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Indian Building Integrated Photovoltaics (BIPV) Report 2022: Status and Roadmap

Status Report
2022

Report by

SUPSI-Swiss BIPV Competence Centre
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The here involved Institute for Applied Sustainability to the Built Environment (ISAAC) is part of the University of Applied Sciences of Southern Switzerland (SUPSI). The institute, under ISO 9001 accreditation, covers several research areas in the field of renewable energy, rational use of building energy with particular attention to green building standards, building maintenance and refurbishment, as well as technological development.
The building sector is active in the field of research concerning building operation, advanced solar building skin, sustainable materials and constructions. The Research unit, with almost 20 years of experience in BIPV, is one of the leader groups active in federal, European and international projects of applied research, including R&D, services at industries, communication and sensitization. The team is active in global experts groups of International Energy Agency, in scientific expert committees for international conferences and journals, in standardization bodies and in the main networks supporting BIPV. The Institute also has a PVlab covering a wide range of electrical, climatic and mechanical tests according to IEC– standards and accredited ISO 17025.
The main research activities of ISAAC and specifically of the BIPV group are focused on:

- Applied R&D for developing, testing, validating, demonstrating and industrializing innovative construction solutions for multifunctional building envelope systems, conceived designed and engineered on the basis of an integrated approach;
- Developing, in collaboration with partners (architects, industries, real estate managers, etc.), innovative pilot buildings integrating PV with the role of building skin components;
- Methodologies and techniques that favor the exploitation of solar energy in the built environment, both for new and existing building stock, by analysing the techno-economic feasibility, the market needs and innovation trends;
- Development of a digitized and integrated process within the BIM-based approach involved simulation and analysis of BIPV systems

CSIR-National Institute for Interdisciplinary Science and Technology
Animesh M Ramachandran, Adersh Asok

CSIR-National Institute for Interdisciplinary Science and Technology (NIIST), is a constituent Laboratory of the Council of Scientific and Industrial Research (CSIR), New Delhi, India. CSIR, established in 1942, is an autonomous society whose Presidential position is carried by the Prime Minister of India. It holds one of the largest R&D conglomerates in the world with a dynamic pan-India network of 38 national laboratories, 39 outreach centres, 3 Innovation Complexes and 5 units located across India. CSIR, known for its cutting edge R&D knowledge-base in diverse S&T areas, is a contemporary R&D organization and categorized amongst the foremost scientific and industrial organizations in the world. CSIR is ranked at 84th among 4,851 institutions worldwide and is the only Indian organization among the top 100 global institutions, according to the Scimago Institutions Ranking World Report 2014 (CSIR holds the 17th rank in Asia and leads the country at the first position).
CSIR-NIIST, one of the prime laboratory of the CSIR conglomerate is located at Thiruvananthapuram, Kerala, the south most part of India. CSIR-NIIST is mandated to conduct interdisciplinary research and development activities of the highest quality in areas related to the effective utilisation of resources of the region and of fundamental importance to the country. Apart from fundamental research of interdisciplinary nature, technology-based interventions have been greatly carried out in the last decade, especially in the field of solar energy. Innovative technological approaches like planar light concentrators, building integrated agrivoltaics, dynamic power windows, organic and inorganic hybrid solar cells, etc., can be mentioned as a few in the BIPV headway. The institute has already established and functionalised state-of-the-art facilities for conducting advanced research in the area of interest.

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Council of Scientific & Industrial Research –
National Institute for Interdisciplinary Science and Technology
(CSIR–NIIST)

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Chapter 1
Photovoltaic sector and its potential in India

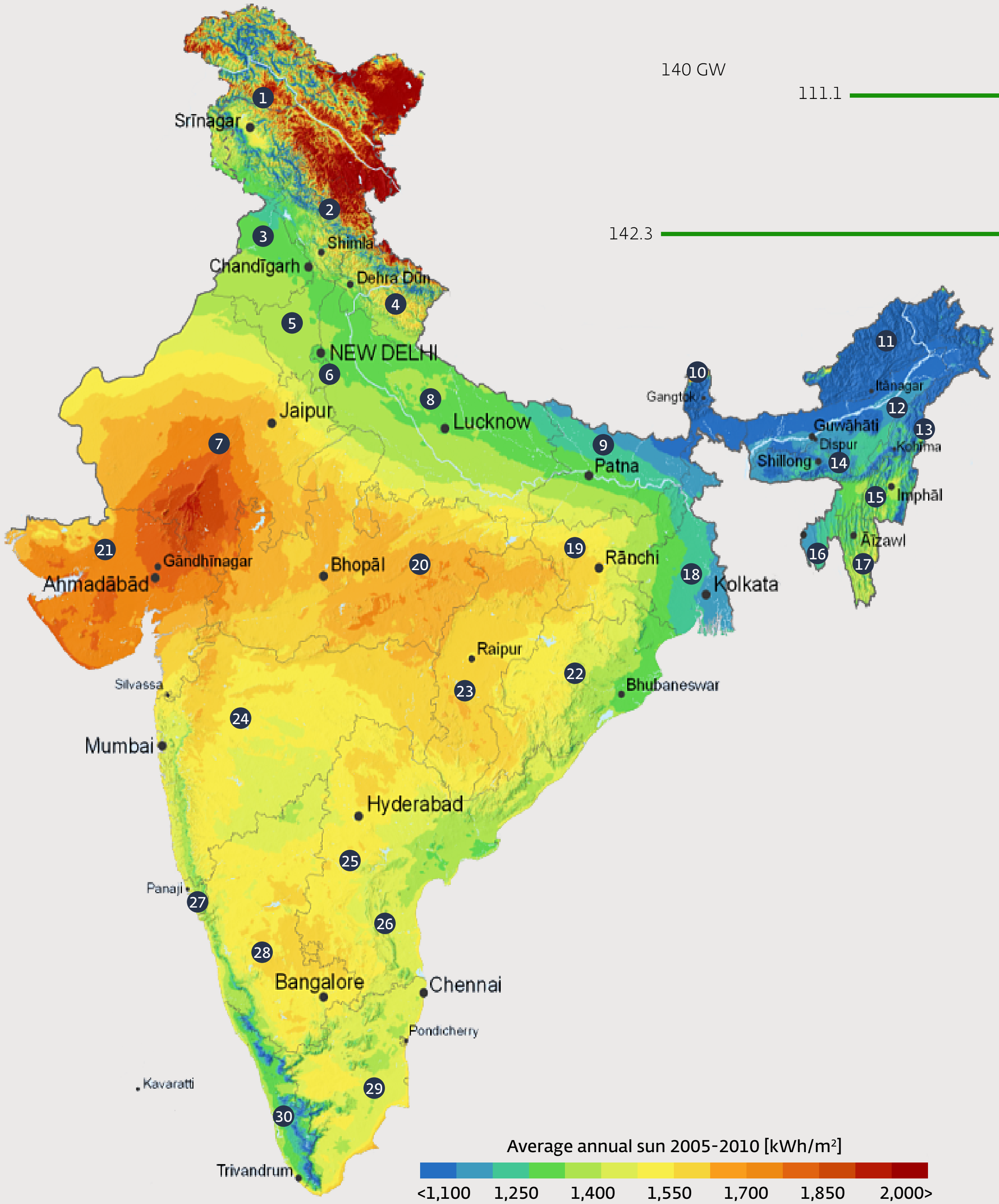
PV sector: potential, market and growth

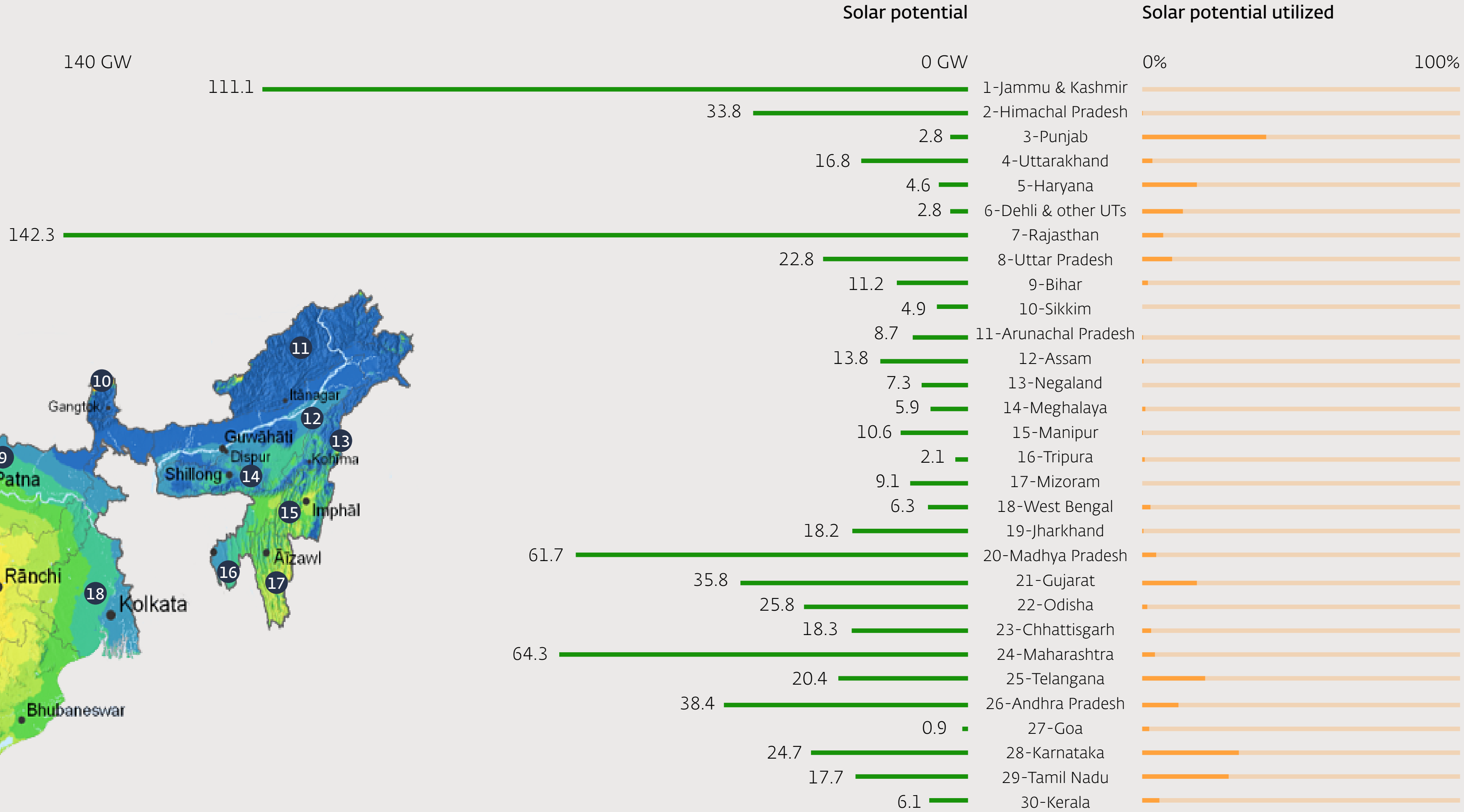
According to the 2016 Paris Climate Accords, countries have established their Intended Nationally Determined Contribution (INDC) by setting their targets and policies for gas emissions. In line with this, India has set an ambitious target to reduce the emissions intensity of Gross Domestic Product (GDP) by 33-35% by 2030 from 2005, by committing a 40% non-fossil-based electricity production by 2030 [1]. Renewable energy targets of 175 GW (with 100 GW from PV and among that 40 GW of grid-connected solar rooftop) by 2022 and 450 GW (with 300 GW from PV) by 2030 was announced to address the cause [2] [3] [4]. Further, in the recently concluded COP26 Glasgow meeting, the Government of India (GoI) announced its timeline to achieve net-zero carbon emissions by 2070. In addition to this, GoI increased its renewable energy target from 450 GW to 500 GW by 2030 to achieve half of its energy from renewables, a reduction of emissions by one billion tonnes and emissions intensity of the GDP by 45% in the same year [2]. Solar energy, being an abundant resource of the country, will play a significant hand in coping with the situation; the rising trend in solar photovoltaics (PV) capacity compared with other renewable energy sources in recent years accords the same [5].

