Grid Parity of Solar PV Rooftop Systems for the Commercial and Industrial Sectors

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DEUTSCHE ZUSAMMENARBEIT

The Energy and Resources Institute

KfW Development Bank

ISBN 9788179935880

Suggested format for citation

RETA, 2016.
Grid Parity of Solar PV Rooftop Systems for the Commercial and Industrial Sectors:
New Delhi: The Energy and Resources Institute. 172 pp.

For information

T E R I
Darbari Seth Block
IHC Complex, Lodhi Road
New Delhi – 110 003
India

Tel. 2468 2100 or 2468 2111
E-mail pmc@teri.res.in
Fax 2468 2144 or 2468 2145
Web www.teriin.org
India +91 • Delhi (0)11

Team

Reviewers

Franz Haller, Principal Project Manager, KfW Development Bank
Maike Lerch, Principal Project Manager, KfW Development Bank
Shirish Garud, Senior Fellow and Director, TERI
Thomas Prien, Senior Project Manager, KfW Development Bank
Daniel Etschmann, Senior Technical Expert, KfW Development Bank
Arjun Guha, Energy Sector Specialist, KfW Development Bank
Christoph Peters, Vice President, KfW IPEX Bank
Jens Deidersen, Vice President, KfW IPEX Bank

Lead Author

Ujjwal Bhattacharjee, PhD, Senior Fellow, TERI

Contributing Authors (in alphabetic order)

Adwit Kashyap, Research Associate, TERI
Feli Visco, Research Analyst, Regain Paradise
Giselle Nunes-Cordes, Senior Project Manager, Suntrace GmbH
Joerg Behrschmidt, Technical Expert, 8.2 Ingenieurpartnerschaft Obst & Ziehmann
Jonathan Donald Syiemlieh, Associate Fellow, TERI
Kaushal Chhatbar, Project Manager, Suntrace GmbH
Kushargra Nandan, Co-Founder, SunSource Energy (P) Limited
Mini Govindan, PhD, Fellow, TERI
Parangat Shukla, Consultant, TERI
Puneet Mathur, Assistant Manager, SunSource Energy (P) Limited
Sanjoy Sanyal, Founder, Regain Paradise
Sugandha Chauhan, Research Associate, TERI
Thomas Layzell, Consultant, TERI
Veena Aggarwal, Fellow, TERI

Executive Support

K. Subrahmanyam, Senior Secretary, TERI
Rita Grover, Executive Assistant, TERI
Pooja Gulati, Secretary, TERI

TERI Press

Spandana Chatterjee, Assistant Editor
Rajiv Sharma, Graphic Designer
R K Joshi, Graphic Designer,
Shilpa Mohan, Proofreader

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Abbreviations

A & N	Andaman and Nicobar
AC	Alternating Current
ACoS	Average Cost of Supply
AMC	Annual Maintenance Contract
ANBC	Adjusted Net Bank Credit
APPC	Average Power Purchase Cost
ARR	Aggregate Revenue Requirement
AT&C	Aggregate Technical and Commercial
BESCOM	Bangalore Electricity Supply Company
BIS	Bureau of Indian Standards
BoB	Bank of Baroda
BOP	Balance of Plant
BSES	Bombay Suburban Electric Supply
CAGR	Compounded Annual Growth Rate
CAPEX	Capital Expenditure
CdTe	Cadmium Telluride
CEA	Central Electricity Authority
CFA	Central Financial Assistance
CGTMSE	Credit Guarantee Fund Trust for Micro and Small Enterprises
CIGS	Copper Indium Gallium Selenide
CIS	Copper Indium Diselenide
CPWD	Central Public Works Department
CREST	Chandigarh Renewal Energy and Science and Technology
CUF	Capacity Utilization Factor
DBE	Design Basis Earthquake
DC	Direct Current
DERC	Delhi Electricity Regulatory Commission
DG	Diesel Generator
DIN	Deutsches Institut für Normung (German Institute for Standardization)
DISCOM	Distribution Company
DSIR	Department of Scientific and Industrial Research
DSP	Digital Signal Processor
DT	Distribution Transformer
DTR	Data Terminal Ready
EEG	Erneuerbare Energien Gesetz (The Renewable Energy Sources Act)
EHT	Extra High Tension
EIA	Environmental Impact Assessment
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EPC	Engineering, Procurement, and Construction
EU	European Union
EVA	Ethylene Vinyl Acetate
FF	Fill Factor
FiT	Feed in Tariff
GBI	Generation Based Incentive
GERC	Gujarat Electricity Regulatory Commission
GERMI	Gujarat Energy Research and Management Institute
GI	Galvanized Iron

GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Corporation for International Cooperation)
GLP	General Lighting Purpose
GSES	Global Sustainable Energy Solutions
GSP	Grid-connected Solar Photovaoltaic
GSPC	Gujarat State Petroleum Corporation
GW	Gigawatt
GWp	Gigawatt peak
HAREDA	Haryana Renewable Energy Department
HP	Horse Power
HT	High Tension
HVAC	Heating, Ventilation, and Air Conditioning
ICICI	Industrial Credit and Investment Corporation of India
IDBI	Industrial Development Bank of India
IDFC	Infrastructure Development Finance Company
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFCI	Industrial Finance Corporation of India
IGBT	Insulated Gate Bipolar Transistor
IIFC	India Infrastructure Finance Company
IIT	Indian Institute of Technology
Imp	Maximum Current
IP	Ingress Protection
IPP	Independent Power Producer
IREDA	Indian Renewable Energy Development Agency
IRR	Internal Rate of Return
IS	Indian Standard
ISC	Short Circuit Current
ISO	International Organization for Standardization
ITI	Industrial Training Institutes
JERC	Joint Electricity Regulatory Commission
JNNSM	Jawaharlal Nehru National Solar Mission
KERC	Karnataka Electricity Regulatory Commission
kV	kilovolt (103 Volt)
kVA	kilovolt Ampere
kW	kilowatt (103 Watt)
kWp	kilowatt peak
kWh	kilowatt hour
L&T	Larsen & Toubro
LOC	Line of Credit
LCOE	Levelized Cost of Energy
LIP	Large Industrial Power
LT	Low Tension
LTMD	Low Tension Maximum Demand
LTP	Low Tension Power
LV	Low Voltage
MCE	Maximum Considered Earthquake
MGA	Multi Government Agency
MLHT	Mixed Load High Tension
MNRE	Ministry of New and Renewable Energy
MoEF	Ministry of Environment and Forests
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MP	Madhya Pradesh
MPPT	Maximum Power Point Tracker
MS	Mild Steel
MSME	Micro, Small and Medium Enterprises
MU	Million Unit

MV	Medium Voltage
MW	Megawatt
MWp	Megawatt peak
NASA	National Aeronautics and Space Administration
NBFCs	Non-Banking Finance Companies
NCEF	National Clean Energy Fund
NCPRE	National Centre for Photovoltaic Research and Education
NCR	National Capital Region
NDHT	Non-Domestic High Tension
NDLT	Non-Domestic Low Tension
NEMA	National Electrical Manufacturers Association
NISE	National Institute of Solar Energy
NPA	Non-Performing Assets
NPV	Net Present Value
NRSE	New and Renewable Sources of Energy
NTPC	National Thermal Power Corporation
NVVN	NTPC Vidyut Vyapar Nigam Ltd.
O&M	Operation and Maintenance
OBC	Oriental Bank of Commerce
OERC	Orissa Electricity Regulatory Commission
OPEX	Operational Expenditure
PACE–D	Partnership to Accelerate Clean Energy–Deployment
PCU	Power Conditioning Unit
PEDA	Punjab Energy Development Agency
PF	Power Factor
PNB	Punjab National Bank
PPA	Power Purchase Agreement
PPAC	Power Purchase cost Adjustment Charges
PR	Performance Ratio
PRDC	Power Research and Development Consultants
PSL	Priority Sector Lending
PSPCL	Punjab State Power Corporation Ltd.
PSU	Public Sector Undertaking
PV	Photovoltaic
PVC	Poly Vinyl Chloride
R&R	Rehabilitation and Resettlement
RBI	Reserve Bank of India
RCC	Reinforced Cement Concrete
RE	Renewable Energy
REC	Renewable Energy Certificate
RECI	Renewable Energy Corporation of India
RERC	Rajasthan Electricity Regulatory Commission
RESCO	Renewable Energy Service Company
RFID	Radio-Frequency Identification
RGP	Residential General Purpose
RIA	Revenue Impact Analysis
RPO	Renewable Purchase Obligation
SBH	State Bank of Hyderabad
SBI	State Bank of India
SBM	State Bank of Mysore
SCADA	Supervisory Control and Data Acquisition
SECI	Solar Energy Corporation of India
SERC	State Electricity Regulatory Commission
SETNET	Solar Energy Training Network
SIA	Social Impact Assessment
SIDBI	Small Industries Development Bank of India
SIP	Small Industrial Power

SIRO	Scientific and Industrial Research Organization
SLD	Service Line cum Development
SMEs	Small and Medium Enterprises
SNA	State Nodal Agency
SPG	Solar Power Generator
SPV	Solar Photovoltaic
SRRA	Solar Radiation Resource Assessment
SRTPV	Solar Rooftop Photovoltaic
T&D	Transmission and Distribution
TDD	Total Demand Distortion
TERI	The Energy Resources Institute
THD	Total Harmonic Distortion
ToD	Time of Day
TPDDL	TATA Power Delhi Distribution Limited
UL	Underwriters Laboratories
UMPP	Ultra Mega Power Projects
UP	Uttar Pradesh
USAID	United States Agency for International Development
UT	Union Territory
UV	Ultraviolet
VAR	Volt Ampere Reactive
VDE	Verband der Elektrotechnik (the Association for Electrical, Electronic & Information Technologies)
Vmp	Maximum Power Point Voltage
VOC	Open Circuit Voltage
WEEE	Waste Electrical and Electronic Equipment
XLPE	Cross Linked Polyethylene
XLPO	Cross Linked Polyolefin

Acknowledgements

We would like to thank the KfW Development Bank for commissioning the "Study on Small-Scale PV Systems for On-Site Electricity Consumption" under contract number 100533. We acknowledge the support of the German Federal Ministry for Economic Cooperation and Development (BMZ). We thank SunSource Energy (P) Limited and Suntrace GmbH for their contributions in carrying out the study. We are grateful to the Director General, TERI, and the Director, EETD Division, TERI, for encouragement, help, and support provided during the course of the study. Finally, we would like to thank an anonymous group of 71 solar PV project developers who voluntarily participated in the rooftop solar market assessment study.

Executive Summary

The Government of India has set an ambitious target of 40 GW rooftop solar power capacity to be implemented by 2022. Grid-connected rooftop solar has played a significant role in countries with large and active solar power markets, notably Germany, Japan, and the USA. In India, grid-connected rooftop solar industry is still in its infancy, at around 400 MW capacity. Upscaling to 40 GW represents a significant challenge.

This study provides a comprehensive assessment of the infrastructure required to reach the rooftop solar target and the level of industry readiness, with a focus on applicability of rooftop solar in the industrial and commercial sectors in India. This study makes an assessment of the policy and regulatory regimes emerging to support implementation of rooftop solar in India, the design of solar photovoltaic systems aimed at self-consumption at the facility level, the ability of the financial institutions to increase lending in the rooftop PV sector, the current state of the rooftop solar market, the expected growth in short and medium terms, and the supply infrastructure needed to boost the rooftop solar segment, including through provision of a skilled workforce. The key findings of this study are summarized below.

Grid Integration and Regulatory Playing Field: The regulations and policies surrounding rooftop solar photovoltaic PV (SPV) for 16 states have been assessed on factors including the cap on rooftop system size, limits to system sizes with respect to consumer connected load, the cap on solar energy generation and grid penetration levels, treatment of excess energy and compliance with the Central Electricity Authority (CEA) on voltage regulations and inter-connection voltage standards.

- Most regulations limit rooftop SPV system sizes to between 1 kW and 1 MW. The policies and regulations encourage self-consumption of solar power at the end use. Regulations limit the system size to 80–100 per cent of the facility connected load;
- Most regulations allow an addition of solar power in the grid of up to 15–30 per cent of the rated capacity of distribution transformer;
- There is a lower incentive for excess generation from SPV systems above the building load since most regulations offer lower financial benefits to supply solar power to the grid compared to what is achieved from self-consumption;
- The settlement period for any excess generation of solar energy is one year in most states.

Review of Electricity Tariffs: For both industrial and commercial categories, we reviewed the tariff orders for the past 10 years in 10 states for medium and high voltage tariff categories:

- Delhi, West Bengal, and Maharashtra offer high tariffs, both in industrial and commercial sectors, which could potentially be beneficial for rooftop solar power deployment.
- Gujarat and Chhattisgarh have registered the lowest commercial and industrial tariffs amongst these ten states, which could potentially make these states less attractive destinations for rooftop solar power.

Operating Layouts: The operating layouts analyse the optimal conditions for maximizing output from a rooftop solar power plant.

- In India, a PV module tilt of 15 degrees allows for optimum usage of the rooftop area.
- For locations lying below 15°N latitude, an east–west-orientated PV system can be used as an alternative to south-oriented PV system.

Load Profiling: Matching PV output with the load profile of the building is important for optimal sizing of rooftop SPV systems.

- The optimal size of a rooftop PV system for self-consumption is up to 80 per cent of the building-connected load.
- There may be additional cost requirements associated with PV system sizes of more than 150 per cent of the connected load, due to required strengthening of the grid interconnection.

PV Cost and Design: A market survey was administered amongst 71 project developers to assess the emerging cost of rooftop SPV systems for current and future applications. The design criteria for solar systems have also been analysed.

- There is a 35 per cent cost differential between small and large rooftop SPV systems;
- The cost of SPV panels has fallen dramatically in recent years. Further reductions of around 15 per cent are expected in 2 years, rising to around 26 per cent in 5 years;
- PV systems synchronized with a diesel generator should be protected from solar power back-feeding to the generator;
- SPV system design should place emphasis on site selection, including assessment of the roof and the structural integrity of the buildings;
- Mounting systems must be designed to take wind loading into consideration;

Overview of Market Potential: A market survey was conducted among 250 project developers, of which 71 responded.

