german cooperation
DEUTSCHE ZUSAMMENARBEIT

Implemented by
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Building Integrated and Urban PV in India

January 2024

EY Building a better working world

CSTEP CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

Fraunhofer ISE

Building Integrated and Urban PV in India

January 2024

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by:
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Registered office:
Bonn and Eschborn, Germany

Address:
46 Paschimi Marg, Vasant Vihar
New Delhi 110057
E:Henrik.personn@giz.de
I:www.giz.de
T: + 91 11 4949 5353

Published under:
Innovative New Solar PV Areas in India

Responsible:
Henrik Personn, Head of Solar Projects (GIZ)

Authors:
MNRE: Dr Anil Kumar, Ms Priya Yadav, Mr Arun Kumar Choudhary

GIZ: Abhinav Jain, Mrinal Madas, Hemakshi Malik, Saptarshi Kar

EY: Sandeep Narang, Anand Upadhyay, Siddhant Awasthi, Mohammed Subhan Khan, Alok Kumar, Arpo Mukherjee

CSTEP: Saptak Ghosh, Mahesh Kalshetty, Jaymin Gajjar, Gopala Krishnan SS

Fraunhofer: Maximilian Trommsdorff, Christian Schill, Jan-Bleicke Eggers, Anirudha Kharote

Reviewers:
MNRE: Dr Arun K. Tripathi

GIZ: Henrik Personn

EY: Somesh Kumar

Designed By:
Madre Designing

As at: New Delhi, January 2024

Contact:
GIZ is responsible for the content of this publication

On behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ)

Acknowledgement

This publication has been prepared under the Indo-German Technical Cooperation on Innovative Solar (IN Solar) in India. The project has been initiated under the guidance of the Ministry of New and Renewable Energy, Government of India and is funded by the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ). Ernst and Young LLP (EY LLP) has led this project along with Center for Study of Science, Technology and Policy (CSTEP) and Fraunhofer ISE (Germany) as partners. The project aims to explore potential of the new and innovative solar applications (NISA) with reduced land utilization having the potential to foster the targeted expansion of solar photovoltaic (PV) applications in India. The NISA areas are agrivoltaics (APV), floating PV (FPV), canal top PV (CTPV), rail/road integrated PV (RIPV) and building integrated PV (BIPV)/ urban PV (UPV).

The project team is grateful for the guidance and support received from the Ministry of New and Renewable Energy (MNRE), especially from Dr Arun K. Tripathi (Scientist G), Dr Anil Kumar (Scientist E), Ms Priya Yadav (Scientist C), Mr Arun Kumar Choudhary (Scientist B). Special thanks to Mr Shashikant Sharma from the Indian Space Research Organization (ISRO) for his continued support throughout the project.

Suggested Citation: GIZ, *Building Integrated and Urban PV in India*, January 2024

Disclaimer

The potential derived for the different integrated PV applications and the methodologies used have been derived with the sole purpose of estimating the national-level potential of these technologies for India. It is subject to certain assumptions to extrapolate the potential on a national scale. Statistical potential estimation methodology was utilized wherever there was a lack of precise GIS data. Realised potential on the ground might differ owing to a more precise system-level design at this scale.

FOREWORD

Henrik Personn

Dear Readers,

The G20 declaration under India's presidency this year emphasizes the importance of "accelerating clean, sustainable, just, affordable and inclusive energy transitions," with a strong emphasis on rapidly expanding renewable energy deployment (G20, 2023). Bilateral efforts related to sustainable energy technologies are recognised as crucial in bringing this commitment to fruition.

In this regard, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH is pleased to present this study on New and Innovative Solar Applications (NISAs). The identified NISAs are Agrivoltaics (AgriPV), Floating Photovoltaics (FPV), Canal Top Photovoltaics (CTPV), Rail/Road Integrated Photovoltaics (RIPV), Building Integrated Photovoltaics (BIPV) and Urban Photovoltaics (UPV). This study is a testament to the Indo-German Technical Cooperation under the Innovative New Solar Areas (IN Solar) project, a bilateral project initiated under the esteemed guidance of the Ministry of New and Renewable Energy (MNRE), Government of India, and funded by the German Federal Ministry for Economic Cooperation and Development (BMZ). The IN Solar project has been at the forefront of exploring NISAs with the potential to revolutionise India's renewable energy landscape.

This report on Building Integrated Photovoltaics (BIPV) and Urban Photovoltaics (UPV) in India focus on exploring the possibility of designing and using future buildings and public infrastructure with integrated PV. Given India's extensive urban development plans and the substantial 70 % of its infrastructure yet to be built, designing and utilising buildings as well as urban public infrastructure such as parking lots in combination with photovoltaics holds immense potential. Both BIPV and UPV can play an essential role in city decarbonisation and reduce electricity costs by providing clean energy directly at the point of consumption. Within this report, the scarcity of 3D city data and the unsuitability of BIPV for the refurbishment of existing buildings posed challenges in estimating the potential for India. Nevertheless, it was possible to provide an estimate of the BIPV potential for the current Indian building stock, which enables conclusions for future construction projects. Readers are encouraged to familiarise themselves with the potential and levelized cost of electricity (LCOE) associated with both technologies by exploring the GIS-based potential atlas available on the website https://staai.cstep.in. Additionally, the report provides policy and regulatory recommendations at both state and central level to promote the adoption of BIPV and UPV across India.

Herewith I express my sincere appreciation to all individuals and organisations who have played a crucial role in the formulation of this report, especially the scientific team led by Ernst & Young (EY) LLP and their distinguished partners, the Center for Study of Science, Technology and Policy (CSTEP) (India) and Fraunhofer ISE (Germany) but also the project teams, stakeholders, diligent researchers, and of course the invaluable guidance of MNRE.

I hope that this document serves as a valuable resource and inspires continued innovation and collaboration in the realm of renewable energy.

Yours sincerely,

Henrik Personn

Henrik Personn
(Head of Solar Projects in GIZ India)

PREFACE

On behalf of the entire project team, it is with great pleasure that we present this comprehensive report on Building Integrated and Urban PV in India, which is a part of a series of six distinct reports showcasing the New and Innovative Solar Applications (NISAs) in India. The reports include:

- Potential Assessment of New and Innovative Solar Applications in India
- Agrivoltaics in India
- Floating PV in India
- Canal Top PV in India
- Building Integrated and Urban PV in India
- Rail and Road Integrated PV in India

The study encompasses potential assessments, various business models, implementation strategies, technical aspects, policy enablers, market dynamics, financial considerations, and the skill sets needed to catalyze the growth NISAs in India.

Another key element of this study includes creation and implementation of an online tool called the Solar Technology and Application Atlas for India (STAAI). This innovative tool is crucial for visualizing and analyzing the solar potential in India, providing stakeholders with a user-friendly experience. The STAAI goes beyond simple potential assessment by including decision tools like the Levelized Cost of Electricity (LCOE) calculator. Additionally, it allows the generation of district-wise or state-wise potential assessment reports for each NISA.

For further details on each of our report and to access the Solar Technology and Application Atlas for India (STAAI), please visit https://staai.cstep.in/

We extend our gratitude to all those who have contributed to the success of this project and express our anticipation for the positive impact that these reports and the STAAI will have on the solar energy landscape in India.

Thanks and Regards

Project Team

TABLE OF CONTENTS

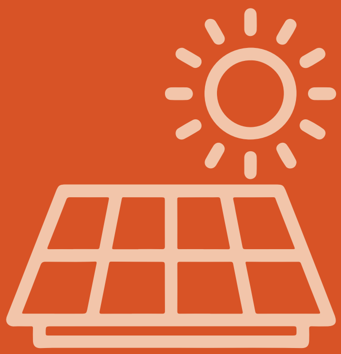
LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

APV	Agrivoltaics
AT&C	Aggregate technical and commercial loss
BAU	Business as usual
BIPV	Building integrated photovoltaic
BU	Billion units
CAGR	Compound annual growth rate
CAPEX	Capital expenditure
CEA	Central Electricity Authority
CTPV	Canal top photovoltaic
DSCR	Debt service coverage ratio
EPC	Engineering procurement and construction
FIT	Feed-in tariffs
FPV	Floating photovoltaic
FTE	Full time equivalent
GBI	Generation-based incentive
GHI	Global horizontal irradiance
GIS	Geographic information systems
GW	Gigawatt
Ha	Hectare

ISUN	India - solar usage in new applications
kV	Kilovolt
kWh	Kilowatt hour
kWp	Kilowatt peak
LCOE	Levelised cost of electricity
LCZ	Local climate zone
LOD	Level of detail
MIS	Management information system
MNRE	Ministry of New and Renewable Energy
MU	Million unit
MW	Megawatt
NISA	New and innovative solar applications
O&M	Operations and maintenance
OPEX	Operating expenditure
PPA	Power purchase agreement
PV	Photovoltaic
QTL	Quintals
RESCO	Renewable energy service company
RIPV	Rail/Road integrated photovoltaic
SOP	Standard operating procedure
TW	Terrawatt
UPV	Urban photovoltaic
VGF	Viability gap funding



EXECUTIVE SUMMARY

00

In the quest for sustainable and clean energy solutions, solar power has emerged as a frontrunner in the renewable energy sector. While traditional land-based solar photovoltaic (PV) plants have proven to be effective in generating electricity, there is a growing need to explore New and Innovative Solar Applications (NISA) that offer distinct advantages. In particular, the concept of land-neutral or dual-use applications has gained significant traction. This approach seeks to maximize the utilization of available land by integrating solar installations with existing infrastructure or employing non-traditional spaces. By tapping into these alternative applications, we can not only overcome the limitations of land availability but also address environmental concerns, reduce conflicts over land use, and enhance overall efficiency and sustainability in the solar energy sector.

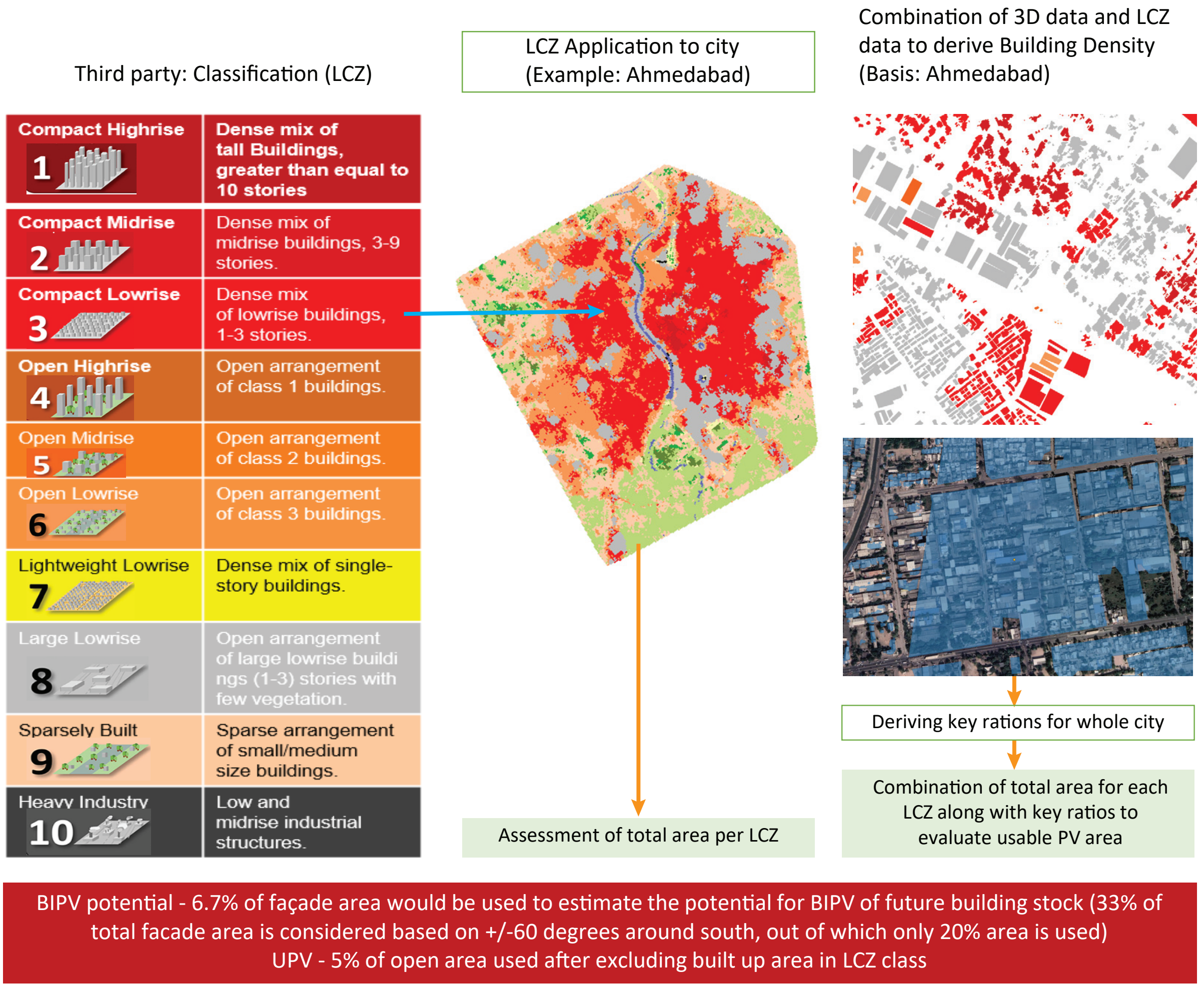
In this context, the Government of Germany and the Government of India signed a new project titled IN-Solar (Innovative -Solar). Under the project, GIZ (German Development Agency) and the Ministry of New and Renewable Energy (MNRE) initiated an activity titled India - Solar Usage in New Applications (I-SUN) which aims to explore the new innovative applications of solar energy with reduced land utilization having the potential to foster the targeted expansion of Solar PV applications in India. The NISA areas are Agrivoltaics, Floating PV, Canal Top PV, Rail/Road Integrated PV and Building/Urban Integrated PV.

In Chapter 1, Building Integrated PV (BIPV) is described as an approach that enhances conventional, passive components of the building envelope with photovoltaic functionality. BIPV systems can take a variety of forms, including solar roof tiles, solar facades, and solar windows. These systems can provide a range of benefits, including reduced energy bills, improved energy efficiency, and a reduced carbon footprint. In addition to their functional benefits, building integrated solar PV systems can also enhance the aesthetic appeal of a building. This is because these systems can be designed to blend in seamlessly with the building's overall design, rather than standing out as an added appendage. This report also covers the concept of Urban PV with respect to the applications in open spaces like public places or parking lots.

The methodology for Building Integrated PV and Urban PV has been discussed in **Chapter 2**, which relies heavily on robust city-level data. Ideally, the potential of BIPV and Urban PV is assessed based on three-dimensional data of each city. This way, the surfaces of buildings suitable for BIPV applications as well as open spaces for Urban PV were identified and the irradiance on all surfaces was calculated to derive the potential in the area, installable capacity, and electric yield.

The Local Climate Zone (LCZ) scheme is an urban classification system which classifies urban areas into discrete local climates by morphological and land-cover characteristics, proposed based on Urban Heat Island (UHI) research. For the assessment of the PV potential under this study, the climatic effects were kept out of scope but the LCZ classes can be used to structure and classify areas in cities, assuming that areas of the same LCZ class have a similar solar potential regarding façade area, shading effects and the presence of open spaces. To make use of this approach, an urban area's LCZ class should be known. The project team has used a third-party research again by Stewart et. al., where LCZ classes have been applied worldwide based on satellite imagery. Also for India, this information is available nationwide.

The methodology is illustrated in the figure below.



The steps include assessment of the total area per LCZ class, and then calculating the building roof area and the façade area using LOD1 data. Building density is calculated based on the building's horizontal surface area divided by LCZ class area. Further, the BIPV ratio for each LCZ class is identified using the ratio of façade and roof area.

For Urban PV, the study focuses on LCZ classes 4, 5, 6, and 8, (with classes 9 and 10 not included in the Ahmedabad data), as densely packed building regimens like in LCZ classes 1-3 are not suitable for the installation of UPV. The total potential comes to around 1.6 GW.

Based on the above methodology, the potential for BIPV and UPV across all the states in India is calculated and it comes around 309 GW and 221 GW respectively.

The business models are discussed in **Chapter 3** of this report, the BIPV business models have been considered for vertical façade integrated PV systems keeping in view a targeted object, fixed boundary conditions, and limited stakeholder interactions. The vertical orientation of the panel results in a higher levelised cost of electricity (LCOE) estimation of INR 8.36 per kWh, which implies the feasibility of technology in states where consumers pay electricity higher than LCOE.

In **Chapters 4 and 5** of this report, the capacity projection of BIPV has been done from 2024 to 2040. It is estimated that the cumulative capacity projection will be 5.5 GW and 17 GW under the moderate and optimistic scenario respectively. The total investment required to realise the 20 GW capacity (moderate case) will be INR 26,588 Crores and INR 80,571 Crores for 17 GW.

In **Chapter 6**, the project team has explored and researched the policy and regulatory landscape for BIPV, prevailing in India, referencing published literature, consulting various stakeholders, and understanding the various stages in the life cycle of the project. This was accompanied by undertaking rigorous engagements with key stakeholders like project developers, regulators, nodal agencies, market developers, etc., - along every stage.