The National Institute of Solar Energy (NISE), under the Ministry of New and Renewable Energy (MNRE) has assessed the solar photovoltaic potential of the country as about 748 GW [6]. India has been ranked 104th in the Global Horizontal Irradiance (GHI) and 98th in the average practical PV potential (Photovoltaic long-term power output produced by a utility-scale installation with fixed-mounted, monofacial c-Si modules with optimum tilt; measured in kWh/kWp/day.) [7]. However, the country has been ranked third in the Renewable Energy Country Attractive Index (RECAI: it ranks the world's top 40 markets on the attractiveness of their renewable energy investment and deployment opportunities) and first in Solar PV according to EY May 2021 Report [8]. Yet the country's solar power generation constitutes less than 4% of total value in contrast to 75% contribution from coal and gas, during the fiscal year 2019-20 [5]. Even though there are conspicuous changes in the PV development and its associated cost reduction in the past decade, yet their deployment is hindered by the limiting spatial availability and disadvantaged locations for grid-connected or Decentralised Distributed Generation (DDG).

India has tremendous potential to harness solar radiation while considering its geographical advantage favouring more solar energy tapping. The country's solar potential is estimated to be 5 quadrillion kWh per year, with an average GHI of 5.1 kWh/m2 per day [7] and an average of 2,300-3,200 sun hours [9]. The PV seasonality index (Ratio between the highest and the lowest of monthly long-term PV output averages) is 1.75 across India, advocating PV output reliability in Indian conditions [4].

The **Fig. 1** shows the annual solar irradiance distribution across the country. The irradiation distribution is higher and even for North-West, Central and most Southern states, covering the majority land area in India. As mentioned, the solar potential of India is about 748 GW, as estimated by MNRE, assuming only 3% of the wasteland area to be covered by solar PV modules [4] [10]. India's current solar power installed capacity (including ground mounted, rooftop and other off-grid installation) is around 49.3 GW till December 2021, which is 47% of renewable energy capacity, and contributing to 46% of India's total renewable energy generation in 2021 (exclusive of large hydroelectric power plants) [10]. The trend of installed PV capacity addition in India for the last decade, according to the MNRE data for the period of 2010-2021, is as shown in **Fig. 3** [10] [11]. For the last decade, a cumulative capacity of 40.1 GW was installed in India, and in 2021, India had added another 9.2 GW (from April 2021 to December 2021) marking the highest yearly addition till date, and reaching a total installed capacity of 49.3 GW. The Indian PV sector is experiencing a positive growth trend, with a more stepper growth during the last 5 years, which persuaded the GoI to raise their target of 22 GW solar power capacity to 100 GW by 2022 (**Fig. 3**) [4]. This can be accounted for around 13% of the MNRE estimated solar PV potential of 748 GW. Hence, there exists a massive opportunity for the Indian PV sector to tap this potential. However, this assumption does not consider the potential of PV integration in the major possible deployment opportunities like buildings that can exploit the market in congruence with the rapid growth of the construction sector in India.





The solar potential of India is about 748 GW assuming a 3% of the wasteland area to be covered by solar PV modules. India's current solar power installed capacity (including ground mounted, rooftop and other offgrid installation) is around 49.3 GW till November 2021.

Fig. 1 left Indian solar irradiation map. Source: 2011 GeoModel Solar s.r.o.
Fig. 2 up Indian PV potential and utilised potential. Source: [11].

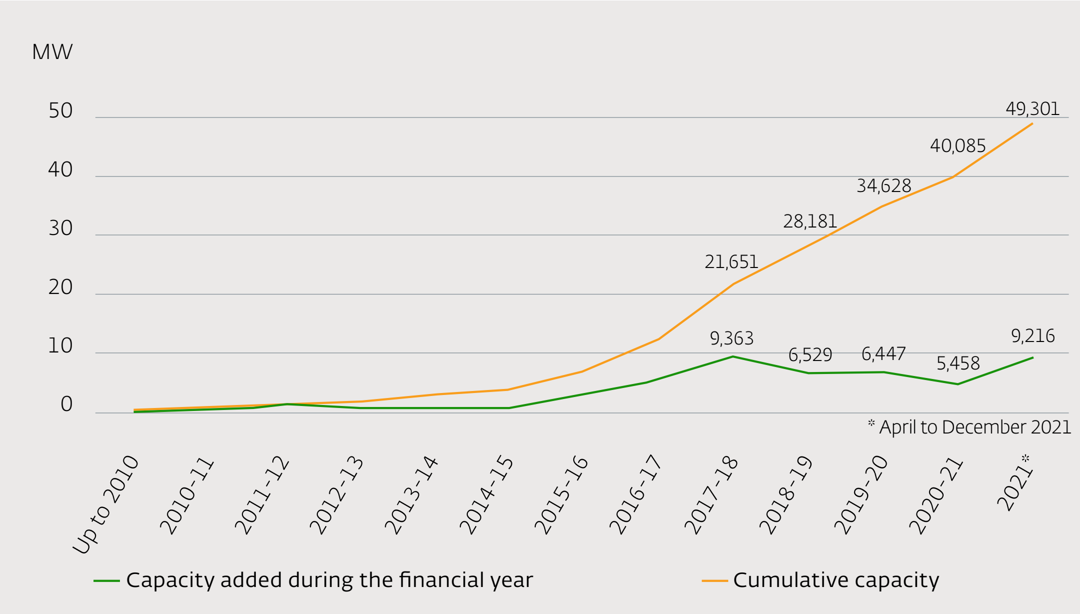


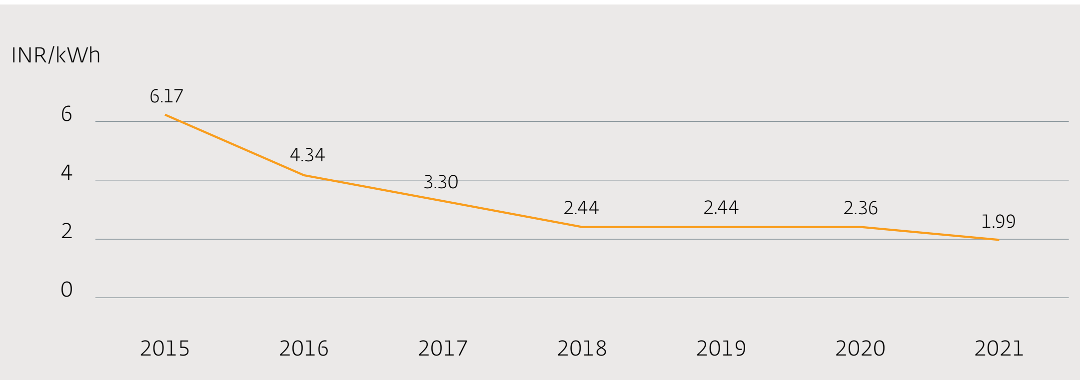
Fig. 3 India total solar PV capacity 2010-2020. Source: MNRE and India Renewables Dashboard.

The PV potential of different states, based on land area, has been calculated by MNRE [12]. **Fig. 2** (previous page) shows the PV potential of the States & Union Territories of India and their utilised potential (% of PV potential utilized by solar PV installations including grid-connected, off-grid and rooftop installations), drawing their corresponding performance (based on MNRE data). Rajasthan, Jammu & Kashmir, Maharashtra and Madhya Pradesh constitute 50% of the total PV potential in India. However, among the states, only Punjab, Karnataka, and Tamil Nadu utilised more than 20% of the PV potential.