- The solar market is poised for significant growth in the next five years. From the sample of 71 participating project developers in the survey, their target for rooftop PV is around 800 MW in 2017 and 3,000 MW in 2020;
- The industrial and commercial sectors are expected to emerge as prime destinations for expansion of the rooftop SPV market;
- The preferred incentive mechanisms to promote the rooftop solar market include low interest loans, accelerated depreciation, and exemption on import/excise duty on PV system components;
- There is a shortage of skilled workers in the solar industry, particularly for the design of SPV systems.

Cost of Energy and Grid Parity: The financial viability of SPV system deployment for the commercial and industrial sectors is assessed in 10 states across India. PV cost to grid parity estimates have been developed for small (25 kW), medium (150 kW), and large sized (1,000 kW) rooftop SPV projects. Results are evaluated with the use of the Levelized Cost of Energy (LCOE), Net Present Value (NPV), Internal Rate of Return (IRR), and Payback metrics.

- The LCOE for all PV system sizes remains higher than the grid tariff in most states in 2015, diverging from the findings of the NPV and IRR metrics that point to profitability for most states with the exception of Chhattisgarh and Gujarat. The LCOE metric may not therefore accurately indicate whether a PV project represents an attractive investment;
- Despite the rising cost of diesel over time, the significant additional capital costs associated with the PV + battery configuration make PV + diesel systems a significantly more cost-effective option during power outages;
- Whilst the IRR may indicate a potentially attractive investment, a potential project should be evaluated against both IRR and NPV metrics to gain a full understanding of project viability;
- The use of a capital subsidy may be effective at bringing forward PV projects within an earlier time scale, with the PV + battery system particularly benefiting due to its higher capital costs.

Supply Infrastructure: Availability of a skilled workforce and adequate codes and standards are essential to ensure quality of solar installations.

- Several institutions offer training courses on rooftop solar for different skill levels. According to the market assessment, more than 2,000 individuals have already received training on SPV systems;
- The technical standards and codes developed by CEA provide detailed requirements for interconnection of rooftop solar systems with the grid and are compatible with international practices;
- The solar policies and regulations should lay down guidelines for consideration of earthquake resistance for building and structures, wind loading, and fire safety norms.

Environmental and Social Impacts: The environmental and social impacts have been mapped using the guidelines issued by the Indian government, as well as the project appraisal metrics of KfW Development Bank's 'Sustainability Guideline'.

- Environmental and social impacts associated with implementation of rooftop solar projects are either negligible or non-existent;
- Recycling of PV modules afterlife will help recover 90 per cent of the module material.

1 Chapter

Introduction: Grid Parity of Solar PV Rooftop Systems for the Commerical and Industrial Sectors

The target set by the Government of India for 40 GW of rooftop solar power capacity is expected to play a major role in India's ambitious plan to boost the country's solar power capacity to 100 GW by 2022. This target is well-supported by a combination of good solar resource, existing and expanding building infrastructure, rising grid electricity tariffs, and falling costs of grid-connected rooftop solar power. Grid-connected rooftop solar power has already played a significant role in countries with large and active solar power markets, such as Germany, USA, and Japan(Figure 1.1).

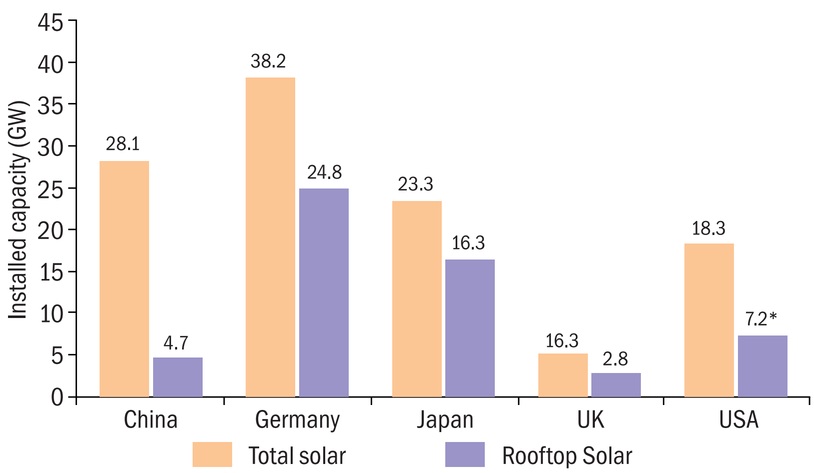


Figure 1.1: Contribution of rooftop solar to overall solar power capacity in different countries

1.1 Market Potential

There is significant potential for large-scale grid-connected rooftop solar photovoltaic (SPV) capacity in India. According to a study conducted by TERI in 2014, the market potential of rooftop solar power in India is estimated at 124 GW (Figure 1.2). The analysis incorporates factors, such as roof space availability across different consumer segments, the paying capacity of roof owners, as well as supply and demand aspects in the existing market. Three categories of solar potential have been identified:

- **Technical Potential**: The fraction of resource potential that can be used under the existing technical, structural, ecological, legal, and regulatory restrictions;
- **Economic Potential**: The fraction of technical potential that can be economically realized, for which paying capacity of roof owners and consumers is considered;
- **Market Potential**: The final rooftop SPV potential after taking into account the market dynamics such as supply, demand, and consumer acceptability.

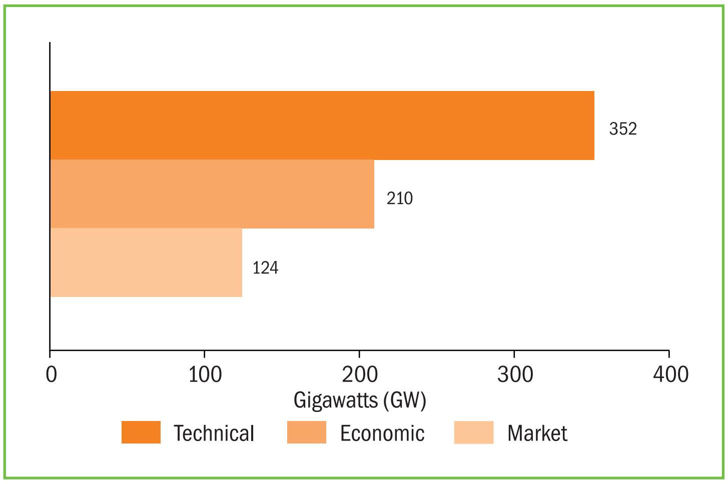


Figure 1.2: Rooftop solar PV market potential in India (GWp)

In 2014, a further assessment on potential SPV capacity in India was undertaken by the National Institute of Solar Energy (NISE). This study estimated a rooftop SPV potential of 42.8 GW and considered certain system sizes on roofs of various public and private building categories, with different levels of penetration of rooftop solar power for each category of building infrastructure, as shown in Table 1.1.

NISE study also estimated the rooftop solar power potential on a state-wise basis, as shown in Figure 1.3. In 2014, Bridge to India estimated that India has a realizable potential of 26–35 GW for small scale (residential) rooftop solar power installations, along with potential for a further 31–41 GW of capacity in the commercial and industrial sectors by 2024.

In 2015, TERI conducted a preliminary estimation of the rooftop solar power potential for 22 of the 53 ministries of the Government of India. The potential for rooftop SPV was estimated at 7.2 GW (Figure 1.4).

Table1.1: Assumptions in rooftop solar potential assessment conducted by NISE

Category of building	Penetration of rooftop SPV	System size assumed for category of building (kW)
Factory, Workshop	20%	50
Hospital, Dispensary	2%	100
Hotel, Lodge, Guest house	20%	10
Place of Worship	2%	50
School, College	10%	50
Shop, Office	25%	1
Other Non-Residential		
(Power Plant, Cinema Hall)	10%	10
Residential	20%	1

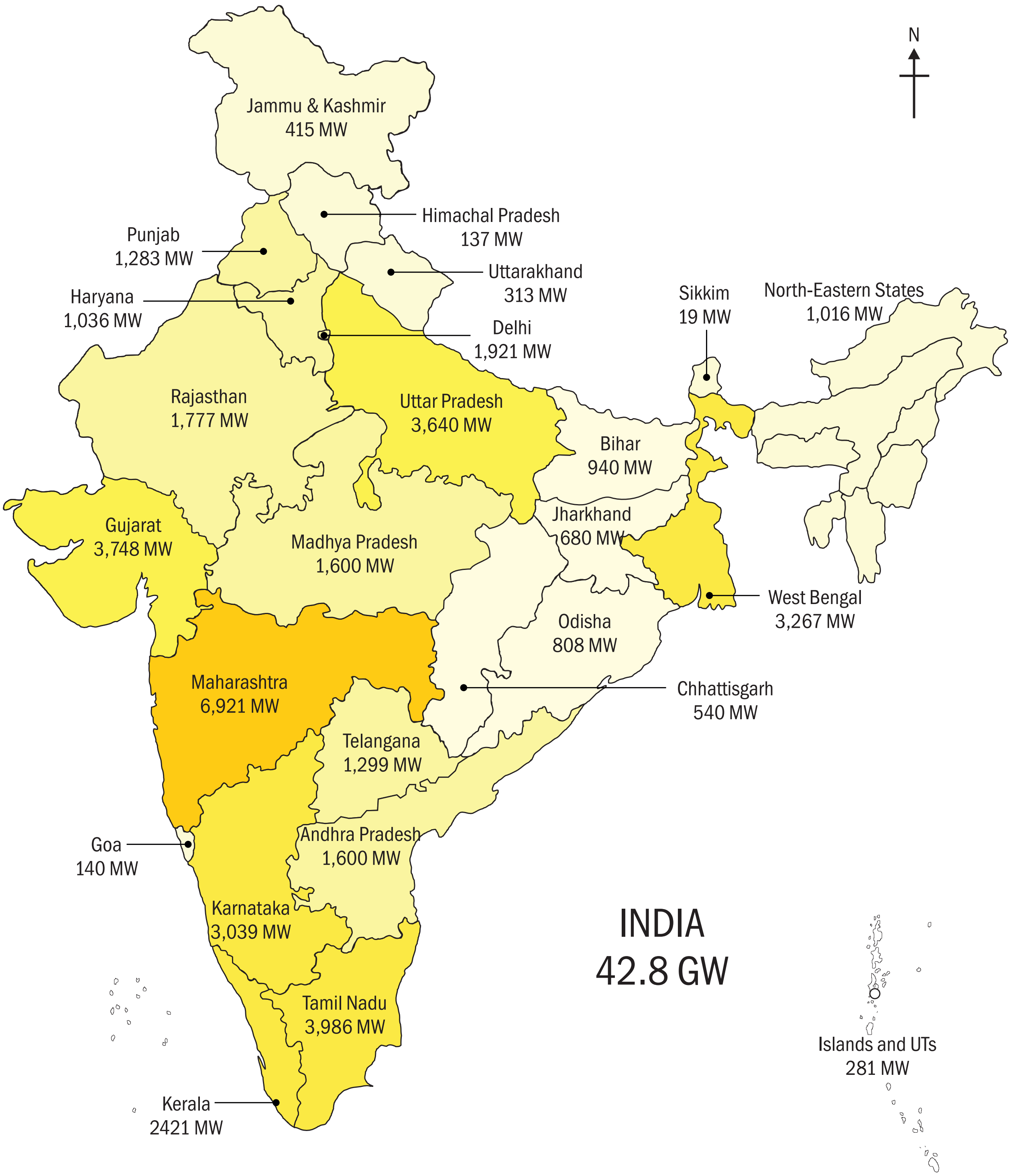


Figure 1.3: State-wise potential of rooftop solar PV in India

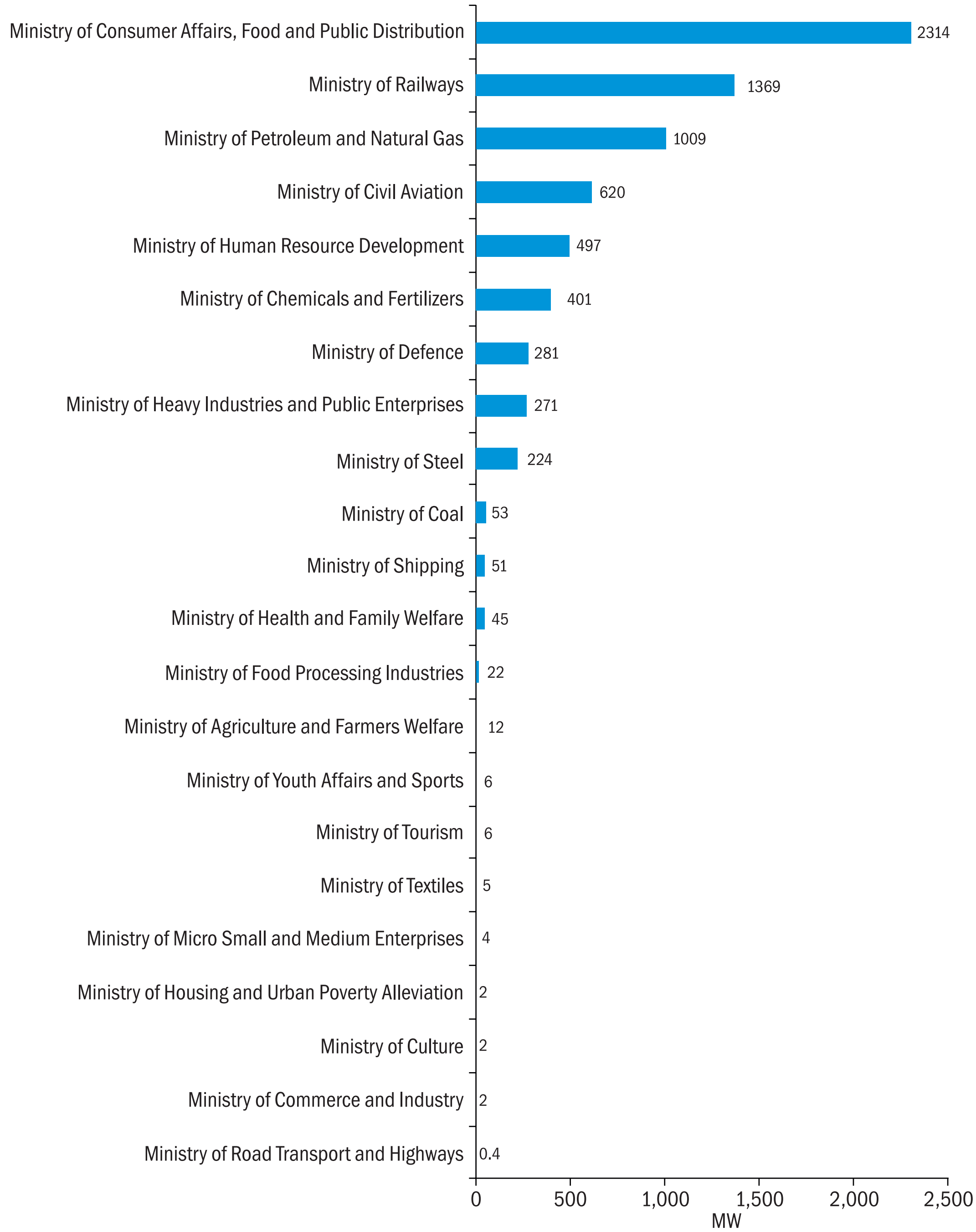


Figure 1.4: Rooftop solar PV potential for the ministry buildings of the Government of India's (in MW)

1.2 Institutional Structure

In addition to the existing institutional structure in the country's solar power sector, in 2011 the Ministry of New and Renewable Energy (MNRE), Government of India, constituted the Solar Energy Corporation of India (SECI) to act as an implementing agency for various government policy initiatives. SECI plays an integral role in bridging the supply–demand gap in the market through diverse facilitation and support services. The major stakeholders facilitating the uptake of rooftop SPV market are shown in Figure 1.5.

