directly responsible for building of the social overhead capital of a state and act as an indicator of direct productivity activity. Backward linkage of any economic activity- industrial, commercial, residential can be traced back to the power requirement and hence direct linkage to solar deployment. Another economic variable used in the model is average electricity tariff (AET) which has been used to account for the average cost of electricity. Energy development has always been a function of energy usage which is dependent on the population of the state. Hence population growth rate (PGR) of a state is used as a control variable for solar deployment.

The proposed relation mentioned above can be formalised as:

- Large-Scale Solar Deployment=f(Solar Potential, Solar Park Capacity, RPO, Ease of Doing Business Improvement, Annual Per Capita Consumption of Electricity, NSDP, Average Electricity Tariff, No. of REC Purchased, Renewable Share in Electricity Generation, Transmission & Distribution Loss of Electricity, Population Growth Rate)

- Distributed - Scale Solar Deployment = f (Solar Potential, Solar Park Capacity, RPO, Ease of Doing Business Improvement, Annual Per Capita Consumption of Electricity, NSDP, Average Electricity Tariff, No. of REC Purchased, Renewable Share in Electricity Generation, Transmission & Distribution Loss of Electricity, Population Growth Rate, SARAL Score, Power Availability, Power Requirement)

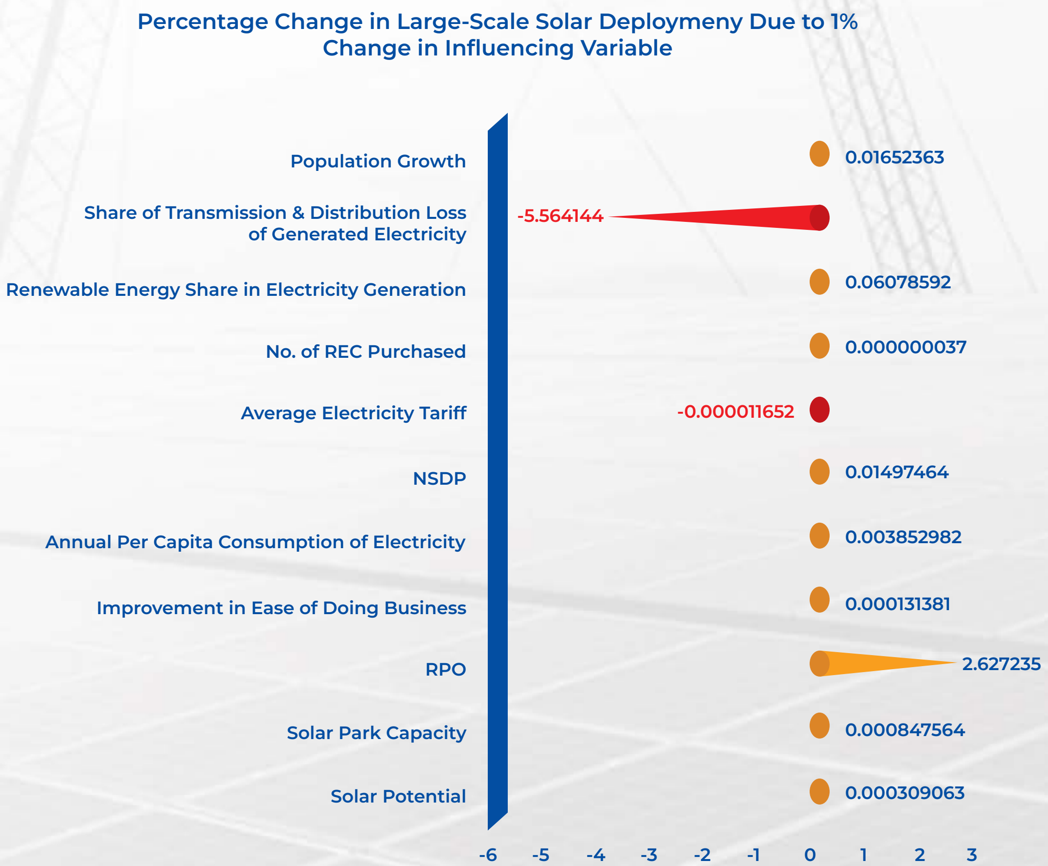
Note: In the above Equations i stands as each state of India

Empirical Results and Discussions

This section deals with the reporting and analysis of the results based on the statistical significance of the regression model of solar deployment in both large-scale and distributed scale.

1. Large-Scale Solar Deployment Analysis:

Exhibit 2.8: Percentage change in Large-Scale Solar Deployment



Source: Authors Calculation, LSI Research

Set of Positive Influencer of Large-Scale Solar Deployment

- We hypothesised that higher wealth of the state (NSDP) means higher solar deployment, because the government will have more resource to invest on development of renewable energy. The coefficient of NSDP from the estimated model is found to be highly statistically significant, and have positive sign, confirming our hypothesis. So, solar deployment will increase by 0.014% due to 1% increase in NSDP.

- Solar energy along with other complementary resources varies across different geographical location and hence solar potential differs. Therefore, solar potential, another important parameter of the estimated model is hypothesised to have a positive relation with the solar deployment and the estimated coefficient of solar potential confirms the relation.

- Structural policy variables - SPC, RPO and REC, which are supporting large-scale solar deployment, are hypothesised to influence the solar deployment positively and from the estimated model the result is indeed so.

- Increase in population growth is hypothesised to have positive relation with the large-scale solar deployment, because solar power is a viable option while catering high demand of electricity with growing population. The result of the model seems to be in parity with the hypothesis.

- Increase in annual per-capita consumption of electricity (APCE), representing the demand variable at the micro level, is having a prior expectation of positively influencing the large- scale solar deployment, and the estimated coefficient of the model entails the same.

- Improvement in ease of doing business index (EODBI) is a vital parameter reflecting the investment climate of a state, infrastructural and institutional support to do a business, and the entire supply chain of the solar power industry can function optimally if and only if EODBI is high for a particular state. Hence solar deployment is hypothesised to have a directly proportional relationship with EODBI and the empirical result is in align with the same.

- It is hypothesised that more the share of renewable energy in electricity generation (SRGE), more will be large scale solar deployment in India, and the reason follows from the fact that solar has the highest share of installed capacity in renewable energy basket. The result from the estimated model with the coefficient of SRGE having positive sign confirms it.

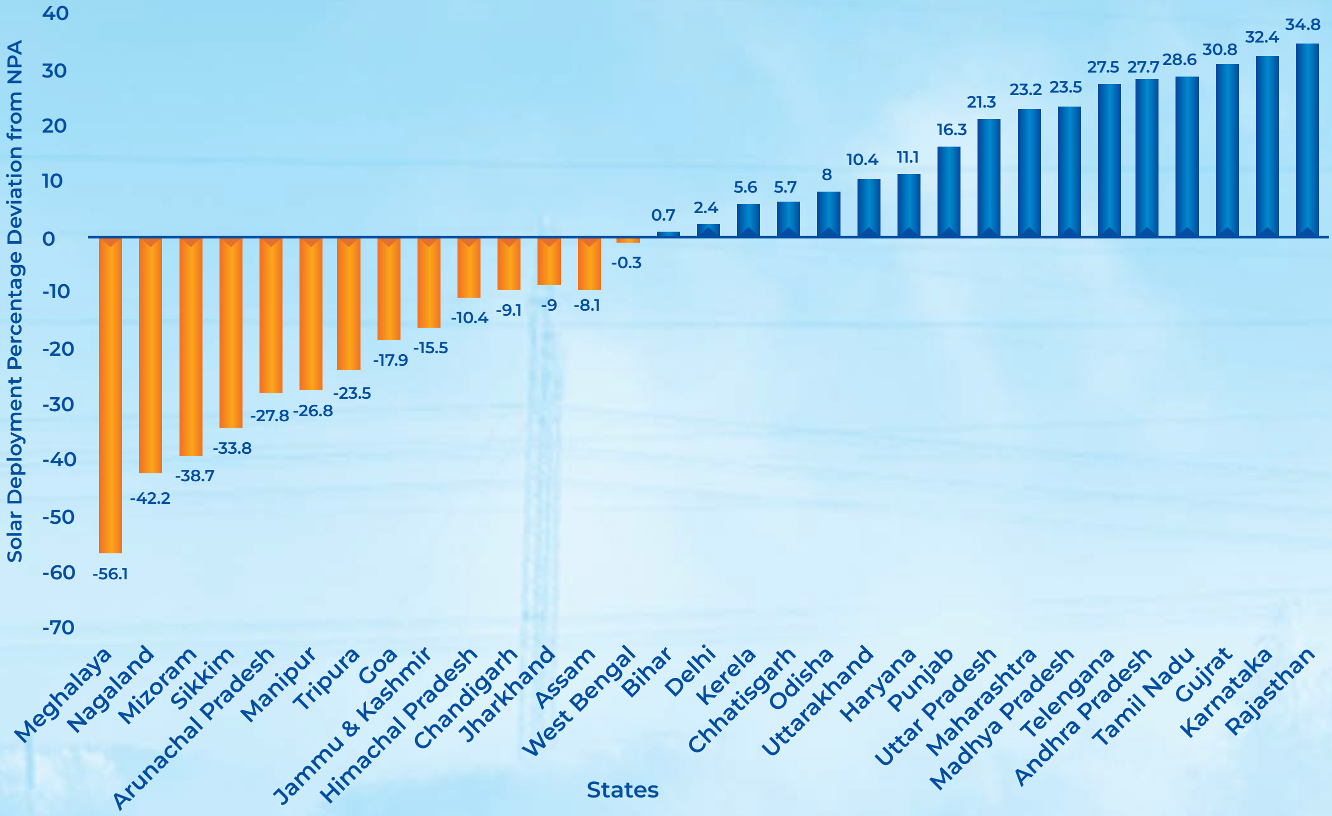
Set of Negative Influencer of Large-Scale Solar Deployment

- It has been hypothesised that share of transmission and distribution loss in gross electricity generated (STDLGE) is an impeding variable for Large-scale solar deployment, because higher transmission and distribution loss is worst structural support. The result from the estimated model confirms the same.