PV tariff and cost breakdown

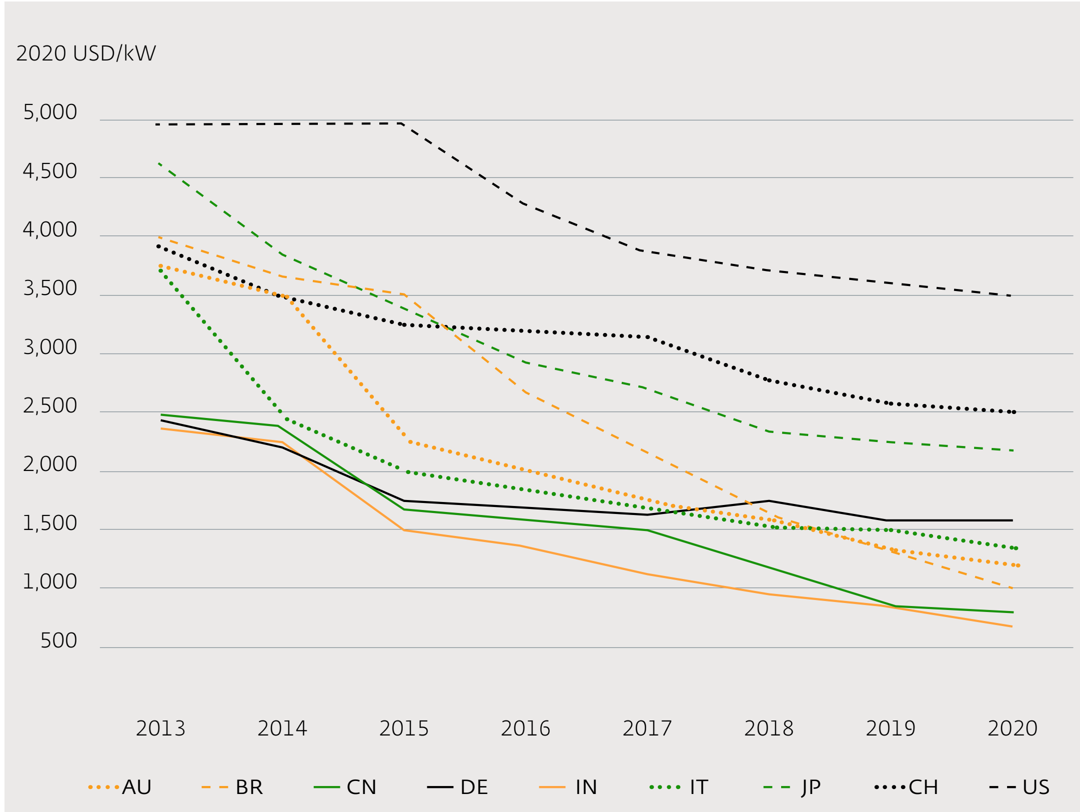
India is now the 5th largest country in terms of installed solar capacity. India intends to procure around 300 GW of its electricity coming from solar by 2030. To achieve that, the two key drivers, as suggested by Solar Power Europe (SPE) for solar energy growth are; i) increasing tender activity and ii) decreasing the solar PV tariff, enabling India to conclude one of the lowest solar auction bids around the globe in 2020. **Fig. 4** shows the decreasing trend of solar PV tariff in India from 6.17 INR/kWh in 2014 to a new low of 1.99 INR/kWh in 2020, for a 500 MW tender in Gujarat [12].

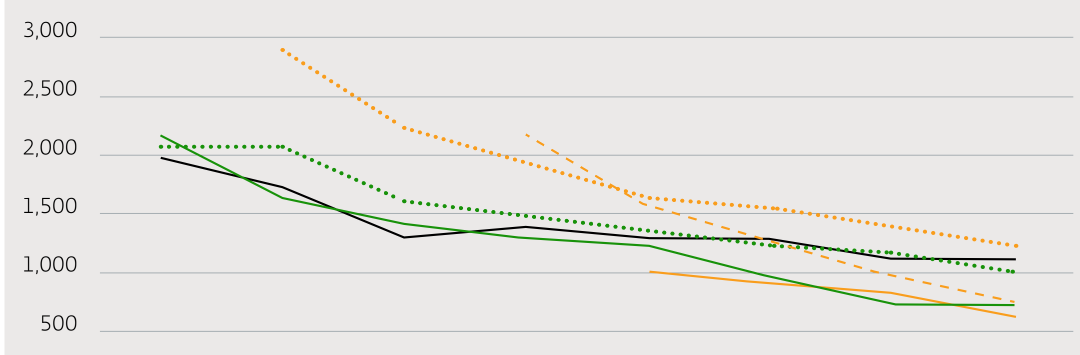
Fig. 4 India trend in solar PV tariffs 2015-2021. Source: MNRE.



One of the major drivers for this cost decline is the rapid decrease of installation costs in the last decade. During 2013-2020, the Indian residential sector solar PV total installed cost attained a reduction of about 70%, from 2,401 USD/kW to 658 USD/kW. Together with Brazil, it is the highest cost reduction in the last decade (**Fig. 5**). From 2017 to 2020, a cost reduction of about 35% is registered within the commercial sector (**Fig. 6**). The primary reason for this reduction is the global decline in PV module cost, which is about 57% in India from 2013 to 2018 for the GW-scale market. Utility-scale PV projects with a very competitive cost in India led to a total installed cost of 596 USD/kW, a value 8% lower than in China. The role of PV modules price is crucial in the Indian PV sector, as it covers a large part of the total installation cost (**Fig. 7**) [13].

Fig. 5 Residential sector solar PV total installed cost by country, 2013-2020. Source: IRENA.
Fig. 6 Commercial sector solar PV total installed cost by country, 2013-2020. Source: IRENA.





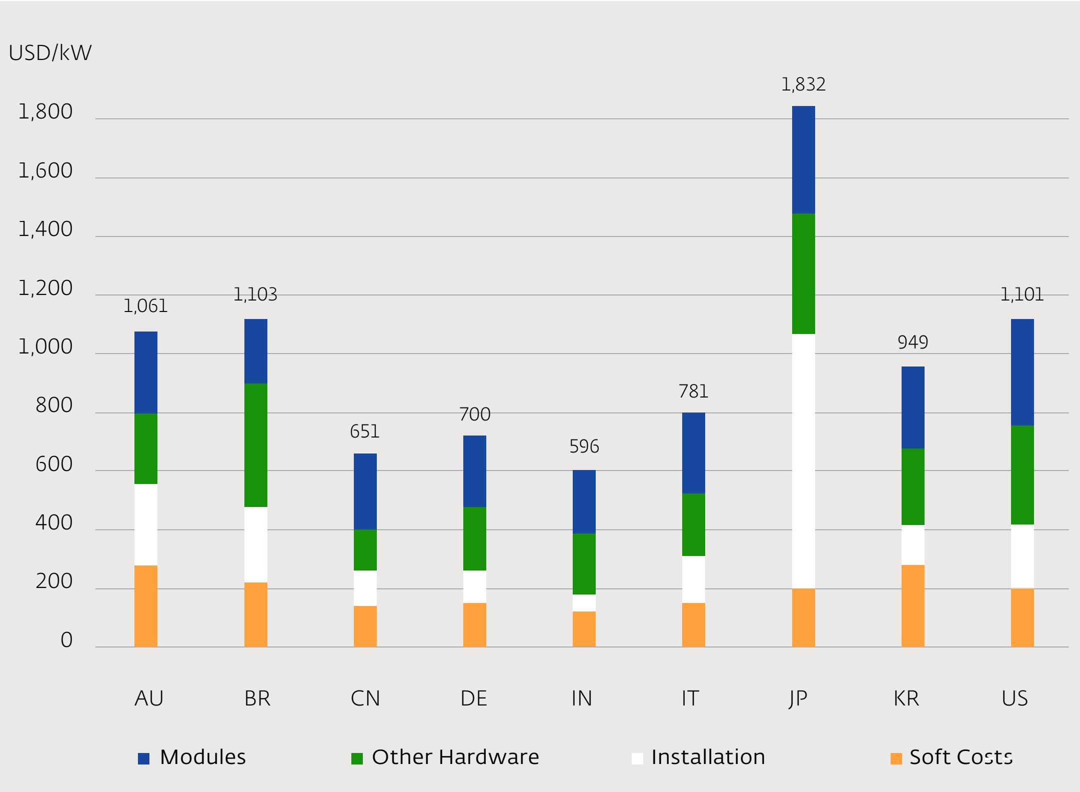


Fig. 7 Detailed breakdown of utility-scale solar PV total installation costs by country, 2020. Source: IRENA.

Council on Energy, Environment and Water (CEEW) conducted a recent survey (May 2020) among the major domestic module manufacturing companies in India having an annual manufacturing capacity ranging from 100MW to 2,000MW to value the cost disintegration of PV module manufacturing in India (considered only manufacturing of modules from cells). The manufacturing companies are Adani Solar, Emmvee Solar, Goldi Solar Private Limited, IB Solar, Jakson Limited, Navitas Green Solutions Private Limited, Renewsys India Private Limited, Tata Power Solar, Vikram Solar Limited, Waaree Energies Limited.

The following assumptions have been considered [14]:

- Production of mono passivated emitter and rear cell (PERC) modules with manufacturing plant capacity of 500 MW (IN) and 2,000 MW (CN)
- Plant's capital expenditure (solar cell to solar module) of 0.3 INR crore/MW (IN) and 0.2 INR crore/MW (CN)
- Plant's useful life of 5 years
- Capacity utilisation of 50% (IN) and 100% (CN)
- Return on equity (pre-tax) of 18% (IN) and 10% (CN)

The cost breakdown revealed that around 86% of the module selling price is associated with bill of materials (**Fig. 8**), and 58% of it corresponds to solar cell price (**Fig. 9**). Thus, the cell price of 9.26 INR/Wp constitutes 45% share of the module selling price of 20.37 INR/Wp. Detailed cost disintegration is shown in **Fig. 8** and **Fig. 9**. The survey was also extended to Chinese manufacturing companies, to compare the cost analysis. Compared to the Indian sector, the selling price is 5.05 INR lesser per Wp (33% cheaper) in China, owing to insignificant contribution from electricity, land lease, other overheads, cost of debt, and return on equity. Bills of material, including cell price, also cost lesser, compared with the Indian context. India currently has a manufacturing capacity of 10 GW of solar modules from solar cells, 3 GW of solar cells from wafers, and zero production of Polysilicon/ Wafer/ Ingots [15]. India mostly relies on countries like China, Vietnam, and Thailand for cell import and China, Vietnam, Malaysia and some domestic supply for other materials (TPT/PVDF sheets, EVA backsheets, Glass, Ribbons, aluminium frames and junction boxes), this is a major reason for the competitive disadvantage of Indian PV modules.