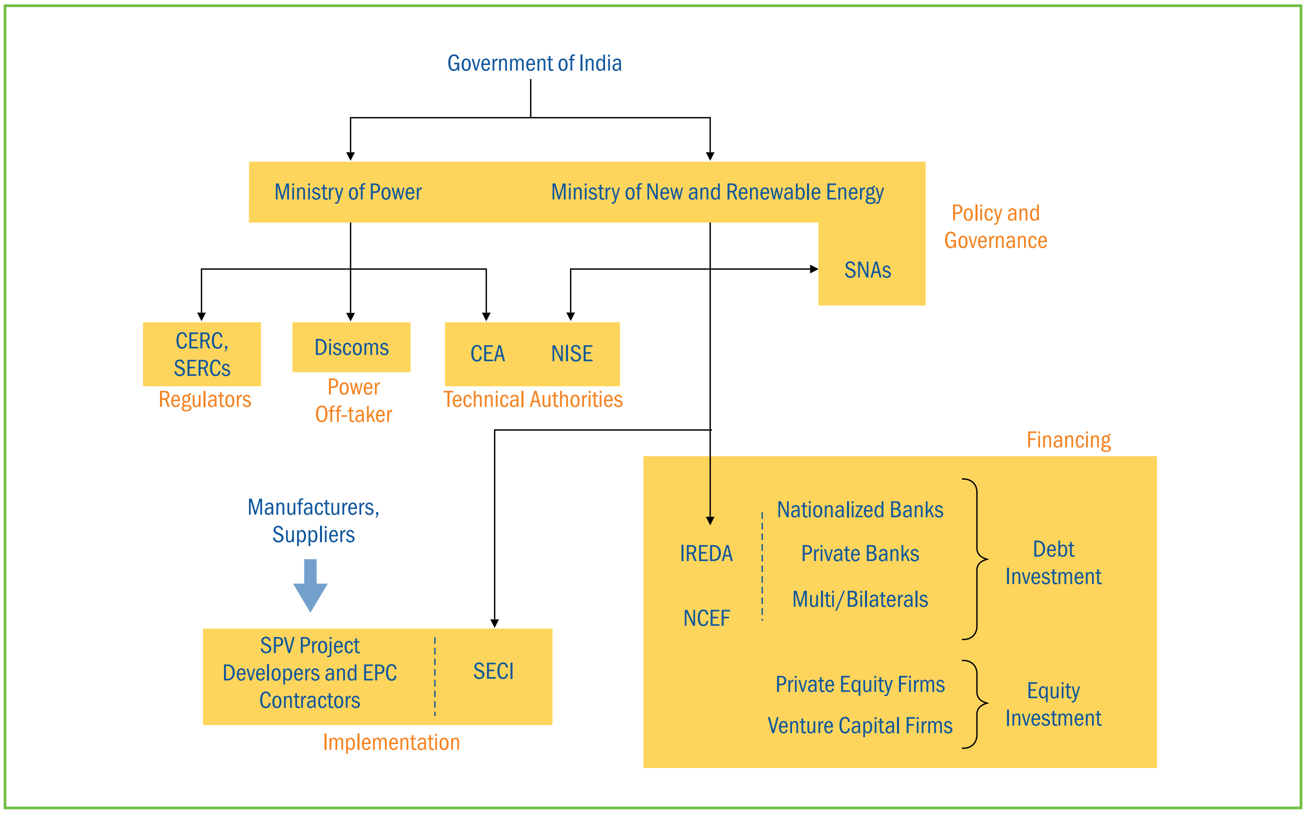


Figure 1.5: Institutional structure and stakeholders promoting rooftop SPV in India

In June 2015, the Union Cabinet approved a proposal for SECI to apply to the Registrar of Companies for renaming it as the Renewable Energy Corporation of India as well as converting it into a Section 3 company under the Companies Act 1956.[1] This would allow SECI to own solar power plants, including rooftop solar power plants, and engage in generating and selling solar power.

The National Institute of Solar Energy (NISE) plays an important role in the development of the grid-connected rooftop solar power market by setting technical quality standards and benchmarks, providing and facilitating capacity building, and carrying out quality testing of PV system components.

1.3 Policy and Regulatory Environment

In addition to the Central Government's policy initiatives, 27 states and union territories in the country have notified policies and/or regulations for the promotion of small-scale rooftop SPV power. MNRE has also developed an overall roadmap of year-wise capacity addition in grid-connected rooftop SPV power on a state-wise basis (Table 1.2).

1.4 Rooftop SPV Programmes of MNRE

SECI, as the implementing agency of MNRE, has so far progressed to Phase IV in capacity allocations for grid-connected rooftop SPV projects. The details of the phases till now are in Table 1.3. So far, approximately 62 MW of capacity has been commissioned across the country under SECI schemes. There are a number of additional SECI schemes in the pipeline:

[1] http://pib.nic.in/newsite/PrintRelease.aspx?relid=122756

Table 1.2: MNRE allocated annual targets (in MW) for rooftop solar for states

Sl. No.	State	2015–16	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22	Total
1.	Andhra Pradesh	10	240	250	300	350	400	450	2,000
2.	Arunachal Pradesh	2	5	5	8	10	10	10	50
3.	Assam	4	30	30	38	42	50	56	250
4.	Bihar	5	120	125	150	175	200	225	1,000
5.	Chhattisgarh	4	84	88	104	120	140	160	700
6.	Goa	1	20	20	22	23	30	34	150
7.	Gujarat	15	385	400	480	560	640	720	3,200
8.	Haryana	5	200	200	235	280	320	360	1,600
9.	Himachal Pradesh	2	38	40	48	56	64	72	320
10.	Jammu & Kashmir	2	54	55	74	80	90	95	450
11.	Jharkhand	4	96	100	120	140	160	180	800
12.	Karnataka	10	275	290	344	403	460	518	2,300
13.	Kerala	4	96	100	120	140	160	180	800
14.	Madhya Pradesh	10	265	275	330	385	440	495	2,200
15.	Maharashtra	20	565	588	704	823	940	1060	4,700
16.	Manipur	4	3	6	8	9	10	10	50
17.	Meghalaya	1	6	6	8	9	10	10	50
18.	Mizoram	1	6	6	8	9	10	10	50
19.	Nagaland	1	6	6	8	9	10	10	50
20.	Odisha	5	120	125	150	175	200	225	1,000
21.	Punjab	10	240	250	300	350	400	450	2,000
22.	Rajasthan	10	275	288	344	403	460	520	2,300
23.	Sikkim	1	6	6	8	9	10	10	50
24.	Tamil Nadu	15	420	438	524	613	700	790	3,500
25.	Telangana	10	240	250	300	350	400	450	2,000
26.	Tripura	1	6	6	8	9	10	10	50
27.	Uttar Pradesh	20	510	538	650	752	860	970	4,300
28.	Uttarakhand	2	42	44	52	60	70	80	350
29.	West Bengal	10	252	263	315	370	420	470	2,100
30.	A & N islands	1	2	2	2	5	4	4	20
31.	Chandigarh	1	12	12	14	18	20	23	100
32.	Delhi	5	132	138	165	190	220	250	1,100
33.	Puducherry	1	12	12	14	18	20	23	100
34.	Lakshadweep	1	1	1	1	2	2	2	10
35.	Daman & Diu	1	12	12	14	18	20	23	100
36.	D & N Haveli	1	24	25	30	35	40	45	200
	TOTAL (MW)	200	4,800	5,000	6,000	7,000	8,000	9,000	40,000

Source: MNRE, GoI notice, D.O.No. 03/13/2015-16/GCRT, dated June 30, 2015.

Table 1.3: Capacity allocation under different phases

Phase no.	Total Capacity (MW)	Capacity Allocated (MW)
Phase I	5.5	5.5
Phase II	11.3	11.3
Phase III	10	10
Phase IV	50	32.5

- 24 MW grid-connected rooftop SPV
  - CFA from MNRE as 15 per cent capital subsidy
  - For residential consumer segment (project size $<$ 10 kW)

- 73 MW grid-connected rooftop SPV for warehouses
  - For warehouses owned by both public and private entities
  - Capital subsidy from MNRE under consideration

- 50 MW grid-connected rooftop SPV for Central Public Works Department (CPWD)
  - For buildings owned by CPWD
  - RESCO model preferred
  - Long-term power purchase by CPWD

- 3 MW grid-connected rooftop SPV for Andaman and Nicobar Islands
  - For government buildings
  - RESCO model preferred

- 500 MW grid-connected rooftop SPV for commercial and industrial consumers
  - No capital subsidy from MNRE

1.5 Upcoming Plans

As of December 31, 2015, 866.06 MW of rooftop solar capacity was either approved and/or sanctioned,[2] Rooftop solar projects are also being implemented by state nodal agencies, PSUs, and other multi-government agencies, and project developers.

Major infrastructure projects for metro rail, railways, airports, shipping, sports stadiums, oil companies, and factories are also coming forward for installation of grid-connected rooftop solar plants.

Work is under way on developing schemes for projects of more than 1,000 MW of SPV capacity. These include: Ministry of Railways (450 MW), Delhi Jal Board (16 MW), Kochi Metro Rail (4 MW), Delhi Metro Rail (30 MW), Chandigarh (10 MW) and Tamil Nadu (300 MW). SECI is also currently re-evaluating its SPV capacity addition targets.

[2] http://mnre.gov.in/file-manager/UserFiles/financing-of-Solar-Rooftop.pdf

1.6 Financing

BOX I: IREDA Low-Cost Loan Scheme for Grid-Connected Rooftop SPV Projects

In July 2015, IREDA launched a low-cost loan scheme for grid-connected rooftop solar power projects. The scheme is targeted at commercial, industrial, and institutional consumers

Loan Interest Rate p.a.	9.90–10.75%
Loan Tenor	9 years (+ 12 months moratorium)
Minimum eligible aggregated project size	1 MW
(including aggregated roofs)	(Minimum size of sub-project = 20 kW)
Loan amount	70–75% of project cost

(http://www.ireda.gov.in/writereaddata/solar-pv.pdf)

It is estimated that around USD40–50 billion worth of investment will be required to meet the stated target of 40 GW in additional rooftop solar capacity. However, financing of grid-connected rooftop solar power has encountered several barriers due to various perceived investment risks. Issues such as performance uncertainty, revenue uncertainty, theft and vandalism, limited experience of project developers, and the credit profile of borrowers are all concerns for potential investors. As MNRE has made efforts to engage lenders and find solutions to existing issues, initiatives by some public and private sector banks are gradually developing the market.[3] For instance,Indian Renewable Energy Development Agency (IREDA) is facilitating availability of debt finance for the sector through a scheme offering low-interest loans for grid-connected rooftop SPV projects. Box I provides features of the recent low-cost loan scheme launched by IREDA.

MNRE has allocated a budget of Rs 5,000 crore for the promotion and development of the grid-connected rooftop SPV sector in the country over the next five years. In addition, MNRE issued a communication in late 2014 to all banks to encourage low-cost lending for grid-connected rooftop SPV projects under standard home loan and home improvement loan products. Twelve national and state banks have since committed to include grid-connected rooftop SPV systems under home loans and home improvement loans.[4]

In April 2015, the Reserve Bank of India provided an impetus to lending for grid-connected rooftop SPV projects by including the solar power sector in the Priority Sector Lending classification.[5] This move potentially offers the rooftop solar power sector with access to up to 14.5 per cent of the Adjusted Net Bank Credit of the Indian banking sector.

1.7 Study Objectives

This chapter provides a background on the current readiness of institutions to promote the SPV industry, with the goal of achieving 40 GW of rooftop capacity by 2022.

This study will attempt to address the following broad questions.

- Are the existing regulatory and policy frameworks conducive with boosting the small grid-connected rooftopsolar power sector?
- Is grid parity attainable for solar power in the commercial and industrial sectors in different states in India?
- Is the supply infrastructure (including the availability of an adequately skilled workforce and identification oftechnical standards and codes for small PV and system designs) adequate to support the small PV segment?
- What is the market potential or firm demand for grid-connected rooftop SPV?
- Are there any detrimental environmental and social aspects that can potentially affect the uptake of this sector?

[3] TERI market research
[4] http://mnre.gov.in/file-manager/UserFiles/financing-of-Solar-Rooftop.pdf
[5] https://rbi.org.in/Scripts/NotificationUser.aspx?Id=9688&Mode=0

Grid Integration and Regulatory Playing Field

2.1 State Policies and Regulatory Frameworks

In August 2013, the Working Group of the Forum of Regulator's came out with a 'Draft Model Regulation for Rooftop Solar Grid Interactive Systems' based on net metering. This model regulation prescribed suggestions on:

- Cumulative capacity targets for a distribution licensee and at particular distribution transformer level;
- Consumer eligibility and individual project capacity;
- Interconnection with the grid;
- Energy accounting and settlement (including treatment of excess power injected during peak hours and a cap on power generation through rooftop solar for individuals);
- Solar renewable energy (RE) purchase obligation (whether rooftop solar qualifies for obligation of utility);
- Applicability of banking, wheeling, and cross-subsidy for third party owned rooftop systems;
- Eligibility to participate under the Renewable Energy Certificate (REC) mechanism;
- Metering arrangement.