- Electricity tariff in a state can act as a booster or can negatively influence the deployment of large-scale solar. In our case the result from the model seems to be negative, implying that cost of solar which is initially high, is causing some negative effect on solar demand. But in the long run with lowering cost by government policy support and domestic manufacturing of technology, the outcome might be in the positive direction.

State-Wise Performance Analysis of Large-Scale Solar Deployment

Exhibit 2.9: Percentage-Difference in Large-Scale Solar Deployment Capacity from National Predicted Average (NPA)



Source: Authors Calculation, LSI Research

The study is extended to understand and analyse the difference in actual large-scale solar deployment from the national predicted average (NPA) at the state-level. The national predicted average of large-scale solar deployment is 156418.1 KW, and it has been computed from the respective estimated model. From exhibit 2.9 we can have a clear depiction that there are two groups of states, one group has been in the positive side of the yard stick and the second one is in the negative side.

Amongst the states performing positively in the large-scale solar deployment, Rajasthan being in the top, is outperforming in deployment with 34.8% above the NPA, followed by Karnataka and Gujrat. On the other side of the stick, among the bottom performing states Meghalaya is having maximum negative deviation of -56.1% from NPA, followed by Nagaland Mizoram and other North-Eastern states.

To explain the bipolar distribution of NPA an in-depth exploration is required, for which Random Forest has been employed in the study.

Note: *Random Forest is a Supervised Machine Learning Algorithm based on the concept of ensemble learning that is used widely in Classification and Regression problems. It builds decision trees on different samples and takes their majority vote for classification and average in case of regression. Here in this case RFM is used to understand the feature selection for further analysis.*

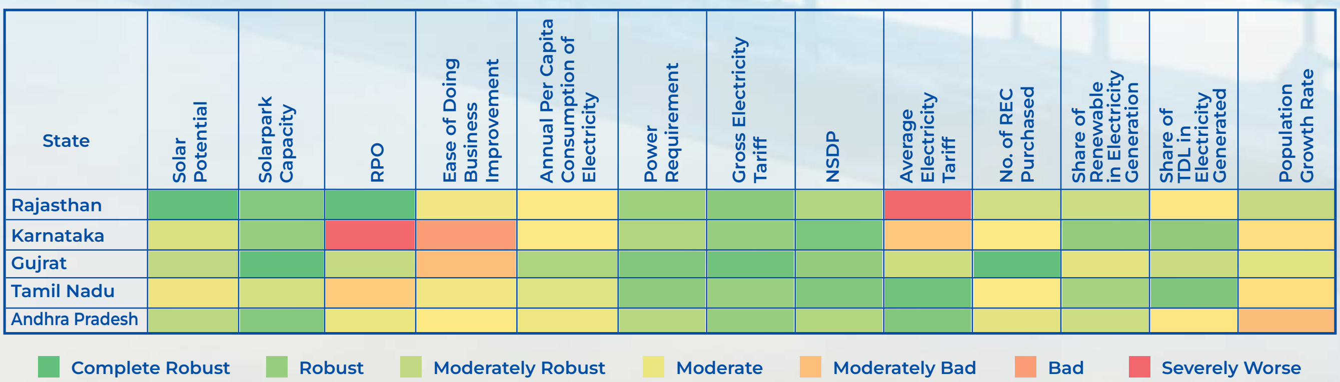
Exhibit 2.10: Relative Importance of Indicators from Random Forest Model (RFM)

Source: Authors Calculation, LSI Research

The classification model in this context is making us understand the relative importance of the factors based on which the states will be more above the current NPA of large-scale solar deployment. Exhibit 2.10 above showing the ranking of the parameters based on their contribution in large-scale solar deployment. Solar potential which is a necessary parameter and RPO which is a vital parameter for solar deployment in absolute sense is going to have their impact to the fullest in bringing the below NPA states above only when the higher-ranking indicators represented in the model will be more robust.

The classification model will help us to dive deep in analysing the fundamentals of the states based on respective indicators. Based on our analysis top five and bottom five performing states in terms of large-scale solar deployment has been identified. For an in-depth understanding of indicator characteristics of those respective states heat maps have been generated.

Exhibit 2.11: Indicator Characteristics of Top 5 States above NPA of Large-Scale Solar Deployment

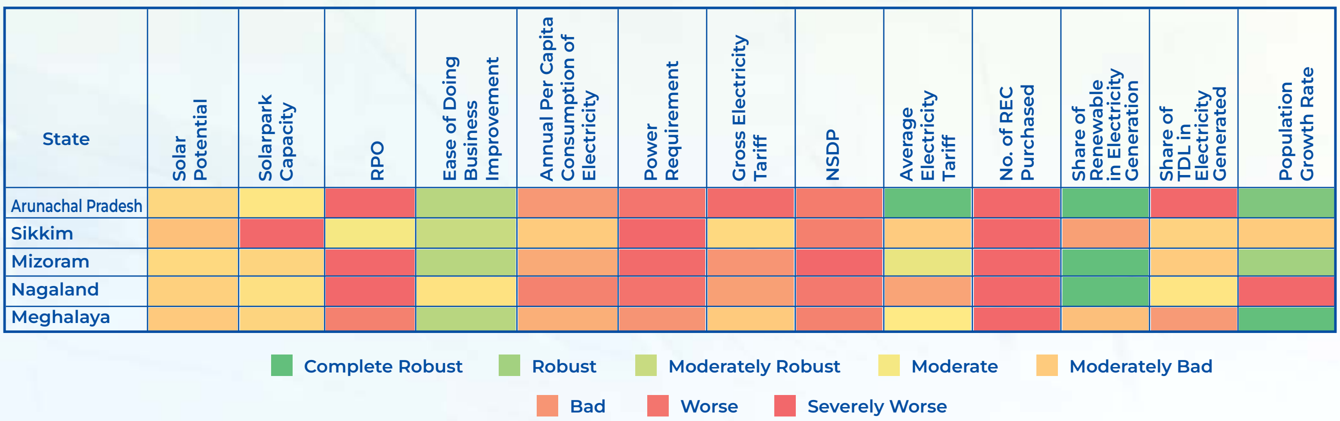


Source: Authors Calculation, LSI Research

Key Insights of Top 5 Performing States:

- According to top 3 indicators- Power Requirement, NSDP, and Gross Electricity Generation, from classification model RFM all the top states are found to be in complete robust position. And these are the most critical pulling factors which are driving these states to top 3 position.
- Solar potential presence ranges from complete robust to moderate in all the top five states.
- Policy variables REC purchased and RPO has a mixed scenario. Status of Rec Purchased ranges complete robust to moderate in all the top five states. Gujrat being the only state to have complete robustness in case of REC purchased. In case of RPO there is significant variation among the respective top states- Rajasthan being in the top is have complete robustness, and Karnataka is depicted to be severely worse but still stands second in terms of performance because of other structural parameters. Whereas other states like Gujrat, Tamil Nadu and Andhra Pradesh lies in robust to moderate zone in terms of RPO. According to RFM, indicator RPO is having the relatively least importance in terms of contribution towards deployment of large-scale solar power, and that is quite evident in terms of Karnataka's position.
- Solar Park Capacity any other important structural indicator is having an almost homogenous presence among all the top 5 states. It ranges between completely robust to robust category. Gujrat and Andhra Pradesh are having the highest solar park capacities.
- Presence of Share of Renewable energy in Electricity Generation ranges from robust to moderate scale in among the top 5 states.
- Price indicator- Average Electricity tariff (AET) which is acting as a deterrent factor, is having an almost complete range of variation among the states. The top ranked state Rajasthan is having severely worse situation in terms average electricity tariff which can negatively affect the large solar deployment, but the other relatively high-ranking parameters than AET is outweighing the negative price effect. Similar explanation goes with the second ranking Karnataka which is having a bad status in terms of AET. Gujrat and Andhra Pradesh are having the most robust average electricity tariff for the purpose of large-scale solar deployment.
- Share of transmission & distribution loss is observe to have been proportionately robust- implying very low in all the top five states and hence the respective indicator is giving a good incentive to deploy large-scale solar.
- Annual per-capita consumption of electricity is having a robust to moderate range. The demand variable is giving a constant support to and showing the urge of solar deployment in all these top 5 states. Herein Gujrat is only showing robust per-capita consumption of electricity, whereas other four states are lying in moderate zone in terms annual per-capita consumption of electricity. But per-capita consumption of electricity stands as crucial luring factor and stands in fourth position in terms of contribution towards solar deployment.
- Ease of doing business is a vital indicator and seems to be present moderately in all the five states.