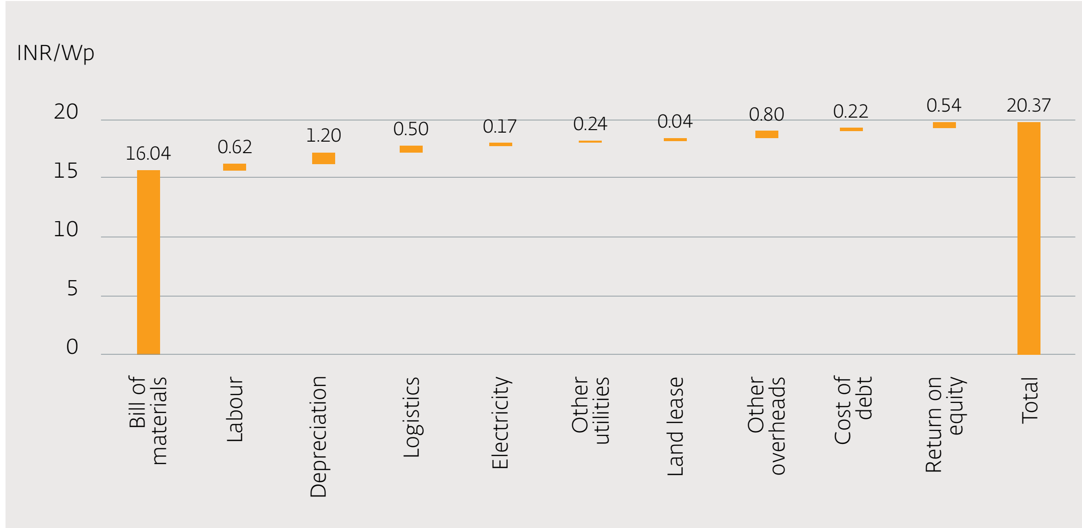


Fig. 8 Total cost PV module. Source: CEEW.

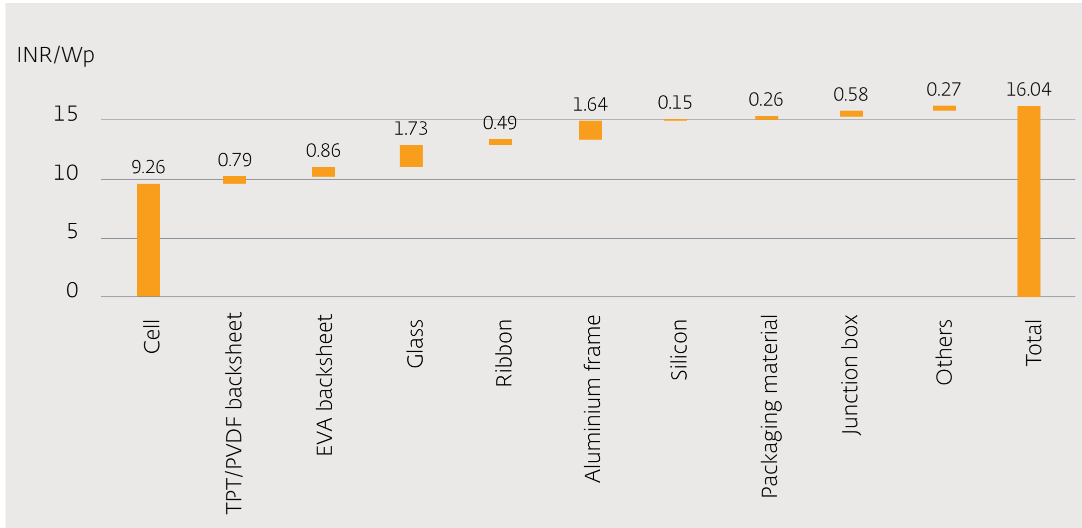


Fig. 9 Cost breakdown of the PV module (only material). Source: CEEW.

Penetration of PV in the building sector

Evolution of PV sector in India

Within this section, the evolutionary process of solar installations in India is analysed with the most representative milestones of the country. The process is assessed by analysing the regulation and policies that influenced the decisions made by the stakeholders of the solar value chain. This historical memory is expected to be useful to foresee new trends and optimise the investments in solar assets. The purpose of this section is to examine and find some key points, trends and breakthroughs defining the evolving path of technological innovation linked to photovoltaic transfer to buildings. The most representative events and case studies within the BIPV framework are shown in a timeline, a graphical tool that includes the core of the first chapter. Finally, an overview of BIPV showcases and best practices is offered to sensitise and apprise architects, designers, industries about the aesthetic, and energetic metrics for BIPV solutions.

The first research and development programs in the field of solar energy utilisation in India were introduced in 1980, about 20 years after the initial discussion of solar energy utilisation in India, in the 3rd Five Year Plan (FYP is introduced for India's economic strategies and planning). The programs initially emphasised industrial energy demand and decentralised implementation potential in rural areas. One year later, in March 1981, the Commission for Additional Sources of Electricity (CASE) was formed, and the National Solar Photovoltaic Energy Demonstration Program (NASPAD) was introduced by Central Electronics Limited (CEL), which marked the beginning of solar photovoltaic activities in India. CASE, more of an autonomous body, was charged with promoting, funding and generally supporting solar power research and integration. The NASPAD program supported R&D activities with CEL for developing reduced cost photovoltaics and improving their efficiency for Multi-Crystalline Silicon Solar Cells and to fabricate Ultra-High Efficiency (UHE) solar cells. During the same year, CEL was engaged in manufacturing solar PV cells and modules, and it achieved a total capacity of 10.35 kW. In 1982, the Department of Non-Conventional Energy Sources (DNES) was formed under the Ministry of Energy for developing the renewable energy sector in India. Between 80's and 90's many groups, agencies and programs have been formed to promote the use of clean energy resources, including the Indian Renewable Energy Development Agency (IREDA), for the promotion and commercialisation of solar-based electricity. IREDA, formed in 1987, focussed for funding, commercialisation and promotion of New and Renewable Sources of Energy (NRSE) programme, which was financially assisted by the Government of Netherlands, World Bank, Asian Development Bank (ADB) and The Danish International Development Agency (DANIDA), and executed by IREDA in coordination with state energy development agencies. In 1992, new ministry was formed for renewable energy sector, with the conversion of DNES to Ministry of Non-conventional Energy Sources (MNES). The Ministry was relabelled as the Ministry of New and Renewable Energy (MNRE) as of now in 2006.

During the 9th FYP, GoI adopted a more far-reaching reform to encourage private sector participation in the renewable energy sector for energy generation, transmission and distribution. The Independent Renewable Power Producers (IRPP) were given the right to power through the existing transmission lines controlled by State Electricity Boards (SEBs) with the liberty to sell the power to any third party. Also, the decentralised approach gave more opportunities to electrify villages in India. Special Action Plan (SAP) was promoted for upgrading and standardising Renewable energy production, especially solar panels in India. With the implementation on one side, GoI also focussed on more technology development through industries for the PV sector with initiatives like, Programme Aimed at Technological Self Reliance (PATSER) promoted by the Department of Scientific Industrial Research (DSIR).

In order to speed up the diffusion of solar installations, around the end of the 2000s, subsidies were introduced by various local governments. In Germany, the Renewable Energy Sources Act came into effect in 2000, and many countries around the world have adopted similar regulatory frameworks. GoI established the Electricity Act in 2003; the act provides a framework for the overall growth of the electricity sector with the private sector's participation and set a reasonable pricing for energy distribution. Provisions for preferential tariffs and quotas were provided for renewable energy. Also, mandatory procurement of renewable energy for distribution licensees and facilitation of grid connectivity were incorporated.

The 2005 National Electricity Policy allows preferential tariffs for power produced from renewable energy sources. It aimed to provide access to electricity to all and increase the minimum per capita availability to 1,000 kWh per year by 2012. The Tariff Policy of 2006 introduced the Renewable Purchase Obligation (RPO) to fix a minimum percentage of the renewable energy purchase of the total energy consumption for the states. Generation Based Incentives (GBIs) were introduced later at that time for small grid solar projects below 33 kW, offering an incentive per kWh of grid-interactive solar and wind energy generation. This was majorly withdrawn for utility-scale plants later due to the rapid growth of the renewable energy sector. Other incentives like accelerated depreciation (AD) and viability gap funding (VGF) were introduced after that.

GoI, under its National Action Plan on Climate Change (NAPCC) launched the Jawaharlal Nehru National Solar Mission (JNNSM) or called National Solar Mission (NSM), in 2010, to revolutionise solar energy as the way forward to attain energy security and mitigate the issue of increasing greenhouse gas emissions. The programme set the foot for rapid photovoltaic implementation in India. In 2010, in India, a PV utility-scale installation cost was about 5,000 USD/kW, while the total installed capacity reached about 11MW/year [16]. Interesting to notice that during the same year in Germany, the cost was about 3,500 USD/kW, 5,000 USD/kW in Italy and 4,000 USD/kW in the United States [13].

Under the JNNSM, Rooftop Phase-I programme was launched in December 2015, which marked the beginning of India's BIPV/BAPV activities supported by GoI. The programme tried to attract residential, commercial, industrial and institutional sectors by providing subsidies and incentives for rooftop PV plants ranging from 1 kWp to 500 kWp capacity. In 2018, India reached their 2022 target of 20 GW ahead of the timeline, and the goal was raised to 100 GW, while in 2019, the Rooftop Phase-II under the JNNSM was launched by targeting a cumulative building rooftop PV capacity of 40 GW by the year 2022. In 2018 the Indian utility-scale solar PV total installed cost achieved a decrease of 84% in comparison with 2010. It represents the highest cost reduction if compared with Countries like China (-77%), Germany (-69%), Italy (-83%), Japan (-74%) and United States (-66%) [13]. The new policies promoted by the GoI permitted to reach a solar PV capacity of about 49.3 GW by the end of 2021, with a rooftop PV capacity of about 6.1 GW, as reported by the distribution companies (DISCOMs) [17] [18] [19] [20] [9] [21] [12].

Landmark PV building installations

The concept of Building Adapted Photovoltaics / Building Integrated Photovoltaics was well realised even before JNNSM, which was marked as the point of growth for the Indian PV sector. Probably the first notable adoption of PV in buildings other than conventional rooftop installations came in 2007, at Samundra Institute of Maritime Studies (**Fig. 10**), Maharashtra, commissioned by Tata BP Solar. The campus was installed with a total of 90 kW PV installations, occupied as both translucent and opaque façades. The three hundred feet long photovoltaic solar wall in the Maritime Workshop structures for 60 KW PV installation. The Administration Building utilises northern light through its wavy glass atrium wall, while 30kW PV was placed at the south-facing façade.

Fig. 10 Institute of Maritime studies. Source: Ramprasad Akkisetti and Deepak Kaw.