Barriers and Challenges Identified

Application Stage	Project Approval	Project Execution & commissioning	Operation & Maintenance
Lack of awareness	Higher Tariff	Limited product availability	Cleaning and Upkeep
High capital cost		Safety issues related to break-in	
		Technical Difficulties	

Further, based on the above identified barriers and challenges, some key recommendations related to addressing the bottlenecks in the effective implementation of BIPV projects are as follows-

Regulatory	Mandate of BIPV	Installing BIPV systems as part of new infrastructure development in new and commercial high-rise buildings should be mandated.
	Technical Standards & Certification	Providing details of readily available designs, materials to use covering construction, and implementation of BIPV within buildings, along with guidelines and technical specifications related to cable connections, inverter placement, and power evacuation.
Technical	Green Building Codes	Rating agencies for green building like GRIHA and IGBC already have made evaluation criterias to have solar PV systems included in a building. However, a separate evaluation criterion for the use of BIPV within building infrastructure is required.
	Testing Procedures	For thermal properties of BIPV modules (U-Value and SHGC for glazing BIPV modules), there is a need for thermal conductivity or resistance for opaque BIPV modules.
Design	Target Inclusion	Pre-engineered systems should be developed for ease of installation by architects, builders, and developers to fit the standard building configurations.
Awareness	Capacity building and Awareness	Training programmes for designers, architects, and engineers in the installation and upkeep of BIPV systems should be launched. A competent workforce will be produced as a result to assist BIPV's expansion in India.

In the last chapter of this report, the project team has identified several gaps where skilling becomes necessary to boost the BIPV sector in India as it is vital for increasing the penetration of BIPV. By creating a skilled workforce, we can ensure better utilization of renewable energy resources with high-quality workmanship on the deployed technologies. Under the moderate case, it is estimated that to meet a demand of 5.5 GW of BIPV by 2040, **44 thousand FTE** jobs will be required and for the optimistic case, **1.3 lakh FTE** jobs will be required to support distinct roles and responsibilities starting from application, project approval, detailed engineering, project execution-commissioning, and operations and maintenance.

INTRODUCTION TO BUILDING INTEGRATED PV TECHNOLOGY

01

The term Building Integrated Photovoltaics (BIPV) describes an approach where conventional, passive components of the building envelope are replaced by components with additional photovoltaic functionality. This means that photovoltaic modules are building-integrated, if, besides the PV functionality, they are designed to also form and/or replace a construction product. Urban PV encompasses the use of PV across all urban infrastructure except for that being covered under BIPV, i.e., buildings. This includes solutions such as solarizing parking lots, public areas, etc.

As can be perceived from the figure below, almost any component of the envelope can be equipped with BIPV, from roof over different kinds of façades to balustrades and external elements like shading devices. It summarizes and classifies these options grouped by application for roofs, façades, and external elements and further defines the different applications according to the Standard IEC 63092-1.

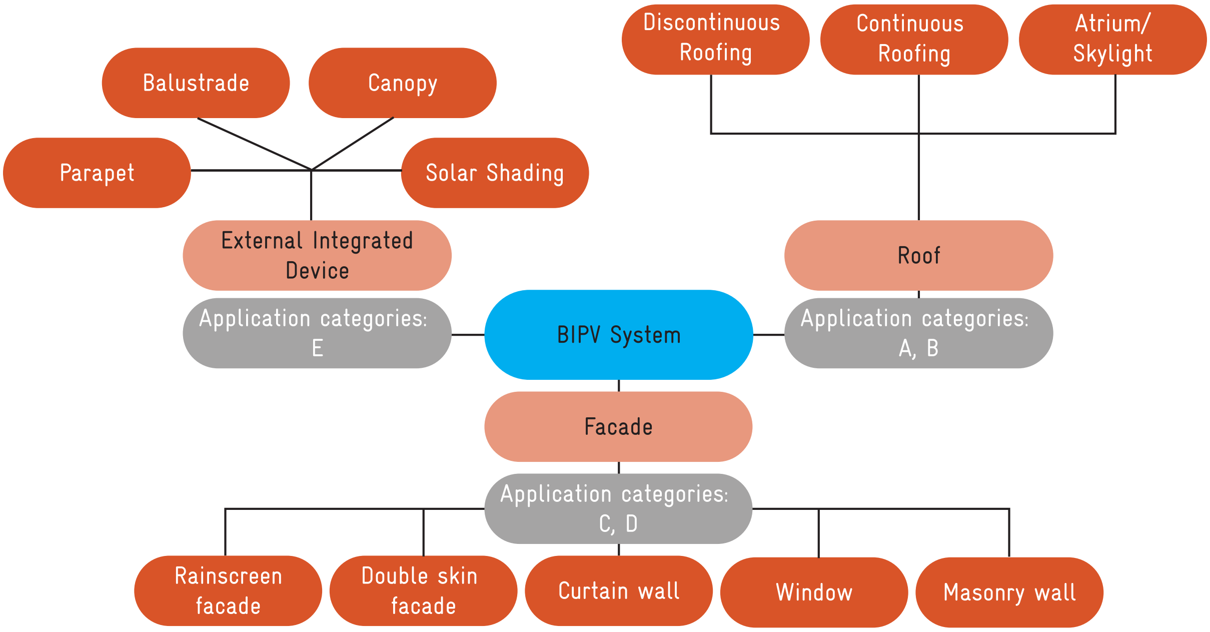


Figure 1: Classifications of different BIPV systems.

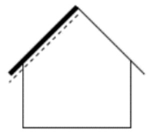
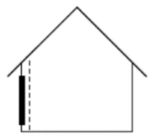
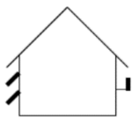
What constitutes BIPV?

In a strict definition, photovoltaic modules are building-integrated, if, besides the PV functionality, they are designed to form and/or replace a construction product. Obviously, this includes that the basic requirements and standards for construction works are followed. Other than building attached PV modules, integrated PV modules would have to be replaced by either new modules or by an appropriate conventional construction product, if dismounted, to ensure the functionality of the building envelope (IEC 2020). A discussion of variants of BIPV definitions can be found in (IEA PVPS 2021).

As part of solar applications with the theme of land neutrality, the ISUN includes "Building Attached PV (BAPV)" as part of the BIPV definition as well. Building integrated PV (BIPV) refers to the integration of photovoltaic (PV) panels into the construction and design of a building in order to generate electricity. This approach differs from traditional solar panel installations, which are typically mounted on top of a building or nearby on the ground.

BIPV systems can take a variety of forms, including solar roof tiles, solar façades, and solar windows. These systems can provide a range of benefits, including reduced energy bills, improved energy efficiency, and a reduced carbon footprint. In addition to their functional benefits, building integrated PV systems can also enhance the aesthetic appeal of a building. This is because these systems can be designed to blend in seamlessly with the building's overall design, rather than standing out as an added appendage.

Table 1: BIPV application categories (IEA)

Category A	Sloping, roof-integrated, not accessible from within the building. The BIPV modules are installed at a tilt angle between 0° and 75° from the horizontal plane [0°, 75°], with another building product installed underneath.	
Category B	Sloping, roof-integrated, accessible from within the building. The BIPV modules are installed at a tilt angle between 0° and 75° from the horizontal plane [0°, 75°].	
Category C	Non-sloping (vertically) envelope-integrated, not accessible from within the building. The BIPV modules are installed at a tilt angle between 75° and 90° from the horizontal plane [75°, 90°], with another building product installed behind.	
Category D	Non-sloping (vertically), envelope-integrated, accessible from within the building. The BIPV modules are installed at a tilt angle between 75° and 90° from the horizontal plane [75°, 90°].	
Category E	Externally integrated, accessible or not accessible from within the building. The BIPV modules are installed from an additional functional layer that provides a building requirement. E.g. balcony balustrades, shutters, awnings, louvres, brise soleil, etc.	

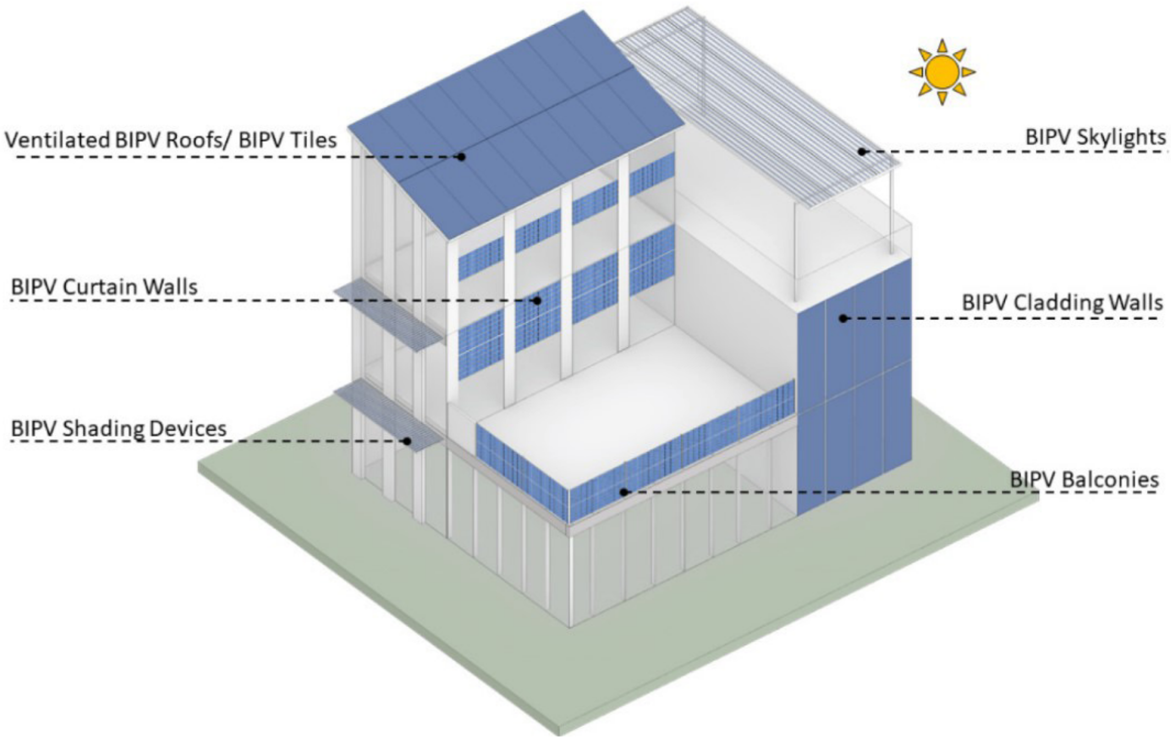


Figure 2: Different system categories of BIPV

(Source:SUPSI Switzerland)

The ISUN program considers BIPV under façade categorization of great relevance to the Indian urban set up, and has been described in detail in the following sections.

POTENTIAL ASSESSMENT OF BIPV AND UPV

02

While the potential assessment for BIPV usually includes the whole building skin, the analysis here focuses on façades because in India roof areas are commonly equipped with roof-top PV which does not fall into the category of 'innovative' anymore. The façades of smaller buildings are often prone to shading from trees, lampposts, and billboards and, additionally, larger buildings offer more façade area. Thus, the potential estimation for the country is limited to buildings higher than three stories, equaling approx 10 meters, and large free-standing buildings. For the example of the city of Ahmedabad, which is used to develop and demonstrate the methodology of the potential assessment, the potential for all buildings will be presented, allowing for evaluation of the effects of the restriction.

The potential for Urban PV here is evaluated with respect to the application in open spaces like public places or parking lots. The methodology presented below for the potential assessment of both BIPV and Urban PV is based on information on the existing building stock and existing urban areas but can also be transferred to newbuilt areas.

The methodology for Building Integrated PV and Urban PV relies heavily on robust city-level data. Ideally, the potential of BIPV and Urban PV is assessed based on three-dimensional data of each city. This way, the surfaces of buildings suitable for BIPV application as well as open spaces for Urban PV could be identified and the irradiance on all surfaces calculated to derive the potential in the area, installable capacity, and electric yield. For this project though, 3D data could only be provided for one exemplary city, Ahmedabad. Besides that, it would also take a lot of effort to evaluate the 3D data of the whole country. Accordingly, the resulting approach had to be adapted to data availability and feasible computational effort.

2.1. AREA CALCULATION AND SOLAR IRRADIANCE SIMULATION

The approach is based on third-party research carried out in the context of urban meteorology, and the definition and application of Local Climate Zones (LCZ)[1] (Figure 3). The idea of LCZ classes assumes that most of the urbanized area of a country (e.g., 80%) can be divided into a reasonable number of representative neighbourhood types (e.g., < 20) which behave similarly, i.e. regarding the 'heat island' effect. These neighbourhood types are characterized by geometrical parameters that can be obtained from detailed geometric data of a city.

1 *Stewart, I. D.; Oke, T. R. (2012): Local Climate Zones for Urban Temperature Studies. In: Bulletin of the American Meteorological Society 93 (12), p. 1879–1900. DOI: 10.1175/BAMS-D-11-00019.1.*

For the assessment of the PV potential, the climatic effects are out of scope but the LCZ classes can be used to structure and classify areas in cities, assuming that areas of the same LCZ class have a similar solar potential regarding façade area, shading effects, and the presence of open spaces. To make use of this approach, it must be known to which LCZ class an urban area belongs. Luckily, we can rely on third-party research again, where LCZ classes have been applied worldwide based on satellite imagery. Also for India, this information is available nationwide.

Figure 4 shows the application of the LCZ classes to the city of Ahmedabad. Within the built types, it is visible that the classes '3 Compact low-rise' (red), '9 Sparsely built' (salmon), '6 Open low-rise' (orange) and '8 Large low rises' (grey) are the most common (refer to Figure 3). The analysis has been summarized in Table 2. Here, the third column specifies this picture in numbers, giving the total area being covered by pixels of the corresponding LCZ class.

This map of LCZ classes is now combined with the 3D data of Ahmedabad (LOD1 model; LOD1: Level of detail 1, simplest 3D model)[2] to derive geometric indicators for the Indian context for each relevant LCZ class. One example is the building density (BD) is shown in column 4 of Table 2 which is calculated by the division of the building footprint area per LCZ class, according to the LOD1 model in column 2 and the total area per LCZ class in column 3.

Another indicator which is calculated based on the 3D data is the ratio of the vertical to the horizontal area of the buildings for each LCZ. As the LCZ classes tend to aggregate multiple buildings to one object, if the gaps between the buildings are small (Figure 3), some filtering has to be done prior to this calculation. The filtering for objects with a ratio of vertical to the horizontal area of greater than two meters plus a height greater than eight meters plus a (convex) horizontal area smaller than 20,000m² solves this problem, providing plausible raw data for the calculation of the above-mentioned factors. The numerical results are displayed in column 5 in Table 2.

2 *Biljecki, Filip; Ledoux, Hugo; Stoter, Jantien (2016): An improved LOD specification for 3D building models. In: Computers, Environment and Urban Systems 59, S. 25–37. DOI: 10.1016/j.compenvurbsys.2016.04.005.*

Figure 3: Urban (1–10) and natural (A–G) Local Climate Zone definitions

Source: adapted from Table 2 in Stewart and Oke[1], default LCZ colors according to Bechtel et al.

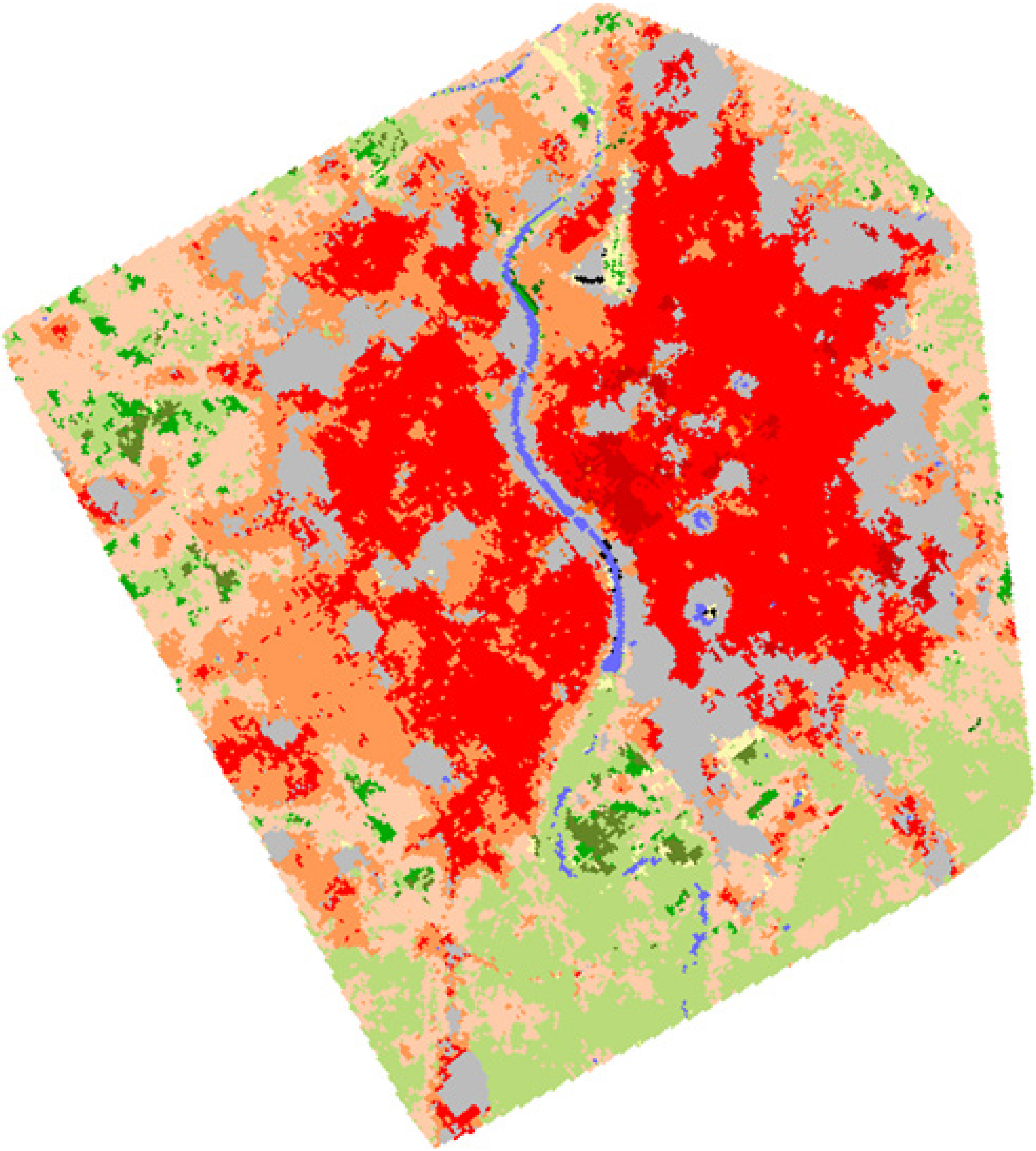


Figure 4: Distribution of LCZ classes across the city of Ahmedabad

LCZ classes considered for potential assessment-

BIPV: LCZ classes 1, 2, 4, 5, 8 and 10

UPV: LCZ classes 4, 5, 6 and 8

Table 2: Total area of building footprints and total area per LCZ class across the city of Ahmedabad