Exhibit 2.12: Indicator Characteristics of Bottom 5 States below NPA of Large-Scale Solar Deployment

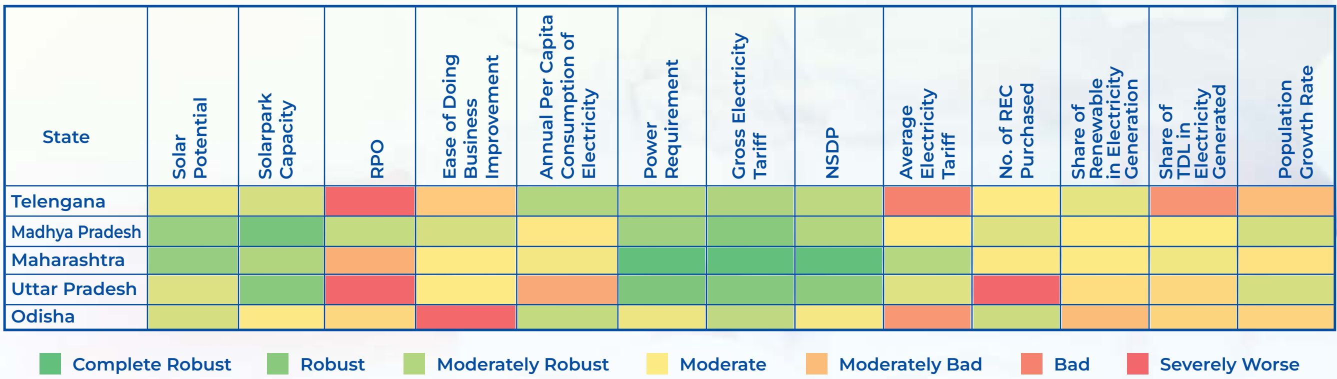


Source: Authors Calculation, LSI Research

Key Insights of Bottom 5 Performing States:

- From the analysis all of the bottom five states that are surfacing are from North-Eastern region of India.
- According to the RFM the top 2 indicators- Power Requirement and NSDP, are having severely worse status among all the bottom 5 states. Another high-ranking indicator No of REC Purchased is having the similar scenario among all the respective 5 states. Two consecutive ranking indicators (3rd & 4th) Gross Electricity Generation and Annual per-capita consumption of electricity is having a moderately bad to worse form of status in these states. Hence, combined effect of these top ranking five indicators are having the most negative impact in terms of large-scale solar deployment.
- RPO as an indicator is performing severely worse in respective states excepting Sikkim where it stands in moderate range.
- Solar Potential and Solar Park Capacity both the indicators are having a moderate presence among the bottom five states. The only differentiating state among them in terms of Solar Park Capacity is Sikkim which is having severely worse status.
- Share of Renewable Energy in Electricity Generation stands in a complete robust position in Arunachal Pradesh, Mizoram and Nagaland, and in Sikkim and Meghalaya it is moderately bad.
- Ease of Doing Business indicator is ranging from mostly robust in the respective states excepting in Nagaland where it is moderate.
- Average Electricity tariff is in moderate to moderately bad status, excepting in Arunachal Pradesh.
- Share of Transmission and Distribution loss in Electricity Generated ranges from worse to severely worse scenario in bottom group of states.
- Many of the factors in spite of having robust to moderate potential towards positively impacting large-scale solar deployment like population growth, Ease of doing Business, Solar Potential, and Share of Renewable in Electricity Generation, are not able to actively in the deployment. The reason being so that the strength of top 5 major indicators are having far outweighing effect on the ultimate deployment.

Exhibit 2.13: Indicator Characteristics of Top 5 Emerging States in Large-Scale Solar Deployment



Source: Authors Calculation, LSI Research

Top 5 emerging states has been identified after filtering out the top and bottom five states in large scale solar deployment, which have been already discussed above. Emerging states have been identified on the basis of top two crucial indicators- Power Requirement and NSDP. Compounded annual growth rate for a period of 10 years has been calculated for each residual states (excluding top and bottom five states) with respect to Power Requirement and NSDP and common top-ranking states have been identified as the emerging states. Exploratory data analysis of other indicators from RFM were also performed to find support to the argument.

Top 5 Emerging States in Large-Scale Solar Deployment are:

- Telangana
- Madhya Pradesh
- Maharashtra
- Uttar Pradesh
- Odisha
- Top three indicators Power Requirement, NSDP, and Gross Electricity Generation are very robust in all the mentioned respective states. And these factors are the major contributor to surface these states as emerging in Large-scale solar deployment.
- Solar Potential an intrinsic indicator and Solar Park Capacity a structural parameter, ranges from robust to moderate nature across the respective states. Implying a promising scenario for large scale solar deployment in these states.
- Considering the demand indicator- Annual Per-Capita Consumption of Electricity, and price indicator- Average Electricity tariff, seems to be ranging from robust to moderately bad degree across the respective states. The price and demand variables are in align with each other, i.e., having an inverse relationship among them, in Madhya Pradesh and Maharashtra. But the scenario is different in states like Odisha and Telangana, where the demand is robust but the price is not that inversely proportionate. In case of Uttar Pradesh the situation stands very opposite where the price is low enough but proportionately demand is not robust.
- Environment and sustainable policy indicator RPO is in a worse position in majority of the emerging states, excepting in Madhya Pradesh and Odisha where it is in robust to moderate degree respectively. These states can be on the higher up the ladder of large-scale solar deployment if government focusses on the policy variable RPO.
- The respective states have performed better in terms of the Number of REC purchased implying the states have a better focus on climate finance. Exception in this category is Uttar Pradesh.
- Share of Renewable in Electricity Generation is moderately present and is having an approximately unform distribution across the states, implying the interest of these respective states to produce electricity with clean energy. Shifting of production activities to non-fossil fuel sources definitely gives an assurance that these states have exploring all opportunities to reduce the negative externalities from the production process.
- Share of Transmission & Distribution loss of electricity generated is also moderately low in these states, excepting in Telangana where TDL is relatively slightly high. TDL being low gives a robust structural support and acts as luring factor towards large-scale solar deployment in these states.
- Among the emerging states maximum Ease of Doing Business Improvement is found to be in Madhya Pradesh followed by Maharashtra and Uttar Pradesh, directly encouraging the states to have higher solar deployment. And indirectly the improvement of EODBI ensures that institutional and infrastructural supports are encouraging more industrial growth and

higher requirement of power. States which are performing poorly in terms of EODBI is Odisha followed by Telangana, and hence policy interventions are required to make EODBI better in both of these states to support large-scale solar deployment directly and indirectly.

Central Financial Assistance (CFA) for Solar Power Deployment

Central Financial assistance available by means of several schemes related to solar power is provided by the central government to state government to develop solar power capacities. Among the states receiving CFA are Gujrat, Haryana, Madhya Pradesh, Maharashtra, Punjab and Rajasthan. Among these states Rajasthan and Gujrat are among the top 5 performing states in terms of large-scale solar deployment. Maharashtra and Madhya Pradesh are belonging to the emerging group of states in large-scale solar deployment. But two states Punjab and Haryana are receiving CFA but are found to be not efficiently utilising the financial assistance in terms of large-scale solar deployment, and the result is reflected in terms having relatively poor solar park capacities and number of REC purchased.

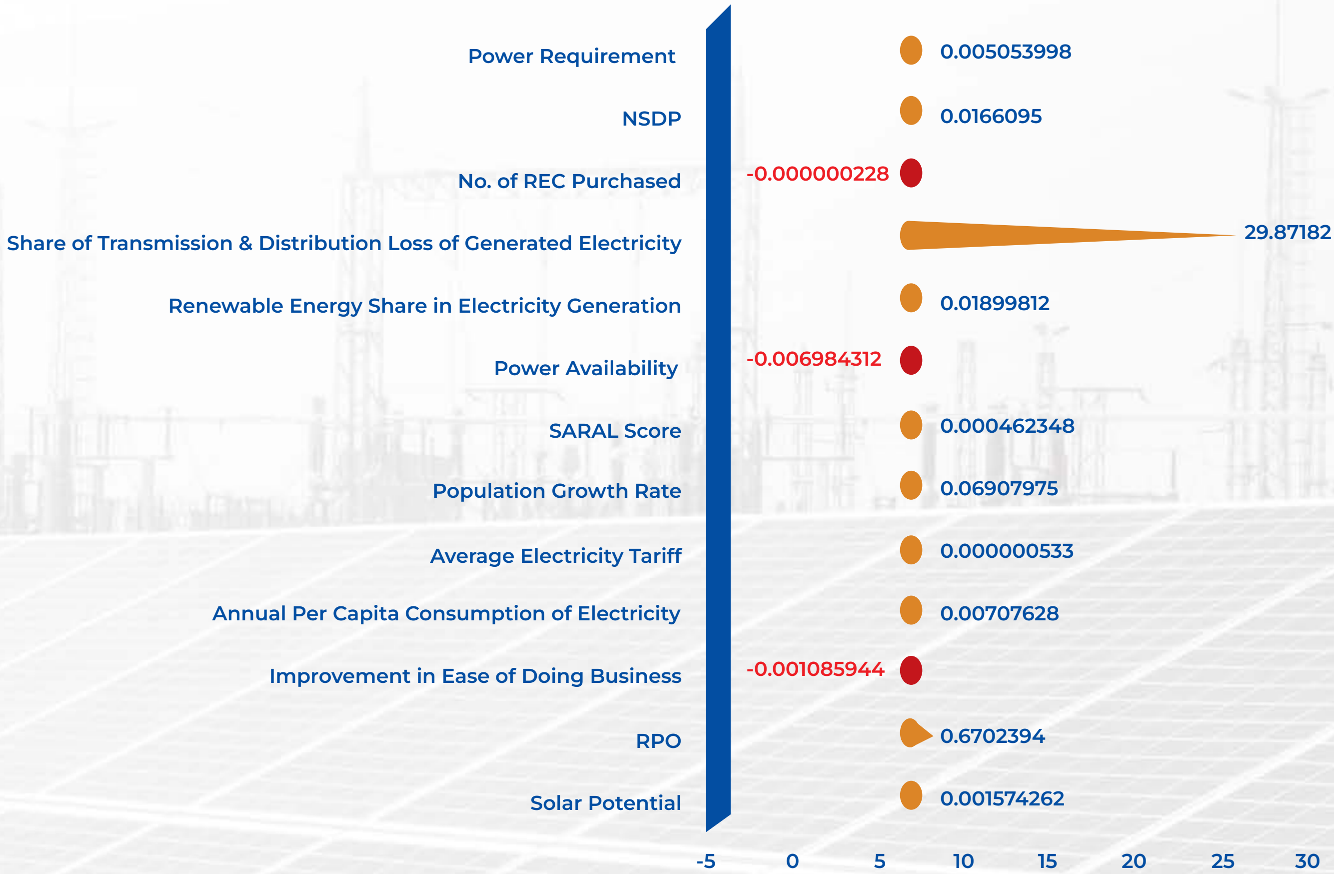
The states which are in bottom five with respect to large-scale solar deployment have not received any CFA. And also, to make the fact more generalise neither of the states which are below NPA of large-scale solar deployment have received any CFA. Hence to drive these states higher up the ladder in large-scale solar deployment the respective state governments have to design the framework for solar power to receive the CFA. The central government also has to redesign or modify the financial assistance programme in a way to expand the net to include such states in CFA programme.