Meanwhile, Tata BP Solar and Moser Baer India Ltd., was also involved in other building projects, such as the façade installation at Tata Consulting Engineers Limited's office building, Jamshedpur in 2009 and 1.8 kWp façade installation at Jubilee Hills shopping complex of Hyderabad in 2011, respectively.

One year after the launch of the JNNSM programme, in 2011, on the administrative building own by Festo in Noida, has been integrated a solar shading device, realised by Tata Power Solar with a capacity of about 20 kWp. This multifunctional installation permits to protect buildings from overheating during the summer and direct solar radiation and, at the same time, it produces renewable electricity for a total of about 17,000 kWh per year. In addition, it helps in avoiding 1.3 tonnes of CO_2 per year. The system is south oriented and mounted on a stainless-steel structure to maximise the energy production. The reduction of the building overheating due to the sunlight helped to reduce the cooling energy demand and increase the comfort for the users.

The concept of Green Buildings or Net-Zero Energy Buildings (NZEBs) is prevailing across the world for almost two decades, yet it has not been fully established or penetrated in the Indian context. Nowadays, State and Central governments, policy makers, architects, and builders are pushing for integration of energy efficiency and renewable energy production at the building design stage itself. The Indira Paryavaran Bhawan, building for Ministry of Environment and Forest (MoEF), in Jorbagh, New Delhi, was inaugurated in 2014, which sets itself as an exemplar for a change from conventional building design to net-zero energy approach (**Fig. 11**). The building is considered as India's first NZEB, one of the highest rated green buildings in India. It received five-star rating of Green Rating for Integrated Habitat Assessment (GRIHA) by MNRE and LEED India Platinum by Indian Green Building Council (IGBC) rating. The building has a solar PV system of 930 kW installed in a 6,000 m2 area. The total PV area is 4,650 m2 by 2,844 solar panels which generate 14.3 lakh unit annually which meets the building's energy demand. PV panels are covered in the building top, courtyard, and edges which effectively creates shade and cooler microclimate in the building [22].

In 2015, Tata Power Solar successfully commissioned the RSSB-Educational & Environmental Society (RSSB-EES) solar rooftop installation at Radha Soami Satsang Beas in Amritsar (**Fig. 12**). It was initially a 12 MW solar rooftop installed across 8 sheltered venues in a single premise. The project was claimed to be the world's largest solar rooftop project, set up in a single phase, and extended to 16 MW later. This rooftop power plant will produce more than 15,000 MWh units of electricity annually, and the whole solar power plant

Fig. 11 Indira Parvavaran Bgawan. Source: Rehau.

Fig. 12 RSSB-EES in Beas. Source: L&T Construction.

(total of 19.5 MW installation in the whole complex) at the site cumulatively offset over 19,000 tonnes of carbon emissions every year. Multi-crystalline modules were used in the project to achieve high performance and low degradation for a sustained 25-years energy generation. The system is provided with a central supervisor control and data acquisition (SCADA) system, enabling real-time solar power plant monitoring. A synchronised module cleaning system, improving the cumulative performance of the entire block, has also been implemented. To have a negligible downtime due to components failure or malfunction, the necessary spares are managed by using hub & spoke model (refers to distribution/management from a centralised hub), maintaining the availability at all times. The grid-connected system, equipped with net metering, can feed surplus electricity to the grid under the Punjab government's grid-connected rooftop solar projects scheme.

In India, the largest BIPV facade, has been realised in 2020 (**Fig. 13**, next page). The U-Solar CtrlS Data Center in Mumbai is an administrative building on which 863 kWp of monocrystalline modules were installed by integrating solar panels in all four walls of the facility, covering over 51,500 square feet of facade area. More than 2,000 high-efficiency PV modules were used to cover the building skin of the construction. The monitored energy production of the Data Center is about 0.6 GWh per year. In this case, the solar modules adopted represent a standardised design intended to be easy to integrate with many common building materials.

This strategy, common in Europe during the first/second decade of the 2000, is a consequence of partnerships among PV manufacturers, architects, and building-materials' suppliers, and approached to address barriers and bring new cost-competitive products and solutions on the market. A detailed specific analysis of this installation is conducted and reported in the case study section at the end of the booklet.

A contemporary and aesthetically pleasant exemplar for simple and effective building rooftop integration of PV is the Rajkumari Ratnavati Girls School located at the Thar Desert of Rajasthan (**Fig 14**, next page). The building was designed as elliptical for practical purposes and aligned with the Indian building construction culture. Herein, the PV panels serve the purposes of energy generation. In addition, the solar canopy offers shade and filters the sand from the desert. The stairs and the ramp serve as a play area for children hidden by a large jali (perforated stone or latticed screen, usually with an ornamental pattern constructed through the use of calligraphy, geometry or natural patterns) under the solar canopy. Being placed as a single row with the inward curve and directed to south with a larger inclination angle, the PV system is well integrated with the building design and purposes

Fig. 13 CTRLS Data Center, Mumbai. Source: U-Solar.
Fig. 14 Rajkumari Ratnavati Girls School, Rajasthan. Source: vinay_panjwani.

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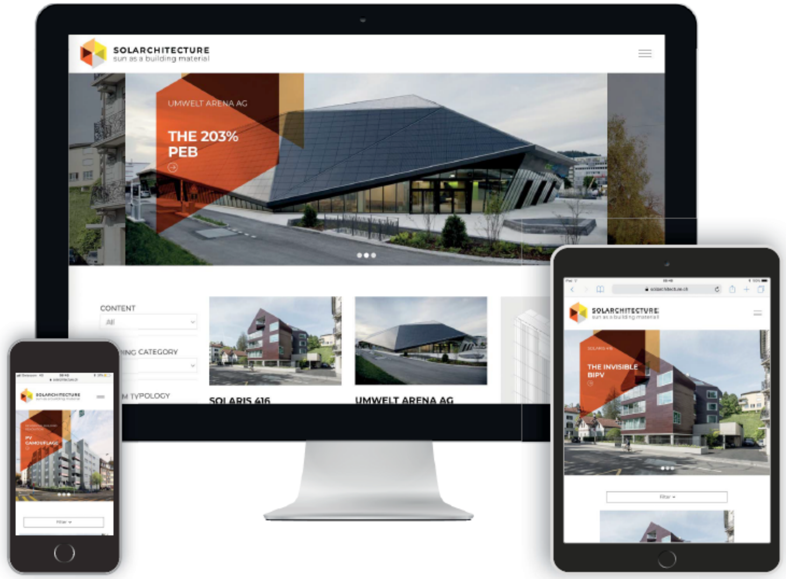


www.solarchitecture.ch

In the age of sustainability, most architects still see the issue of energy in buildings primarily as a constraint to work on. Particularly in the case of solar energy many of the new technological possibilities and integration potentials are not known and therefore not applied in the current design practice due to perceived barriers. Nowadays, new technological possibilities and inspiring projects of solar architecture have been demonstrated and need to be promoted in order to captivate architects, showing the architectural quality of "solar" and the huge potentials of a multidisciplinary approach bridging energy, design and construction. To appeal to architects, it is important to communicate in their language, in an innovative way and using a more complex approach where energy, architecture and construction are part in a unique design concept.

The main goal of www.solarchitecture.ch is to promote the construction of solar buildings by shifting the attention from technology to architecture. Real examples and stories of best practice prove today the feasibility and the quality of solar buildings in terms of aesthetics, construction technology and sustainability.
Solachitecture.ch, as a multidisciplinary and inclusive Swiss platform on solar energy, is managed and defined thanks to the collaboration between four main partners:

- SUPSI – ISAAC
- ETH Zurich
- Swissolar
- SwissEnergy

1981

The NASPAD marked the beginning of PV activities in India

1983

CEL achieved a module capacity of 31.75 kW

Institute of Maritime Studies

Credits: Ramprasad Akkisetti & Deepak Kaw

2007

The first BIPV building in India

Tata consulting engineers

Credits: Amit Basuri

2009

BIPV facade in Jamshedpur, India

2010

The JNNSM revolutionises solar energy as the way forward to attain energy security and mitigate the issue of increasing GHG emissions. The program set the foot for rapid photovoltaic implementation in India.

Festo building

Credits: Aseem Kumar Sharma

2011

A BIPV shading system (Noida, India)

2015

Rooftop phase-I programme was launched on December 2015, which landmark the beginning of the BIPV/BAPV sector in India

RSSB-EES

Credits: L&T Construction

2015

The largest solar rooftop plant in the world (Beas, India)

Malabar HQ

Credits: Sunsenz

2017

60 kWp installed as canopy

2018

Rooftop Phase II integration of 40 GW of rooftop PV installations by 2022

CTRLS Data Center

Credits: U-Solar

2020

The largest BIPV power plant in India (863 kWp capacity)

Ponnore Group

Credits: TopSun

2020

Cost efficient BIPV curtain wall

R.R. Girls School

Credits: vinay_panjwani

2020

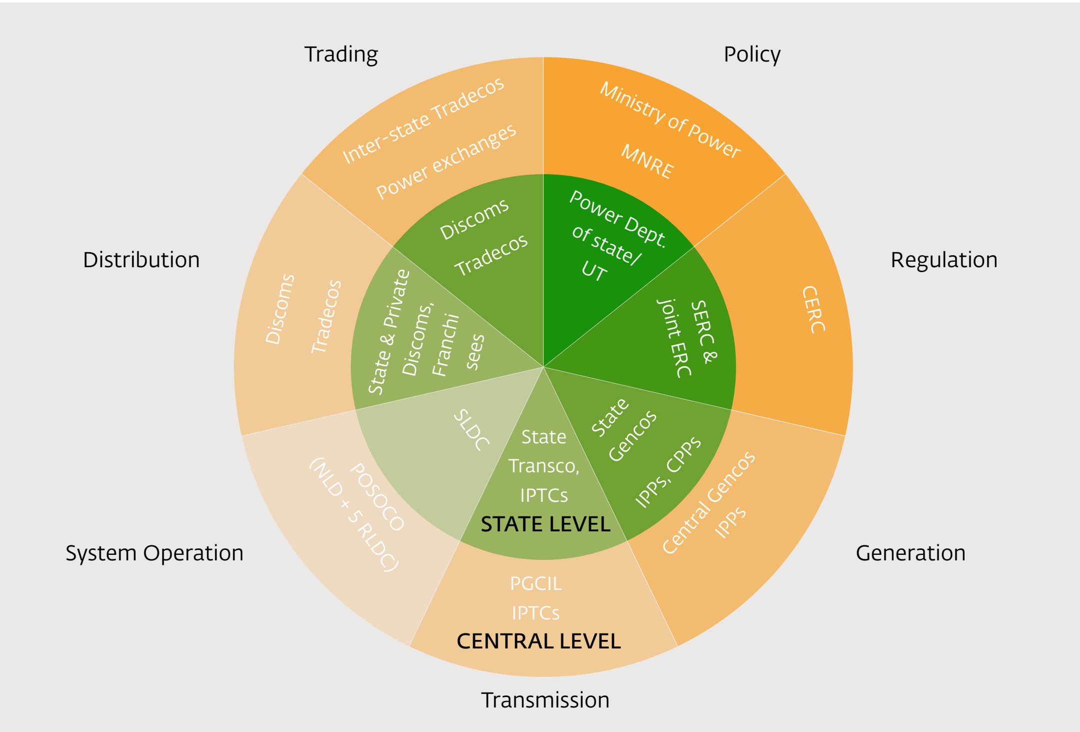
Photovoltaic solar canopy

Fig. 15 Indian BIPV Timeline. Source: SUPSI.