Most state regulators have subsequently issued net metering regulations based on the above model regulations, but with some modifications in the treatment of certain parameters. Based on a comprehensive review of solar policies and net metering regulations of 16 states, the following sections capture the major differences across important parameters from state to state. The differences in certain aspects of regulation explain why some states are progressing on rooftop solar quicker than others. The rooftop solar regulations for 16 states have been assessed for seven key parameters:

- Limits on rooftop solar system size;
- Limits on grid-connected solar capacity;
- Treatment of excess energy generated from solar rooftop;
- Treatment of surplus energy during peak hours;
- Applicability of banking, wheeling, and cross-subsidy for third party owned rooftop systems;
- Renewable Purchase Obligation (RPO);
- Metering regulation compliance and interconnection voltage standards.

Table 2.1 summarizes the parameters that determine a ceiling on rooftop system size and on integration with the grid. Table 2.2 summarizes how excess solar energy is treated (including energy supplied at peak hours) and the price for financial settlement. Table 2.3 summarizes metering specifications as well as the issued inter-connection voltage standards.

2.1.1 Size of Rooftop Solar System

Under the net metering regulation, electricity generation from rooftop solar is promoted primarily for self-consumption. Most state regulators have capped the rooftop SPV system to 80 to 100 per cent of the individual consumers connected load/contracted demand. For instance, the states of Punjab, Rajasthan, Himachal Pradesh, and Uttaranchal have capped the individual rooftop system at 80 per cent of the sanctioned connected load/ contract demand whereas Delhi, Haryana, Maharashtra, and Uttar Pradesh have opted to allow rooftop systems with a capacity up to the connected load/sanctioned demand of individual consumers. Delhi has gone a step further in promoting rooftop solar by suggesting that if individual consumers prefer a higher connected load, they can pay the service line development charge to augment their system and support a higher load. Most state regulators have also specified a minimum capacity of 1 kW and maximum capacity of 1 MW for individual consumers. West Bengal and Himachal Pradesh have a higher minimum capacity requirement of 5 kW and Chhattisgarh of 50 kW.

2.1.2 Limit on Grid Interactive Solar Capacity

In the states of Punjab, Rajasthan, Himachal Pradesh, Odisha, and Tamil Nadu, regulators have specified that the cumulative solar capacity to be fed to a particular distribution transformer shall not exceed 30 per cent of the rated capacity of the distribution transformer, while in Maharashtra and Uttar Pradesh this figure is 15 per cent of the transformer's rated capacity. Haryana makes a distinction that the solar capacity should not exceed 15 per cent of the transformer's peak capacity while Karnataka and Kerala have proposed higher capacities of up to 80 per cent of the total capacity of the distribution transformer. Delhi regulations require utilities to ensure that at least 20 per cent excess capacity is made available to rooftop solar at the local distribution transformer level.

2.1.3 Treatment of Excess Energy Generated from Solar Rooftop Systems

Most state regulations stipulate that the overall generation from rooftop solar should not exceed 90 per cent of a customers' total consumption over a year. However, on a regular or hourly basis, solar electricity can be fed into the grid when the supply from the SPV system is greater than the electricity demand of a facility. This can be averaged out over the billing cycle, with electricity being drawn from the grid when the customers' electricity demand exceeds supply. Net electricity consumption from the grid is calculated at the end of the billing cycle. Most state regulations permit excess electricity generation to be carried forward by a year. A settlement is made at the end of the year for the excess energy that has been fed into the grid. In some states, excess rooftop solar energy fed into the grid is compensated, while in others, it becomes void at the end of the settlement period. There are various arrangements for compensating excess energy. Andhra Pradesh compensates based on the Average Cost of Serve calculation, although most use the average power purchase cost (APPC) (Delhi). A few use the levelized (generic) tariff determined by the Commission (Rajasthan, Karnataka). Rajasthan is willing to buy excess energy at the feed in tariff (FiT) every month if the excess energy in the billing month is more than 50 units. Uttar Pradesh follows a different approach for compensation, where DISCOMS are required to pay Rs 0.5 per unit (one unit is equal to one kWh) of excess power fed into the grid. In the case of Maharashtra, the regulations stipulate that compensation will be paid for up to 10 per cent of the excess energy generated in a year. In Chhattisgarh, regulations stipulate that the annual addition to the grid should not exceed 49 per cent of the annual net generation and for such additions, the distribution licensee will pay 50 per cent of the levelized tariff determined for solar photovoltaic (PV) based Power Projects. If the additional energy is more than 49 per cent, then no payment will be made for such excess energy.

2.1.4 Treatment of Surplus Solar Energy During the Peak Hour

Most state regulators allow off-setting of electricity consumption in a given time period with electricity generation in the same time period (whether peak, off-peak). Accumulated excess generation in any other time period in a billing cycle is then considered as off-peak generation. In Uttar Pradesh, any excess generation in a billing cycle is carried forward to the corresponding time period of the subsequent month for adjustment. In Delhi, there is also a proposal to provide incentives to the consumers who feed energy into the grid during peak hours when the distribution licensee faces more demand.

2.1.5 Applicability of Banking, Wheeling, and Cross-Subsidy for Third Party Owned Rooftop Systems

Several states have exempted any cross subsidy charges, banking charges, and wheeling charges for third party sale. These charges would be accrued if a third party sets up a rooftop SPV system on the consumer's premises and sells power to the grid.

2.1.6 Renewable Purchase Obligation (RPO)

In all states, electricity produced from an SPV system by an eligible consumer who is not defined as an obligated entity, shall qualify towards the fulfilment of the RPO of the distribution licensee.

2.1.7 Metering Regulation Compliance and Interconnection Voltage Standards

All states are required to comply with the CEA Metering Regulations, 2006, and any subsequent regulations prescribed by CEA on metering. On inter-connection, most states require compliance with the state's own Electricity Supply Code specified by the SERC, CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations, 2013, and CEA (Measures relating to Safety and Electric Supply), Regulations, 2010. In addition, some state regulations have specified the voltage levels at which different size PV systems will be integrated with the distribution lines of the utility.

Table 2.1: Cap on rooftop system size and solar energy for grid connection

State	Cap on Rooftop System Size			Cap on Solar Energy for Grid Interaction	
	Net metering regulation (year) /other	Minimum and maximum (kWp)	Percentage of consumer connected load	Percentage of cumulative solar capacity allowed at DT level	Cap on energy generation from PV system (percentage of consumer total annual energy consumption)
Andhra Pradesh	Yes (2015)	1 kWp–1 MWp	Not Specified	50% (2015–16) ; 60% (2016–17)	Not specified
Bihar	Yes (Draft)	1 to 1000	1	15% of the peak capacity	90%
Chandigarh	Yes	50 to 1000		Up to 49% of the solar energy generated	
Chhattisgarh	No (Solar policy)	50 kWp–1 MWp	51%	Not specified	49%
Delhi	Yes (2014)	>1 kWp (no upper limit)	No restriction (>100% on SLD charges)	Utility to ensure 20% rated DT capacity	No
Goa & Union Territories	Yes	1–500		30%	
Gujarat	No (Solar policy and orders)	1 kWp–1 MWp	50%	Not specified	Not specified
Gujarat	Yes	>1	0.5		

State	Cap on Rooftop System Size			Cap on Solar Energy for Grid Interaction	
	Net metering regulation (year) /other	Minimum and maximum (kWp)	Percentage of consumer connected load	Percentage of cumulative solar capacity allowed at DT level	Cap on energy generation from PV system (percentage of consumer total annual energy consumption)
Haryana	Yes (November 2014)	≤1 MWp	100%	30% DTR peak capacity (LT) & 15% DT peak capacity (HT)	90%
Himachal Pradesh	Yes	LT (1 phase): 5 kWp; LT (3 phase): 15 kWp ; HT/EHT: 1 MWp	80% (consumers under two part tariff); 30% (consumers under single part tariff)	30%	No
Karnataka	No	≤1 MWp	Not specified	80%	Not specified
Kerala	Yes (one regulation for gross and net same as of UP)	1 kWp–1 MWp	Not specified	Till cumulative capacity is <80% of the average min load	Not specified
Madhya Pradesh	Draft	0.5 kWp to 250 kWp	Not specified	Not specified	Not specified
Maharashtra	Yes		100%	40%	
Manipur	Yes	1–500		30%	80%
Odisha	Yes	≤1 MWp	100%	30%	No
Punjab	Yes (May 2015)	1 kWp–1 MWp	80%	30% DT capacity	90%
Rajasthan	Yes	1 kWp to 1 MWp	80%	30%	No
Tamil Nadu	No (Solar policy & orders)	Not specified	Only specific category of consumer allowed	30%	90%
Telangana	Yes	>1		50%	
Uttar Pradesh	Yes (one regulation for gross and net metering	≤1 kWp	100%	15% of DT capacity	No
Uttarakhand	Yes	0.3 to 100 kW (with Battery); <500 kW (without Battery)			

State	Cap on Rooftop System Size			Cap on Solar Energy for Grid Interaction	
	Net metering regulation (year) /other	Minimum and maximum (kWp)	Percentage of consumer connected load	Percentage of cumulative solar capacity allowed at DT level	Cap on energy generation from PV system (percentage of consumer total annual energy consumption)
West Bengal	No (RE Regulations, 2013)	> 5 kWp			90%

Table 2.2: Accounting of energy and treatment of excess energy

Energy Accounting and Treatment of Excess Energy				
State	Treatment of excess solar energy	Treatment of solar energy supplied during peak hours	Price for financial settlement	Settlement period
Andhra Pradesh	Carry forward to next month and financial settlement	Not specified	Average cost of supply (ACoS)	Monthly
Bihar	Carry forward, no financial settlement	Settlement of peak at peak, non-peak at non-peak		Yearly
Chattisgarh	No carry forward or financial settlement if more than 49% of annual generation is injected	Not specified	50% of the levelized tariff	1 year
Delhi	Carry forward and financial settlement	Settlement first at peak but extra at off-peak (utility can pay higher charge too)	APPC of utility	1 year
Goa and Union Territories	No carry forward, financial settlement			Twice a year (September 30, March 31)
Gujarat	Carry forward and financial settlement	Peak charges shall be applicable for consumption during peak hours.	APPC	End of billing cycle
Haryana	Carry forward and financial settlement	Settlement first at peak but extra at off-peak	Rs 0.25 per unit for 2015–16	1 year
Himachal Pradesh	Carry forward and financial settlement	Settlement of peak at peak hours and non-peak at non-peak hours	Rs 5 (single part tariff customer) and Rs 4.5 (two part tariff customer)	Financial year (March–April)
Karnataka	Carry forward and financial settlement	Not specified	As determined by SERC	Not specified
Kerala	Carry forward and financial settlement	Settlement first at peak but extra at off-peak	APPC	Financial year
Madhya Pradesh	Carry forward and no financial settlement	Not specified	NA	Not specified
Maharashtra	Carry forward and financial settlement for 10% of units generated in a year	No	APPC of utility	1 year
Manipur	No carry forward, reset to zero.	NA	NA	NA

Energy Accounting and Treatment of Excess Energy				
State	Treatment of Excess Solar Energy	Treatment of Solar Energy Supplied during Peak Hours	Price for Financial Settlement	Settlement Period
Odisha	Carry forward; no financial settlement	As per ToD tariff specified by OERC	NA	Financial year
Punjab	Carry forward and no financial settlement	Settlement first at peak but extra at off-peak	NA	1 year (October–September)
Rajasthan	Carry forward till excess energy reaches 50 units	Settlement first at peak but extra at off-peak	FiT determined by RERC	Financial settlement in each billing cycle
Tamil Nadu	Carry forward; no financial settlement	GBI for Domestic Consumers (Rs 2 for first two years, Rs 1 for next two years, and 0.5 for next two years)	NA	Annual (August–July)
Telangana	Carry forward, financial settlement		APERC	6 months (December, June)
Uttar Pradesh	Carry forward; financial settlement	Settlement first at peak but extra at off-peak	Rs 0.5 per unit or as determined by SERC	Financial year
West Bengal	Carry forward and no financial settlement	Not specified	NA	Not specified

Table 2.3: Metering regulation compliance and interconnection voltage standards

State	Compliance with CEA metering regulations	Interconnection voltage standards
Delhi	Yes	Not specified
Haryana	Yes	As per Regulation 3.2 of the State Electricity Supply Code CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations, 2013, and CEA (Measures relating to Safety and Electric Supply), Regulations, 2010
West Bengal	No net metering regulations issued	No standards issued
Madhya Pradesh	Yes	MP Electricity Supply Code, 2004
Punjab	Yes	CEA (Technical standards for connectivity of the distributed generation resources) Regulations, 2013
Karnataka	Yes	0–5 MWp-240 V/single phase, 5–50 KWp-3phase 415 V, > 50 kWp at 11 kV
Maharashtra	Yes	<8 kW-230/240 volts, <80 KW (Municipal area)-400/415 V and up to 1000 KVA-11 kV and above
Rajasthan	Yes	0–5 kW-240 V (single phase), >5 KW up to 18.65 KW-415 V (three phase), >50 KW/kVA (HT/EHT level)
Himachal Pradesh	Yes	Technical Standards for Connectivity of the Distributed Generation Resources) Regulations, 2013, CEA measures relating to Safety and Electricity Supply), Regulations, 2010

State	Compliance with CEA metering regulations	Interconnection voltage standards
Tamil Nadu	Yes	0–4 kw-240 single phase or 415-three phase, >4 Kw, 0–112 kw-415 three phase, >112 kV-HT/EHT level
Odisha	Yes	OERC Distribution (Conditions of Supply) Code, 2004
Uttar Pradesh	Yes	0–5 KW-single phase 230 V, 5 kW-50 kW/63 kVA-415 V (3 phase), 50 kW-1 MW-111 KV
Kerala	Yes	Kerala Electricity Supply Code 2014
Gujarat	Yes	As per Gujarat Electricity Grid Code, 2013, and GERC's orders, as amended from time to time
Andhra Pradesh	Yes	Strictly adhere to the standards specified by CEA/MNRE
Chhatisgarh	Yes	As per CEA Regulations on "Installation and Operation of Meters"

2.2 Key Observations on Net Metering Regulations in Different States

Of the 16 states, Karnataka, Tamil Nadu, Chhattisgarh, West Bengal, and Gujarat do not have separate regulations on net metering,although their solar policy makes certain provisions for rooftop solar. States such as Kerala and Uttar Pradesh include both net and gross metering under one regulation. Madhya Pradesh's regulations are still in draft stages while Maharashtra's net metering regulations have recently been finalized. Net metering regulations were issued in 2014 and 2015 by the respective states and the regulations are still evolving.