LCZ class	Total area of building footprint according to LOD1 model A_{hor} [m²]	Total area of LCZ raster A_{total} [m²]	Building density BD as ratio of building footprint divided by total area [-]	Ratio of vertical to horizontal area (A_{vert}/ A_{hor}) of buildings after applying filters [-]
1		Not present		
2	32,45,386	63,40,249	0.512	3.81
3	8,27,13,358	15,25,62,247	0.542	3.49
4	8,679	1,40,894	0.062	4.97
5	1,13,372	17,61,180	0.064	3.47
6	1,00,00,462	10,37,51,134	0.096	3.43
8	2,22,92,655	8,93,00,649	0.250	3.18
9	11,78,050	10,84,79,903	0.011	3.71
10	256	26,418	0.010	7.46

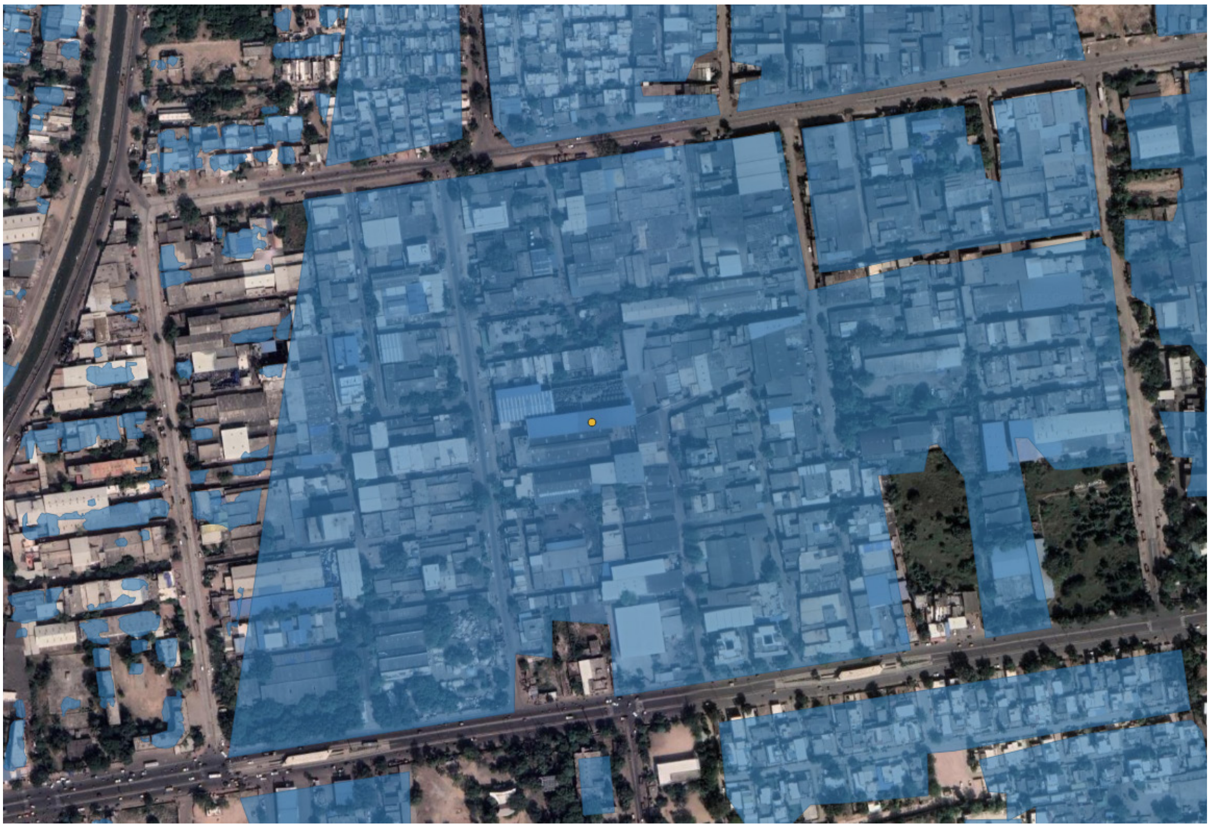


Figure 5: Example of the unwanted aggregation of multiple buildings to one LoD1-building-object within the city of Ahmedabad

Figure 6: Example of a filtered and usable combination of LCZ classes and 3D data for buildings in the city of Ahmedabad

With these two factors and under the assumption that they are transferrable to other Indian cities, the absolute façade area of all buildings belonging to a certain LCZ class in an area depends solely on the total area of an LCZ class in the area of investigation.

$$A_{vert} = \frac{A_{vert}}{A_{hor}} \cdot A_{hor} = \frac{A_{vert}}{A_{hor}} \cdot Building\ Density \cdot A_{total}$$

While, technically, all orientations can be equipped with BIPV, this study focusses on the potential for the orientations with the highest annual sums of irradiance which are +/-60 degrees around south. Assuming, that all orientations are equally distributed across the façades of the building stock, this means that only 33% of the total façade area are selected for the following potential analysis. Still, not all of this area is usable for the application of BIPV as there are façade openings for example. A (conservative) share of 20% has been shown to work in a per building evaluation of the city of Freiburg in Germany. Combining both factors, only approx. 6.7% of the total façade area are regarded as potential area for BIPV application. The resulting PV area for façades in m² thus equals to

$$A_{BIPV,vert} = 0.33 \cdot 0.2 \cdot A_{vert} = 0.067 \cdot \frac{A_{vert}}{A_{hor}} \cdot BD \cdot A_{total}$$

UrbanPV, per definition, can only be installed in urban areas. Therefore the LCZ GIS layer needs to be prefiltered to only contain urban areas. This can be done using a GIS layer with the perimeter of urban areas. Of the remaining total area, only the open space between buildings is relevant. It can be calculated as the difference between the total area and ground floor area of the buildings.

$$A_{open} = A_{total} - A_{hor} = A_{total} - BD \cdot A_{total} = A_{total}\,(1 - BD)$$

Table 3: Results for the potential of BIPV and UPV per LCZ class for the city of Ahmedabad

LCZ class	Total area of LCZ raster A_{total} [m²]	Total vertical area for BIPV installation $A_{BIPV,vert}$ [m²]	BIPV Potential $P_{BIPV,vert}$ [kW_p]	Annual yield from BIPV installations $W_{BIPV,vert}$ [MWh/a]	Total horizontal area for UPV installation $A_{UPV,hor}$ [m²]	UPV Potential $P_{UPV,15°}$ [kW_p]	Annual yield from UPV installations $W_{UPV,15°}$ [MWh/a]
1				Not present			
2	63,40,249	8,16,291	1,63,258	1,39,276	-	-	-
3	15,25,62,247	1,90,46,524	38,09,305	32,49,729	-	-	-
4	1,40,894	2,865	573	489	6,608	1,322	1,797
5	1,761,180	25,814	5,163	4,404	82,423	16,485	22,419
6	10,37,51,134	22,54,769	4,50,954	3,84,710	46,89,551	9,37,910	12,75,558
8	8,93,00'649	46,85,605	9,37,121	7,99,461	33,48,774	6,69,755	9,10,867
9	10,84,79,903	2,92,186	58,437	49,853	-	-	-
10	26,418	130	26	22	-	-	-
Sum	46,23,62,674	2,71,24,186	54,24,837	46,27,944	81,27,357	16,25,471	22,10,641

From this open area, the area for UPV applications can be derived, assuming that a share of 5% of the open space can be covered by UPV installations. Within this factor also the existence of power lines, trees, and other obstructions which are not present in the available data is considered.

$$A_{UPV,hor} = A_{open} \cdot 0.05 = A_{total}\,(1 - BD) \cdot 0.05$$

The resulting potential area for BIPV and UPV applications is shown in Table 3. It sums up to approx. 27.1 million square meters for BIPV if all LCZ classes are considered. *LCZ classes 1, 2, 4, 5, 8 and 10, which represent either buildings above 3 stories or large free-standing buildings without the presence of greenery, seem particularly suitable for façade integration of BIPV.* Limiting the selection to those classes an area of 5.5 million square meters remains *for BIPV. For UPV only the sparsely built LCZ classes 4, 5, 6 and 8 are considered.* The corresponding potential sums up to an area of approx. 8.1 million square meters.

2.2. CAPACITY CALCULATION

Based on the calculated areas and in combination with a typical module efficiency of 20% of the installable BIPV or UPV capacity in Watts corresponds to this.

$$P_{BIPV,vert} = A_{BIPV,vert} \cdot \eta_{module} \cdot IRR_{STC} = 0.067 \cdot \frac{A_{vert}}{A_{hor}} \cdot BD \cdot A_{total} \cdot 0.2 \cdot 1000W/m^2$$
$$= 0.013 \cdot \frac{A_{vert}}{A_{hor}} \cdot BD \cdot A_{total} \cdot 1000W/m^2$$

$$P_{UPV,hor} = A_{UPV,hor} \cdot \eta_{module} \cdot IRR_{STC} = 0.05 \cdot A_{total}\,(1 - BD) \cdot 0.2 \cdot 1000W/m^2$$
$$= 0.01 \cdot A_{total}\,(1 - BD) \cdot 1000W/m^2$$

The numeric results are shown in Table 3. Please note that they are given in kW_p for smaller numbers which means that the results from the equations above have been divided by 1000. Overall, the evaluation indicates an installable capacity of approx. 5.4 GW_p for BIPV considering all LCZ classes and of 1.1 GW_p for the limited selection (considering only LCZ classes 1, 2, 4, 5, 8 and 10). More than 1.6 GW_p can be installed for UPV, considering LCZ classes 4, 5, 6 and 8.

2.3. ENERGY GENERATION CALCULATION

The achievable electric yield in first place depends on the local annual sum of irradiance while other climatic factors like the ambient temperature can be neglected for this first assessment. For the location of Ahmedabad, the annual irradiance (IRR_{ann}), in its dependency on different orientations and tilting angles and excluding shading effects is shown in Figure 7. It can be seen that the maximum is achieved for a surface being oriented south and tilted by approx. 25° towards a horizontal surface. A vertical surface pointing south receives approx. 70% of this yield and for western or eastern orientation still approx. 50% of this yield are achievable.

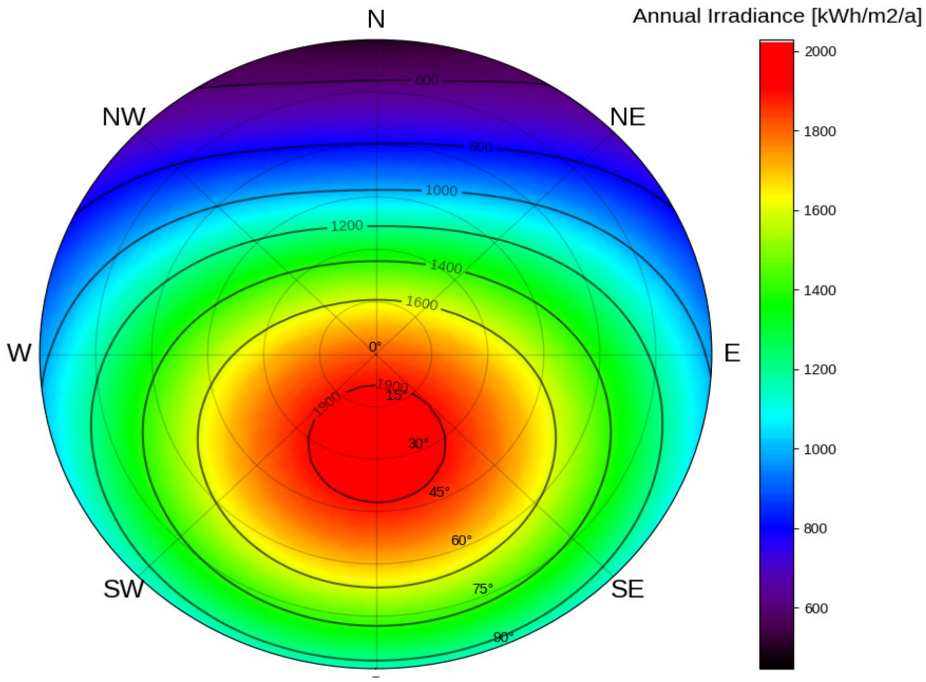


Figure 7: Influence of the orientation and tilting angle on the annual sum of irradiance for the city of Ahmedabad

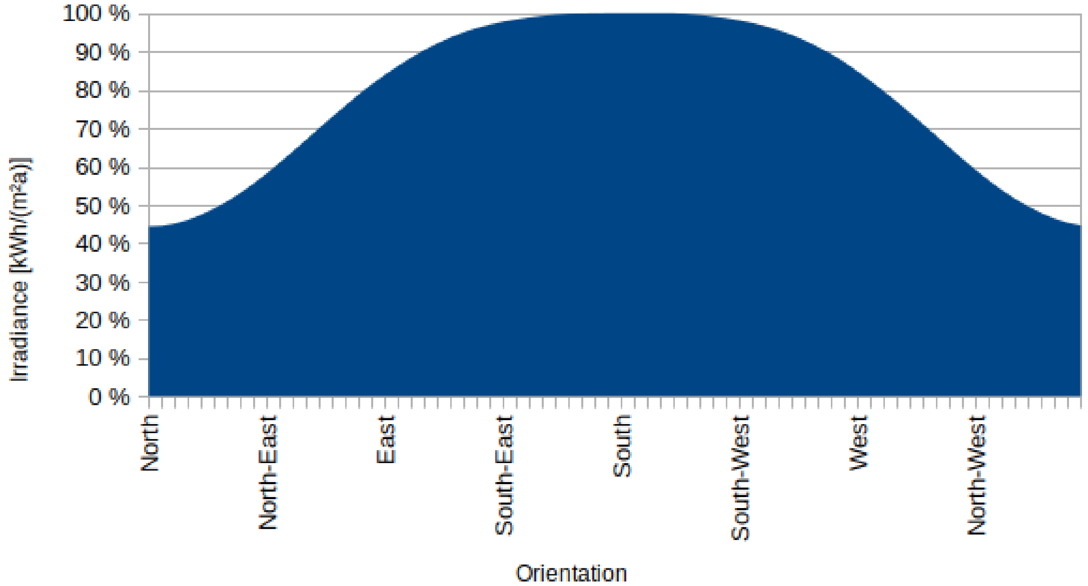


Figure 8: Influence of the orientation on the annual sum of irradiance for facades (90°) for the city of Ahmedabad

Figure 8 extracts the results for façades (90 degrees tilting angle) and displays them as relative values to the maximum. Averaging the absolute values from the Meteonorm 10-year TMY3 data set leads to an annual sum of 903 kWh/(m²a), if all orientations are considered equally, and to a value of 1137 kWh/(m²a) when limiting the considered orientations to +/- 60 degrees around south. *This exercise is then conducted for every taluk in the country for 90 degrees tilting angle and a step of 5 degrees from 0 to 60 degrees and 300 to 355 degrees for orientation denoting south-east to south-west facing facades.* ARCGIS modules have been used for these calculations.

In real life, shading by own but also by adjacent structures like neighbouring buildings or trees plays an important role in the use of BIPV. This means, that the achievable electric yield of a PV installation does not only depend on the general irradiance at a location and technical parameters but also on the surroundings. Looking at the LCZ classes and their building densities, classes 4, 5, 6, 9, and 10 with low building densities are less likely to be affected by shading effects – at least with respect to floor levels above the typical height of vegetation, while classes with high densities are more prone to shading (LCZ classes 1, 2, 3, and partly 8; see Figure 3 and Table 2).

These shading effects are usually integrated into the system efficiency, called performance ratio (PR). While values of up to 90% can be achieved for technical good installations in the absence of shading and soiling, 85% is a typical value in such a case. In contrast, the performance factor for installations more affected by shading and/or soiling can go down notably. For this study, it is assumed that a factor of 75% can be reached also under these circumstances while areas which would suffer from more shading are already excluded by limiting the usable area to 20% of the total façade area in the selected orientations.