Financial schemes in solar buildings in India

Power Sector in India:
The Indian power sector is highly organized with functionally distinct organizations, departments and associations for the generation of electricity, its distribution and operation. The key stakeholders of the India power sector are shown in **Fig. 16**, framed with the involvement of both Central and State Governments with other private participants at different levels for efficient functioning. Ministry of Power, which oversees the entire energy sector and the Ministry of New and Renewable Energy (MNRE), is concerned with the central level policy making. Individual energy departments are also concerned with the policy making at the state level for the states & UTs. MNRE and its state nodal agencies are associated with the country's whole renewable energy sector, its promotion, international corporation, R&D activities, etc. MNRE also embodies five technical institutions in India: (1) National Institute of Solar Energy (NISE), (2) National Institute of Wind Energy (NIWE), (3) Sardar Swaran Singh National Institute of Bio-Energy (SSS-NIBE), (4) Indian Renewable Energy Development Agency (IREDA), (5) Solar Energy Corporation of India (SECI). NISE is the apex R&D institute for solar energy, which is also involved in solar component testing and certification. IREDA is a non-banking financial institution engaged in development and extension financial assistance for new and renewable energy projects. SECI is a Central Public Sector Undertaking (CPSU), formed to facilitate the implementation of Jawaharlal Nehru and National Solar Mission (JNNSM) activities. Apart from the ministries, the Central Electricity Authority of India (CEA), a statutory organization, advises the government on policy matters and formulates plans for the energy sector in India. CEA is also responsible for statistical data publishing of the Indian power sector for both state and central government utilities. Along with MNRE, CEA compiles the statistics on electricity capacity addition, generation, trade and forecasts. The Central Electricity Regulatory Commission (CERC) is a statutory body in India functioning to regulate the generation, transmission, and distribution in the country.

Fig. 16 Organisational chart for the power sector in India. Source: [23].



The State Electricity Regulatory Commission (SERC), is involved in the rationalization of electricity tariffs, policies, subsidies, inter-state transmission and trade etc. In the electricity generation sector, both public and private involvement (including Central and Sate Generation Companies, Independent Power Producers (IPPs) and Captive Power Plants (CPPs)) equally contributes to India's energy sector [24]. Considering the electricity transmission in India, the Power Grid Corporation of India Limited (PGCIL) is the Central Transmission Utility (CTU) and is held responsible for most inter-state transmission projects. State Transmission Utility (STU) and Independent Private Transmission Companies (IPTCs) set up other transmission projects within the states. For monitoring and ensuring hassle-free operation of the electricity sector, companies like Power System Operation Corporation (POSOCO) and National, Regional and State Dispatch Centres (NLDC, RLDC, SLDC) work in conjunction to ensure grid security and balance. Considering the energy distribution sector, mostly state-owned companies conduct distribution and retail operations. Some private companies are also involved in Indian electricity distribution at different states. In addition to this, inter-state and other energy trading companies, power exchanges, and distribution companies (DISCOM) set the balance for demand and supply. As represented in **Fig. 1.16**; this whole ecosystem makes the energy sector in India, created for the smooth functioning of the power sector at both national and state levels.

Rooftop Solar Program & Policies in India
India launched JNNSM on 11th January 2010, which is the key solar program developed in India until now. The program was developed in accordance with India's National Action Plan on Climate Change to promote the concept of ecological sustainable growth and addressing the issue of energy security in India with the diffusion of solar technology across the country. The mission targeted 100 GW of grid connected solar energy capacity by 2022, and installed a total capacity of 49.3 GW grid connected solar installations as of December 2021. In order to achieve the above target, the Government of India (GoI) has launched various schemes like Solar Park Scheme, VGF Schemes, CPSU Scheme, Defence Scheme, Canal bank & Canal top Scheme, Bundling Scheme, etc. to encourage the solar power sector of the country. Considering the fact that integration of PV in the building sector provides a huge potential to tap for the Indian energy sector, the Grid Connected Solar Rooftop Scheme has been greatly promoted by GoI in the second phase of JNNSM. By this programme, it is targeted a cumulative capacity of 40 GW Rooftop Solar (RTS) installations by 2022. As reported by DISCOMs, an overall of 3.7 GW capacity of grid connected rooftop solar plants has been installed in the country by December 2020, and was extended to 6.1 till November 2021 [12] [25]. As of now, the Solar Rooftop Scheme remains the only programme promoting solar PV in the building sector, and discussions are based on the programme.

Main RTS program actors
Solar Energy Corporation of India (SECI)
SECI is a CPSU under the administrative control of MNRE, set up to facilitate the implementation of solar plants under the JNNSM. SECI plans of the targets of RTS installations in the country and decides on the allotted capacity following the competitive bidding process.

State Nodal Agencies (SNAs)
Under MNRE, SNAs have been established in the states and UTs for the promotion, coordination, finance and development of renewable energy projects in their state/UT. For the RTS program, the SNAs prepare targets as sanctioned by MNRE and select channel partners/installers through tendering with the rate contracts. SNA are also involved with the monitoring and inspection of the RTS installations.

Distribution Company (DISCOM)
Various public and private DISCOMs are concerned with the interpretation and implementation of the policies and regulations provided by both the Central Government and Governments of individual states. The overall technical feasibility study, evaluation of design and installation parameters for grid connected RTS system, installing metering arrangements have been carried out by the DISCOMs.

Chief Electrical Inspector to Government
The Chief Electrical Inspector (CEIG) ensures safety compliance and operations of RTS system. They involve in the approval of design and drawings, the pre-commissioning inspection and issuing of Charging Certificate.

Channel Partners
Channel Partners are the agencies associated with the sourcing of equipment/ solar components, or the implementation of RTS system for the clients, being empanelled by MNRE. The Channel Partners could include the solar Renewable Energy Service Companies (RESCO), vendors/ suppliers of solar equipment,

project developers, manufacturer of solar components/ equipment, solar ambassadors etc. The empanelment with MNRE is based on certificate from a rating agency in the country for technical and financial strength. SNAs and DISCOMs have to undertake competitive bidding for selection of developers for RTS plants with the claim for Central Financial Assistance (CFA)/ subsidy. The channel partners submit the proposal to the clients (rooftop owners), sign the EPC/Power Purchase Agreement (PPA) agreement with clients and submits for the metering arrangement (to DISCOM) and subsidy (to SNA).

Financial Institutions/Banks
The financial Institutions and financial Integrators like NABARD, National Housing Banks, other Banks, IREDA, etc. are also eligible for implementing the RTS program. They may source funds from MNRE, their own resources or any other sources i.e., carbon credits, National Clean Energy Fund, funds from States, beneficiary contribution, CSR sources etc. Other Govt. Departments/ Agencies i.e., Railways, Defense/ Para Military Forces, Local Government Bodies including Municipal Corporations/ Municipalities, State Departments, etc. interested in directly implementing the program are also encouraged [26] [27] [28] [29].

Boundary conditions for PV in relation to building typologies (based on RTS scheme)

This section presents an overview of the different boundary conditions for the present state of solar PV adoption in Indian buildings. Financial relaxations for the different building typologies (residential, commercial and industrial) according to the benchmark cost provided under the RTS scheme establish the investment of solar installations in building. The cost of electricity and the levelized cost of electricity (LCOE) lays the foundations for an accurate cost analysis for solar installations. The analysis of electricity costs, the benchmark cost and financial relaxations will help to understand the framework and the strategies adopted for the RTS consumers in the country. The electricity costs within the different building typologies, the metering methods and available business model form the basis of attractiveness of RTS scheme in India. The different boundary conditions of Indian RTS scheme are discussed below.

1. Financial relaxations and benchmark cost

For residential buildings
Under Phase II of Grid Connected Rooftop Solar, the CFA has been approved for the beneficiaries until 31st December 2022. Under the scheme, only domestic manufactured modules and solar cells have to be used and the CFA shall be on percentage of benchmark cost of MNRE for the state/ UT or lowest of the costs discovered in the tenders for that state/ UT in that year, whichever is lower. For the residential sector, the CFA is 40% for capacity up to 3 kWp, 20% for capacity beyond 3 kWp and up to 10 kWp, and 20% for Group Housing Society (GHS) / Residential Welfare Association (RWA) capacity up to 500 kWp (limited to 10 kWp per house). The scheme is to be implemented through Power Distributing companies (DISCOMs), and for the residential consumer the CFA can be availed by operating through the DISCOMs [30]. The benchmark costs for Grid-connected Rooftop Installation under Phase II for the financial year 2020-21, decided by MNRE as presented in the **Tab. 1** and **Tab. 2**. Cost are referred to turnkey PV plants (including installation and put in operation) for conventional PV plants (e.g. BAPV on-roof systems). The benchmark cost includes the cost of PV panels, inverter, balance of system (cable, switches/ circuit breaker/ connectors/ junction box, mounting structure), earthing, lightning arrester, Comprehensive Maintenance Contract (CMC) for 5 years, transportation, insurance, applicable taxes, etc. The cost for metering and battery backup are not included [31] [32] [33].