The minimum and maximum capacity for generating solar power from rooftop solar was found to be limited to between 1 kWp to 1 MWp by most states. Regulations for Delhi do not indicate an upper limit for solar system capacity whilst the system size was between 80 and 100 per cent of the consumers connected load. Delhi however does not impose any such restrictions. Most regulations prescribe a limit of 15–30 per cent of cumulative solar capacity at distribution transformer level for integration with the grid. Karnataka, Andhra Pradesh, and Maharashtra allow for a higher limit for grid integration of 80 per cent, 50–60 per cent, and 40 per cent respectively of transformer capacity.

A few states have specified upper limits on energy generation from the system as a percentage of consumer's total annual energy consumption. This ceiling has been fixed at 90 per cent of consumers total energy consumption in a year. Chattisgarh has however fixed a lower ceiling at 49 per cent. Some states have stipulated regulation pertaining to treatment of solar energy supplied during peak hours. The settlement of excess solar energy supplied at peak hours is done with supply by the utility at peak hours. The remaining energy supply by SPV system at peak hour is settled at tariffs for off-peak hours. It was observed that nine states allowed for financial settlement for supplying extra energy at the end of the year while others do not allow for any financial settlement. Maharashtra however limits financial settlements to 10 per cent of the extra units generated by the SPV system. Rajasthan on the other hand allows for financial settlement for more than 50 units of excess energy. Rajasthan and Karnataka offer a more attractive financial settlement using the FiT determined by the Commission for Solar Power. Some commissions allow for the settlement based on the APPC of the utility. On the other hand, Haryana and Uttar Pradesh allow a tariff of Rs 0.25 and Rs 0.5 per unit, which doesn't represent a significant incentive for extra generation.

2.2.1 Application Process for Deployment of a Rooftop SPV System

Table 2.4 summarizes the mode of application for solar rooftop and the proposed time taken by the distribution licensee to approve the application for rooftop solar after checking the feasibility of the project. The licensees have indicated a proposed time frame to set up the solar rooftop project and extensions are also granted as indicated in the case of Punjab and Andhra Pradesh. If the project is not set up within the time frame, the application will lapse and a new application will need to be made.

Table 2.4: Application process

State	Application form available	Application fee	Approval time	Project completion time	Extension	Inspection
Andhra Pradesh	Online/Cash	Rs 25	07 days	90 days	15 days	Yes (10 days)
Bihar	NA	NA	NA	NA	NA	NA
Chhatisgarh	Online	Connectivity charges (50–100 kW) Rs 10,000; (101–500 kW) Rs 20,000; (501–1,000 kW) Rs 40,000; Registration fee with SLDC (1,000 kW) Rs 1,000	NA	NA	NA	Yes
Delhi	Online	Rs 500	30 days	NA	NA	Yes
Goa and UTs	Online	50 per kVA	30 days		2 months	
Gujarat	Online	1,000 (Residential) 10,000 (Industrial)		12 months	No	Yes
Haryana	Online	Rs 1,000	15 days	NA	NA	Yes
Himachal Pradesh	Offline (HimUrja)	5,000	NA	NA	NA	Yes
Karnataka	Online/ Offline	Rs 500 (5 kWp), Rs 1000 (5–50 kWp), Rs 2,000 (>50 kWp)	07 days	180 days	NA	Yes
Kerala	Online	Rs 1,000	15 days	NA	NA	Yes
Madhya Pradesh	Online	Rs 2,000	30 days	90 days	NA	Yes
Maharashtra	Online	Rs 1,000	15 days	180 days	NA	Yes (15 days)
Odisha	Online	Rs 500	15 days	NA	NA	Yes
Punjab	Online	Rs50/KVA; Max Rs10,000	30 days	180 days	2 Months	Yes
Rajasthan	Online	Rs 200 (LT—1Ph), Rs 500 (LT—3 ph), Rs 1,000 (HT—11kV), Rs 2,000 (HT—33kV)	15 days	90 days (inter-connection)	NA	Yes
Tamil Nadu	Offline (TANGEDCO)	100	10 days	6 months	3 months	Yes
Telangana	Online	1,000	15 days	6 months		Yes
Uttar Pradesh	Online	Rs 250 (<50 kW), Rs 750 (50kW–1 MW)	30 days	NA	NA	Yes
Uttarakhand	Online	500 per kW (Max. 30,000)	NA	NA	NA	Yes

State	Application form available	Application fee	Approval time	Project completion time	Extension	Inspection
West Bengal	Nodal Agency		90 days (120 days for projects involving approval by MoEF)	6 months	Yes, case by case	Continuous monitoring of project milestones

2.2.2 Observations

In all the study states, an application form can be downloaded online, although the form has to be physically submitted to the distribution licensee for the area. The utility carries out an inspection on receipt of the application. A few states have stipulated a time frame in which the inspection will be carried out, though most have not. It has been observed that utilities/regulators have prescribed a time limit ranging between 90 and 180 days for consumers to set up the system. Generally, the application becomes invalid if the system is not installed within the stipulated time. Inspection of meters is undertaken jointly by the distribution licensee and the consumer or as per supply codes specified by the commission.

2.3 Rooftop Solar Policies: International Experiences

The net metering polices of three countries have been analysed in Table 2.5 in order to understand the key features that can be applied in the Indian context.

Table 2.5: Benchmarking net metering policies

	Germany	Brazil	California (USA)
Installed PV rooftop capacity[1]	8.7 GW	0.6 GW	2 GW
Metering arrangement	Emphasis on self-consumption. Any surplus production is fed to the grid	Net metering[2]	Net metering[3]
Treatment of surplus energy generation	No banking, monetary payment Two ways of selling solar electricity: By feed-in-tariff or by direct sale (market premium)[4]	The surplus generation will be treated in the same billing period with these priorities: 1. Offset against peak/off-peak tariffs. 2. Transferred among multiple registered sites. 3. Banked monthly against future consumption for a maximum period of 36 months	Yes Monthly bill for excess generation, net surplus generation is based on 12-month rolling average of the market[5]

1 Germany and USA (2013): http://marketrealist.com/2015/02/german-rooftops-domniate-global-photovoltaic-capacity/; Brazil (2015): http://www.pv-tech.org/news/print/net_metering_policy_to_boost_brazils_rooftop_solar; California (2014): http://thinkprogress.org/climate/2014/01/02/3110731/california-rooftop-solar-2013/

2 https://energypedia.info/wiki/Net_Metering_in_Brazil [2] http://www.aneel.gov.br/cedoc/ren2012482.pdf (Portuguese)

3 http://www.cpuc.ca.gov/PUC/energy/DistGen/netmetering.htm

4 http://www.germanenergyblog.de/?page_id=283

5 http://www.cpuc.ca.gov/PUC/energy/DistGen/netmetering.htm

6 http://www.gosolarcalifornia.ca.gov/solar_basics/net_metering.php

7 BSW Solar (2012): http://www.solarwirtschaft.de/fileadmin/media/pdf/EEG-Novelle2012_EN.pdf

8 http://docs.cpuc.ca.gov/PublishedDocs/PUBLISHED/FINAL_DECISION/137431-06.htm#P308_93684

9 http://www.bloomberg.com/news/articles/2015-04-14/california-power-grid-seen-able-to-handle-100-renewables

	Germany	Brazil	California (USA)
Cap on the rooftop system	No, but ranges for financial compensation set in the rage of 1 kW to 500 kW[9]	1 kW to 1 MW	1 kW to 1 MW[6]
Caps on rooftop power generation for individual consumers (kWh)	Yes Output is regulated by the utility through remote control. All systems must be equipped with this mechanism. For systems up to 30 kW, there is also the option to simply reduce the power of the installed capacity to 70% at the grid feed-in point[7]	Yes, distribution companies shall purchase up to 10% of their load in its supply area	System is "intended primarily to offset part or all of the customer's own electrical requirements" and "intended to address random, modest, inadvertent net exports"[8]
Managing impact of solar generation on grid	Grid operator can shut down renewables; owners are compensated for 95 per cent of the economic loss[9]	Grid operator can shut down renewables, no information about compensation. More than 70 per cent of energy supply come from hydro energy	According to California Public Utilities Commission they "have the technical problem of too much electricity on occasions" and "had to curtail renewables"[9]
Need for system strengthening/ up-gradation/augmentation of the distribution network	According to a study (2012), there are no significant problems to be expected with regard to the expansion of the low-voltage distribution network. However, cost of upgrading may be up to €100 million per year[10]	Distributed companies are obliged to expand of the low-voltage distribution network	Controversial—Study found that rooftop solar "actually saved utility ratepayer USD 90 million a year in avoided costs for new transmission lines that would have been occurred if rooftop solar panel owners had relied on utilities for their entire power consumption"[11]
Are industry/commercial consumers keen to go for solar rooftop than domestic consumers?	For total PV capacity in the country, private, and farmer ownership is about 45 per cent. Hence, rooftop shares should be substantially higher on the private side[12]	Due to lack of tax incentives and the small number of installations, no trend available yet	No. The length of the feasibility process, financing process and permitting, residential and large-scale projects have limited the keenness to go for solar rooftop. Although there is a 30 per cent investment tax credit in place[13]

[10] http://www.ecofys.com/files/files/ecofys_2011_paper_on_frequency_stability_challenge.pdf
[11] http://www.kcet.org/news/redefine/rewire/solar/passive-solar/public-utilities-commission-slams-net-metering.html
[12] http://www.greentechmedia.com/articles/read/why-germanys-solar-is-distributed
[13] Breaking Energy (2015): http://breakingenergy.com/2015/06/08/us-commercial-solar-sector-has-lagged-but-now-looks-cleared-for-takeoff/
[14] http://cleantechnica.com/2015/06/08/california-rolls-out-default-time-of-use-rates/
[15] http://www.pge.com/includes/docs/pdfs/myhome/saveenergymoney/solarenergy/CSI_Guide_To_Going_Solar.pdf
[16] http://www.greentechmedia.com/articles/read/Third-Party-Owned-Solar-Drives-California-Market

	Germany	Brazil	California (USA)
Is there a possibility for the SPV system owner to earn more revenues by supplying extra power to the grid during peak hours?	No	No	Currently not. But there are reform plans of the electricity rates that could consider different charges at peak hours[14]
What is the role of the electricity supply company and the consumer, respectively, in the installation of solar rooftops in individual premises?	Installation and maintenance is taken care of by a contractor, application for feed-in-tariff to the utility (8 weeks examination), utility will (in cooperation with contractor) make an on-site interconnection/meter inspection	Installation is taken care of by the contractor. The utility will (in cooperation with contractor) make an on-site interconnection/ meter inspection and is responsible for operation and maintenance, including testing and eventual replacements	Installation, application for interconnection and net-metering, building permit, city county site inspection all done by a contractor (utility(-ies) provide a database), utility finally make an on-site interconnection/meter inspection[15]
Is the third party ownership model a more popular model for rooftop solar?	NA	Not yet. The conditions are currently under revision	Third party owned solar makes up more than 50% of the California home solar market (2011); upward trend since 2009[16]

The key points that emerge from international experience (discussed in the Table 2.5) that are relevant for India:

- Regulations in Germany encourage self-consumption, whereas Brazil and California (USA) have a net metering arrangement. The California and Brazil experience is therefore more relevant for India, with more and more states moving towards a net metering arrangement;
- In Germany, in order to reflect the high generation costs of solar energy, high FiT's were initially set. The FiT's were higher than the retail tariff for grid-connected power and hence it was attractive for customers to set up an SPV system. After the regulatory reforms of 2014, FiT's are adjusted on a monthly basis and have reached parity with grid-connected electricity;
- In Brazil, surplus energy from the SPV system can be banked or carried forward for up to 36 months, while in India, states limit the carry forward for up to one year after which either the excess units are financially settled or they become invalid;
- As in India, both Brazil and California limit the size of the rooftop system to between 1 kW and 1 MW. In Brazil, distribution companies are required to purchase up to 10 per cent of their load in the supply area. In India, most states limit grid interaction to up to 15–30 per cent of the transformer capacity in the local area;
- In California, a study suggests that rooftop solar saved USD90 million a year in avoided cost for transmission lines that would have occurred if rooftop solar panel owners had relied on utilities for their entire consumption. The network investment savings are one of the reasons why utilities such as in Delhi are interested in rooftop solar systems;
- Brazil allows for the transfer of solar energy credits to multiple sites of the registered rooftop owner. A similar initiative has now been proposed by Delhi under its Draft Solar Policy;
- In case of voltage fluctuations due to RE, grid operators in Germany shut down the renewable source. Importantly however, they pay compensation to the extent of 95 per cent of the economic loss;

3

Chapter

Review of Electricity Tariffs

Retail electricity tariffs in India are determined on a regulated cost-plus basis where the justifiable/prudent expenditures of the distribution utility are allowed to be recovered from consumers along with a fixed return on equity for the distribution company. On account of the varying costs from state to state and their technical performances, retail electricity tariffs vary from state to state. While there are commonly three or four utilities serving each state, the tariffs are generally kept uniform across utilities.[1]

Regulators estimate the cost of serving each category of consumer (industrial, commercial, domestic, and agriculture) and charge the consumer based on this cost of serve calculation. However, cross-subsidies also exist, where the industrial and commercial sectors cross-subsidize the domestic and agricultural consumers. The National Tariff Policy recognizes that some amount of cross-subsidy needs to continue and therefore mandates that cross-subsidies should be limited to $\pm$20 per cent of the cost of serving price for each category. Agricultural consumers (i.e., for tube wells) in general pay the least, and in some states are supplied with power at no charge. In addition to cross-subsidies, State Governments often provide additional support from the state budget in the form of subsidies to ensure that tariffs remain low for domestic and agricultural consumers. Because of the presence of cross-subsidies and subsides, the actual tariff charged to consumers may not reflect the true cost of serving that category.