The achievable annual electric yield $W_{BIPV,\ vert}$ results to:

$$W_{BIPV,vert} = \frac{IRR_{ann}}{IRR_{stc}} \cdot P_{BIPV,vert} \cdot PR = \frac{\frac{1137kWh}{m^2a}}{\frac{1000W}{m^2}} \cdot P_{BIPV,vert} \cdot 0.75$$

For the city of Ahmedabad, the results are summarised in Table 3. In total an annual electric yield of approx. 4630 GWh/a is identified as the BIPV potential across all LCZ classes for the city. *When only classes 1, 2, 4, 5, 8 and 10 are considered, the annual electric yield sums up to approx. 940 GWh/a.* For the results for other locations presented in the next section, the annual sums of irradiance have been adapted in the equation.

For Urban PV, the study focuses on LCZ classes 4, 5, 6, and 8, (with classes 9 and 10 not included in the Ahmedabad data), as densely-packed building regimens like in LCZ classes 1-3 are not suitable for the installation of UPV. For many UPV applications, modules are only slightly tilted, i.e., 15°. The annual sum of irradiance for Ahmedabad at this tilting angle is 1775 kWh/(m²a) as a mean over all azimuth angles. To consider soiling effects, a reduction of 10% is assumed, equalling an annual sum of approx. 1600 kWh/(m²a). Due to the small tilting angle, the module area is almost identical to the covered ground floor area. The performance ratio is assumed to be at 85%. This exercise is then conducted for every taluk in the country using Meteonorm 10-year TMY3 solar radiation values for 0-30 degrees tilting angle with a step of 5 degrees, and another step of 5 degrees from 0-360 degrees for orientation. ARCGIS modules have been used for these calculations and the annual irradiance in the following equation has to be adapted accordingly for the different locations.

The UPV potential for the city of Ahmedabad is summarised in Table 3. The annual electric yield $W_{UPV,hor}$ reaches approx. 2210 GWh/a.

$$W_{UPV,hor} = \frac{IRR_{ann}}{1000W/m^2} \cdot P_{UPV,hor} \cdot PR = \frac{\frac{1600kWh}{m^2a}}{\frac{1000W}{m^2}} \cdot P_{UPV,hor} \cdot 0.85$$

Application of the presented methodology to the rest of India to assess the national BIPV and UPV potential

The presented methodology has been developed based on the example of the city of Ahmedabad. It then has been transferred and applied to other locations across India (Section 2.4). As long as the technical assumptions remain the same, the presented methodology depends only on two variables to be applied to other locations: first, the annual sum of irradiance at 90° tilting angle for BIPV or at 15° tilting angle for UPV, and second, the total area per LCZ class. The latter can be derived from existing studies across India (no need for 3D data). All other parameters are independent from the location and thus can be directly copied. As a consequence, the method cannot only be applied to existing built-up areas but also to sites subject to planning by linking the new construction area to the corresponding LCZ class.

2.4. STATE-WISE TECHNICAL POTENTIAL ASSESSMENT

In the preceding sections, we meticulously developed a comprehensive methodology to assess the potential of BIPV and UPV for Ahmadabad city of Gujarat. Building upon the foundational principles explained earlier, we now present a detailed table encapsulating the quantified potential of BIPV and UPV across various states. The total area for each LCZ class has been evaluated for each taluk.

Table 4: State wise potential of BIPV and UPV

State	BIPV (GWp)	BIPV Generation (GWh)	UPV (GWp)	UPV GENERATION (GWh)
ANDAMAN AND NICOBAR	0.11	109.21	0.19	288.52
ANDHRA PRADESH	9.88	8628.84	7.71	12244.60
ARUNACHAL PRADESH	0.00	0.38	0.00	1.14
ASSAM	2.42	1886.50	3.62	4796.99
BIHAR	7.45	6804.77	5.37	8094.22
CHANDIGARH	0.59	511.78	0.72	1069.53
CHHATTISGARH	6.64	5729.92	5.44	8557.36
DAMAN AND DIU AND DADRA AND NAGAR HAVELI	0.61	523.05	0.55	867.68
DELHI	11.29	10781.47	5.26	8025.34

State	BIPV (GWp)	BIPV Generation (GWh)	UPV (GWp)	UPV GENERATION (GWh)
GOA	1.42	1222.62	2.29	3598.09
GUJARAT	28.72	24736.75	11.98	19683.34
HARYANA	12.30	11276.66	5.30	8151.15
HIMACHAL PRADESH	0.55	454.95	0.68	965.03
JAMMU AND KASHMIR	2.51	2053.18	2.98	4150.82
JHARKHAND	6.98	6445.80	8.72	13231.33
KARNATAKA	20.76	18005.34	14.78	23971.20
KERALA	8.15	7291.02	13.18	20010.00
LADAKH	0.03	22.11	0.02	32.50
LAKSHADWEEP	0.00	0.00	0.00	0.00
MADHYA PRADESH	16.32	13792.83	12.06	19120.57
MAHARASHTRA	36.47	31432.97	23.03	36815.50
MANIPUR	0.72	580.57	0.63	859.81
MEGHALAYA	0.27	198.18	0.30	349.62
MIZORAM	0.22	186.40	0.27	387.99
NAGALAND	0.21	160.86	0.19	249.87
ODISHA	5.56	5129.57	7.59	11651.83
PUDUCHERRY	0.47	408.69	0.47	770.84
PUNJAB	11.55	10263.24	5.51	8304.53
RAJASTHAN	19.48	16813.54	11.91	19619.26
SIKKIM	0.04	25.16	0.05	47.14
TAMIL NADU	25.75	22205.88	20.62	33385.04
TELANGANA	13.80	11778.37	8.09	13187.19
TRIPURA	0.86	705.63	1.45	2025.11
UTTAR PRADESH	39.23	36407.24	17.80	27353.66
UTTARAKHAND	2.42	2059.43	2.11	3057.88
WEST BENGAL	15.57	13649.85	20.02	29482.37
Total	**309.36**	**272282.75**	**220.90**	**344407.03**

In total, a technical potential of more than 309 GWp of installable capacity and an achievable annual electric of 272283 GWh/a have been assessed for BIPV. For UPV almost 221 GWp of installable UPV capacity and an achievable annual electric of 344407 GWh/a have been evaluated. The exploitation of this potential will take time of course but it should be seen as a huge resource that can be utilized step by step, supporting India's way towards climate neutrality.

BUILDING INTEGRATED PV BUSINESS MODELS

03

The Building Integrated PV business models have been undertaken to keep in view a targeted object, fixed boundary conditions, and limited stakeholder interactions. The ISUN program limited itself to an energy generation standpoint and does not focus on distribution/load-side analysis. In line with this understanding, the following depicts the model objective, boundary conditions and stakeholder involvement in the model.

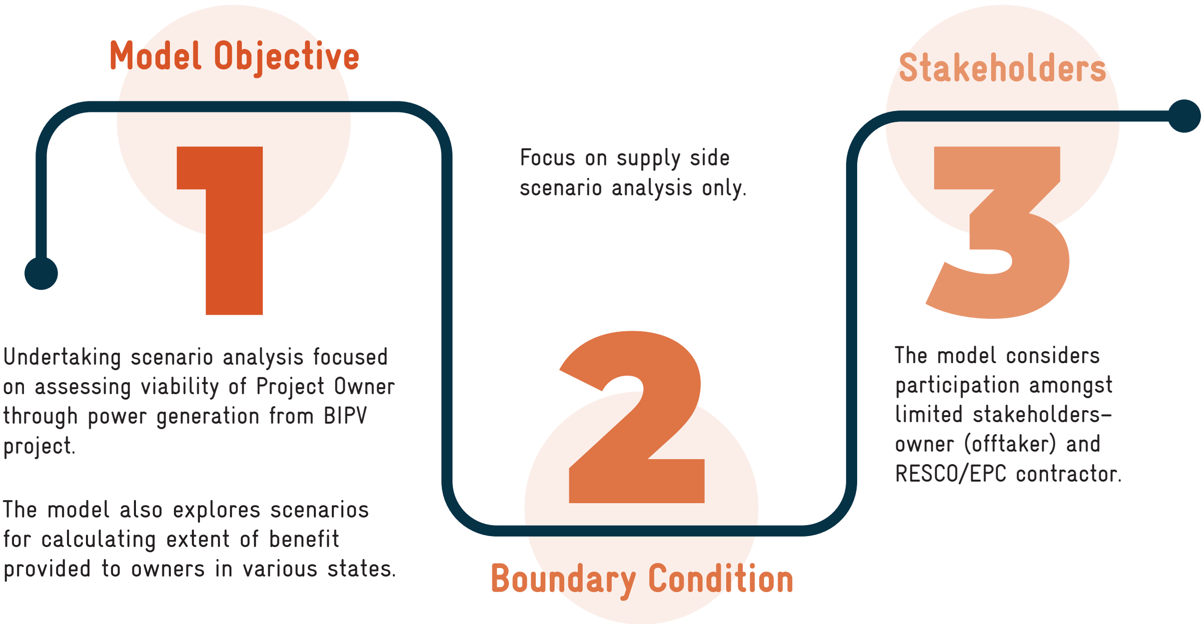


Figure 9: BIPV business model objective, boundary conditions, and stakeholders.

Financial Model

The financial model for Building Integrated PV has been considered for vertical façade integrated PV systems. The detailed breakup of a sample 1 MW system along with its capital cost is described in the table below.

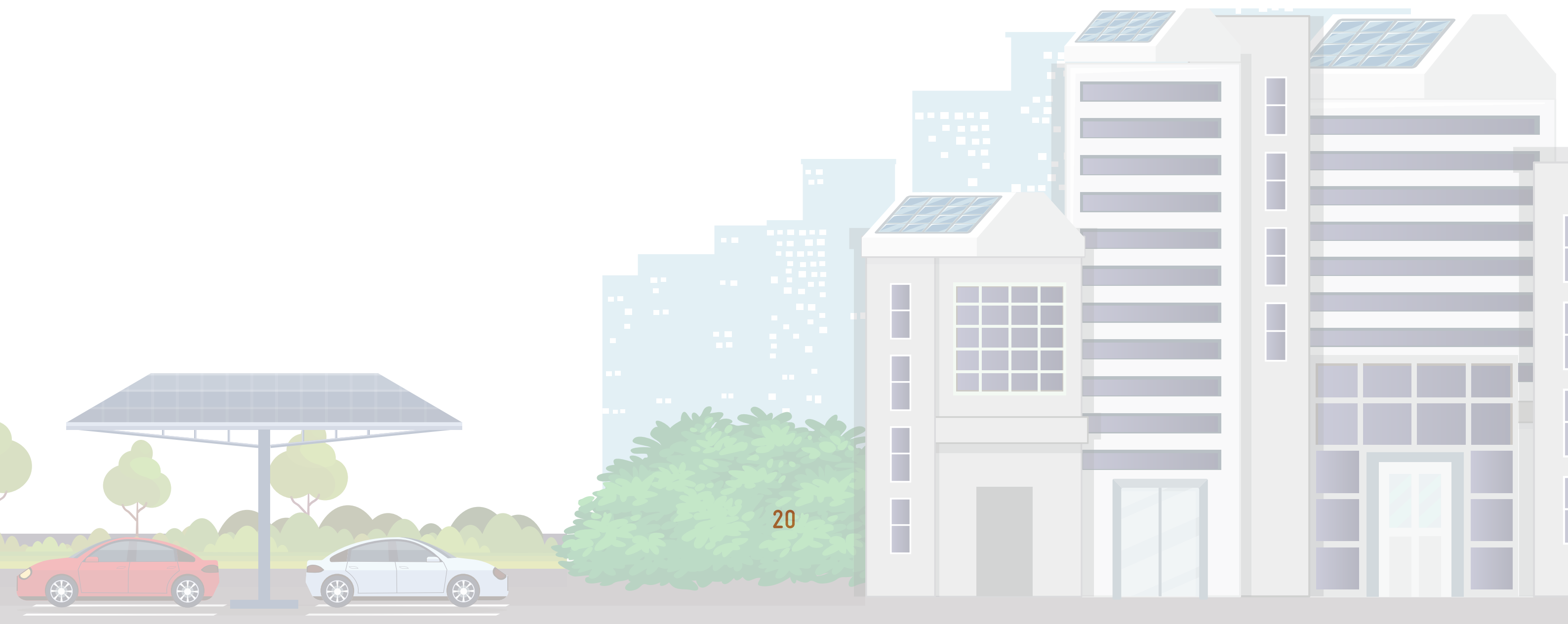


Table 5: Cost breakup of BIPV projects

Cost Components	Sub-components	No.	INR Lakhs per MW	% Share	Assumptions Rationale
Preliminary Cost			3		Cost pertaining to preliminary assessment, PFR, DPR, site visits, etc.
EPC Cost	Modules Wattage (Wp)	480			Module wattage considered as per prevailing specs.
	Module Cost (INR/Wp)	28			
	Number	2500			
	DC Capacity (MWp)	1.2	336	64.52%	Conservative ratio of 1:1.2
	DC: AC (Ratio)	1.2			
	Inverter (INR/Wp)	3	36.00	6.91%	Considered same as large scale PV systems.
	ACDB/DCDB (INR/Wp)	1	12.00	2.30%	Considered same as large scale PV systems.
	Structure (INR/Wp)	4	48.00	8.06%	Structural costs are relatively more compared to conventional systems, primarily due to site specific structures and reinforced foundation requirement.
	Cables (INR/Wp)	0.75	9.00	1.73%	Considered same as large scale PV systems.
	Other Item Transportation (INR/Wp)	1.2	14.40	2.77%	Same as conventional systems.
	Installation and Erection (including civil)	3.5	42.00	8.06%	Same as conventional systems.
	Line Cost		0.00	0.00%	
	Evacuation (INR/Wp)	2	24.00	4.61%	Considered same as conventional systems.
	SCADA		0.00	0.57%	Fixed standard cost for conventional systems.
	Earthing (INR/Wp)	0.2	2.40	0.46%	Same as conventional systems.
	Sub Total		523.80		
	GST	13.80%	72.28		
	Total	480	596.08		

Infrastructure Cost		0.00	
Project Management (@0.5%)		2.52	Industry standard
Contingency (@0.5%)		2.84	Industry standard
Interest during Construction (IDC)		14.82	Industry standard
Total Costs		**619.26**	

The aforementioned assumptions contribute to the capex required for an assumed systems size of 1 MW, with the help of which the levelised cost of energy for 25 years has been calculated, using standard financial assumption, which equals INR 8.36 per kWh (Annexure A).

3.1. BUSINESS-AS-USUAL SCENARIO FOR BUILDING OWNER

Before delving into the discussion of business models for BIPV, the current business-as-usual scenario is being presented in this section. Building owners, at present, heavily rely on electricity consumption from the local grid, adhering to a tariff slab system where the cost of electricity varies based on usage levels. Notably, both commercial and domestic consumers, including building owners, are grappling with high charges for their electricity consumption.

Table 6: Business-as-usual scenario for the building owner

S. No	Stakeholders	BAU characteristics
1	Building owner	**Energy Generation** – Building owners consume electricity for consumption from the local grid, as per the tariff slab. Commercial and domestic consumers pay high charges.

3.2. BUSINESS MODEL FOR BUILDING INTEGRATED PV

The business model for BIPV technology presents the various benefits acquired by the building owner while considering the technology. Here, there is no involvement of a third party and it is primarily financed by the building owner (CAPEX model). As indicated in the section above (financial model), the vertical orientation of the panel results in a higher LCOE estimation of INR 8.36 per kWh, which implies the feasibility of the technology in states where consumers pay for electricity higher than LCOE. An evaluation of various tariff segments of commercial and residential consumers indicated that most states have higher tariff slabs for target consumers. In fact, states like Maharashtra and WB charge consumers electricity rates as high as INR 16 per kWh, making BIPV strongly viable despite a higher LCOE rate.

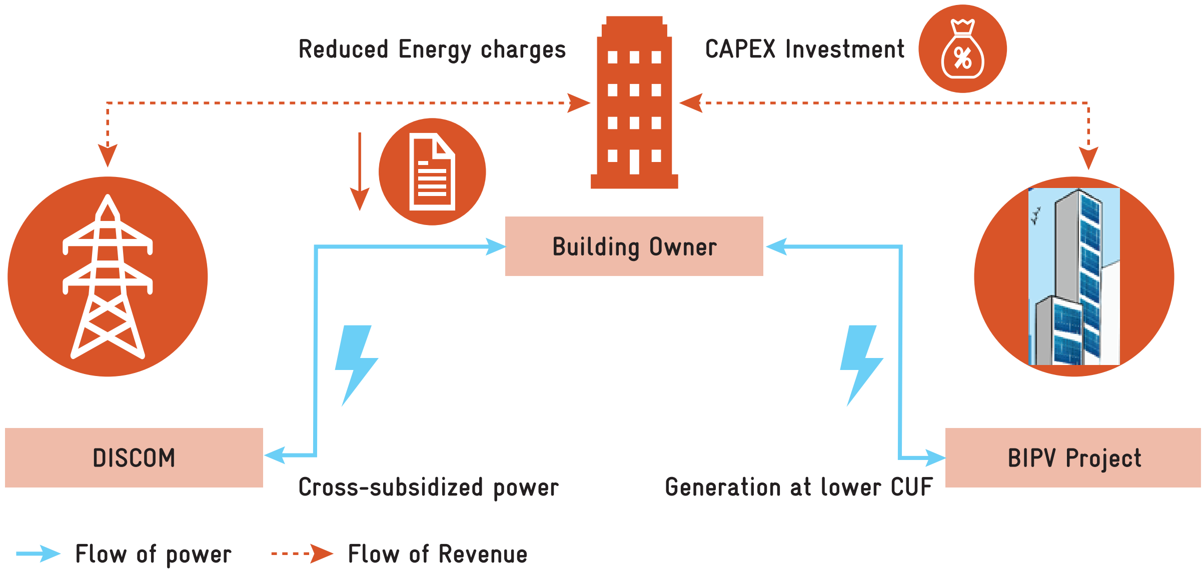


Figure 10: Business model for the building owner

The following figure plots the payback period for two types of consumers in sample states, giving an idea of consumer CAPEX recovery.