For other buildings
In the Phase II of RTS scheme, institutional, educational, social, government, commercial and industrial sectors are excluded from availing CFAs, as the beneficiaries of these sectors are advantaged without CFA, since they are mostly high tariff paying consumers. However, for the penetration of solar systems in these sectors for the implementation of 40 GW rooftop solar installation target, acceleration depreciation (AD) benefits and Viability Gap Funding (VGF) is provided by the GoI under JNNSM Scheme [34] [35].

For the DISCOMs
For DISCOMs progressive incentives provided by the government are based on achievement levels, calculated above baseline, i.e. the cumulative rooftop capacity achieved at the end of previous financial year. For capacity addition up to 10%, there is no incentive. For 10%-15% capacity addition there is 5% incentive, and for above 15% capacity addition 10% incentive is provided. The incentives are limited to the initial 18 GW capacity [30].

System capacity range	< 1 kWp	1-2 kWp	2-3 kWp	3-10 kWp	10-100 kWp	100-500 kWp
Benchmark cost (Rs/kW)	46,932	43,140	42,020	40,991	38,236	35,886
Benchmark cost (2021 €/ kW)	554	509	496	484	451	424

Tab. 1 Benchmark costs for grid-connected rooftop installation under Phase II for the financial year 2020-21 for general category states/UTs (currency conversion 17/01/2022). Source: MNRE.

System capacity range	< 1 kWp	1-2 kWp	2-3 kWp	3-10 kWp	10-100 kWp	100-500 kWp
Benchmark cost (Rs/kW)	51,616	47,447	46,216	45,087	42,056	39,467
Benchmark cost (2021 €/ kW)	609	560	545	532	496	466

Tab. 2 Benchmark costs for grid-connected rooftop installation under Phase II for the financial year 2020-21 for special category states/UTs: North eastern states like Sikkim, Himachal Pradesh, Uttarakhand, Jammu and Kashmir, Ladakh, Andaman and Nicobar and Lakshadweep islands (currency conversion 17/01/2022). Source: MNRE.

2. Billing mechanism and RTS considerations

The type of metering greatly influences the growth of the PV sector, as it directly affects both the consumer economy and the energy sector. The types of metering are detailed below.

Net Metering
In net metering systems, a bi-directional meter is used to measure the difference in energy consumption from the grid and energy export to the grid. Consumers are provided with the opportunity to offset their electricity bills accordingly. Surplus injection compensation may or may not be provided (depends on state regulations) for the excess energy supplied to the grid.

Gross Metering
In gross metering or feed-in metering, all the energy generated from the system is exported to the grid and is separately recorded through a different 'feed-in meter'. In this case, the third-party investors/RESCO developers enter into a long-term PPA with the utility. The developer exports the solar energy to the utility at a predetermined feed-in-tariff (FiT) approved by the regulator. The model is particularly aimed at rooftop owners/third party investors who would like to sell energy to the DISCOM.

According to the latest amendment by the Ministry of Power, every consumer can avail net metering system for RTS installation below 500 kWp [36]. Further, any state government can extend the limit according to their regulations for any solar installations. The net metering regulations for commercial and industrial buildings, the electricity retail tariff, feed-in-tariff for gross metering and the surplus injection compensation for consumers who supply excess energy to the grid (in the case of net metering) for the different building typologies are determined by the state commissions and the DISCOMs. These state regulations greatly determine state's friendliness for the RTS scheme and other solar PV integration in residential, commercial and industrial buildings [37].

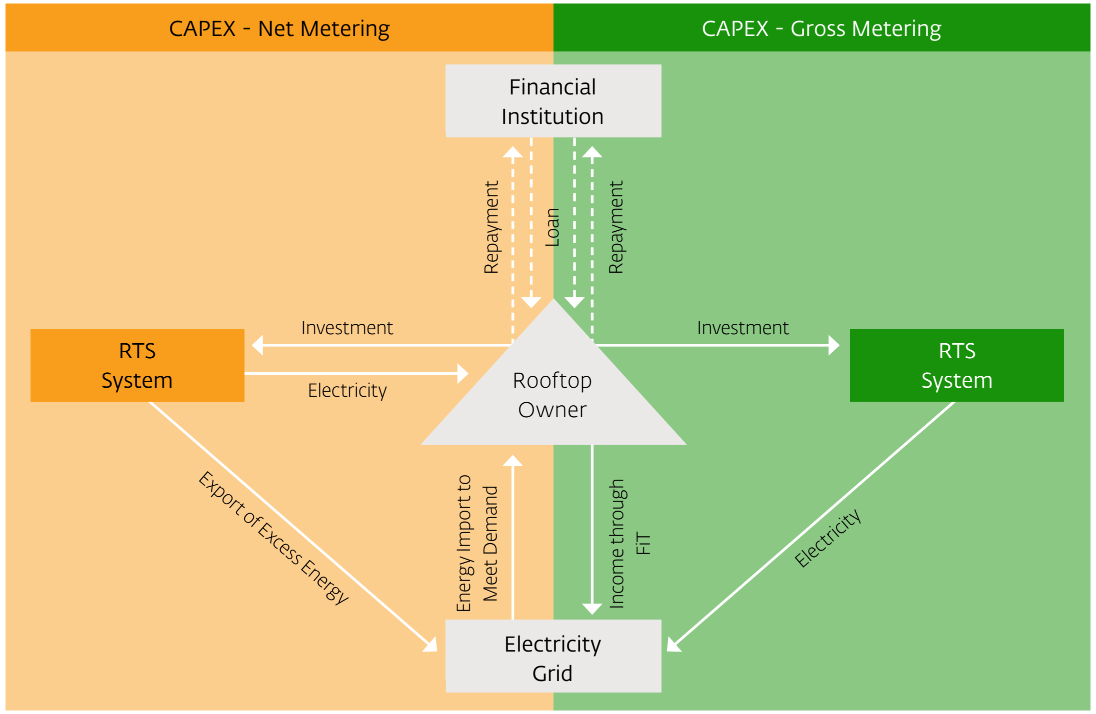
Appropriate business is always necessary to have a satisfactory revenue model for the stakeholders under consideration. In particular, it permits to the investor to understand the value of the investment in solar installations and to optimize the strategies of investment in solar systems. CAPEX model is considered as the first-generation model, which is a consumer self-owned model. RESCO model is the second-generation business model revolved around third party ownership and operation. Currently, these two models are majorly prevailing in India for PV building installations, the policies for each are according to DISCOMS and state government regulations. The third-generation, utility ownership driven model is considered as a future scope in global solar energy sector, but it is only emerging in Indian solar rooftop/ solar building scenario. Within these paragraphs, the two most popular business models in India for grid connected solar rooftops are elaborated. For other BIPV systems, CAPEX models are considered unchallenging, because of the ownership provision; other dedicated business models are necessary for the sector in future. CAPEX model is the most common business model for rooftop solar deployment in India. In this model, the consumer (rooftop owner) owns the system (expenses include the installation cost, O&M cost), by upfront payment or with other financial aid, often through a bank. These expenses include the cost to set up, maintain and operate the system. The power is either consumed or injected to the grid with a Feed-in-Tariff (gross metering) or net metering, as shown in **Fig. 17**. CAPEX models are well suited for consumers that can bring the investment upfront, and has a stake on the building.

In RESCO model, third party (RESCO) involves in financing and development of solar rooftop systems. Third party may rent rooftop space from rooftop owner and sell the electricity generated to the grid or the rooftop owner through a PPA, or may also lease out the PV system to the rooftop owner who may utilize the power from the system. For consumers who does not have a stake on the building, such as government building, public educational institutions, leased building, etc., or consumers who cannot bring the investment upfront, the RESCO operation models are best suited. The possible models upon different agreements are described and represented in **Fig. 18** and **Fig. 19**.

Solar system leasing

In this, third party investor leases the PV system to rooftop owner who makes payments as per the agreement for the consumption of the electricity generated. The third-party investor earns month-to-month lease payment. The savings from the generated electricity is the source of revenue for the rooftop owner.

Fig. 17 Financial schema: CAPEX net and gross metering. Source: NIIST.



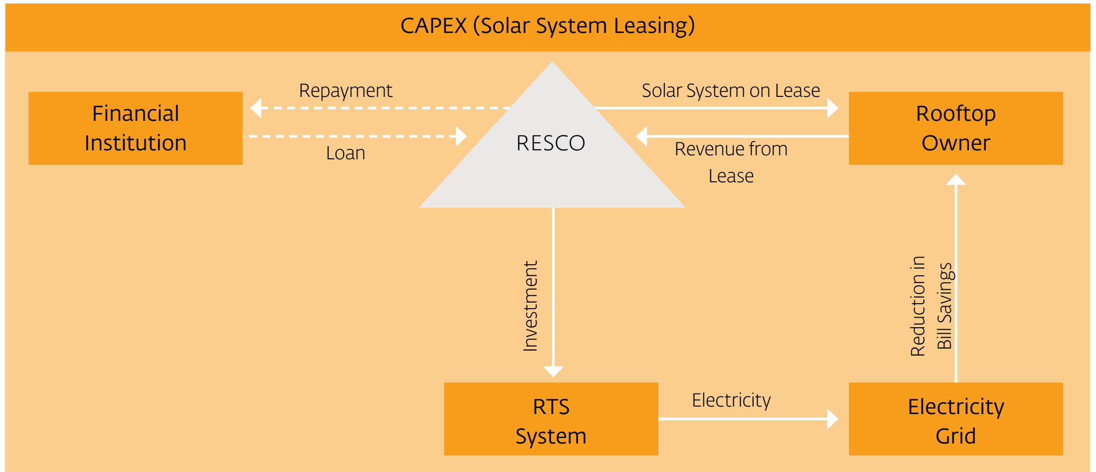


Fig. 18 Financial schema: CAPEX solar system leasing. Source: NIIST.