For small-sized rooftop solar projects aimed at self-consumption, it is important to understand how the cost per unit of generation compares with the cost of grid-based electricity supply. A study of tariff trends across the last 10 years will help to improve understanding of the states and consumer categories that have either reached grid parity or are close to reaching grid parity. With this objective in mind, this chapter aims to provide an analysis of electricity tariff schedules applying to low- and medium-voltage consumers in the industrial and commercial sectors (structure and level of rates/charges up to 66/33kV, regional and service area differences) based on actual tariff regimes and cost of supply scenarios covering the next 2–3 years.

- A graphic representation[2] of the tariffs for the residential (domestic), agricultural, commercial, and industrial sectors in Andhra Pradesh for 2015–16 is provided in Figure 3.1. There is a clear variation in tariff rates between sectors, showing varying electricity tariffs across sectors. Generally, the commercial and industrial sector tariffs tend to be higher than the domestic and agricultural consumer categories. The graph highlights the highest and lowest tariffs for different categories of consumers under commercial, industrial, and agriculture sectors. . The domestic segment is also indicated in the graph.

[1] There are however a few private distribution companies, primarily supplying electricity in industrialized cities (such as Mumbai, Ahmedabad, Surat) whose tariffs may differ from what the state utility charges in their respective states. These private companies are also under the purview of the regulator and their tariffs are determined on a cost-plus basis based on their expenditure.

[2] Domestic 1 = LT I (A): up to 50 units; Domestic 2 = LT I (D): above 500 units; Commercial 1 = LT II (A): up to 50 units; Commercial 2 = LT II(C): advertising hoardings; Industrial 1 = LT IV: cottage industries; Industrial 2 = LT III: seasonal industries (off season); Agriculture 1 = LT V (A): wet land farmers; Agriculture 2 = LT V (C): others.

A regression analysis for calculating tariff projections was considered for this chapter. However, it was not adopted for the following reasons:

- **Data availability and quality:** It was difficult to find appropriate data that was easily accessible, methodologically transparent, and consistent. For instance, coal price is one of the most important inputs into the electricity tariff. However, historical coal price data is not available in the public domain, with only current coal prices being available. A regression analysis without coal prices as an independent variable would make the exercise redundant.
- Overall, while a cost-plus approach is followed in tariff fixing, it is the government that ultimately limits the tariff increase to a level it considers possible for the public to sustain. Hence, tariffs do not truly represent costs. A simpler compounded annual growth rate (CAGR) based projection therefore seemed appropriate.

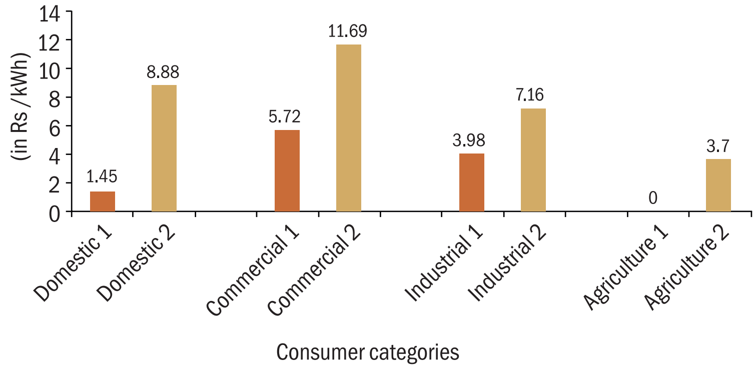


Figure 3.1: Tariff for Andhra Pradesh for 2015–16

Tariffs for low and medium voltage industrial and commercial categories were collected for the last 10 years (2005–06 to 2014–15) across 10 states in order to estimate the tariff CAGR.[3] The states were carefully selected to ensure a representative sample of all the regions in India. States were selected based on parameters including; level of industrialization and economic activity, whether states had significant coal reserves and subsequently low tariffs, whether states were stably governed, and whether the state has potential and progressed in promoting solar power.

This data was obtained from the tariff orders issued over the last 10 years by the respective state electricity regulatory commissions. In some cases, the trend analysis was not possible for all 10 years as tariff revisions did not take place over a sufficient number of years. For instance, in Rajasthan there was no tariff revision between 2005–06 and 2011–12. Subsequently, tariffs were revised every year and hence tariff data had to be considered only between 2011–12 and 2013–14 (4 years). In Gujarat, there was a major change in tariff categorization in 2011–12. Tariffs for prior years could not therefore be compared with tariffs for subsequent years across categories. Hence, the trend analysis was undertaken only from 2011–12 to 2015–16. In West Bengal, there was no tariff revision between 2005–06 and 2006–07 so data had to be considered from 2007–08 to 2014–15 when annual tariff revisions had taken place. For all other states, data was available for the previous 9–11 years.

The following graphs show the industrial and commercial tariffs of Karnataka and West Bengal (Figure 3.2–3.5). Karnataka displays a lower increase in tariff for last 11 years while West Bengal indicates a higher increase in tariffs over the last eight years. It can be inferred that an increase in tariff rates differ from state to state and over the long run. This may have an impact on the viability of solar rooftop projects.

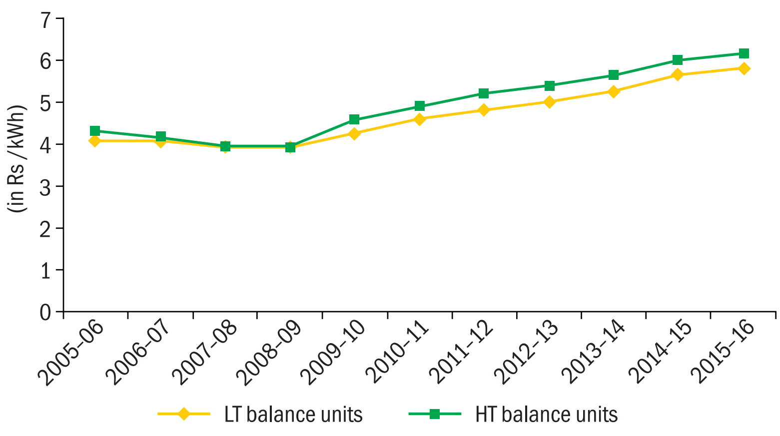


Figure 3.2: Industrial tariffs for Karnataka

Annexure A2.1 provides the year-wise tariffs and CAGR's for all the low tension (LT) and medium tension (MT) categories in the industrial and commercial consumer categories.

[3] T Delhi, Haryana, Gujarat, Chhatisgarh, West Bengal, Punjab, Karnataka, Andhra Pradesh, Rajasthan, and Maharashtra

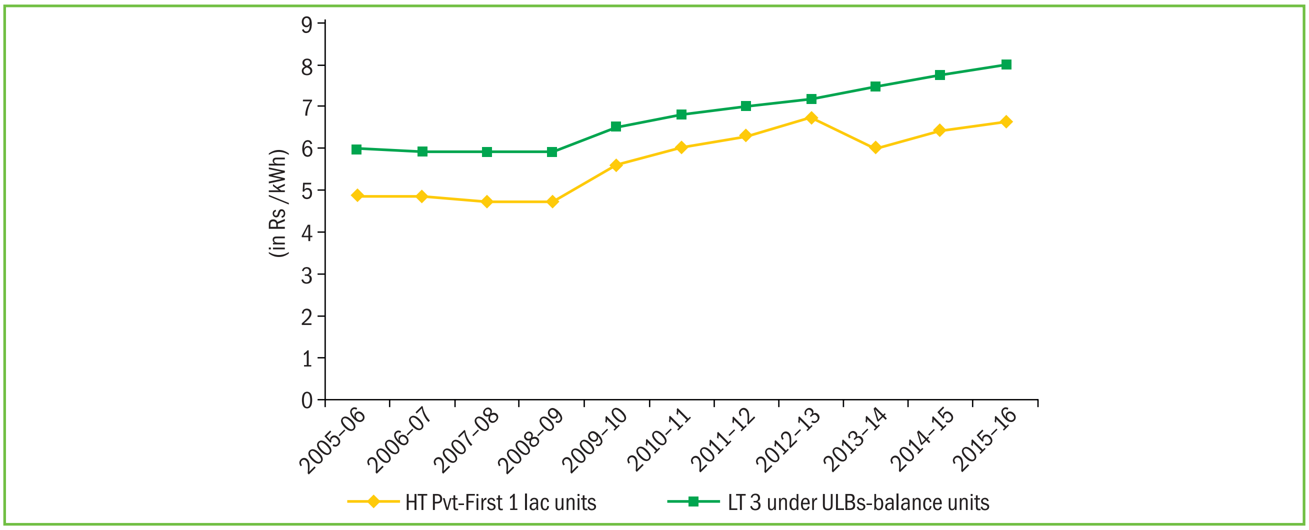


Figure 3.3: Commercial tariffs for Karnataka

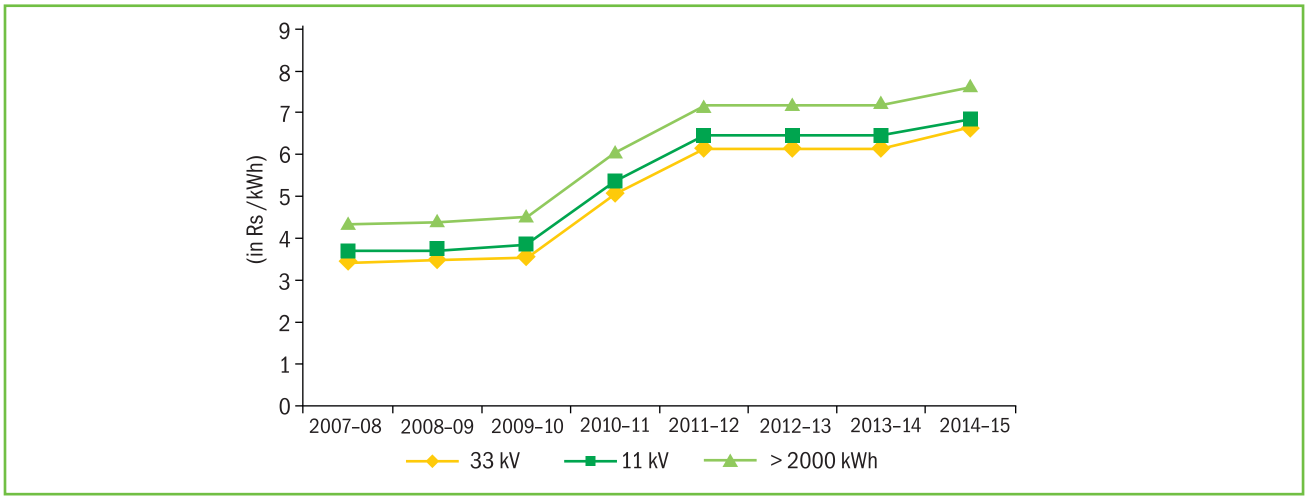


Figure 3.4: Industrial tariffs for West Bengal

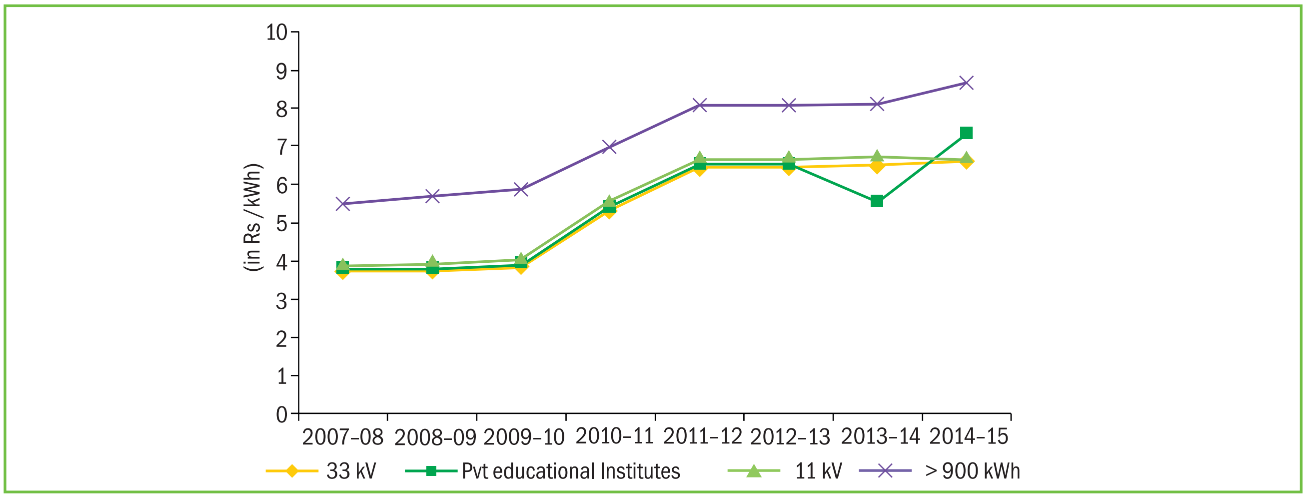


Figure 3.5: Commercial tariffs for West Bengal

3.1 Projection of Commercial Tariff Across Study States

The following table provides a summary of the projected tariffs for selected[4] commercial categories between 2016–17 and 2019–20 for the 10 states in India.

Table 3.1: State-wise projections of commercial tariff (Rs/kWh)

State	Categories	CAGR	Latest tariff (2014-15)	2015[5]–16	2016–17	2017–18	2018–19	2019–20
Delhi	Between 10 kW(11 kVAh) and 100 kW(108 kVAh) (NDLT)[6] (NDLT I)	6.38%	8.5	9.04	9.62	10.23	10.89	11.58
	Greater than 100 kW (108 kVA) (NDLT) (MLHT[7])	6.51%	9.95	10.60	11.29	12.02	12.81	13.64
	For supply at 11 kV and above (for load greater than 108 kVA) (NDHT)[8] (MLHT)	6.17%	8.4	8.92	9.47	10.05	10.67	11.33
	Non-domestic Light/Power on 11 kV Single Delivery Point for Commercial Complexes (NDHT) (NDLT II)	8.18%	8.4	9.09	9.83	10.63	11.50	12.44
Haryana	Existing consumers above 50 kW up to 70 kW (LT)[9]	5.44%	6.75	7.12	7.50	7.91	8.34	8.80
	Consumers above 50 kW (HT)[10]	4.73%	6.35	6.65	6.96	7.29	7.64	8.00
Gujarat	GLP[11]	3.11%	3.9	3.9	4.02	4.02	4.15	4.15
	Non-RGP[12] between 10 kW and 40 kW	2.58%	4.65	4.65	4.77	4.77	4.89	4.89
	LTMD[13] (above 40kW and up to 100 kW) LTP-III[14]	2.55%	4.7	4.7	4.82	4.82	4.94	4.94

[4] These categories have been selected as these are the consumer categories for which, in our view, rooftop solar could make business sense based on units consumed and connected load.