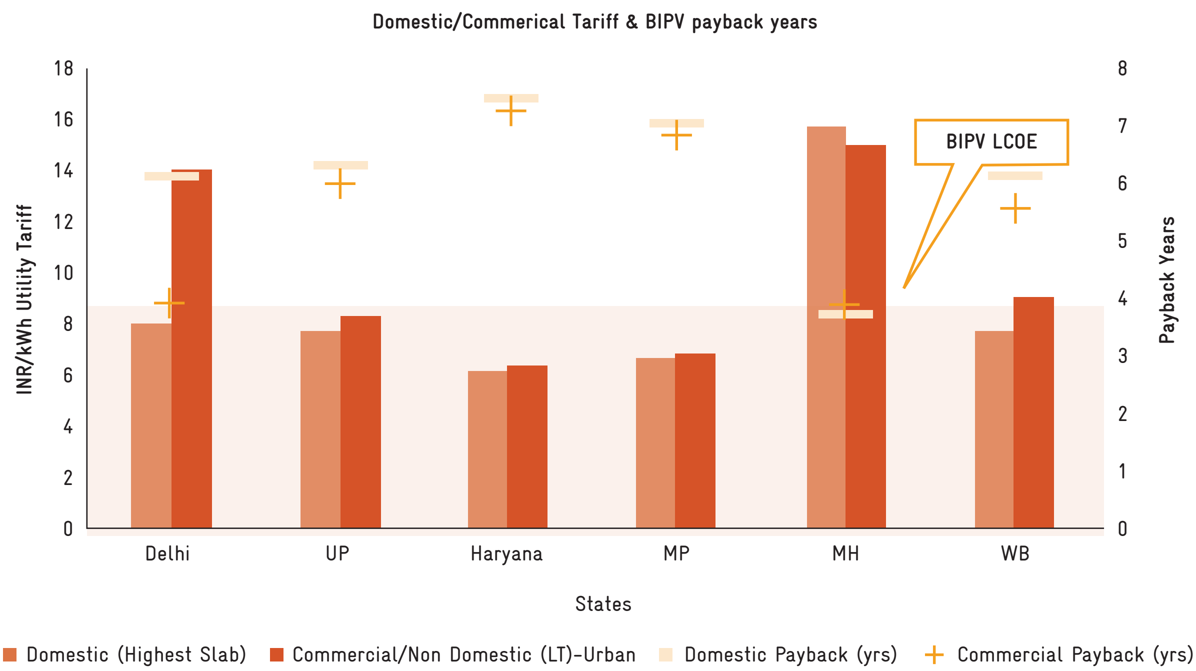


Figure 11: Consumer tariff in various states mapped with BIPV LCOE, providing an insight into project viability

The graph depicted above provides a detailed analysis of selected states, including Delhi, Uttar Pradesh, Haryana, Madhya Pradesh, Maharashtra, and West Bengal. The utility tariffs for both domestic and commercial segments, measured in INR per kWh, have been graphically represented alongside the corresponding payback years associated with the installation of BIPV projects on buildings in these states. A significant observation from this analysis is that the payback period for commercial consumers is consistently lower than that for domestic tariff consumers. This suggests that, despite the initial investment in BIPV projects, commercial consumers are likely to experience a quicker return on investment compared to their counterparts in the domestic segment. This insight underscores the potential financial benefits and faster economic viability of adopting BIPV technology for commercial entities across the specified states.

The model activity framework for BIPV projects outlines a collaborative approach involving key stakeholders. A project developer is enlisted to spearhead the Engineering, Procurement, and Construction (EPC) of the BIPV project, catering to the building owner's requirements. Additionally, the project developer assumes responsibility for operations and maintenance for a duration of 5 years. On the building owner's end, the strategy involves replacing expensive utility units with captive consumption sourced from the BIPV project. This transition enables the building owner to achieve a payback of Capital Expenditure (Capex) within a commendable time-frame of 10 years. However, this shift also implies that electricity distribution companies may experience a reduction in revenue from their high-paying consumers, translating to a financial setback for them.

The model architecture has been illustrated below.

Table 7: BIPV model activity framework

Operation	Project Developer	DISCOM	Building Owner
Operating BIPV Project	Engaged as an EPC in setting up the BIPV project Undertakes O&M for 5 years	Less recovery from high-paying consumers	Shelves of expensive utility units with captive consumption from BIPV project Payback of Capex within 10 years

CAPACITY PROJECTION OF BIPV IN INDIA (2024-40)

04

India has witnessed significant growth in electricity demand over the years, driven by numerous factors such as population growth, urbanisation, industrialisation and rising standards of living. This has led to a rising need for electricity in residential, commercial and industrial sectors. Additionally, the expanding middle class and improving living standards have resulted in increased usage of appliances and electronic devices, further driving up electricity consumption. This surge in electricity demand has posed both opportunities and challenges for the country's energy sector.

In 2021-22, the power demand of India was 1,374 billion units (BU) and is expected to reach 1,500 BU during 2022-23[3]. As per the Central Electricity Authority (CEA)'s optimal generation capacity mix report for 2029-30, the demand is further expected to reach 2,280 BU by 2030[4]. The current installed RE capacity as of July 2023 is around 177 GW. Within this, solar PV capacity takes the lead, contributing a cumulative capacity of 71 GW, followed by wind energy at 44 GW, bioenergy at 11 GW and hydro power at 51 GW. The percentage share of RE in total installed capacity is around 42%[5] and is estimated to reach 60% by 2030 (excluding pumped storage power). The solar PV installed capacity is expected to increase at a compound annual growth rate (CAGR) of 20% from 71 GW in 2023 to 293 GW in 2030 (CEA Optimal energy mix 2029-30). Thereby making it the largest among all other sources of power generation.

The International Energy Agency has also done some similar demand projections for electricity in India under the following scenarios:

- **The Stated Policies Scenario (STEPS)** assumes that the current policy settings and objectives are expected to apply to India's energy sector, taking into account several practical factors that would prevent their execution.
- **The India Vision Case (IVC)** takes a more optimistic stance on the speed of economic recovery and long term growth, and on the prospects for a fuller implementation of India's stated energy policy ambitions.
- **The Delayed Recovery Scenario (DRS),** by contrast, examines the implications of a more prolonged pandemic with deeper and longer lasting impacts on a range of economic, social and energy indicators than is the case in the STEPS.
- **The Sustainable Development Scenario (SDS) takes** a different approach, working backwards from specific international climate, clean air and energy access goals, including the Paris Agreement, and examining what combination of actions would be necessary to achieve them.

3 *Outlook India, Power Consumption Grows 9.5% To 1,503 Billion Units In 2022-23: Govt Data, Aug 2023*
4 *CEA, Report on Optimal Generation Mix 2030- version 2.0, Apr 2023*
5 *MNRE and CEA installed Capacity Reports*

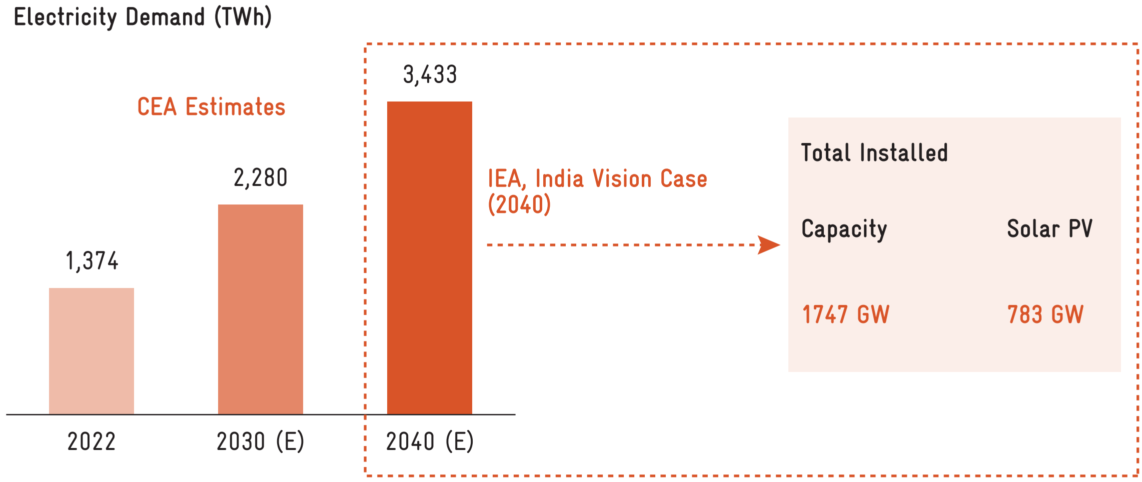


Figure 12: Electricity demand of India in 2030 and 2040

Source: CEA Optimal Energy Mix 2029-30 and India Energy Outlook 2021 (IEA)

The IVC scenario considers the achievement of 450 GW of non-hydro renewable energy capacity by 2030, with a higher level of financial de-risking supported by an enabling regulatory environment. Further, it encompasses higher penetration of natural gas for power generation and batteries for widespread uptake of electric vehicles in the transport sector along with bioethanol/biodiesel as a fuel. A longer-term focus on the industrial sector's deep decarbonisation, which entails a boost in carbon capture and storage technology, along with early efforts to investigate hydrogen production pathways, results in some initial output from low-carbon sources. The estimated installed capacity is illustrated below for 2030 and 2040.

4.1. CAPACITY PROJECTION OF NISAs

For calculating the capacity for NISAs based on the IVC scenario, three different cases were considered:

- ***Business as Usual (BAU):*** The total solar PV installed capacity remains the same as stated under IEA's IVC scenario, i.e., 783 GW by 2040, with no additional NISA getting installed by 2040. The solar PV mentioned here only covers ground mount and rooftop solar.
- ***Moderate:*** The total solar PV installed capacity remains the same as stated under IEA's IVC scenario, i.e., 783 GW by 2040. It is assumed that under this scenario the percentage share of NISA grows to 10%, which will be 78 GW and the rest is ground mount and rooftop solar PV.
- ***Optimistic:*** The total solar PV installed capacity remains the same as stated under IEA's IVC scenario, i.e., 783 GW by 2040. It is assumed that under this scenario the percentage share of NISA will be 30%, which will be 235 GW, followed by ground mount solar at 50% and rooftop at 20%.

Table 8: Capacity projection scenarios of NISAs

	BAU		Moderate		Optimistic	
	% Share	Capacity (GW)	% Share	Capacity (GW)	% Share	Capacity (GW)
Total Solar PV Installed Capacity (2040)		783		783		783
Ground Mount	90%	705	60%	470	50%	392
Rooftop solar PV	10%	78	30%	235	20%	157
NISA	0%	-	10%	78	30%	235

Based on the above scenarios, the annual Capacity of NISAs for both moderate and optimistic scenarios is illustrated below. The Capacity projections for each NISAs are done using the optimistic scenario trajectory.

Annual Demand of NISAs (GW)

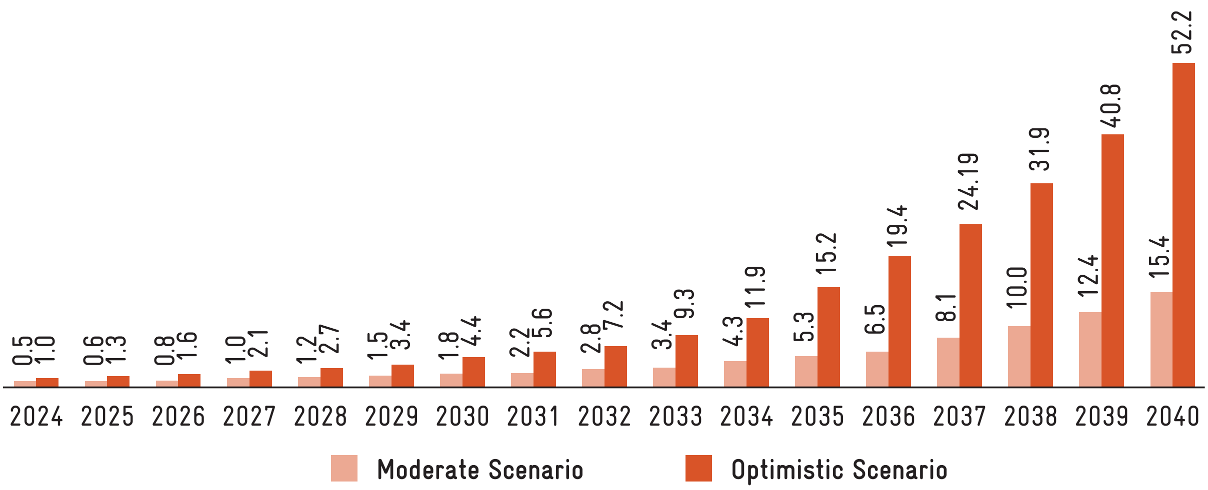


Figure 13: Annual demand of NISAs (moderate and optimistic case)

4.2. PENETRATION OF BIPV AMONGST OTHER NISAs (2024-40)

Amongst all NISAs, it is challenging to predict with certainty which specific solar integration technology will penetrate more in India by 2040. However, based on current trends, considerations, stakeholder inputs, and future demand, some key observations are highlighted below:

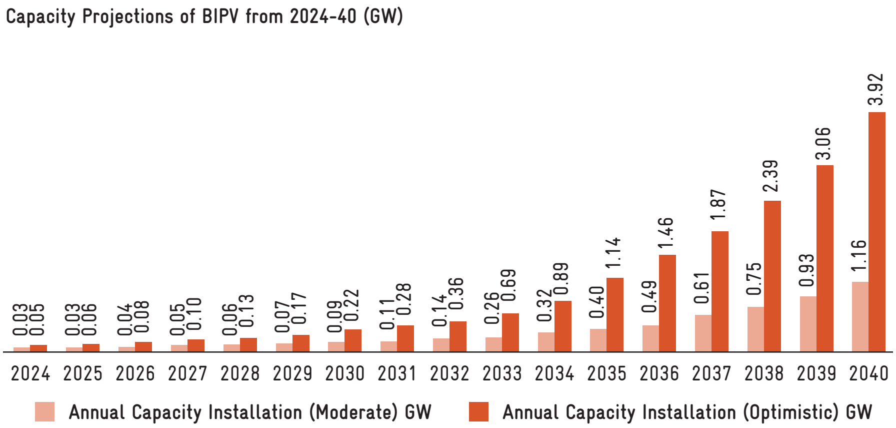
Table 9: Penetration matrix of NISAs

Annual Penetration Matrix of NISAs*	2024			2030			2040		
	% Share	Annual Demand (Moderate) MWp	Annual Demand (Optimistic) MWp	% Share	Annual Demand (Moderate) MWp	Annual Demand (Optimistic) MWp	% Share	Annual Demand (Moderate) MWp	Annual Demand (Optimistic) MWp
BIPV	5%	25	50	5.0%	90	220	7.5%	1,157	3,919
Other (FPV, CTPV, APV, RIPV)	95%	475	950	95.0%	1,718	4,188	92.5%	14,264	48,330

- Floating Solar PV: Due to their potential for using water bodies like reservoirs, lakes, and ponds, floating solar power projects have gained popularity both internationally and in India. The use of floating solar projects is projected to rise in the upcoming years due to India's abundant water bodies. The capacities that are being installed in India are usually in Megawatts, with LCOE ranging between 3 to 4 rupees per unit, therefore making it one of the most feasible technologies amongst all NISA in the initial years. The current penetration level is considered to be 50% in the initial years and reduced to 35% by 2040.
- Agrivoltaics: Land utilisation plays a significant role in the implementation of Agri PV in India, which allows dual use of land where power generation, as well as an agricultural activity, can simultaneously take place on a single piece of land. Given the enormous potential of Agri PV found under this project, it is expected to penetrate from 18% to 27.5% from 2024 to 2040 amongst all other NISAs.
- Canal Top Solar PV: India has already witnessed the implementation of canal top solar projects in certain regions under the MNREs pilot scheme for canal top and canal bank solar PV projects. Presently the penetration of canal top projects is assumed at 15 %and is expected to decrease to 10% by 2040 as other NISAs also grow.

- Rail/Road Integrated PV: The Indian railways has invited bids for 3 GW solar projects on vacant land parcels and land parcels along the railway track through Railway Energy Management Company Ltd. (REMCL). Given this ongoing procurement, the current penetration level is 10% amongst all NISAs and further reduced to 12.5% by 2040. For Roadways there has been no target or long-term vision, hence for estimating capacity for road-integrated PV, it is assumed that new projects might take off a bit late (after 2028) as compared to other NISAs.

Based on the above trends and assumptions, the annual capacity projection for BIPV is illustrated below for both moderate and optimistic cases.



BIPV Capacity Projection

Moderate Scenario: Cumulative Capacity from 2024-40: 5.5 GW

Optimistic Scenario: Cumulative Capacity from 2024-40: 16.9 GW

Figure 14: Capacity projections of BIPV from 2024-40

FINANCING BIPV AND UPV IN INDIA

05

5.1. INTERVENTIONS TO SUPPORT THE FINANCING OF BIPV AND UPV

Governments, financial institutions, and development organisations throughout the world are supporting clean energy projects through various means such as budgetary support, easy finance, and running various programs for building the right ecosystem respectively. These are primarily done for various reasons such as:

- Overcoming barriers to developing renewable energy; and
- Promoting the adoption and growth of renewable energy

The section will primarily cover government interventions. These interventions can be classified into two types:

- Capital support
- Revenue support

Capital support reduces the capital required for the project and therefore reduces the requirement of debt to be raised and equity infusion. Revenue support comes every year once the project gets commissioned and therefore, it does not reduce the capital requirement.

