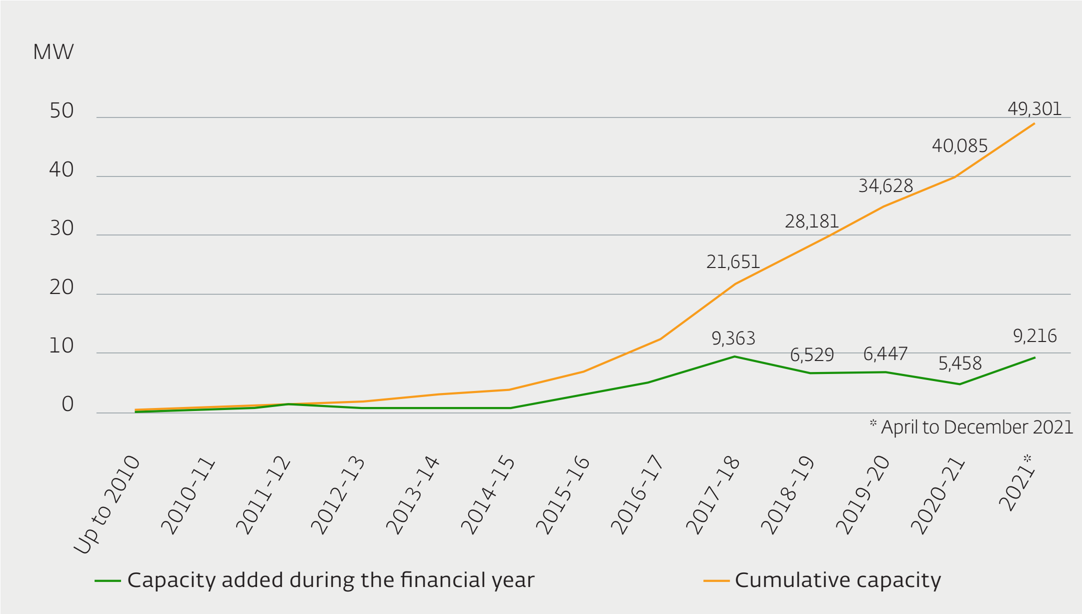


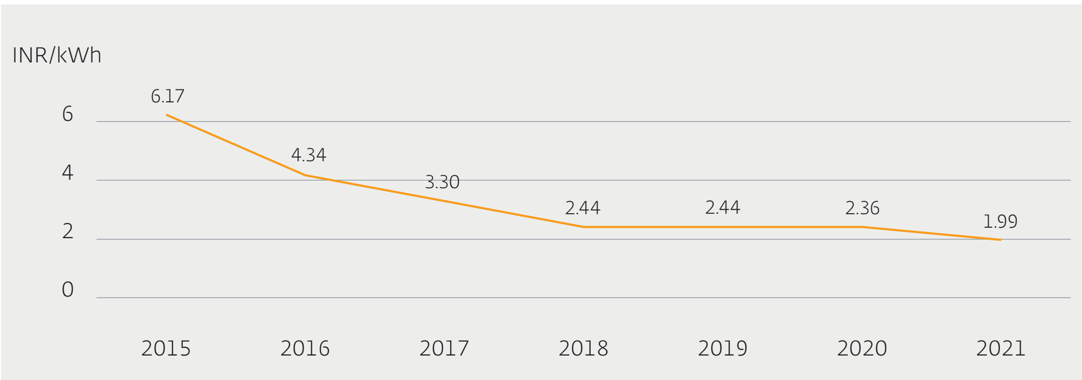
Fig. 1.3 India total solar PV capacity 2010-2020. Source: MNRE and India Renewables Dashboard.

The PV potential of different states, based on land area, has been calculated by MNRE [12]. **Fig. 1.2** (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