[5] Tariffs for the year 2015–16 for Gujarat, Punjab, Karnataka, Andhra Pradesh, and Mumbai are actual tariffs whereas it is projected tariff for remaining states

[6] NDLT–Non-domestic LT = 230 V (single phase), 400 V (three phase)

[7] MLHT-Mixed Load High Tension

[8] NDHT—Non Domestic High Tension = above 11kV

[9] LT = 230 Volts (single phase) or 400 Volts (three phase)

[10] HT = above 11 kV

[11] General Lighting Purpose (GLP) = LTP-II + LFD-III (educational and other institutions registered with Charity Commissioner and research and development laboratories)

[12] Non-RGP Non-residential = LTP-I + LFD-II (shops, offices, banks, distribution pumping stations, hostels, laboratories, hospitals, telephone exchanges, training centres, public gardens, theatre, recreation places, multiplexes, malls, workshop, hotels, restaurants, educational institutes)

[13] LTMD—Tariff applicable to the services for the premises those are not covered in any other tariff categories and having aggregate load above 40 kW and up to 100 kW = Commercial/industrial/office/institutional premises

[14] LTP-III = Commercial/industrial/office/institutional premises
LTP-I = Commercial/industrial premises.
LTP-II = educational institutions and research and development laboratories
LFD-II = shops, workshop, hotels, restaurants, showrooms, offices, etc.
LFD-III = educational and other institutions registered with the Charity Commissioner
LTP—Lift Irrigation category—Applicable for supply of electricity to low tension agricultural consumers contracting load up to 125 HP requiring continuous (twenty-four hours) power supply for lifting water from surface water sources such as cannel, river, and dam and supplying water directly to the fields of farmers for agricultural irrigation only
LFD–For Residential Premises

State	Categories	CAGR	Latest tariff (2014-15)	2015[5]–16	2016–17	2017–18	2018–19	2019–20
	Up to 500 kVA	2.77%	4.35	4.35	4.47	4.47	4.59	4.59
West Bengal	above 900 kWh	6.72%	8.67	9.25	9.87	10.54	11.25	12.00
	Commercial (11 kV)	8.07%	6.68	7.22	7.80	8.43	9.11	9.85
	Commercial (33 kV)	8.69%	6.63	7.21	7.83	8.51	9.25	10.06
	Private Educational Institutions	9.82%	7.32	8.04	8.83	9.69	10.65	11.69
Chhattisgarh	HT 11 kV	2.31%	4.2	4.30	4.40	4.50	4.60	4.71
	HT 33 kV	2.25%	4.3	4.40	4.50	4.60	4.70	4.81
	Normal Tariff (0-500 units)	4.40%	6	6.26	6.54	6.83	7.13	7.44
	Demand-based tariff (15-75 kW)	7.39%	5	5.37	5.77	6.19	6.65	7.14
Punjab	Exceeding 100 kW	5.01%	6.9	6.9	7.25	7.61	7.99	8.39
Karnataka	HT2 c(ii) Pvt -First One Lakh Units	3.13%	6.6	6.6	6.81	7.02	7.24	7.47
	LT3 under ULBS-Balance Units	2.85%	7.95	7.95	8.18	8.41	8.65	8.90
Andhra Pradesh	LT-Above 500 units a month	4.37%	9.59	9.59	10.01	10.45	10.90	11.38
	HT-11 kV	5.12%	7.25	7.25	7.62	8.01	8.42	8.85
	HT-33 kV	5.39%	6.59	6.59	6.94	7.32	7.71	8.13
Mumbai	LT-Greater than 50kV	2.99%	7.62	7.62	7.85	8.08	8.32	8.57
	HT	7.31%	8.11	8.11	8.70	9.34	10.02	10.75
Rajasthan	LT supply above 500 units	9.99%	7.85	8.63	9.50	10.45	11.49	12.64
	HT supply (Contract demand over 50kVA)-All	8.09%	7.45	8.05	8.70	9.41	10.17	10.99

The tariffs given below and in Annexure A2.1 only include the energy charges. In addition to this, industrial and commercial customers pay a contract demand charge (fixed charge), which is based on their contracted demanded/ sanctioned load. Typically, the energy charge comprises around 90–95 per cent of the total tariff. To explain this, two scenarios were created, using the relevant tariffs for the industrial and commercial consumers in Delhi. The first scenario assumes the industry or commercial consumer operates for eight hours, whereas the second scenario assumes 24 hour operation. It was assumed that 70 per cent of the contracted capacity is utilized and that the sanctioned load is 100 KW. This analysis suggests that:

- For consumers operating for 24 hours a day, the energy charge accounts for between 96 and 98 per cent of the total tariff.
- For consumers operating for eight hours a day, the energy charge accounts for between 91 and 95 per cent of the total tariff.

A fuel surcharge is levied on the fixed and energy charge, which can range between 5 and 20 per cent, depending on the state. The State Government collects an electricity duty over and above this, either as percentage of the total tariff or as an additional per unit charge in Paise. This charge will vary from state to state. For instance in Delhi, it is a charge of 5 per cent of the sum of energy and fixed charges.

Furthermore, since there are variations in the price of fuel, the utility is allowed to include a fuel price adjustment charge on a quarterly or monthly basis which is typically in the range of 5–10 per cent. In addition, industrial and some commercial consumers may be charged higher tariffs during peak hours. Some states may also levy additional surcharges to meet particular requirements. For instance, Delhi DISCOMS are allowed to levy a surcharge of 8 per cent to recover expenditures incurred in earlier years that were not allowed to be passed on to consumers in the past. In addition, State Governments levy an electricity duty (typically 5–10 paisa per unit) and occasionally cesses, such as the environment cess. The actual tariff paid by the consumer is therefore typically around 20–30 per cent higher than the original energy charge.[15]

Table 3.2 provides a summary of the projected tariffs for select commercial categories from 2016–17 to 2019–20 for the 10 states.

Table 3.2: State-wise projections of industrial tariff (Rs/kWh)

State	Categories	CAGR	Latest tariff 2014-15	2015–16[16]	2016–17	2017–18	2018–19	2019–20
Delhi	Greater than 100 kW (108 kVA) (400 volts) No supply on LT for load > 215kVA (SIP)	7.51%	9.50	10.21	10.98	11.81	12.69	13.64
	Industrial Power on 11 kV Single Point Delivery for Group of SIP Consumers	7.51%	7.10	7.63	8.21	8.82	9.49	10.20
	LIP (Supply at 11 kV and above) (above 100kW)	6.22%	7.40	7.86	8.35	8.87	9.42	10.01
Haryana	HT-Supply at 11 kV	3.77%	5.80	6.02	6.25	6.48	6.73	6.98
	HT-Supply at 33 kV	3.49%	5.70	5.90	6.10	6.32	6.54	6.77
	LT-Above 20 kW and up to 50 kW	4.48%	6.35	6.63	6.93	7.24	7.57	7.91
	LT-Existing consumers Above 50 kW up to 70 kW (LT)	3.82%	6.00	6.23	6.47	6.71	6.97	7.24
Gujarat	GLP	3.11%	3.90	3.90	4.02	4.15	4.28	4.41
	Non-RGP between 10 kW and 40 kW	2.58%	4.65	4.65	4.77	4.89	5.02	5.15
	LTMD (above 40 kW and up to 100 kW) LTP-III	2.55%	4.70	4.70	4.82	4.94	5.07	5.20
	Up to 500 kVA	2.77%	4.35	4.35	4.47	4.59	4.72	4.85
West Bengal	11 kV	9.39%	6.86	7.50	8.21	8.98	9.82	10.75
	33 kV	9.88%	6.67	7.33	8.05	8.85	9.72	10.68
Chhattisgarh	Above 25 HP up to 100 HP	0.92%	3.80	3.83	3.87	3.91	3.94	3.98
	Demand-based Tariff for contract demand of 15 kW to 75kW	1.82%	4.00	4.07	4.15	4.22	4.30	4.38
	33 kV—Other Industries	3.25%	4.20	4.34	4.48	4.62	4.77	4.93
	33 kV—Working between 6am and 6pm	3.06%	4.20	4.33	4.46	4.60	4.74	4.88
	11 kV—Other Industries	3.34%	4.30	4.44	4.59	4.75	4.90	5.07

[15] Based on analysis of industrial and commercial bills for Delhi DISCOM

[16] Tariffs for the year 2015–16 for Gujarat, Punjab, Karnataka, Andhra Pradesh, and Mumbai are actuals whereas it is projected tariff for remaining states

State	Categories	CAGR	Latest tariff 2014-15	2015–16[16]	2016–17	2017–18	2018–19	2019–20
	11 kV—Working between 6am and 6pm	2.98%	4.30	4.43	4.56	4.70	4.84	4.98
Punjab	Large (more than 100 kVA; 11 kV or higher)—General	6.25%	6.82	6.82	7.25	7.70	8.18	8.69
	Medium (20 kW–100 kVA; 400V or 11 kV—General	5.78%	6.52	6.52	6.90	7.30	7.72	8.16
Karnataka	HT—Balance Units	3.64%	6.15	6.15	6.37	6.61	6.85	7.10
	LT—Balance Units	3.66%	5.80	5.80	6.01	6.23	6.46	6.70
Andhra Pradesh	LT—General	5.46%	6.38	6.38	6.73	7.10	7.48	7.89
	HT—General 11 kV	5.88%	6.02	6.02	6.37	6.75	7.15	7.57
	HT—General 33 kV	5.22%	5.57	5.57	5.86	6.17	6.49	6.83
Mumbai	LT—Greater than 11.2 kW	6.92%	7.35	7.35	7.86	8.40	8.98	9.61
	HT	9.93%	8.44	8.44	9.28	10.20	11.21	12.33
Rajasthan	Up to 50 kVA (LT)	9.58%	6.25	6.85	7.50	8.22	9.01	9.87
	above 50 kVA (HT)	9.58%	6.25	6.85	7.50	8.22	9.01	9.87
	Large Industries (above 125 kVA (150 HP)	9.14%	6.50	7.09	7.74	8.45	9.22	10.07

3.2 Observations from Review of Tariffs

Tariff revisions for electricity generation are significantly influenced by political economy considerations and do not always rise in proportion to any increase in fuel prices or operation and maintenance costs. For instance, Rajasthan did not see a hike in tariffs from 2005–06 to 2010–11 whereas Chhattisgarh saw a sudden drop in commercial tariffs (from around 3.5–4.5 Rs/kWh to 1.5–2.5 Rs/kWh) in the years 2011–12 to 2013–14. Governments prefer to limit tariff increases in the range of between 5–6 per cent to avoid tariff shocks. In some states where industrialization is not a key economic driver, industry and commercial tariffs may increase by around 7–8 per cent. However, while state electricity regulatory commissions are mandated to review tariffs every year, in some states such as Tamil Nadu and Rajasthan, tariff revisions only take place after several years. Key observations across the included study states in the commercial and industrial categories are:

Commercial Category

- Of the ten states for which a tariff analysis has been conducted, Delhi recorded the highest tariffs (8.4 to 9.95 Rs/kWh in 2014–15), followed by West Bengal (7.3–8.6 Rs/kWh).
- West Bengal recorded a growth in tariffs of between 7 and 10 per cent, followed by Delhi at the rate of 6–8 per cent.
- Gujarat and Chhattisgarh have registered the lowest commercial tariffs amongst the ten states studied of between 4 Rs/kWh and 6 Rs/kWh; while, Gujarat (1–3 per cent), Karnataka (2–4 per cent), and Chhattisgarh (2-4 per cent) witnessed the lowest growth in tariffs in the last 10 years.

Industrial Category

- Among the ten states, Delhi (7–9.5 Rs/kWh) recorded the highest tariff followed by Mumbai (7.3–8.5 Rs/kWh) and West Bengal (6.5–7 Rs/kWh).

- The highest rates of growth in industrial tariffs were observed in West Bengal (9.5 per cent) followed by Mumbai (6.92–9.3 per cent) and Delhi (6–7.5 per cent) in the last 10 years.
- On the other hand, Chhattisgarh (3.8–4.3 Rs/kWh) and Gujarat (4.35–4.7 Rs/kWh) have the lowest industrial tariffs amongst the ten states under study while Chhattisgarh (1–3 per cent) have seen the lowest increase in industrial tariffs followed by Gujarat (2.5–2.8 per cent).

Chapter 4

Operating Layouts

The performance of a rooftop solar photovoltaic (PV) system is influenced by many factors such as location, solar irradiation values at the site, and panel tilt angle. The operating layout is one of the most important issues when studying PV systems and has been discussed in this section.

4.1 Irradiation Data

4.1.1 Solar Radiation Analysis

In this study, the following irradiation sources are considered:

- Solar Radiation Resource Assessment, commonly known as SRRA, is the database developed by the Ministry of New and Renewable Energy, Government of India. The government plans to set up the world's largest network of solar radiation resource assessment stations all over the country.[1]
- Meteonorm is the database providing comprehensive meteorological references covering solar, wind, temperature, precipitation, as well as other data. With more than 8,000 monitoring stations worldwide, it gives access to a catalogue of meteorological data for solar applications and system design at any desired location in the world.[2] This database is used in the PV design analysis software PVSyst. Meteonorm receives regular updates and the version assessed in our study was Meteonorm 7.1.
- NASA's Atmospheric Science Data Center has produced the Surface Meteorology and Solar Energy Data set, which is used extensively worldwide. The RETScreen clean energy management software uses NASA's database whilst performing analyses and provides data for more than 200 meteorological parameters that are monthly averaged from 22 years of data, thus affirming its reliability.[3]

The datasets from the three sources were compared for various locations in India. The average daily global solar irradiation values on horizontal plane are compared for five cities that represent north (Delhi), west (Ahmedabad), east (Kolkata), south (Bengaluru), and coastal (Mumbai) regions, using different irradiation sources. It can be inferred that the SRRA data tends to be on the lower side, while Meteonorm 7.1 gives the highest values of the three. NASA's data on the other hand gives values close to the average of the two as shown in Figure 4.1. Therefore, the NASA's Surface Meteorology and Solar Energy data set has been used for all the simulations in this study.