Below are some of the interventions classified under both heads:

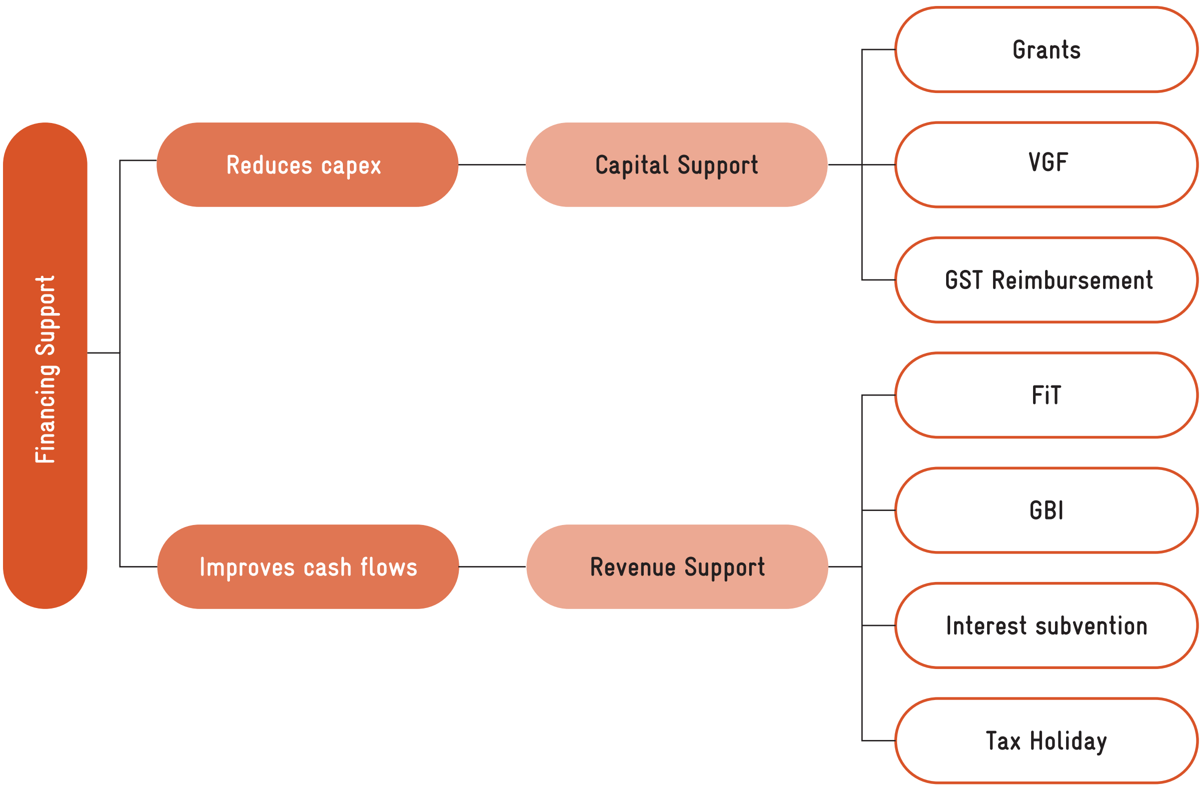


Figure 15: Financing interventions

A comparative analysis of the above interventions is shown in the table below:

Table 10: Comparative analysis of financing interventions

	Type	Impact on developer	Impact on Exchequer
Grant	Capital Support	Reduces the funding obligation upfront.	Upfront burden
VGF	Capital Support		
GST Reimbursement	Capital Support	It does not reduce funding obligations upfront but boosts cash inflow once reimbursement is met.	
FiT	Revenue Support	Improves the cash flows.	Benefits need to pass over a period based on KPI. Therefore, a monitoring and disbursement agency needs to be appointed.
GBI	Revenue Support		
Interest Subvention	Revenue Support	Reduces the financing cost.	Benefits need to pass over a period but no disbursement or monitoring is required.
Tax Holiday	Revenue Support	Reduces tax burden but developers generally use financing instruments such as quasi-equity instruments to reduce the tax burden.	

GRANTS:

Grants in the renewable sectors refer to financial assistance provided by governments, non-profit organisations, and other entities to support the development, installation, or research of new technologies. The funds can be used to offset the upfront expenses and make solar installations more affordable for individuals, businesses, or communities. The implementation of pilot demonstration projects may be supported through grants. These initiatives demonstrate the viability and advantages of any project in practical contexts like residential communities, business structures, or public infrastructure. Equipment, installation, and monitoring costs might all be partially covered by the financing.

VIABILITY GAP FUNDING (VGF):

Viability Gap Funding (VGF) is a financial assistance to close the financial gap between project costs and expected developer revenues. It tries to make projects profitable and appealing to private investors. The VGF mechanism was established by the Indian government under the Jawaharlal Nehru National Solar Mission (JNNSM) in 2013 to support grid-connected solar power plants. Through a process of open competition, the government supplies VGF. For instance, solar projects were chosen through a reverse auction procedure in Phase-II Batch-I of JNNSM where developers stated their tariffs. The government awarded the projects with the lowest tariffs, and VGF was granted to close the viability gap and support the projects' financial sustainability.

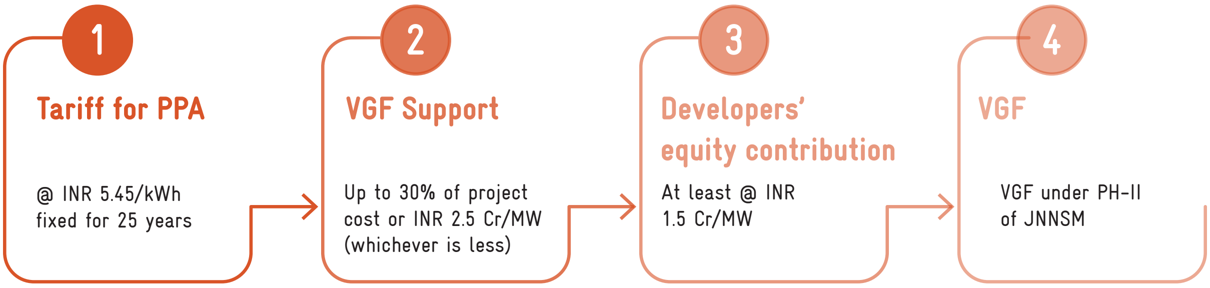


Figure 16: Viability gap funding under Ph-II of JNNSM

FEED-IN TARIFFS:

Governments utilise feed-in tariffs (FiTs) as a policy tool to promote the use of renewable energy technology, particularly in the production of electricity. It is a type of monetary reward given to producers of renewable energy, who are often individuals or companies, for the electricity they produce and feed into the grid. The government or regulatory authority establishes a predetermined payment rate per kilowatt-hour (kWh) of electricity produced by renewable energy sources under an FiT programme. This rate is often guaranteed for a specific period, frequently between 10 and 20 years. A reasonable return on investment for the renewable energy project is ensured by the payment rate level.

To give producers of renewable energy a financial incentive, FiTs are often higher than the going rates for power on the market. This helps to make renewable energy technologies more economically viable and appealing to investors by offsetting their greater upfront costs.

Feed-in tariffs' primary goals are to encourage the growth of renewable energy projects, raise their proportion in the total energy mix, and lower greenhouse gas emissions. FiTs minimise the financial risks involved with such investments by ensuring a fixed payment rate and offering renewable energy providers a steady and predictable revenue stream. Many nations around the world, including Germany, Spain, and numerous other European countries, have effectively implemented feed-in tariffs. To assist the development of renewable energy, several nations have switched to alternate mechanisms such as auctions or quota systems. It is important to note that the acceptance and efficacy of feed-in tariff schemes have fluctuated over time.

INTEREST SUBVENTION:

Interest subvention in solar projects refers to a financial support mechanism where the government or another entity provides a subsidy or reduces the interest rate on loans taken for financing solar energy projects. It aims to make the cost of borrowing for solar projects more affordable, thereby incentivising investment in the sector. In certain situations, the government might offer a subsidy or reimburse a portion of the interest paid by the borrower rather than lowering the interest rate directly. Direct payments or interest amounts, offset against taxes or other debts, may be used to accomplish this. Here's how interest subvention typically works for a renewable energy plant:

Loan Application

To finance the renewable energy project, the project developer or owner seeks for a loan from a financial institution or a government body. In order to apply for a loan, you must provide information about your project, financial projections, and other required paperwork.

Eligibility Criteria

The financial institution or governmental body providing the interest subsidy has certain qualifying requirements that the loan applicant must satisfy. Project size, technology kind, project location, and adherence to social and environmental standards are a few examples of these factors.

Approval & Loan Disbursement

The loan is granted after completing the requirements, and money is given to the project developer. The borrower and the lender come to an agreement on the loan's terms and conditions, which covers the interest rate, repayment duration, and timetable.

Interest Subvention

When the loan is disbursed, the interest subvention kicks in. For a set amount of time, the government or financial institution offers a subsidy or lowers the loan's interest rate. This time frame can change depending on the particular plan or policy, but it is normally for a set amount of time, like a few years.

Reduced Interest Payment

The borrower gains from a lower interest payment as a result of the interest subvention. The project becomes more financially feasible and appealing as a result of the subsidy or lower interest rate, which also decreases the overall cost of borrowing. The project's feasibility and financial sustainability are enhanced as a result.

Figure 17: Steps of interest subvention

GENERATION-BASED INCENTIVE:

A generation-based incentive (GBI) is a financial incentive offered by the government to encourage the production of energy from solar power facilities. The GBI scheme provides solar power developers with a subsidy based on the actual electricity generated to encourage them to produce clean and renewable energy.

Developers of solar power gain an extra incentive under the GBI programme for each unit of electricity their solar power plants generate. Usually, this incentive is given in addition to the money made by selling electricity to the grid. The GBI aids in closing the cost gap between the production of conventional power and the production of solar power, increasing the viability of solar projects.

- In 2008, India implemented the first generation-based incentive (GBI) for renewable energy, including solar electricity. As a component of the Jawaharlal Nehru National Solar Mission (JNNSM), the Indian government introduced the GBI initiative.
- The GBI programme was initially developed for solar photovoltaic (PV) power projects to encourage the construction of grid-connected solar power plants. In addition to the applicable feed-in tariff (FIT) or power purchase agreement (PPA) prices, the GBI was offered to the power producers.
- The GBI programme was created to last for 10 years from 2010 to 2020. However, because each state in India had the freedom to choose whether to adopt the GBI plan and set its unique terms and conditions, the GBI's implementation and length differed among the country's various states and regions.
- 4Presently, new mechanisms like competitive bidding, tariff-based auctions, and subsidies under various state and central government schemes are being adopted to support renewable energy development in India. However, GBI provided a push to achieve a larger participation and portfolio development in the initial years.

TAX HOLIDAY:

A tax holiday is a governmental incentive that temporarily reduces or eliminates taxes for businesses. By providing a tax holiday for a specified number of years, the effective tax rate in those years shall be zero. The business losses and/or unabsorbed depreciation guidelines may remain as such. Such a scheme reduces the tax outgo and hence boosts the cash flow, and hence the returns. This will enable developers in lowering the LCOE.

5.2. INVESTMENT REQUIRED IN BIPV (2024-40)

5.2.1. MODERATE SCENARIO (5.5 GW BY 2040)

Under the moderate scenario, the cumulative demand for building integrated PV in India is projected to be 5.5 GW from 2024 to 2040. To realize this potential, a calculated investment of INR 26,588 crores is deemed necessary—a commitment that not only addresses the growing energy needs of India but also aligns with global initiatives promoting renewable energy and eco-conscious urban development.

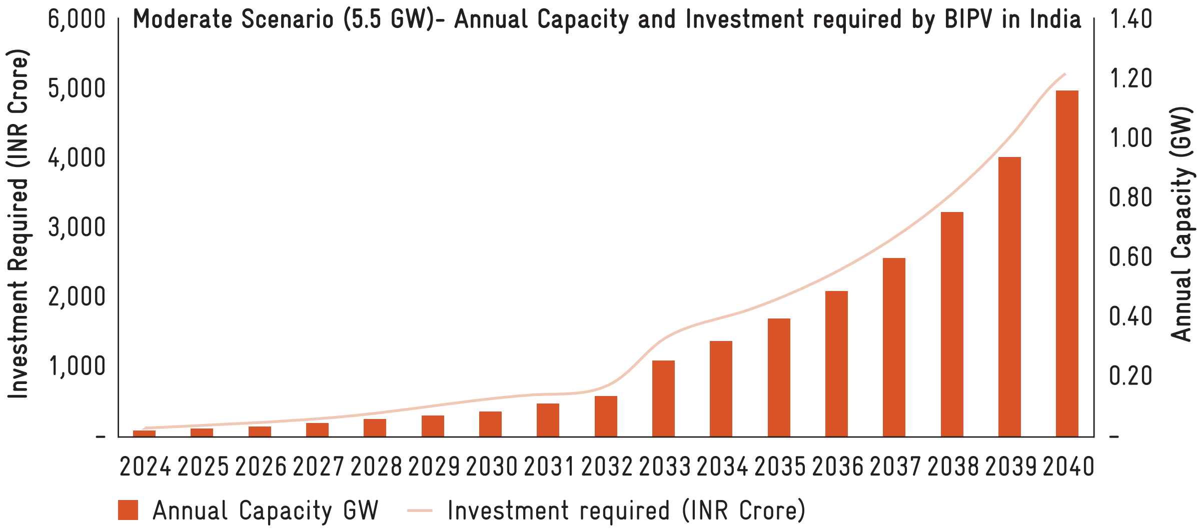


Figure 18: Annual capacity and investment required by BIPV (moderate scenario)

5.2.2. OPTIMISTIC SCENARIO (17 GW BY 2040)

Under the optimistic projection, the cumulative demand for BIPV is anticipated to surge significantly, reaching an ambitious 17 gigawatts from 2024 to 2040. This soaring demand reflects a robust belief in the transformative power of integrated photovoltaics to redefine the country's energy infrastructure. To bring this ambitious vision to fruition, a substantial investment of INR 80,571 crores is envisioned—a testament to the profound commitment required to unleash the full potential of solar energy integration.

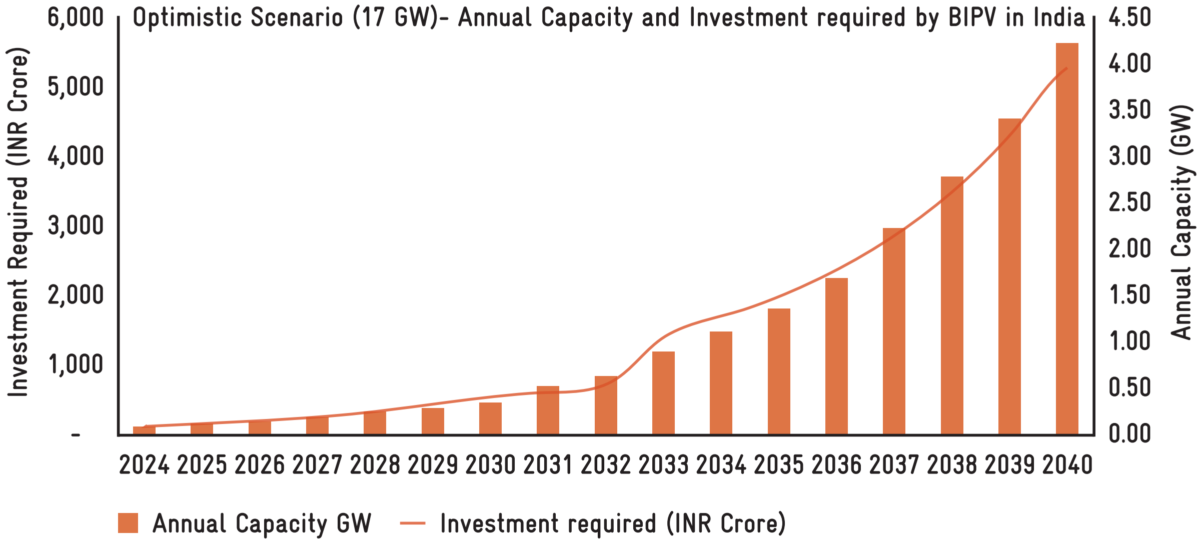


Figure 19: Annual capacity and investment required in BIPV (optimistic scenario)

5.3. FINANCING INTERVENTIONS RECOMMENDED FOR BIPV AND UPV

The Ministry of New and Renewable Energy (MNRE) has undertaken commendable initiatives through the Rooftop Solar Programme Phase-2 to propel the widespread adoption of solar energy. Under this program, subsidies play a pivotal role in incentivizing the installation of rooftop solar systems, including grid-connected Building Integrated Photovoltaic (BIPV) systems.

As part of the subsidy framework, residential consumers stand to benefit significantly, with a substantial 40% subsidy on the project cost for the installation of Rooftop Solar systems of 3 KW. Beyond this capacity and up to 10 KW, a 20% subsidy is provided, making solar energy solutions more financially viable for residential consumers. However, it is crucial to acknowledge certain limitations inherent in the current subsidy structure. While the Rooftop Solar Programme Phase-2 takes strides in promoting clean energy practices, a key constraint arises from the predominantly residential focus of the subsidies. This emphasis poses challenges for the commercial and industrial sectors seeking to harness the benefits of solar energy on a larger scale to integrate BIPV.