Exhibit 2.14: States Receiving Central Financial Assistance

2. Distributed-Scale Solar Deployment

A similar empirical analysis like the large-scale solar deployment has been performed to understand the impact of the independent variables on the dependent variable- distributed-scale solar deployment.

Exhibit 2.15: Percentage Change in Distributed-Scale Solar Deployment Due to 1% Change in Influencing Variable



Set of Positive Influencer for Distributed-Scale Solar Deployment

- NSDP a macroeconomic indicator representing the wealth level of the state is found to have positive impact on distributed-scale solar deployment similar to its large-scale, but the magnitude of impacting is higher compared to its counterpart. Apart from the government investing more in solar power development due to more NSDP, the implication extends further to signify that the micro economic unit (which are also contributor to that NSDP) has more resource to invest in setting up and developing distributed-scale solar power unit.
- Power Requirement is a crucial indicator and is hypothesised to have positive relationship with development of distributed-scale solar deployment, and the result from the regression model confirms it to be so, with high statistical significance. If there is more demand generated from the micro-economic unit (industry, commercial, and large size residential), and power supply through grid connectivity is not sufficient to meet the corresponding demand (Excess Demand situation) then it is a compelling factor to develop distributed-scale solar power as an alternative power source.
- High Share of renewables in electricity generation (SRGE) in a state encourages the enterprises to participate in development of off-grid system of solar i.e., distributed-scale solar deployment, and to propel system to significant degree, production. linked incentives

- (PLI) are provided by the state government. Among all the form of renewables solar has the highest potential and consistent supply capability. Hence as hypothesised SRGE is having a positive relationship with distributed-scale solar deployment.
- Solar potential a necessary factor for the development of solar power is having a positive impact on the distribute-scale solar deployment. The fact, holding attention is - impacting magnitude is relatively higher than the large-scale deployment, implying solar potential is more effectively utilised in off-grid solar power.
- Policy variable RPO is having a positive relationship with distributed-scale solar deployment and is in align with the hypothesis. States having high obligation to purchase renewables, is meeting the target partly by means of off-grid set up. The enterprises are incentivised through net-metering, accelerated depreciation charges and easy financial assistance to set up distributed-scale solar.
- The hypothesis goes like, higher the annual per-capita consumption of electricity, more will be distributed-scale solar deployment and so is confirmed by the empirical result. The rationale behind it is- if electricity consumption exceeds the supply of it generated from the fossil-fuel sources, then alternative non-fossil fuel sources are the only option. And with the compliance of environment and sustainability goals in current times solar power has a very towering viability to meet high consumption of electricity.
- We hypothesised Average Electricity tariff is having a positive relationship with distributed-scale solar deployment, and indeed the result from the model surfaces to be so. There are two fold reason behind this phenomena- Firstly, if the average electricity tariff from grid is very high in a state, then the micro-units (industrial, commercial, and residential) will be finding off-grid solar (roof-top solar or captive solar power plant) to be lucrative because they can lower down the power cost; Secondly, excess power generated from the micro-unit's own off-grid set up can be supply to the main electricity grid and they can earn monetary benefits through net-metring policy.
- Population growth rate and SARAL score has been hypothesised to have a directly proportional relationship with the deployment of distributed-scale solar, and the regression model results confirms the same.
- TDL is hypothesised to have positive relation with distributed-scale solar deployment, and the result confirms the same. The micro-units find it profitable to have their own power source completely or an alternative power source when share of transmission & distribution loss increases and provides poor structural support for industrial & household activity.

Set of Negative Influencer for Distributed-Scale Solar Deployment

- Number of REC purchased is hypothesised to have negative impact on distributed scale solar deployment, the reason being micro-units especially the industries will not be developing captive solar plant to supply power for themselves, rather they will be complying to their environment and sustainable goals by means of purchasing RECs. The result from model is in align with our hypothesis.
- Power availability status in a state is an important supply side determinant for developing off-grid solar. If supply of power is undisrupted and available in proportion to the demand then need for deploying distributed-scale solar is less. The result from the model also indicates the same.
- An important feature i.e., Improvement in Ease of Doing Business seems to be negatively affecting deployment of distributed-scale solar. The plausible reason behind this relationship could be with improved structural support in terms of power supply reduces the need for deploying distributed-scale solar power, unless the electricity tariff is not economical. The result is bolstered by the fact that power availability indicator is having negative relation with the distributed-scale solar deployment.

Chapter 3

Financing of Solar Projects

Financials of Solar Power Projects

Solar and Wind Energy sectors are extremely dynamic in India. Over the traverse of three years more than 16,000 solar home systems have been financed through 2,000 bank branches, especially in rural territories of South India. Launched in 2003, the Indian Solar Loan Program was a four-year association between United Nations Environment Programme (UNEP), the UNEP Risoe Centre, and two of India's largest banks, the Syndicate Bank and the Canara Bank. On 11th January 2010, our former Prime Minister, Dr. Manmohan Singh launched Jawaharlal Nehru National Solar Mission (JNNSM) under the National Action Plan on Climate Change.

Capacity Addition Target of JNNSM

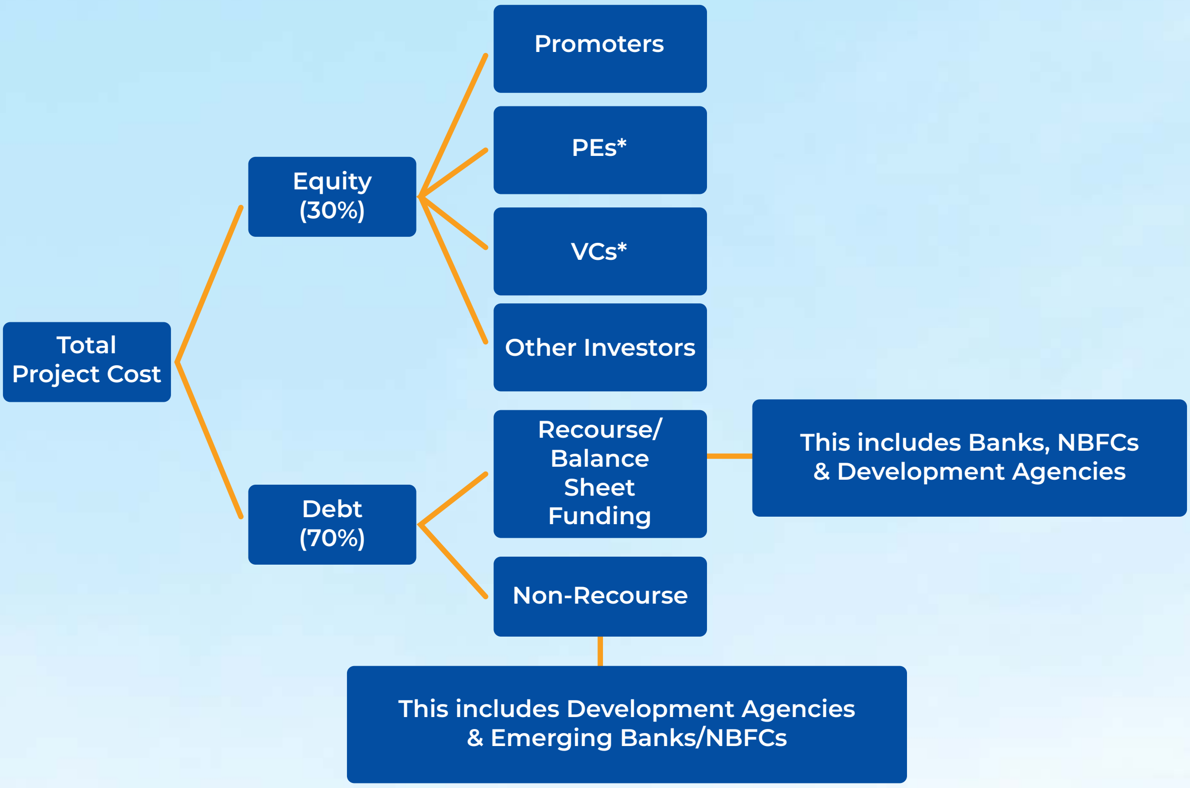
Application Segment	Target for Phase I (2010-13)	Target for Phase 2 (2013-17)"	Target for Phase 3 (2017-22)
Utility Grid Power including roof top	1,000-2,000 MW	4,000-10,000 MW	20,000 MW revised to 100,000 MW in 2015
Off-grid solar applications	200 MW	1000 MW	2000 MW
Solar thermal collectors (e.g., SWHs, solar cooking/ cooling, industrial process heat applications)	7 million sq. meters	15 million sq. meters	20 million sq. meters

Cost of Setting-up a Solar Power Plant in India

The usual cost of setting up a solar power plant is around Rs 3.5 to Rs 4 crores/MW. On general basis 30% of the cost is met by equity funding, and the rest through debt financing. Equity funding either comes from internal resources or from other investors. The EPC (Engineering Procurement Construction) contractors in India generally go for setting up solar plants with a debt-equity mix.

Debt-Equity Financing of Solar Projects

The following charts gives details of the financing options for setting up a solar power plant in India:



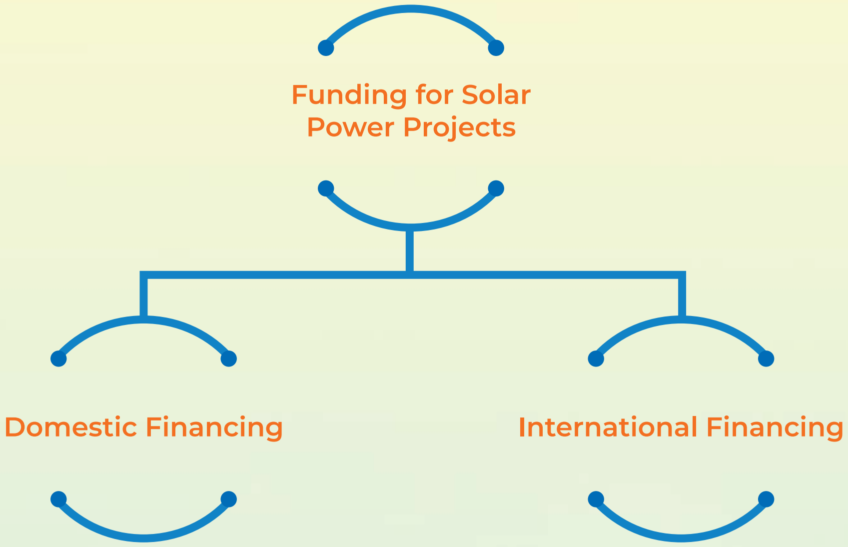
**PE: Private Equity; VC: Venture Capital Financing*
Source: Vivaan Solar; LSI Research

The financing of a Solar Power Project usually has a ratio of 70:30 (Debt: Equity). Debt financing is done via two sources- **Recourse / Balance Sheet Funding and Non-Recourse Project Financing.**

Balance Sheet Based Financing: This option is available mostly for large conglomerates with a healthy balance sheet that can support large projects. Using this option, the large corporate houses get lower interest rates using their existing relations with the banks. However, this model does put a lot of stress on the company's balance sheet and the entire burden of the project has to be borne by the developer.