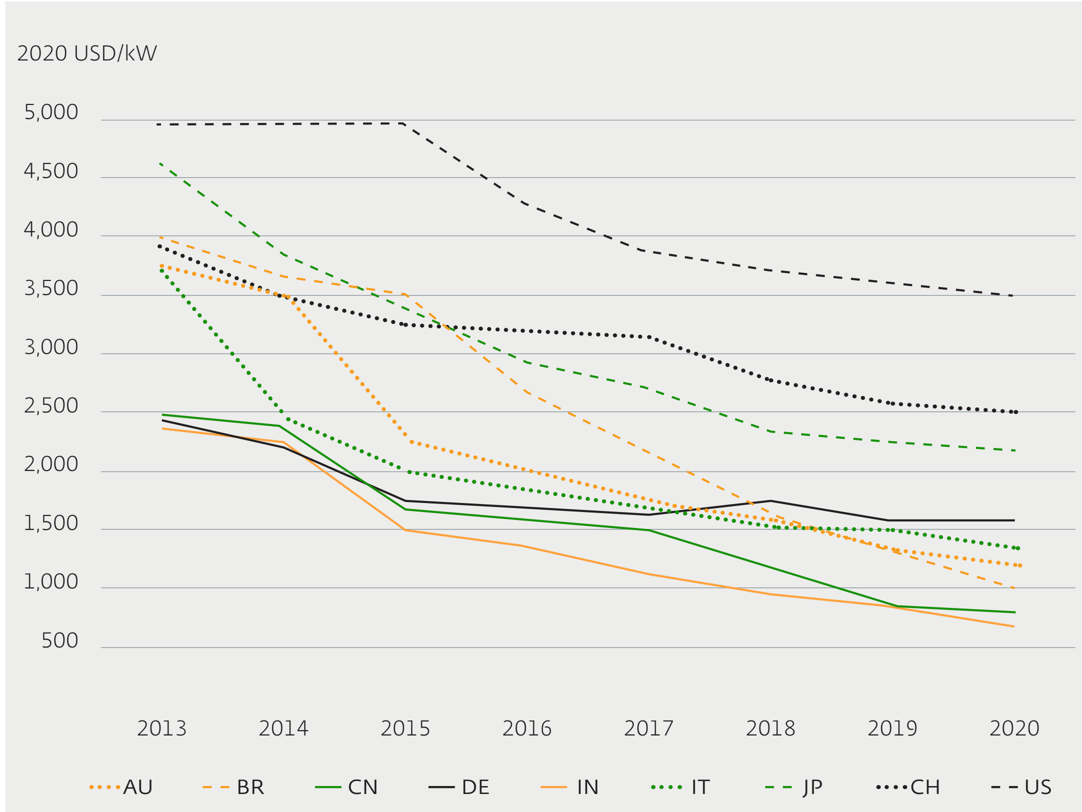
India is now the 5th largest country in terms of installed solar capacity. India intends to procure around 300 GW of its electricity coming from solar by 2030. To achieve that, the two key drivers, as suggested by Solar Power Europe (SPE) for solar energy growth are; i) increasing tender activity and ii) decreasing the solar PV tariff, enabling India to conclude one of the lowest solar auction bids around the globe in 2020. **Fig. 1.4** 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].

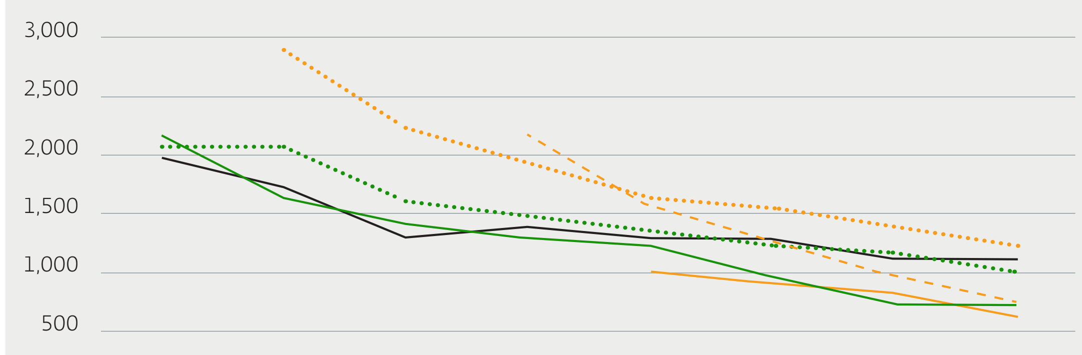
Fig. 1.4 India trend in solar PV tariffs 2015-2021. Source: MNRE.



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. 1.5**). From 2017 to 2020, a cost reduction of about 35% is registered within the commercial sector (**Fig. 1.6**). 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. 1.7**) [13].

Fig. 1.5 Residential sector solar PV total installed cost by country, 2013-2020. Source: IRENA.
Fig. 1.6 Commercial sector solar PV total installed cost by country, 2013-2020. Source: IRENA.