To encourage the scaling of BIPV installations in India, several financial interventions can be considered:

- **Energy Performance Contracts (EPCs)** represent a strategic financial mechanism that can revolutionize the adoption of Building Integrated Photovoltaics (BIPV) within the construction industry. This innovative approach involves collaboration between builders or building owners and specialized entities known as Energy Service Companies (ESCOs). The objective is to secure funding for BIPV installations while leveraging the energy cost savings generated by these systems to repay the investment over time.

  Builders or building owners collaborate with ESCOs, specialists in energy efficiency, and sustainable solutions. ESCOs, backed by financial resources and technical expertise, fund the design, procurement, and installation of Building Integrated Photovoltaic (BIPV) systems. This relieves builders and building owners of the upfront financial burden, facilitating the adoption of sustainable energy solutions. EPCs, a distinctive aspect of this collaboration, introduce a novel repayment model. Instead of conventional fixed monthly payments, EPCs link repayment directly to the energy cost savings realized through BIPV. As BIPV systems generate electricity and reduce energy bills, a portion of these savings is used to repay the investment. EPCs also incorporate performance guarantees, ensuring that BIPV systems meet specified energy efficiency and production targets. This alignment of interests benefits both parties, with builders or building owners enjoying reduced energy costs, and ESCOs gaining confidence in the success of their investments.

- **Green Building Certification Incentives** involve rewarding builders and developers for incorporating environmentally friendly and sustainable practices, including the integration of Building Integrated Photovoltaics (BIPV), into their construction projects. Green building certifications, such as LEED (Leadership in Energy and Environmental Design), GRIHA (Green Rating for Integrated Habitat Assessment), or IGBC (Indian Green Building Council) certification, are established frameworks that assess and recognize buildings for their environmental performance.

These incentives may include tax credits, reduced permit fees, or direct monetary rewards. The inclusion of BIPV components in the certification criteria would make it more likely for builders to invest in solar technologies.

Urban photovoltaic (PV) initiatives within municipal bodies represent a progressive approach toward sustainable urban development in India. As urbanization accelerates and energy demands rise, integrating solar technologies into the fabric of cities becomes imperative. The implementation of urban PV aligns seamlessly with India's ambitious Smart Cities initiative, launched to enhance urban living standards through the integration of technology, sustainability, and efficient governance. Some of the financing interventions for scaling UPV in India are illustrated below:

- Municipal Financing Programs can establish special financing programs dedicated to supporting urban photovoltaic projects. This could involve offering low-interest loans or grants for the installation of solar trees and elevated structures in public parking spaces to residents, businesses, or communities interested. This can be done by establish a dedicated fund within the municipal budget or seek financial partnerships with external entities. Design the loan program with favorable interest rates and extended repayment terms to incentivize widespread participation.
- Grants and Incentives for Public Spaces and Community Areas will encourage the installation of solar trees and elevated structures in public spaces by providing grants to municipalities, community groups, or NGOs. Further, additional incentives such as property tax rebates, expedited permitting processes, or recognition awards for entities that install and maintain solar PV infrastructure.

BIPV AND UPV – POLICY & REGULATORY ANALYSIS

06

In India, BIPV (Building Integrated Photovoltaic) system installation is covered under the National Building Code of India (NBC). These guidelines are part of NBC's Part 10: "Sustainability in Buildings."

Some of the key provisions for BIPV in the NBC are:

- Integration of BIPV with the building envelope: The NBC mandates that BIPV systems must be integrated with the building envelope and should not compromise the structural integrity, durability, or safety of the building.
- Electrical safety: The NBC requires that BIPV systems must comply with the electrical safety codes and standards in India, including the Indian Electricity Rules.
- Performance and efficiency: The NBC requires that BIPV systems must be designed to maximise energy generation and minimise losses due to shading, soiling, or other factors.
- Maintenance and access: The NBC mandates that BIPV systems must be designed for ease of maintenance and access, to ensure that they can be inspected, cleaned, and repaired as needed.
- Building permits and approvals: The NBC requires that BIPV systems must comply with all local building codes and regulations and obtain all necessary permits and approvals before installation.
- Interconnection with the grid: The NBC requires that BIPV systems must comply with the guidelines for grid interconnection of solar power systems issued by the Central Electricity Authority.

In this chapter, the ISUN team has tried to understand the barriers and challenges in the implementation of BIPV plants in India and thereby provided recommendations, the methodology is mentioned in the subsequent section below.

International Policies and Regulations

California, USA: The California Energy Code, often known as Title 24, has been established by the state of California and requires the installation of PV systems on new residential and commercial structures. There are different thresholds for residential and non-residential constructions, and the need is based on the size and kind of the building[6].

The "RE2020" (Réglementation Environnementale 2020) standards, which were implemented in France, call for new buildings to produce a minimum amount of renewable energy and have a specific level of energy efficiency. One of the renewable energy technologies that can be employed to satisfy the needs is the utilisation of PV systems[7].

The "Shams Dubai" project, which requires the installation of PV systems on the rooftops of new buildings in Dubai, has been put into place by the Dubai Electricity and Water Authority (DEWA). Buildings that are residential, commercial, or industrial must comply with the regulation[8].

6 *California Energy Commission, Building Energy Efficiency Standards, https://www.energy.ca.gov/title24/*
7 *Interreg Europe, Environmental Regulation 2020-RE2020, https://www.interregeurope.eu/good-practices/environmental-regulation-2020-re2020*
8 *Dubai Electricity & Water Authority, Shams Dubai, https://www.dewa.gov.ae/en/consumer/solar-community/shams-dubai*

6.1. METHODOLOGY TO UNDERSTAND BARRIERS AND CHALLENGES

The project team has reviewed the available literature to understand the various stages available in the life cycle of a BIPV plant. This was followed by the identification of relevant stakeholders in each of the stages of the BIPV life cycle. A questionnaire was developed to interview relevant stakeholders to understand the policy and regulatory barriers to the large-scale adoption of BIPV in India.

Step 1	Step 2	Step 3	Step 4	Step 5
Mapping BIPV/UPV lifecycle	Identification of stakeholders	Consultation/ Interviews	Identification of Challenges & Barriers	Recommendations

Figure 20: Methodology for understanding barriers and challenges

In **step 1**, the project team has analysed and mapped out the various stages involved in developing a BIPV/ UPV plant. Analysing the full lifecycle allows stakeholders to make informed decisions and establish strategies for successful implementation by identifying the barriers and challenges connected with each step of the lifecycle.

The lifecycle of BIPV/UPV has the following phases:

- **Inception Phase:** For new buildings, the initial design of BIPV starts even before the construction is carried out. The architects are required to prepare layouts of the building structure keeping in mind that some of the materials will be replaced by BIPVFor UPV, this phase involves identifying suitable sites within urban areas for PV installations, considering factors such as solar potential, available space, and proximity to the grid.
- **Application Stage:** This step in the lifespan of a BIPV and UPV plant entails selecting prospective installation site/buildings and submitting requests for permission to the necessary authorities like municipal bodies. Doing feasibility studies and assessing the project's economic viability may also be part of this step.
- **Project Approval:** Following the submission of the application, the project will be examined by the pertinent authorities to make sure it conforms to all applicable laws and standards. Obtaining licences, consents, and clearances from various governmental organisations may be necessary.

- **Execution of the Project:** At this phase, the required hardware must be purchased, installed, and the electrical and mechanical systems must be laid out. Moreover, the building envelope and other supporting structures must be built in case of BIPV installations. This also includes physical construction of the urban PV plant, including the installation of solar panels, electrical systems, and any necessary civil works.
- **Commissioning:** After the BIPV/UPV plant's construction is complete, the system must go through testing and commissioning to make sure it is operating correctly and producing the anticipated amount of power. Doing performance testing, confirming that safety regulations are being followed, and making sure the system is connected to the electrical grid may all be part of this stage.
- **Operations and Maintenance:** The BIPV/UPV plant moves onto the operations and maintenance phase after it has been put into service. This entails keeping an eye on the system's functioning, doing regular maintenance, and resolving any problems that might develop over time. The BIPV/UPV system's long-term dependability and effectiveness depend heavily on this phase.

During **Step 2**, the project team engaged in extensive conversations with key stakeholders in the BIPV/UPV domain, ranging from those responsible for project implementation to the authority's overseeing regulations, agencies coordinating efforts, and individuals shaping the market.

Figure 21: Stakeholders consulted

6.2. BARRIERS AND CHALLENGES IN BIPV AND UPV

Based on the in-depth literature review and stakeholder consultations, the project team was able to identify the following barriers and challenges in different stages of the BIPV/UPV plant life cycle. This is a part of step 4 of the methodology as discussed in the section above (figure 20). A summary of barriers and challenges is illustrated in Table 11.

Table 11: Summary of barriers and challenges

Barriers and Challenge	Category	Criticality Factor	
Lack of Awareness	Knowledge	Low	★☆☆
High Capital Cost	Economic	High	★★★
Building Infrastructure	Infrastructure	Low	★☆☆
Existing regulations and policy	Regulatory	Medium	★★☆
Technical Design	Technical	Medium	★★☆
Limited Product Availability	Market	Medium	★★☆
Safety Issues	Operational	Medium	★★☆
Heat Envelope	Operational	Medium	★★☆
Budget Constraints	Economic	Medium	★★☆

APPLICATION STAGE

Knowledge

- Lack of awareness: A lot of parties involved, including building owners, architects, engineers, and policymakers, are not aware of the advantages and potential of BIPV systems. A lack of knowledge may result in a lack of demand for BIPV systems, which would restrict the market's size and impede the industry's expansion.
  - Building owners and project developers lack financial and technological awareness, which makes them skeptical of the project's implementation and financial benefits.
  - Public resistance due to concerns about visual impact, land use implications, and potential disruptions during construction can impede the progress of urban photovoltaic projects. Overcoming these concerns requires effective communication, community engagement, and transparent planning to address and mitigate perceived negative impacts.

Economic

- High initial capital costs: BIPV (Building Integrated Photovoltaic) systems are generally more expensive than conventional solar PV systems. This is because BIPV systems are integrated into the building's architecture and replace traditional building materials such as glass, roofing materials, and facade elements. This integration requires specialised design, manufacturing, and installation processes, which add to the overall cost of the system.
- Indian building infrastructure: A lack of enthusiasm among building owners in a community or locality may result from uneven implementation feasibility of BIPV systems due to issues like shading, building type, building orientation, etc. Further, the success of BIPV is dependent on the nearby buildings or structures, i.e. it should get adequate sunlight free from any obstruction.
  - Retrofitting of BIPV could be highly expensive and moreover not feasible due to obstruction from nearby/adjacent buildings in most of the cities in India.

PROJECT APPROVAL

Regulatory

- Regulatory and policy obstacles: The current building design and energy efficiency laws and regulations in Indian cities do not sufficiently encourage the deployment of BIPV systems. There aren't any incentives, requirements, or laws that force or boost building owners to install BIPV systems.

PROJECT EXECUTION

Technical

- Technical difficulties: BIPV systems need to be installed correctly with the building's design in order to function securely and effectively. Technical ignorance can result in bad design decisions, problematic installations, and ineffective operations.

Market

- Limited product availability: BIPV systems demand a high degree of customisation and integration with the building's construction, in contrast to traditional solar panels, which can be installed on the ground or on the roof. They become more difficult to manufacture and expensive to install as a result, which may reduce their marketability. The Indian market has a limited supply of BIPV systems, making it difficult to identify goods that are suited for the building's design and energy requirements.

COMMISSIONING

Operational

- Safety issues: A conventional solar PV plant mounted on a roof is less vulnerable to theft or damage as compared with BIPV used on facades or roof structures. Several building owners are still reluctant to use BIPV as roofing or on windows as it might be easy to break in for theft or burglary.

Operational

- Heat envelope: In the context of BIPV, the term "heat envelope" refers to the perimeter of a building or other structure that encloses the interior area. This includes the building's exterior envelope, which includes the insulation, roof, walls, windows, and doors. In a BIPV system, the heat envelope is crucial for controlling the building's temperature and maximising the efficiency of the solar panels.
  - In BIPV, the solar panels are incorporated into the building shell and have a high solar heat absorption capacity. Improper management of the heat produced by the solar panels may result in uncomfortable conditions for building users and decreased solar panel performance.

MAINTENANCE

Regulatory

- Maintenance and repair: BIPV systems require regular maintenance to ensure optimal performance and longevity. The lack of skilled manpower and technical expertise to maintain and repair BIPV systems can be a significant challenge, especially in small cities and towns.

Economic

- Budget Constraints: UPV projects, designed to be installed in common or public areas by municipalities, societies, and other community entities. Municipalities or project operators may face budget constraints for routine maintenance activities, potentially affecting the long-term performance of the plant.

6.3. KEY RECOMMENDATIONS

In this section, the project team have formulated recommendations based on the insights and findings gathered during the previous steps of the methodology (figure 20). These recommendations are essential for guiding the project's direction, addressing identified challenges, and optimizing its overall success. I-SUN Program proposes the following recommendations

- Public education programmes are necessary to raise awareness about the advantages of BIPV and UPV. This can be accomplished by running awareness campaigns to inform the public about the technology and how it can reduce their need for energy.
- Rating agencies for green buildings like GRIHA and IGBC already have made evaluation criteria to have solar PV systems to be included in a building. However, it should include a separate evaluation criterion for the use of BIPV within building infrastructure This can further be explored for Urban PV installations within the common areas of the buildings or complexes.
- An SoP should be created within the National Building Code (NBC) on readily available design, materials, construction, and implementation of BIPV within the building infrastructure. The SoP guidelines should also cover technical specifications related to cable connections, inverter placement, and power evacuation. Thereby, acting as a guiding document for architects, builders, and developers.
- Capacity building: Training programmes for designers, architects, engineers and municipal bodies in the installation and upkeep of BIPV/UPV systems should be launched. A competent workforce will be produced as a result to assist BIPV/UPV expansion in India.
- Standardisation of components and installation methods can help reduce the cost of BIPV systems. This can be achieved through the use of pre-engineered systems that are designed to fit standard building configurations.
- Demand aggregation and pipeline creations: Increasing the scale of production can help reduce the cost of BIPV/UPV systems. This can be achieved through the use of larger manufacturing facilities and higher production volumes, long-term demand creation and a visible pipeline for implementation.
- Mandatory installations in new buildings/complexes: The government can make it mandatory to install BIPV systems as part of new infrastructure development in new and commercial high-rise buildings, reinforcing the installation of solar technologies in public spaces and common areas. This would also require incentives or rebates in terms of system components.

SKILL GAP ASSESSMENT AND JOBS REQUIRED IN BUILDING INTEGRATED PV SECTOR

07

Skilling is vital for increasing the penetration of NISA (New Innovative Solar Applications). By creating a skilled workforce, we can ensure better utilisation of renewable energy resources with high-quality workmanship on the deployed technologies. The skilling interventions must ensure better sustainability of the technology, quality of the deployment and increased rate of deployment, which will create new jobs and livelihood opportunities for many. Skill development initiatives will be majorly required in project engineering, project execution, project commissioning, operation and maintenance, and creating awareness. The following four major reasons are crucial for increasing adaptation of NISA:

Technical Expertise
As solar technology advances, there is a growing need for skilled workers who can design, install, operate and maintain these systems. Skilled workers are required to ensure that the solar systems are installed and maintained correctly, which in turn ensures maximum energy output and efficiency.

Quality Assurance
Solar energy systems must meet strict quality standards to ensure their safety, reliability, and performance. Skilled workers are essential to ensure that these standards are met, which is especially important for ensuring the safety of people and the environment.

Innovation and Research
Skilled workers are required to innovate and research new solar solutions, which are vital for the industry's growth. With skilled workers, there is a greater chance of identifying and developing new solar technologies, which can help in improving the efficiency and reducing the cost of solar systems

Education and Awareness
Skilling can help to educate and raise awareness about the benefits of solar energy, which can lead to increased demand and adoption of solar solutions. By creating a skilled workforce, people will be better informed about solar technology and its benefits.

Figure 22: Crucial requirements for skilling

Number of Jobs

- Sector Experts, Policy/Regulator/ Finacial/ Designers
- Project Managers / Site Managers/ Supervisors
- Installation / operation and Maintenance Technician and their assistants/ Helpers

Figure 23: Number of jobs as per skills and designations

The targeted skilling measures not only increases the penetration of new innovative solar application but also creates numerous direct and indirect jobs across the sector, most jobs will be at the operational level of manufacturing, installation, and maintenance.

The majority of the jobs will be created at the technician level or below, whereas the high-paid jobs, which will be doing value addition in the sector, will be comparatively less.

Though all the skilling initiatives will not result in new job creation but may provide better/alternate livelihood opportunities for existing manpower migrating from other sectors to these new sectors.

7.1. SKILLING REQUIRED IN BIPV

The project team has identified several gaps where skilling becomes necessary to boost the BIPV sector in India.

Table 12: Skill gap assessment and interventions

Stakeholder	Gaps	Skilling Required	Skilling Intervention
BIPV Architect	Greenfield BIPV projects are more feasible than retrofitting. Less/no knowledge of BIPV among the architect community. BIPV project developers generally approach customers when the building is already under development.	Architects need to be upskilled on the BIPV concept.	A short-term training program on BIPV needs to be carried out for architecture students.
BIPV HSE	No separate HSE standards for BIPV are available.	The HSE standards for BIPV need to be developed.	The HSE Standards for BIPV may be notified to relevant stakeholders.
BIPV Design Engineer	Lack of designing knowledge BIPV, taking into account access to cable and ducts for operation and maintenance, replacement of panels or BOS if needed.	Solar PV designers need to be upskilled on various designing parameters of BIPV.	Separate training modules and capacity development programs need to be developed.
BIPV O&M Technician	O&M will be a challenge in future, as O&M needs to plan for 50 years (life of the building), with sufficient inventory of spares for at least 25 years.	Site-specific O&M plans and layouts need to be developed by the designer and O&M technicians.	O&M technicians must be trained to read electrical and civil layouts as required.
BIPV module cleaner	There is no capacity, current high-rise window cleaners will only be deployed for cleaning BIPV	Capacity developments need to be carried out including Do's and Don'ts while cleaning PV modules.	Upskilling programs need to be conducted for BIPV cleaners.