Non-Recourse Project Financing: This is the financial model followed usually by a Special Purpose Entity. The lending institution provides the debt and has lien on the project's cash flow. However, since this financing model does not provide for recourse to the developers' balance sheet, the lending institution requires concrete agreements with the developer and solid revenue statements from the projects.

Domestic Financing: The Domestic Financing mainly comes from Banks. The Banks lend at rates between 11-13% while NBFCs lend at slightly higher rates in comparison. The Indian government's renewable energy lending arm (IREDA) lends at lower rates than the banks. IREDA lends to solar power project developers at rates between 10.2-11.4%. The collaterals required against the loans vary between 20% to 100%, usually IREDA has much lower collateral requirements when compared to Banks. The domestic loans are usually for a period of 7-10 years.

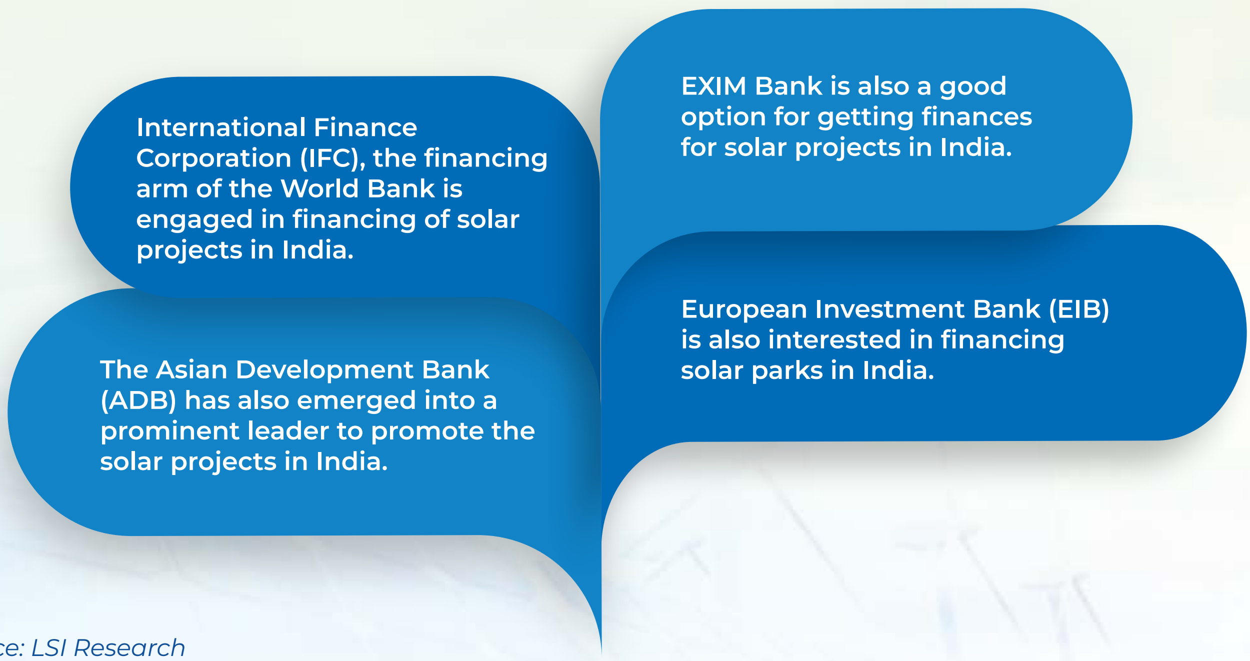


- Whether the company has a positive cash flow from its operations;
- Whether the company debt is less than 40% of its net worth;
- If the Debt Service Coverage Ratio (DSCR) of the company is greater than 1.5

International Financing: Interest rates for funding of solar projects from international sources is usually lower and between 8-10% though getting an international financier for a solar project is a time-consuming affair. Finding an international financier may take anything between 9-12months and this will delay the starting of the project. Further, even though international rates are lower than the domestic rates, the cost of hedging against currency fluctuations also needs to be factored in.

It is usually easier to get funding from international investors if the components used in setting up the solar project are also imported from the lending country; however, this is now becoming an issue as there are rules and regulations in place by the Government of India to stipulate domestic sourcing of solar components including solar modules, solar cells, etc.

Some of the International Financiers in India are as follows



Source: LSI Research

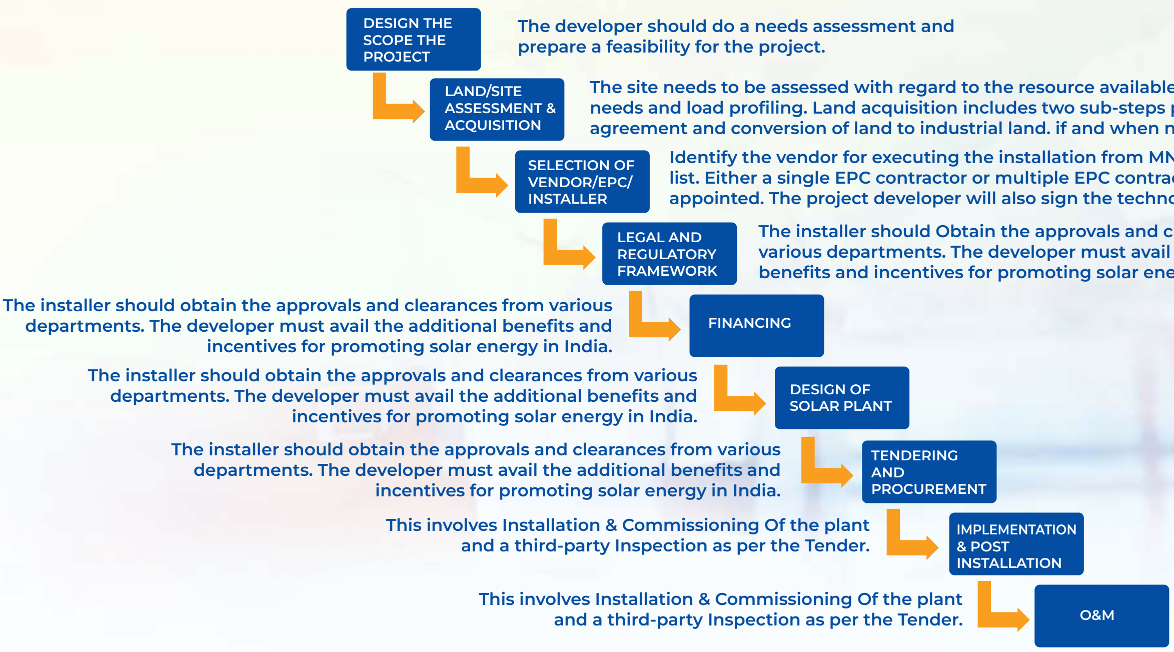
Apart from the sources listed above, many **green energy funds** are **providing equity** funding at cheap rates for the development of solar power.

Exhibit 3.1: Investment Model for 10MW Solar Plant All over India

Particulars	Unit	Details	
		From	To
Plant Capacity	MW	10.00	
Land Required per MW of Solar Capacity	Acre	3.5	4.00
Land Cost	Rs. Crore per Acre	0.05	0.07
Solar Plant Cost	Rs. Crore	35	40
Total Cost	**Rs. Crore**	**35.05**	**40.07**
Plant Load Factor	%age	18.00%	20.00%
Annual Degradation	%age	0.50%	0.70%
PPA Rate	Rs. per unit (kwh)	2.50	3.50
O&M Cost	Rs. crore per MW per Year	0.03	0.04
Insurance Cost	%age	0.25%	0.35%
Power Generated	Million Units	15.77	17.52
Revenue from Solar Power Generation	Rs. Crore	3.94	6.13
O&M Cost	Rs. Crore	0.30	0.40
Insurance Cost	Rs. Crore	0.09	0.14
EBIDTA	Rs. Crore	3.55	5.59
EBIDTA %age	%age	90.17%	91.19%
Rate of Interest	%age	8.00%	10.00%
Repayment Period	Years	18	20

Source: LSI TEV Studies on Solar Projects

Steps to Set-up a Solar Plant in India



Source: TERI ENVIS Centre; LSI Research

Chapter 4

Climate Finance- Special Focus on Solar Power

Climate Finance

In recent times financial economic researchers have begun exploring the important aspects of climate change economics that are financial in nature. The pricing and hedging of risks stemming from climate change and their effects on investment decisions play a crucial role in understanding climate change through the lens of financial economics. The flow of investment capital toward green projects and away from brown industries and firms proposes several directions in the mitigation of climate risk. Climate-aware investment portfolio focuses on investments in companies that are making efforts to reduce their carbon footprint and transitioning toward renewable energy technology like wind power or solar power.

Climate risks can be categorized into Physical Risk and Transition Risk

Physical risk	Transition risk
Results directly from the effects of climate changes on economic activity.	Results from the effects of transition to a low carbon economy on firms' operations and business models.
Example - The damage and destruction of real estate values from the rising sea level to firm's production hub close to the sea.	Example - The introduction of carbon tax that might leave fossil fuel companies with stranded assets that are no longer profitable to operate.