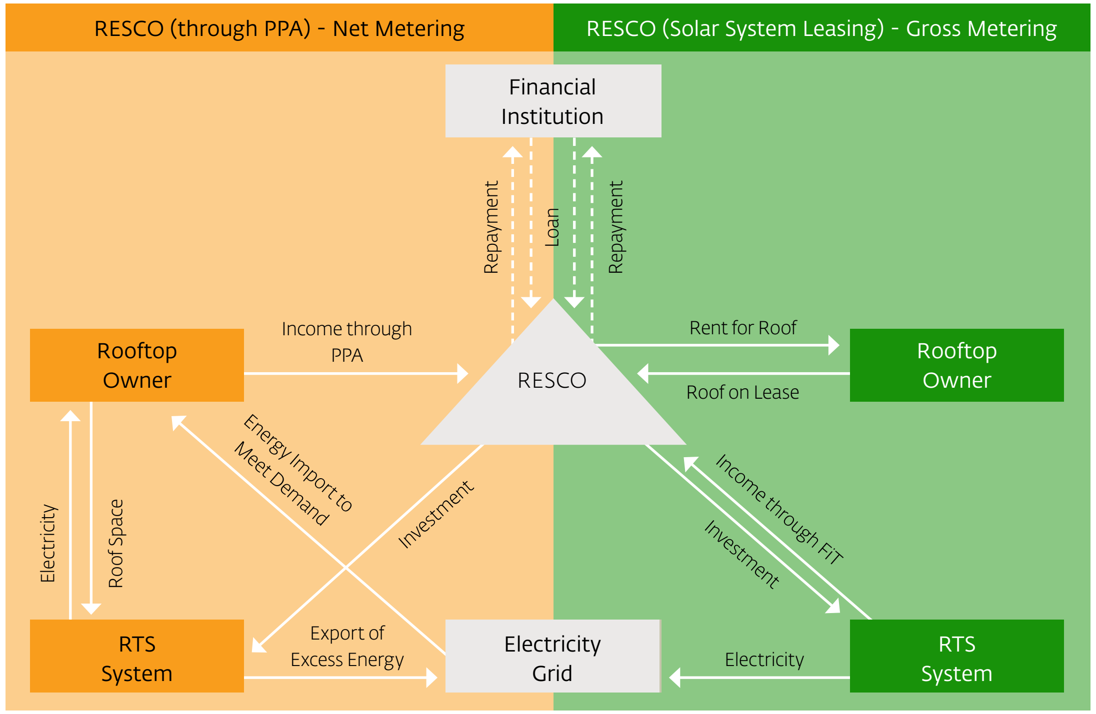
Rooftop Leasing (Under Gross Metering)

In this third party leases the rooftop and pays lease/ rent to the building owner in the lease period. The RESCO developer exports the generated power to the utility at a predetermined FiT approved by the regulator.

PPA (Under net metering)

In this, the third party invests in the solar system, and sells the generated power to the rooftop owner in with a lower solar power tariff compared to the grid tariff and the export of excess power through net metering makes savings for the rooftop owner.

Fig. 19 Financial schema: RESCO net and gross metering. Source: NIIST.



3. State-wise attractiveness of RTS scheme

Indian PV scenario has not achieved uniformity regarding the attractiveness of solar programmes, especially RTS installations. Many state-wise physical, technical, political, social, institutional, and economic factors such as solar policies, incentives, metering regulations and rooftop availability, electricity tariffs, distribution infrastructure differ the sector in each state. An ambiguous situation is thus prevailing for the stakeholders associated with the solar sector in India, especially for the renewable energy companies, entrepreneurs, developers, financial institutions, as well as government in policy making. Thus, it is critical to have a platform at national level for the evaluation of states' support level for the RTS programme.

Considering this, State Rooftop Solar Attractiveness Index (SARAL ranking) has been designed by MNRE in collaboration with Shakti Sustainable Energy Foundation (SSEF), Associated Chambers of Commerce and Industry of India (ASSOCHAM) and Ernst & Young (EY) for ranking the overall attractiveness of RTS programme in different Indian states with a dedicated evaluation method. The aspects considered for the evaluation are:

- Comprehensiveness/robustness of policy framework (Level of policy support, Covenants, Billing mechanism)
- Ease of implementation/effectiveness of policy support (Ease of application, Power offtake attractiveness, State of affairs of DISCOMs, Impact of Policy)
- Investment climate for the rooftop solar sector (Driver for rooftop solar uptake, Ease of financing, Maturity of market)
- Consumer experience (Pre-installation consideration, During installation, post-installation experience/costs)
- Business ecosystem (Business Enablers, Fiscal and Regulatory environment, Economic outlook)

The detailed evaluation mechanism is explained in SARAL reports. According to the 2018-19 report Karnataka, Telangana, Gujarat, Andhra Pradesh scored the first four positions in the ranking [38].

4. Electricity cost & Levelized Cost Of Electricity

The electricity cost in India is calculated under consumption slab basis, i.e., the final cost is determined by the range of total energy consumption. The average electricity cost for residential building in India is around 4.2 INR/kWh to 6.7 INR/kWh, which varies according to the state, the DISCOM, and the amount of unit (in kWh) consumed. For commercial buildings, it is coming around 7.5 INR/kWh to 8.6 INR/kWh, and for industries it is around 6.6 INR/kWh to 7.6 INR/kWh. The determination of average electricity cost does not clearly indicate the overall scenario and unevenness of electricity cost in India, which changes with the electricity policies adopted by different state governments and DISCOMs. As for example, the electricity cost in residential sector varies from 0.85 INR/kWh in Tamil Nadu to 7.38 INR/kWh in Rajasthan up to 100 kWh slab, and the maximum rate of 13.4 INR/kWh can be seen in Maharashtra for up to 1000 units' slab. CEA has published the electricity tariff across India for the different building sectors [39].

The price of electricity influences the economic payback of solar systems. The revenues, which consist in savings on the yearly electricity bill, are also associated to the self-consumed electricity. For each kWh that is self-consumed, a saving up to the amount of the compensable retail electricity price can be made in the case of net metering arrangement. In this sense, consumers (rooftop owners) have a better payback rate for states having higher electricity cost. However, the revenues coming from building integrated solar systems includes the excess electricity that is fed-back to the grid and also from the multifunctionality of any Building Integrated Photovoltaic (BIPV) systems that can be considered as a replaceable element for conventional construction materials and power generators [40].

LCOE can be considered as the best measure of an electricity generating system in an economic perspective. It denotes the average net present cost (including the fixed and variable cost) of generating electricity from a system in its lifetime to break even. Lower the LCOE value denotes better economics from the consumer point of view.

A recent study conducted by Siddharth Joshi et.al., for evaluating the potential of rooftop solar PV installations across the globe (with building footprints, solar radiation mapping with seasonal variability, and technology-specific information like panel size, conversion efficiency, and system losses) showed the potential competency of Indian conditions. The study concluded that, India is one of the countries with least LCOE value of 66 $/MWh for attaining the country-specific potential of 1,815 TWh/yr. The global map generated in the study for the assessed LCOE value is shown in **Fig. 20**.

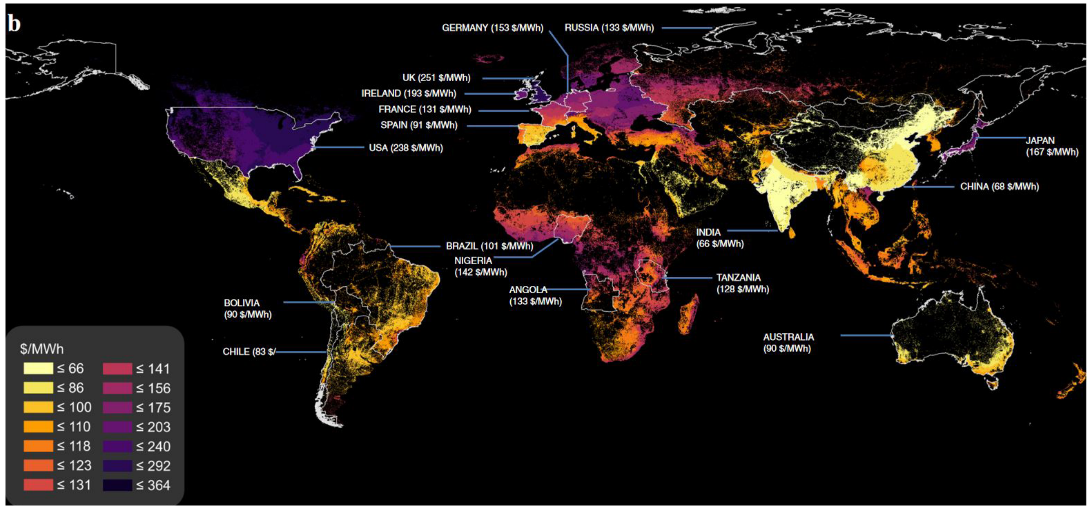


Fig. 20 Global Distribution of RTS technical potential and LCOE values. Source: [41].

In 2018, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Germany collaborated with MNRE for economic analysis of rooftop PV systems for different building sector and business models, across India. The tables below show the LCOE and grid tariff for residential, commercial and industrial buildings in different regions in India. The grid tariff, which is represented by bars, is the compensable retail electricity price, that represents the amount of money considered as savings, in case of net-metering systems. The LCOE, represented by lines, is referred to different PV system sizes and business models (CAPEX and OPEX). If the solar LCOE line lies below the grid tariff value, the PV system can be considered as competitive for the consumers. Large size PV systems reached the cost competitiveness even at that time, in almost all the regions of India, while small size PV systems are more competitive for eastern and western states. For the commercial and the industrial sector, the competitiveness is achieved in most cases, while the grid tariff is higher [42].

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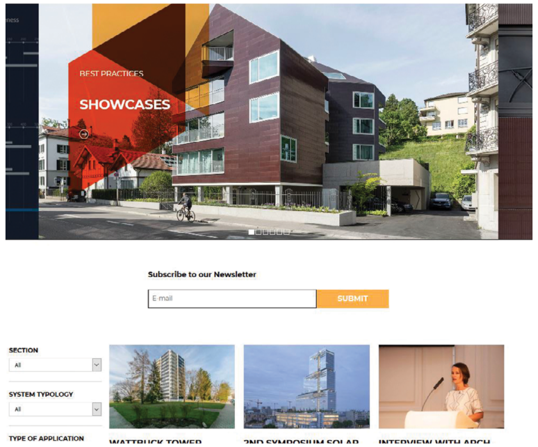

The website www.solarchitecture.ch is one of the communication means of the Swiss BIPV Competence Centre.
Here you find essential information concerning pv technology integration in buildings and different projects realized both in Switzerland and abroad. Moreover, a large database of BIPV modules and fastening systems collecting the main product's information in a datasheet is available. The website is an active interface opened towards different stakeholders thanks to the possibility to upload and store your BIPV examples (architects, installers, owners, etc.), products (manufacturers, suppliers, installers, etc.) as well as to the technological/client support through the contact info@bipv.ch.

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