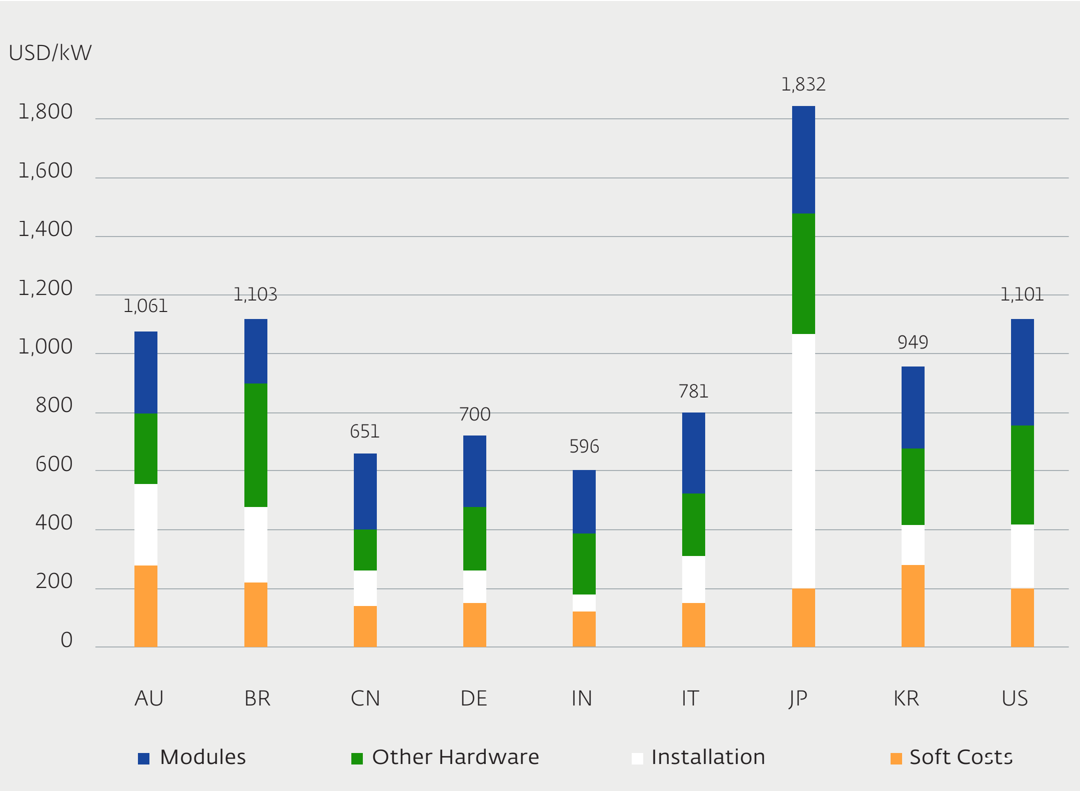


Fig. 1.7 Detailed breakdown of utility-scale solar PV total installation costs by country, 2020. Source: IRENA.

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. 1.8**), and 58% of it corresponds to solar cell price (**Fig. 1.9**). 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. 1.8** and **Fig. 1.9**. 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

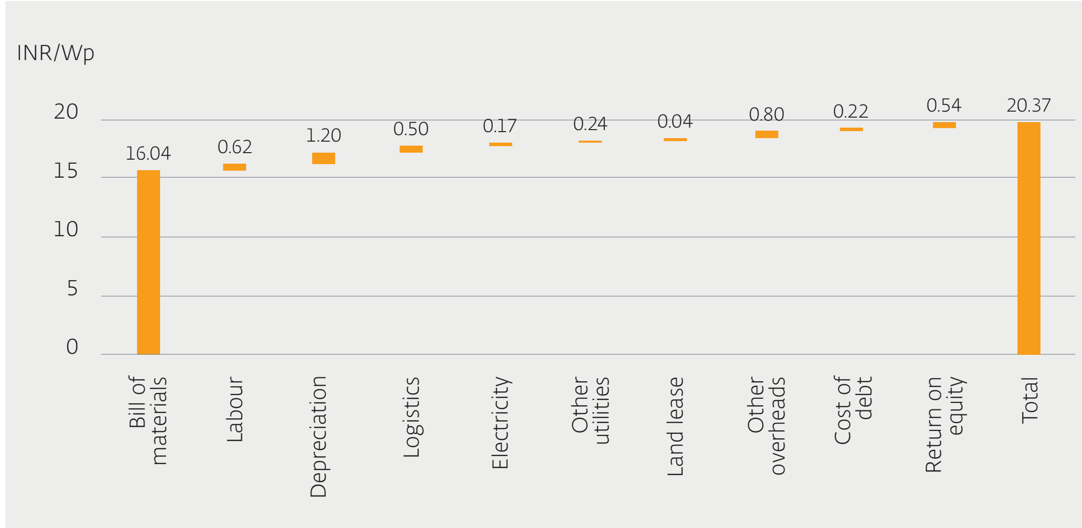


Fig. 1.8 Total cost PV module. Source: CEEW.