Climate risk and Financial Assets - The role of ESG

ESG scores assess how well companies manage risk based on their exposure to, and management of financially relevant ESG risks. The important elements of ESG are –

a) E – Environmental criteria which includes the energy a company takes in. It incorporates carbon emissions and climate change.

b) S – Social criteria which includes the relationships of a company with people and institutions.

c) G – Governance that addresses the internal system of company practices, controls and procedures in making effective decisions.

A correlation analysis has been done based on the ESG scores and investment amounts of different Renewable power manufacturing companies in order to examine the degree and direction of association between the two variables. ESG scores where the risk scores are categorized across five levels based on the severity of the risk.

Negligible	Low	Medium	High	Severe
0-10	10-20	20-30	30-40	40 and above

Exhibit 4.1 - ESG scores and investment outlays

Renewable Power Manufacturers	ESG score	Investment (crores)
Solar Industries India Ltd.	22.3	1492.53
Tata power Vikram Solar	67	40073.25
Adani Solar	35.9	24720
Suzlon Energy	28.1	3983.69
Azure Power Global Limited	15.4	37229
JSW Energy Ltd.	23.9	19713.96
Renew Solar	14.1	506131
Borosil Renewables Ltd.	27.9	1082.01
Siemens Gamesha Renewable energy	15.3	9702
Welspun	14.8	3457.94

Source: LSI Research, Sustainalytics and Company's Balance Sheet

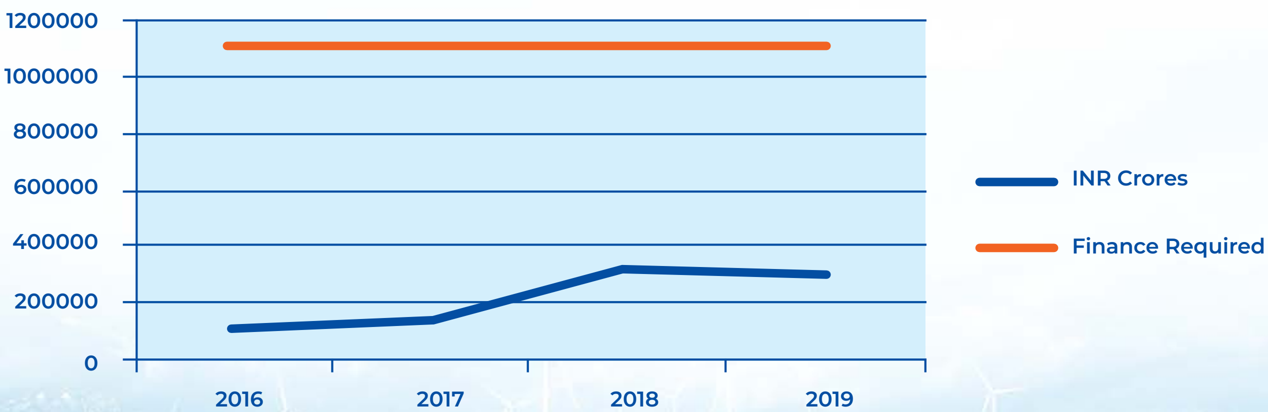
The correlation coefficient between the two variables is -0.2239. It shows negative association between the two. The companies with high ESG score are more exposed to environmental, social, and governance risks and any amount of their investment level is not considered as responsible investment behaviour. Hence, high ESG scores should be associated with low investment level.

The above analysis made it clearer that the power from renewable energy is not always clean from the environmental point of view. For example, a Photovoltaic (PV) solar cell is manufactured from the burning of dirty fossil fuels which requires huge amount of energy starting from the mining of quartz sand to the coating with ethylene-vinyl acetate. 100 percent renewable energy does not mean 100 percent carbon-free energy. A company that claims to be purchasing 100 percent renewables or generate enough renewable energy to match 100 percent or more of their electricity use for the year. For solar power energy generation, a company generates far more electricity than it uses during the day time and sells the excess. Then the same company purchases power from the grid at night time which is much carbon-intensive if it is generated from burning fossil fuels. Therefore, the companies are finding a way to leverage a portion profit by means of this price arbitrage mechanism. **Hence, power consumption needs to be matched with renewable generation on an hourly basis.**

Climate Finance Approach in India

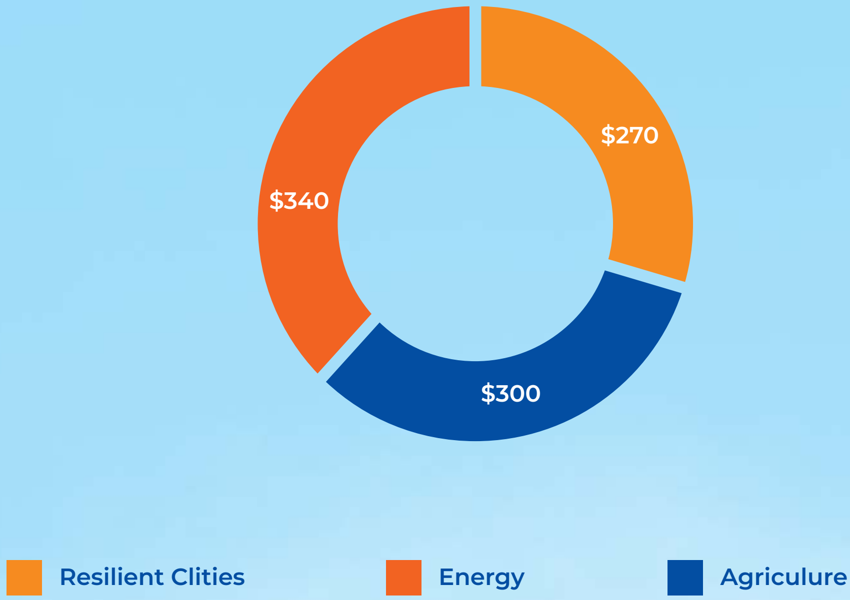
It is estimated that India requires approximately INR 162.5 lakh crores from 2015 to 2030 or roughly INR 11 lakh crores per year to achieve Nationally Determined Contributions (NDCs) under the Paris Agreement.

Exhibit 4.2: Green finance investments from 2016 to 2019



Source: LSI Research, Climate Policy Initiative

Exhibit 4.3 Total requirement of investment in three priority zones



Source: LSI Research- Authors calculations based on data from A study by the William Davidson Institute, University of Michigan

The three coloured zones in Exhibit 5.3 reveals the following three priorities –

a) Priority 1: 100% Renewable energy to be efficiently consumed

Under the Paris agreement India's Renewable energy target of 450GW would require the storage and related infrastructure to manage and balance grids efficiently which would increase the investment level to around US $300 billion.

b) Priority 2: Investment in Sustainable Agriculture

From a climate action perspective, food production has two critical implications-

i) reduction of GHG emissions associated with rice cultivation, food processing and livestock rearing

ii) creation of accompanying infrastructure for sustainable food supply.

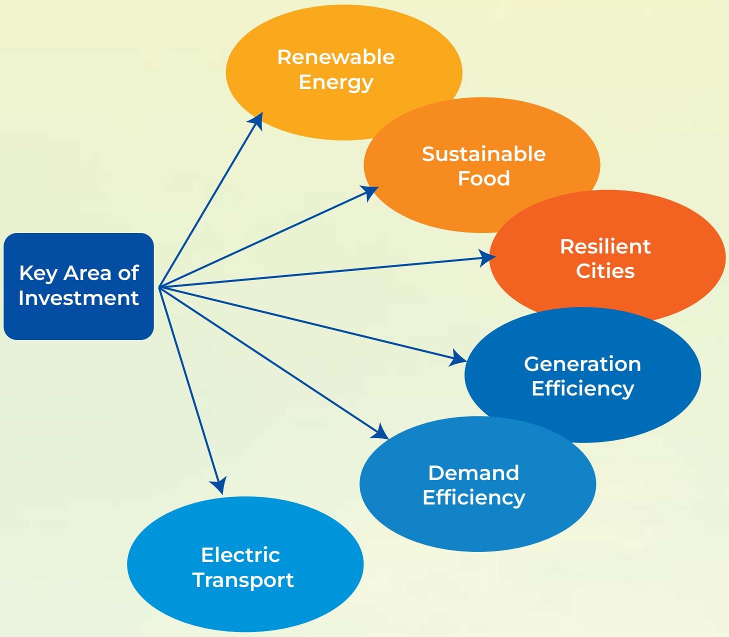
Estimation suggests that implementing these climate adaptation and mitigation measures in agriculture would require US $340 by 2030. CO2 mitigation through adoption of solar assets (pumps, dehydrators. etc.) is encouraging.

c) Priority 3: Building of Resilient Cities

Straining cities that already have poor infrastructure demand the need for greater resilience. The country will require around US $270 billion of investment in climate adaptation in cities.

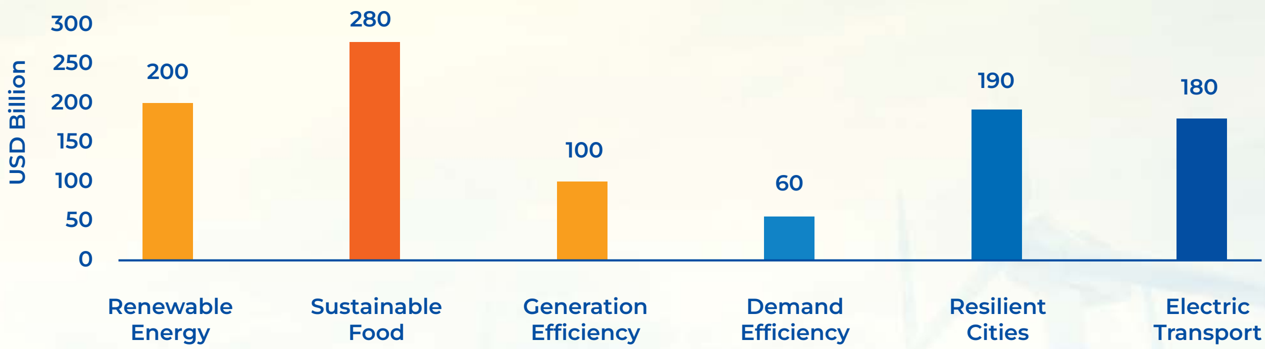
Climate Action Plan: India's Roadmap to 2030

India's climate action investments from 2022 to 2030 are estimated to be USD 1.01 trillion, an average of USD 112 billion annually.