7.2. WORKFORCE REQUIRED FOR BIPV

To analyse the number of jobs created and workforce required in the BIPV sector based on the potential derived under this assignment, the project team referred to previously developed reports on skilling and workforce by CEEW (Council on Energy Environment and Water), NRDC (Natural Resources Defense Council), and SCGJ (Skill Council of Green Jobs) along with stakeholder consultations.

The analysis was done under different job roles during the application stage, project approval, detailed engineering, project execution and commissioning, and operations & maintenance. i.e., the workforce required to perform these job roles per MW of installation. The full-time equivalent is simply a ratio of the time spent by an employee on a particular task/project each year to the standard total working hours in that particular year.

	Application Stage	Project Approval Stage	Engineering Stage	Proj Exec. & Comm.	O&M
Job Roles	Site Surveyor, Designer,	Proposal evaluation expert, solar PV engineer (grid interconnection, HSE, Site)	Solar PV Designer, Energy modeller, Electrical design eng., CAD/Draughts man (Mech/Elect)	Solar site incharge, Solar PV project manager, Solar PV installer (civil), Solar PV installer (electrical), Solar Project helper	Solar PV maintenance technician (Elect./Civil), Solar project helper, Solar PV operations and maintenance engineer, Solar PV operations and maintenance manager
New Job Roles	BIPV Architect	BIPV HSE	BIPV Design Engineer	BIPV HSE	BIPV O&M Technician, BIPV module cleaner

FTE per MW: 8

Figure 24: FTEs required in the BIPV sector

Source: Author's analysis, stakeholder discussions and literature review[9]

Under the moderate case, it is estimated that to meet a demand of 5.5 GW of BIPV by 2040, **44 thousand FTE** jobs will be required and for the Optimistic case, **1.35 lakh FTE** jobs to support distinct roles and responsibilities starting from application, project approval, detailed engineering, project execution, commissioning and operations, and maintenance. The table is annexed below.

Table 13: FTE required under moderate and optimistic case

Moderate Case	Optimistic Case
It is estimated that the total capacity that may be installed from 2024-40 in India will be **5.5 GW**.	It is estimated that the total capacity that may be installed from 2024-40 in India will be **17 GW**.
To realise 5.5 GW of capacity, a total of **44 thousand FTE Manpower** will be required from 2024-40.	To realise 17 GW of capacity, a total of **1.35 lakh FTE Manpower** will be required from 2024-40.

9 *India's expanding clean energy workforce- opportunities in solar and wind energy sector (2022), CEEW, NRDC, SCGJ; Greening India's workforce- gearing up for expansion of solar and wind power in India (2017), CEEW, NRDC; Skill gap report for solar, wind and small hydro sector (2016), SCGJ*

CONCLUSION AND WAY FORWARD

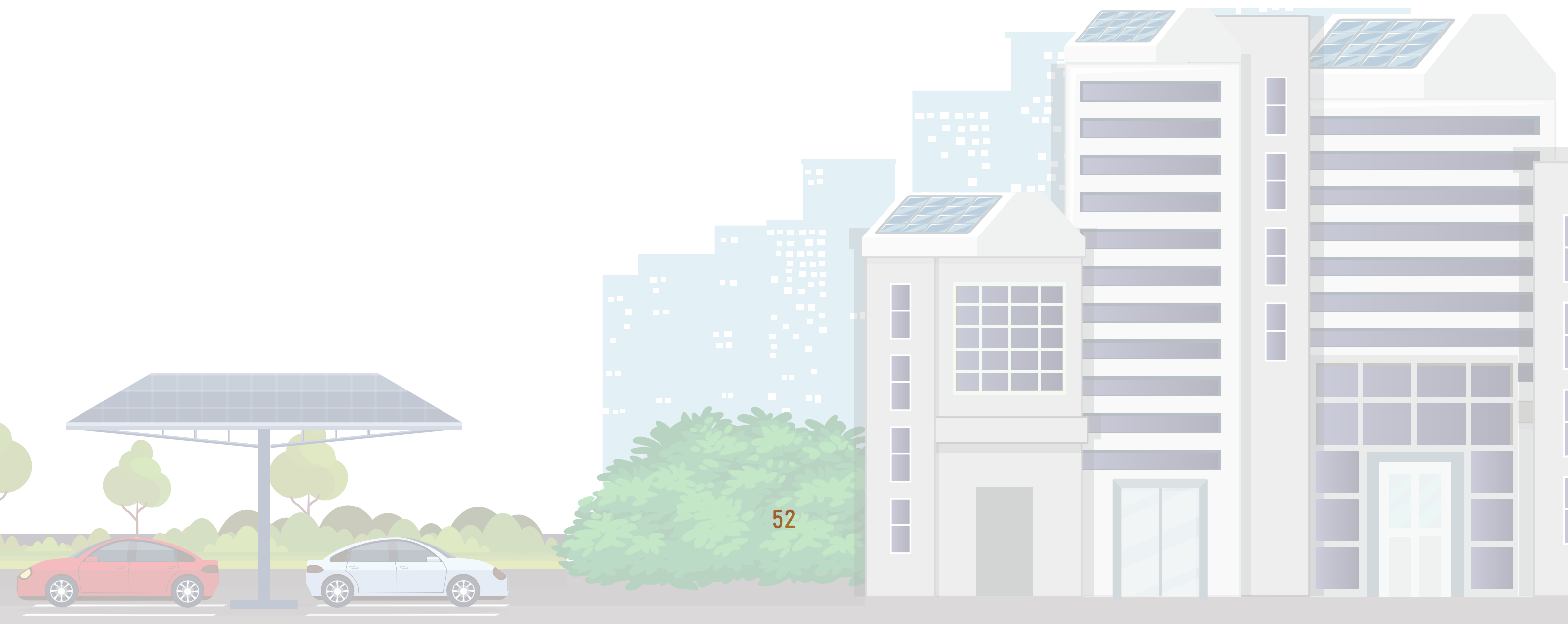
08

In this comprehensive report, a thorough examination has been conducted on the subject of Building-Integrated Photovoltaics (BIPV) and Urban Photovoltaics (UPV) within the context of India. The principal objective of this analysis was to ascertain the potential inherent in these solar technologies and to discern any impediments that may impede their realization. Throughout the course of this report, various facets have been explored, encompassing diverse business models, estimations of the capacities these technologies could potentially achieve, and the requisite financial investments necessary for their implementation. Moreover, attention has been directed towards delineating the challenges and impediments that may hinder the widespread adoption of these technologies, accompanied by thoughtful recommendations for mitigating these issues. Lastly, the report meticulously outlines the requisite skill sets and personnel essential for the successful execution of these solar projects. Through this in-depth exploration, we aim to provide a comprehensive understanding of the viability and challenges associated with integrating Building-Integrated Photovoltaics and Urban Photovoltaics into the Indian context.

This report serves as a valuable resource for various stakeholders involved in the realm of solar energy development in India. For policymakers and government bodies, the insights provided can inform strategic decisions, aiding in the formulation of effective policies and incentives to promote the widespread adoption of BIPV and UPV across the city planning activities. Financial institutions, investors and banks can leverage the information on business models, capacity projections, and financing requirements to make informed investment decisions, thereby contributing to the growth of the solar industry. For architects, the report offers insights into innovative design approaches that seamlessly integrate solar elements, enhancing energy efficiency and aesthetic appeal. It also outlines the skills required for designing structures that incorporate BIPV, enabling architects to stay ahead of industry trends and contribute to sustainable building practices. Builders and construction professionals can leverage the report's findings to understand the practical aspects of implementing BIPV and UPV in construction projects. This includes considerations for capacity projections, cost implications, and logistical challenges.

For educational institutions and training providers, the mapping of skills and manpower requirements serves as a guide for developing relevant programs and courses, ensuring the availability of a skilled workforce to drive the solar energy sector forward.

Our methodology for estimating BIPV and UPV potential, demonstrated using Ahmedabad as an example, relies on two key factors: the annual irradiance at specific tilting angles for BIPV and UPV, and the total area per Local Climate Zone (LCZ) class. This approach ensures adaptability to different locations across India, as long as technical assumptions remain consistent. The LCZ class areas can be derived from existing studies, eliminating the need for complex 3D data. Importantly, all other variables, such as technology efficiency, are location-independent and can be directly applied. This method is not limited to existing urban areas but can also be extended to planned sites by linking new construction areas to corresponding LCZ classes. The



flexibility and scalability of this methodology make it a robust tool for assessing solar potential in diverse Indian locations. Based on this above methodology, the potential for BIPV and UPV across all the states in India is calculated and it comes around 309 GW and 221 GW respectively.

The anticipated surge in BIPV adoption in India, particularly under the moderate and optimistic cases, is poised to catalyze substantial job creation across various sectors. To meet the estimated demand of 5.5 GW of BIPV by 2040 under the moderate scenario, approximately 44 thousand Full-Time Equivalent (FTE) jobs are expected to be generated. In the optimistic scenario, where the demand for BIPV is projected to be even higher, reaching 1.35 lakh FTE jobs. This job spectrum will encompass a range of roles and responsibilities, spanning from initial application processes to project approval, detailed engineering, project execution, commissioning, and ongoing operations and maintenance.

As next steps, to advance the adoption BIPV and UPV in India, a series of actionable steps are recommended. Launching public education programs will involve initiating targeted awareness campaigns to inform the public about BIPV technology and its energy-saving potential. Advocating for enhanced evaluation criteria within green building rating agencies, such as GRIHA and IGBC, is essential, necessitating engagement to develop specific criteria incentivizing BIPV integration. The creation of Standard Operating Procedures (SoP) within the National Building Code is proposed, involving collaboration with industry experts to establish guidelines covering BIPV design, materials, construction, and technical specifications. Capacity-building programs can be implemented through partnerships with educational institutions and industry experts to design and execute training programs for architects, builders, and engineers. Encouraging standardization of BIPV components and installation methods requires collaboration with stakeholders to establish standardized designs and pre-engineered systems. To boost BIPV production, actions involve facilitating collaboration between manufacturers and developers to establish larger production facilities and working with government bodies to create long-term demand. Lastly, making BIPV installations mandatory in new infrastructure development, particularly in commercial high-rise buildings, requires collaboration with government departments to introduce regulations and provide incentives or rebates for system components.

ANNEXURE A: PROJECT FINANCIAL ASSUMPTION

Sl. No.	Assumption Head	Sub-Head 1	Sub-Head 2	Unit	Value
1	Power Generation	Capacity	Installed Power Generation Capacity	MWac	1.0
			Capacity Utilisation Factor (CUF)	%	8.2%
			Useful Life	Years	25.00
2	Project Cost	Capital Cost/MW	Power Plant Cost	INR Lakhs/ MWp	619.26
			Lease	INR/sqm	-
			Area for 1 MW	sqm	-
			Total Lease annum	INR Lakhs	-
			6 mm Glass + errection (double glazed Glass)	INR Sq. feet	300.00
			Lease escalation	%	0%
			Area of BIPV façade	Sq. feet	53,819.50
			Offtaker Equity	%	20.00%
			Power Plant Cost to RESCO	INR Lakhs/ MWp	495.41
			Tariff Period	Years	25.00
3	Financial Assumptions	Debt Equity	Debt	%	70.00%
			Equity	%	30.00%
			Total Debt Amount	INR Lakhs	346.79
			Total Equity Amount	INR Lakhs	148.62
		Debt Component	Loan Amount	INR Lakhs	346.79
			Moratorium Period	Years	-
			Repayment Period (Including Moratorium)	Years	15.00
			Interest Rate	%	9.00%
		Equity Component	Equity Amount	INR Lakhs	148.62
			Nominal RoE	%	14%
			Return on Equity for First 20 Years	% p.a	16.96%
			Return on Equity 21ST Year onwards	% p.a	21.52%
			Weighted Average of ROE	% p.a	20.55%
			Discount Rate (Post Tax WACC)	%	9.55%

4	Financial Assumptions	Fiscal Assumptions	Corporate Tax	%	34.94%
			MAT Rate	%	17.47%
		Depreciation	Book Depreciation Rate for First 15 Years	%	4.67%
			Book Depreciation Rate 16th Year Onwards	%	2.00%
			Depreciation tax purpose SLM	%	5.28%
			Depreciation tax purpose AD	%	40.00%
5	Working Capital	For Fixed Charges	O&M Charges	Months	1.00
			Maintenance Spare (%age of O&M Expenses)	%	15.00%
			Receivables from Debtors	Months	1.50
		For Variable Charges	Interest on Working Capital	%	10.50%
6	Operation & Maintenance	Power Plant	O&M Charges	INR Lakhs	6.19
		O&M Expense Escalation		%	3.84%

LEVELISED COST OF GENERATION – BUILDING INTEGRATED PV

Levelised COG	Unit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
O&M Expenses	INR Lakh		6.19	6.43	6.68	6.93	7.20	7.48	7.76	8.06	8.37	8.69	9.03	9.37	9.73	10.11	10.49	10.90	11.32	11.75	12.20	12.67	13.16	13.66	14.19	14.73	15.30
Depreciation	INR Lakh		23.14	23.14	23.14	23.14	23.14	23.14	23.14	23.14	23.14	23.14	23.14	23.14	23.14	23.14	23.14	9.91	9.91	9.91	9.91	9.91	9.91	9.91	9.91	9.91	9.91
Interest on Term Loan	INR Lakh		30.17	28.09	26.01	23.93	21.85	19.77	17.69	15.61	13.52	11.44	9.36	7.28	5.20	3.12	1.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interest on WC	INR Lakh		1.42	1.42	1.43	1.44	1.44	1.45	1.46	1.46	1.47	1.48	1.49	1.50	1.50	1.51	1.52	1.53	1.54	1.55	1.56	1.58	1.59	1.60	1.61	1.63	1.64
Return on Equity	INR Lakh		25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	31.98	31.98	31.98	31.98	31.98
Lease Payment Requirement	INR Lakh		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total COG	INR Lakh		86.13	84.29	82.46	80.65	78.84	77.04	75.25	73.48	71.71	69.96	68.22	66.50	64.79	63.09	61.41	47.55	47.98	48.42	48.89	49.37	56.64	57.15	57.69	58.25	58.83
Discount Rate	%	9.55%																									
Discount Factor			1.00	0.91	0.83	0.76	0.69	0.63	0.58	0.53	0.48	0.44	0.40	0.37	0.33	0.31	0.28	0.25	0.23	0.21	0.19	0.18	0.16	0.15	0.13	0.12	0.11
Present Value of COG	Rs Lacs		86.13	76.94	68.71	61.34	54.74	48.83	43.54	38.80	34.57	30.79	27.40	24.38	21.68	19.27	17.13	12.11	11.15	10.27	9.47	8.73	9.14	8.42	7.76	7.15	6.59
Per Unit COG		Levellised																									
Per Unit of O&M	INR/kWh		0.72	0.68	0.64	0.61	0.58	0.55	0.52	0.49	0.47	0.44	0.42	0.40	0.38	0.36	0.34	0.32	0.30	0.29	0.27	0.26	0.25	0.23	0.22	0.21	0.20
Per Unit value of Depreciated Amount	INR/kWh		2.67	2.44	2.23	2.03	1.86	1.69	1.55	1.41	1.29	1.18	1.07	0.98	0.90	0.82	0.75	0.29	0.27	0.24	0.22	0.20	0.18	0.17	0.15	0.14	0.13
Per Unit Interest of Term Loan Interest	INR/kWh		3.49	2.96	2.51	2.10	1.75	1.45	1.18	0.95	0.75	0.58	0.43	0.31	0.20	0.11	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Per Unit value of WC Interest	INR/kWh		0.16	0.15	0.14	0.13	0.12	0.11	0.10	0.09	0.08	0.08	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02
Per Unit Value of ROE	INR/kWh		2.91	2.66	2.43	2.22	2.02	1.85	1.69	1.54	1.40	1.28	1.17	1.07	0.98	0.89	0.81	0.74	0.68	0.62	0.56	0.52	0.60	0.54	0.50	0.45	0.41
Per Unit Lease Required	INR/kWh		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Per Unit Value of Cost of Generation	INR/kWh		9.96	8.89	7.94	7.09	6.33	5.64	5.03	4.49	4.00	3.56	3.17	2.82	2.51	2.23	1.98	1.40	1.29	1.19	1.09	1.01	1.06	0.97	0.90	0.83	0.76
Levellized Tariff	INR/kWh	8.36																									

ANNEXURE B: LIST OF STAKEHOLDERS CONSULTED

Organisation	Name of Person
Ornate Solar	Mr. Aditya Goel
TERI	Mr. Shirish Garud
EnergyX	Mr. Tejasvi Verma
PhD Scholar NTU	Mr. Kiran Kumar
IIEC	Mr. Anant Joshi

NOTES

german cooperation
DEUTSCHE ZUSAMMENARBEIT

Implemented by

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
46 Paschimi Marg, Vasant Vihar, New Delhi 110057
E: Henrik.personn@giz.de | **W**: www.giz.de | **T**: + 91 11 4949 5353