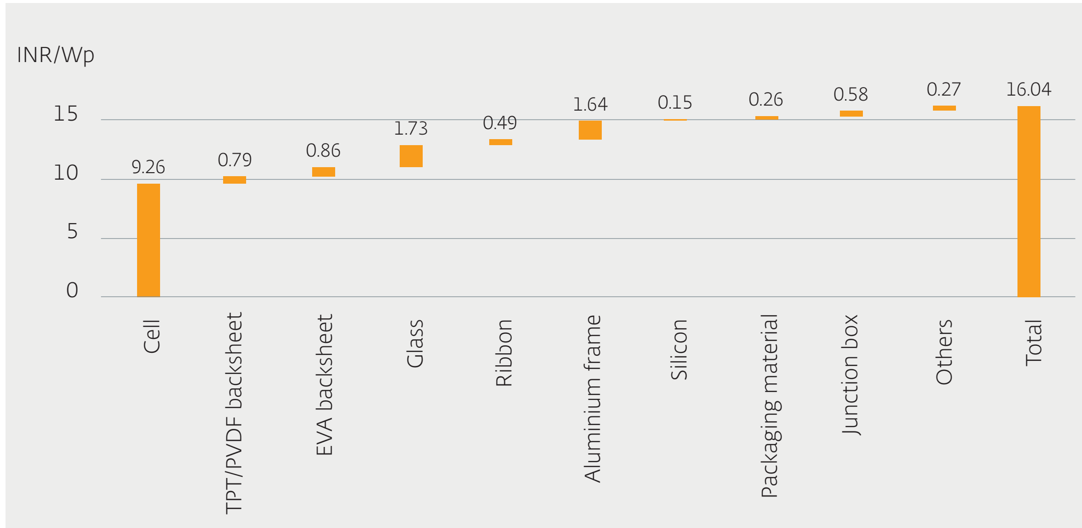


Fig. 1.9 Cost breakdown of the PV module (only material). Source: CEEW.

1.2 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. 1.10**), 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. 1.10 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 CO2 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. 1.11**). 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. 1.12**). 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 (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.

Fig. 1.11 Indira Parvavaran Bgawan. Source: Rehau.

Fig. 1.12 RSSB-EES in Beas. Source: L&T Construction.

In India, the largest BIPV facade, has been realised in 2020 (**Fig. 1.13**, 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 1.14**, 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. 1.13 CTRLS Data Center, Mumbai. Source: U-Solar.
Fig. 1.14 Rajkumari Ratnavati Girls School, Rajasthan. Source: vinay_panjwani.

Sponsored content

TopSun Energy

Residential building in Idukki, Kerala

Completion year	2021
Planning & Installation	2020
Building typology	Residential, bungalow
Category	Canopy
Installed PV power	18 kWp
Energy production	23,725 kWh/y

Tel. +91 7573 006 633
www.topsunenergy.com

Credits: Aurial Solar and Greentech

"TOPSUN'S Solar BIPV can be used in a variety of applications mainly stationary fenestrations for commercial buildings and residential construction and many other areas where energy conservation & comfort are part of the design.
1) Orientation, slope options, sizes or wind loads are some key variables that should be measured accurately in order to get a correct design for the main structure for which we have specialists team which works for tailor made projects with all customization.
2) Green Building design is becoming a great interest for real estate companies today. Qualitative facts such as return on investment (ROI), enhanced indoor comfort and productivity level due to the radiation filtration with optimal natural light contribute in earning Green certifications such as LEED and BREAM and we help you analyze that better with our customizations.
3) Topsun BIPV can be customized in different sizes, shape, colors, thickness & percentage of transparency to suit client taste of aesthetics.

We strongly believe Topsun being an experienced company can prove to be a great association to you as we value work ethics, commitment and business relations. We hope and would be glad to receive you interest in our product range."

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. 1.15 Indian BIPV Timeline. Source: SUPSI.