The investment in Renewable energy includes adding of 400 GW capacity which is USD 200 billion, around 19.8 % of the estimated total requirement. Sustainable food focuses on farm productivity, food supply chains, plant-based alternatives and reduction of methane emission in farming and diary. To make cities resilient, significant investment in waste management, water sanitation and disaster management is necessary. Generation efficiency consists of grid modernization and smart metering. Investment in decarbonizing industries, switching to alternative heating and cooling technologies increase the demand efficiency. Studies show that the yearly cost of running an Electric Vehicle (EV) is significantly low and emissions from EVs are 43% lower than diesel vehicles. Investments in EVs help to lower lifetime climate impacts than internal combustion engines.

Exhibit 4.4 Estimate of climate investments by 2030



Source: LSI Research, based on data from Unitus capital

Solar – The Biggest Game in Climate Town

India has crossed the Renewable energy installed capacity of 100 GW in 2021. Though 175 GW targets set for the end of 2022 had not been met, but the country has now upped its ambitions. Getting to 500 GW renewable energy capacity by 2030, India needs project execution at a significantly faster pace accompanied with positive policy push and investment environment. By 2030, 280 GW of solar energy capacity is expected which is 7 times greater than the current levels. Solar started off as a crowded field with hundreds of start-ups but in past two years large companies continue to thrive.

Companies	Investments	Committed for
Reliance	$80 billion	100 GW solar + giga factories for modules, fuel cells and storage over 10-15 years.
Adani	$50 billion	Renewable investment by 2030.
Renew	$9 billion	New solar and wind projects by 2025.
Eversource	$1 billion+	Investment through solar platforms: Radiance, Ayana.
Virescent	$270 million	Solar investments through InvIT (Infrastructure Investment Trust) backed by investment firm KKR.

Exhibit 4.5 Renewable energy capacity trends in India (GW)

Source: LSI Research - Authors Calculations based on data from Ministry of New and Renewable Energy, Government of India

Chapter 5

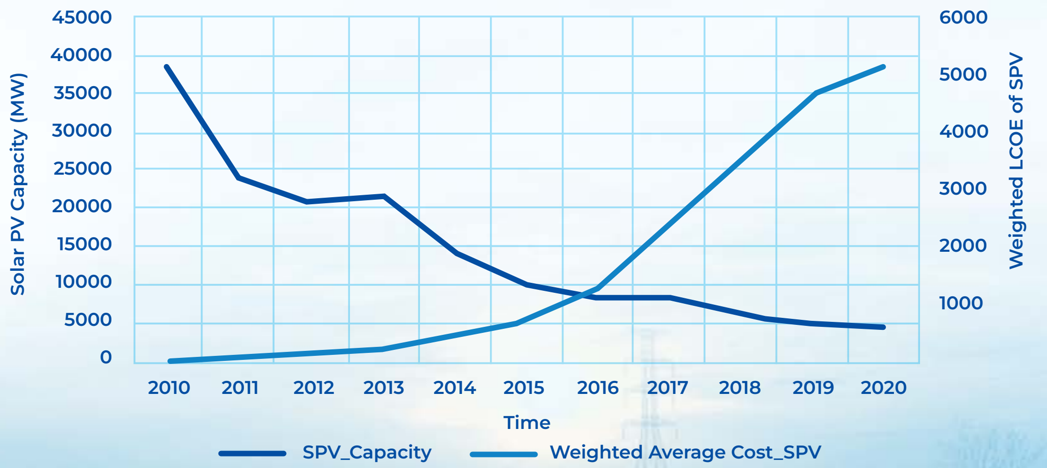
Transition to a Solar-Powered Future

India's energy policy action has gained momentum in 21st century in the direction of environmental and sustainability goals. Clean and environment-friendly energy harvesting, are of prime interest today as it is one of the key enablers in achieving the Sustainable Development Goals (SDGs), as well as it accelerates social progress and enhances living standards. Holding on to the pledge made in Paris Agreement, 2015, India is keeping up with the global trend and gradually shifting to renewable energy in response to its energy demand. As discussed previously in this report, among all the renewables solar energy potential is profuse in India, and hence it becomes a rationale choice of clean and attainable replacement of the extremely harmful polluting and depleting fossil fuel sources. India is continuously developing policies to harness solar energy and make viable utilization of it. Solar mission is undergoing through gradual setting and revision of targets in terms of solar grid electricity capacity addition. In this chapter of the report, we present a comprehensive study of how progressive the solar energy action plans has been so far, and to what extent it will be steering the desired outcome of reduction in carbon emission in subsequent times.

Growth and Productivity Dynamics of Solar Power in India

According to the Paris accord in 2015 India has pledged to source 40% of its power generation from renewable energies, by 2030. Till 2022 India has been able to add 64,380 MW of solar capacity cumulatively, and has set target to add up 270,000 MW. To achieve the desired target of solar capacity addition by 2030 the required CAGR is 17.26%. Solar Capacity addition is dependent on the levelized cost of electricity (LCOE). LCOE is defined as the average cost of the unit generated by a system and is calculated by the ratio of total annual cost of the system to the total electrical load served. LCOE includes both capital cost and operating cost.

Exhibit 5.1: Relation Between SPV Capacity Addition & LCOE of Solar PV in India

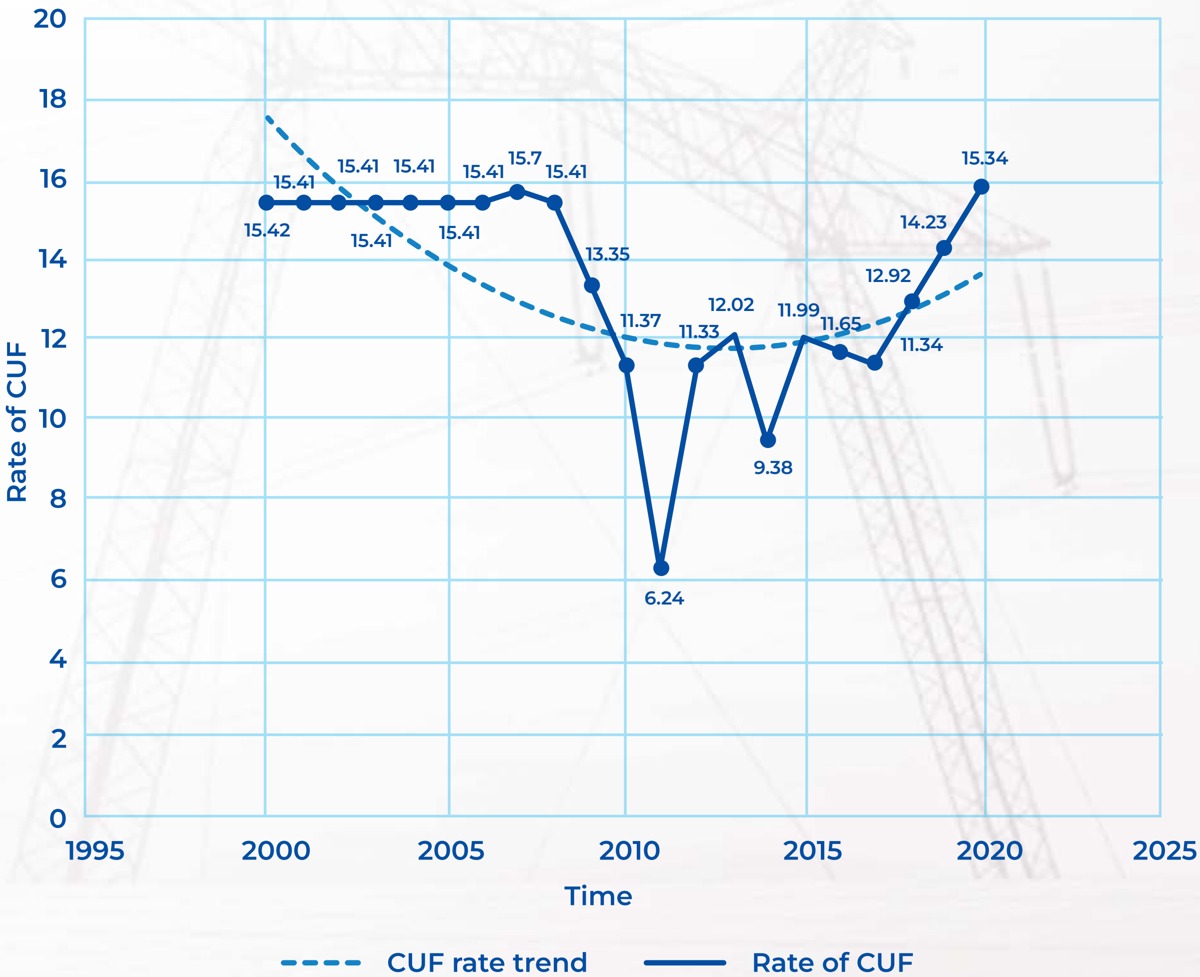


Source: LSI calculations based on IRENA data

From exhibit 5.1 it is evident empirically that there exists inverse relation between weighted LCOE of SPV and solar capacity addition. Lower the LCOE, more profitable the solar power project would be and hence more capacity addition is feasible.

Efficiency in productivity of solar power is understood by capacity utilization factor (CUF). Stakeholders including power purchaser, operator and regulator are always very sensitive to the rate of CUF. Lower rate of CUF will make the solar project non-economical and also won't be efficiently be acting as a substitute to the conventional form of energy (fossil fuel). Adoption of advance level of technology in PV can increase the CUF, and more significant increase in rate of CUF is possible with better power storage provision (through battery) at low cost. In this section we seek to understand dynamically the behaviour of aggregate CUF of solar power in India.

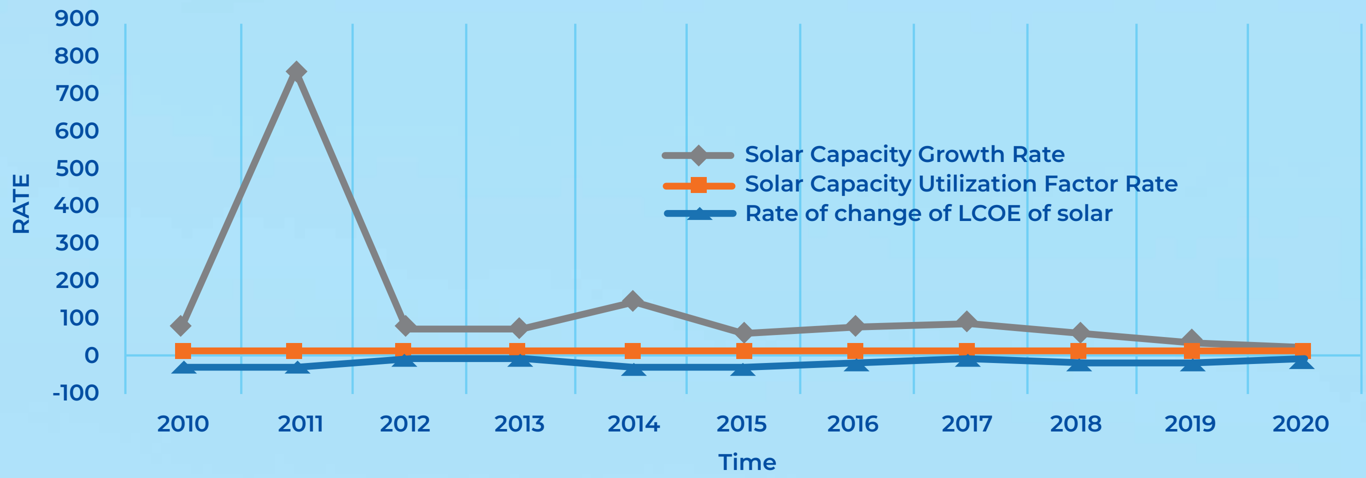
Exhibit 5.2: Rate of Solar Power Capacity Utilization Factor in India during the Period of 2000-2020



Source: LSI Research- Authors Calculations based on IRENA database

- From exhibit 5.2 it is observed that since the beginning of this century, rate of CUF of solar power in India has been constant with an average rate of 15%. The rate of CUF is found to be declining from 2007 and reached the minimum point in 2011. The solar energy policy programme came into action in 2010 and the effect in terms of solar capacity addition started rising exponentially thereafter. The effect on rate of CUF of solar power was found to be increasing after 2012 but at a moderate rate. The rate of CUF of solar power started increasing in full swing after the Paris Accord in 2015 and the long run trend is found to be of increasing nature subsequently.

Exhibit 5.3: Dynamic Relation between Rate of- Solar Capacity Growth Rate, CUF of Solar Power & LCOE of Solar PV



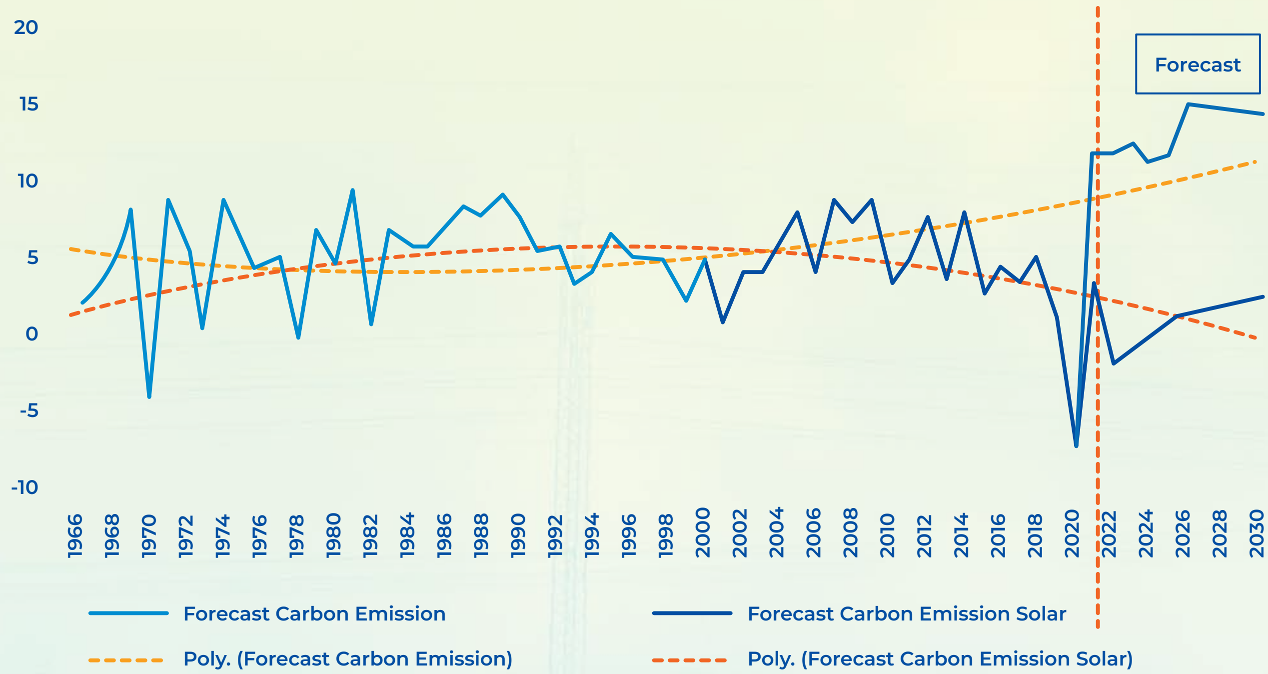
Source: LSI Research- Authors Calculations based on IRENA database

- Exhibit 5.3 presents the dynamic relation between the growth rate of solar capacity addition with the rate of change of LCOE of solar and alongside behaviour of rate of CUF of solar power. The period of study has been chosen after the National Solar Mission was introduced in 2010. The change in rate of LCOE of solar is found to be negative all through the span of the study and the rate of change of LCOE is dynamically oscillating over time. Following the declining LCOE of solar power, steepest growth rate of solar capacity addition is found in 2011 after the advent of extensive solar energy action plan but had a steep fall in the next period itself, and then onwards, nevertheless there has been continuous increase in solar capacity addition but the growth rate has increased relatively at a lower rate. Dynamically it is observed that the rate of change of LCOE is having a lagged effect on the growth rate of the solar capacity addition implying the change in cost in the current period is going to have an inverse impact on the solar capacity addition the next subsequent periods. The reason for the lagged impact is because of the rigidity of the nexus of formal contracts made between the concerned stakeholders in regards to the solar capacity addition.
- Though it is found to have a strong solar capacity addition in absolute terms but the rate of CUF of solar is proportionately very low with respect to the growth rate of solar capacity addition is near to uniform dynamically over the period of study. This proportionate lower rate of CUF of solar is hinting at the lower efficiency in productivity of solar power sector. Since solar PV comprises of the major share in the solar capacity addition, plausible reasons for lower CUF rate of solar is arising due to intrinsic limitations of PV, which is- high storage cost of power and the due to the loss in technical efficiency arising out of the imprecise prediction of solar energy at a given point of time. CSP technology can fill this gap of efficiency in terms of storage of power and can improve the rate of CUF of solar power. Another solution could be improving the prediction of solar energy by using Artificial Intelligence models and optimally operating the solar PV plant following those predictions.

Dynamic Relation of Carbon Emission and Solar Power in India – A Scenario Analysis

Behaviour of carbon emission in India has been previously explored in relation to primary energy consumption and GDP growth, in chapter 1 of this report. In this section we will be analysing the carbon forecast situation incorporating renewable energy i.e., solar power into the model.

Exhibit 5.4 Forecast of Growth Rate of Carbon Emission incorporating the Impact of Solar Power



Source: LSI Research- Authors Calculations

- Exhibit 5.4 depicts the long run behaviour of the carbon emission in India. The carbon emission series is being observed for the period of 1966-2020 and forecasted period of carbon emission is 2021-2030.
- Solar power series in the model has been introduced since 2000, and then onwards carbon emission behaviour in terms of growth rate has been analysed in terms rate of CUF of solar in India. Growth rate of carbon emission and rate of CUF of solar has been found to be integrated of the same order indicating a long run equilibrium relationship between them.
- Exhibit 5.4 represents a scenario analysis of forecast of growth rate of carbon emission excluding solar power impact, vis-à-vis forecast of growth rate of carbon emission incorporating rate of CUF of solar power. CAGR of forecast of growth rate of carbon emission (excluding impact of solar power) is found to be of 2%, and CAGR of forecast of growth rate of carbon emission incorporating the impact of solar power is found to be of decelerating nature, -2.6%. it is quite evident from exhibit 5.4 that there is a trajectory change in downward direction growth rate of carbon emission in the forecasted period after the inclusion solar power by means of rate of CUF. The long-run trend of growth rate of carbon emission (excluding solar power) is found to be of increasing nature whereas after the inclusion of the impact of solar power in the economy the long-run trend of growth rate carbon emission is of decreasing nature. Implication of the analysis stresses on the fact that carbon emission can be reduced further more if rate of capacity utilization factor (CUF) of solar power is being increased from the current state.

Data Source:

- MOSPI
- RBI – Handbook of Statistics
- Central Electricity Regulatory Commission
- Ministry of New and Renewable Energy
- BP-Statistics
- NITI Aayog
- IRENA
- Our World in Data
- NREL
- Institute of Energy Economics and Financial Analysis
- Union Ministry of Power, India
- William Davidson Institute, University of Michigan
- Sustainalytics
- Unitus Capital
- Bijlibachao.com

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