[1] http://niwe.res.in/department_srra.php
[2] http://meteonorm.com/en/features
[3] https://eosweb.larc.nasa.gov/sse/

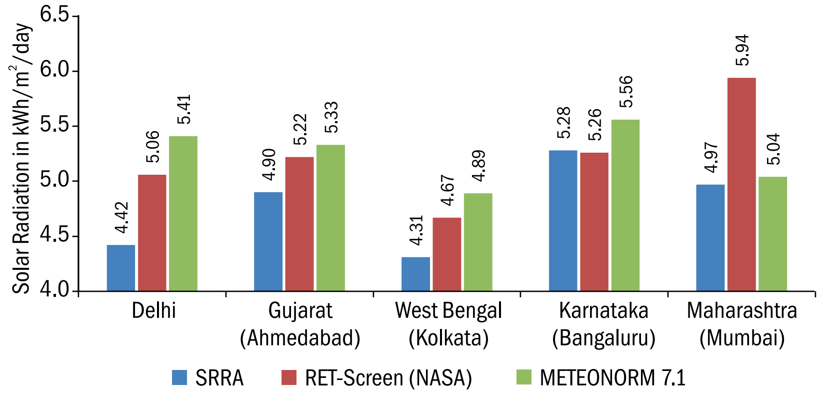


Figure 4.1: Solar radiation values on horizontal plane for major cities in India

4.1.2 Selection of Locations

After identifying the major industrial and commercial regions and studying the prevailing climatic conditions, the aim was to select at least one commercial and industrial centre from each of the zones that exhibit contrasting weather conditions. The cities selected for analysis are:

- Ahmedabad
- Bengaluru
- Chennai
- Delhi
- Kolkata
- Pune

4.2 Operating Layout—Basic Settings

4.2.1 Basic Specifications

This study considers the various components and configurations of a PV system, which are discussed below:

Solar Modules

Popular solar PV technologies in the current market can be categorized as:

- Crystalline—mono-crystalline, poly-crystalline.
- Thinfilm—CdTe, CIGS, Amorphous-Si.

The cells in a thin-film module are made using microscopic layers of Silicon (or CdTe, CIGS), as opposed to crystalline modules, which use much thicker silicon wafers. Thin film modules are made with a plastic gazing, ensuring the modules are both flexible and lightweight as well as offering a better temperature coefficient when compared to crystalline modules. In India, most of the solar installations used thin-film modules in the initial solar development phase but are now shifting to crystalline modules after experiencing module failure at temperatures between 40°C and 50°C. Crystalline modules have emerged as a time tested and superior technology, offering lower degradation rates with a lengthy operating life. Crystalline modules have developed into a mature technology, making up more than 90 per cent of today's module industry, which includes a multitude of manufacturers of both modules and compatible installation equipment.

String Inverter

The inverter plays an important role in a PV system, converting the direct current (DC) produced by the solar module into alternating current (AC), enabling the electricity to be used for appliances. There are three types of inverters used in practice for solar installations—micro inverters, central inverters, and string inverters. A micro inverter converts electricity from one panel whereas a string inverter converts electricity from multiple, or a string of panels. The advantages of using string inverters over micro inverters are listed below:

- String inverters are not only less complex to install, but also offer low initial cost per watt peak;
- They are generally used in installations with capacities up to 1 MWp and are ideal for roofs with external shading caused by the surroundings;
- It is easier to set up monitoring systems with string inverters as it does not require installation of additional sensor cards or equipment;
- They are easier to maintain and replace as the inverter unit can be exchanged or replaced entirely. This also results in ease of training of workers for maintenance;

Cable

The cables must be designed to bear long-term exposure to sunlight and extreme weather conditions. They are built to resist UV radiations, ozone, and water absorption, as well as to provide flexibility in the cold (sub-zero) regions and resistance to deformation in regions with high temperatures. Upon installation, the bending radius of the cable needs to be considered and the cable should be placed away from objects protruding from the surface. The manufacturer aims to minimize cable losses to the practiced design criterion of 1 per cent cable loss in DC, and 1 per cent cable loss in AC. The rooftop system may experience overloads in some situations and the cable should have a high current carrying capacity to avoid fire hazard.

Row Shading Losses

Photovoltaic systems usually have a lower energy yield than what is assumed from the mean solar irradiance data, primarily due to shading losses. With flat roof installations, there is often shading of the lower cell rows of the modules during the morning and evening hours. In a crystalline module, the cells are connected in series, so shading of the lower cell rows affect the output of the whole module. With optimized module structures, shading losses can be minimized and the yield can be increased by up to 50 per cent. The inter-row spacing of modules can be optimized to minimize row shading losses to 2 per cent.

Performance Ratio (PR)

By definition, PR is the ratio between the actual and theoretical energy outputs of the PV plant. It is expressed as a percentage and is independent of the location of the project. In India, capacity utilization factor is a more commonly used measure of a plant's performance, but it does not take into account the variations in performance due to temperature, grid outage, time of the day and seasons. PR is therefore a better metric and is used in this study. Based on the prevailing climatic and temperature conditions in India, a performance ratio of 80 per cent is expected for crystalline modules.

4.2.2 Module Tilt and Azimuth

The power density of a solar panel does not only depend on the incident solar irradiation but also on the angle at which the radiation strikes the surface of the module. Maximum power density is achieved when the solar radiation strikes the panel at a perpendicular angle, but as the angle between the radiation and a fixed surface changes continuously, the power density is always lower than that of the incident sunlight. To enhance the output, the modules are tilted at an optimum angle called module tilt, which varies depending on the location and the load profile. Alternatively, the azimuth angle is the measure of the compass angle, normally with respect to south, of the panel from the position of the sun.

Analysis of Winter–Summer Optimization

In regions that experience distinct summer and winter seasons, the load curve for a building varies according to the season. A PV system with a fixed module tilt can be optimized to fit the load curves for either season. To determine

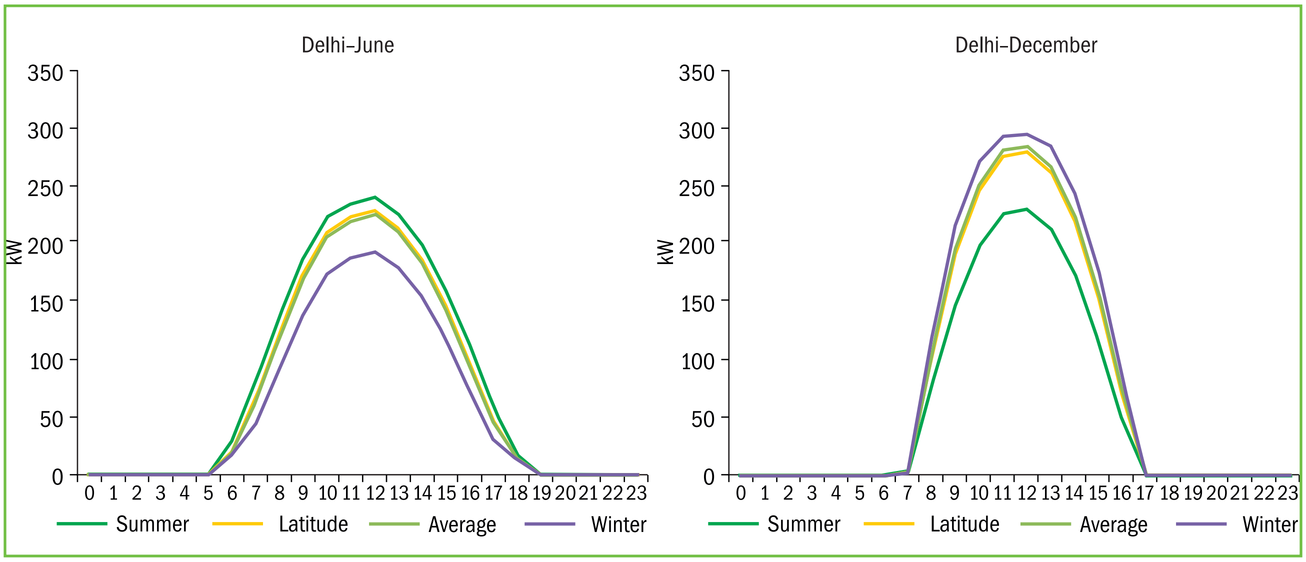


Figure 4.2: PV output for summer and winter optimized tilt angles

the type of optimization feasible for India, a simple PV system was simulated in PVSyst for different locations. The system was simulated once with a summer optimized tilt, and then with a winter optimized tilt. The output of the PV Systems was then compared for the months of June and December (Figure 4.2).

- For the summer optimized tilt, there is a big difference in the power output between June and December. The power output during the winter months is considerably lower than in summer, resulting in a big variation in the power output throughout the year.
- For the winter optimized tilt, the power output for the winter months is considerably higher than in the summer months.
- The difference between the winter optimized curve and the average curve in June exceed the difference between these curves in December, whereas the difference between the summer optimized curve and the average curve in December exceed the difference between curves in June. Therefore, it is shown that the seasonal optimized plants have significant losses on yearly production.

Based on the above inferences, we conclude that a season-based optimization is not helpful for load optimization in the Indian context. In the next section, we analyse an optimum module tilt for the region.

Analysis of Different Module Tilts

An optimum module tilt should make maximum use of the available rooftop area to resemble the load curve of the buildings in this study. In order to determine the optimum tilt angle, a simple PV system with multiple rows of modules was simulated on PVSyst for different locations, with panels facing towards South, that is, Azimuth angle = 180° (with respect to North). The inter-row distance was selected in a way to keep the shading losses at 2 per cent. Another simulation considered a module tilt of 10°, oriented along the East–West direction. The distance between the rows was kept at minimum 0.5 m for operation and maintenance convenience. Table 4.1 summarizes the results for Delhi. It can be observed that the irradiation loss and the yield loss per power is less than 4 per cent between optimal tilt and tilt of 15°, and the yield gain per square metre is around 120 per cent. Another inference is that the irradiation loss and the yield loss per unit of power is around 10 per cent between 15° tilt and east–west, and the yield gain per square meter is around 108 per cent.

Table 4.1: PVSyst simulation results for Delhi

New Delhi		Optimal tilt for fixed tilted module 32°				
Module tilt	Orientation (*N* = 0°)	Irradiation into plane	Specific yield	Power/ground area	Yield per square meter roof space	PR
[°]	[°]	[kWh/m²a]	[kWh/kWp]	[Wp/m²]	[kWh/m²]	[%]
30	180	2,236	1,821	49.4	90.0	81.5
25	180	2,226	1,813	70.6	128.0	81.5
20	180	2,202	1,793	92.7	166.3	81.4
15	180	2,165	1,762	112.0	197.3	81.4
10	90/270	1,964	1,617	132.6	214.4	82.4

Table 4.2 summarizes the results with the western city Pune as the location. It can be observed that the irradiation loss and the yield loss per power is less than 5 per cent between optimal tilt and tilt of 15°, and the yield gain per square metre is around 120 per cent.

Table 4.2: PVSyst simulation results for Pune

Pune		Optimal tilt for fixed tilted module 23°				
Module tilt	Orientation (*N* = 0°)	Irradiation into plane	Specific yield	Power/ground area	Yield per square meter roof space	PR
[°]	[°]	[kWh/m²a]	[kWh/kWp]	[Wp/m²]	[kWh/m²]	[%]
20	180	2,182	1,769	92.7	164.0	81.4
15	180	2,169	1,760	115.0	202.4	81.4
10	90/270	2,040	1,679	132.6	222.6	82.4

Table 4.3 summarizes the results, with the southern city of Chennai as the location. It can be observed that the irradiation loss and the yield loss per power is around 2.5 per cent between optimal tilt and east–west, and the yield gain per square metre is around 118 per cent.

Table 4.3: PVSyst simulation results for Chennai

Chennai		Optimal tilt for fixed tilted module 15°				
Module tilt	Orientation (*N* = 0°)	Irradiation into plane	Specific yield	Power/ground area	Yield per square meter roof space	PR
[°]	[°]	[kWh/m²a]	[kWh/kWp]	[Wp/m²]	[kWh/m²]	[%]
15	180	1,978	1,594	107.9	171.9	80.6
10	90/270	1,929	1,576	132.6	209.0	81.7

4.3 Conclusions

Whilst the weather conditions in India vary across different states, the irradiation levels far exceed that of southern European countries. Due to the high temperature of India's climate, the expected performance ratio of the systems is around 80 per cent. This is lower than in northern countries like Germany or England, but comparable to regions such as the South of France and Italy.

Globally, different module technologies are under development and are being installed. The common technology used for most of these installations is based on crystalline cells. Because of the vast experience and the status of development, the use of crystalline modules is the preferred module technology. Many manufacturers offer to replace damaged modules of various module types, even if the original module is no longer available.

For rooftop systems, string inverters are advisable due to their scalability, which can help in reducing costs. The maintenance cost can also be reduced if the inverter can be exchanged in case of failure. This will also help to reduce training costs. In India, the power density (Watts per square metre of available roof) is assumed as 100 W/m^2, with the module tilt at 15° and an Azimuth angle of 180° (with respect to North) can be used as the parameter for optimum usage of the rooftop area.

For locations lying below 15°N latitude, an east–west oriented PV system provides a potential alternative. The specific yield is close to that of the south-oriented system with a module tilt of 15°, but the yield per square metre available roof top area is around 20 per cent higher and appears to be comparable with for example, Delhi. Generally a yield of 200 kWh per square metre rooftop size can be assumed for all regions considering the recommendations above.

5

Chapter

Load Profiling

Rooftop solar photovoltaic (PV) systems are an attractive option to reduce the amount of electricity taken from the grid during the day. To ensure cost-efficient sizing of a PV system, an understanding of the building load profile is vital. The aim of this chapter is to understand the substitution rate (coverage rate) of the total building load along with total electricity produced using a PV system.

5.1 Load Curves and Available Roof Area

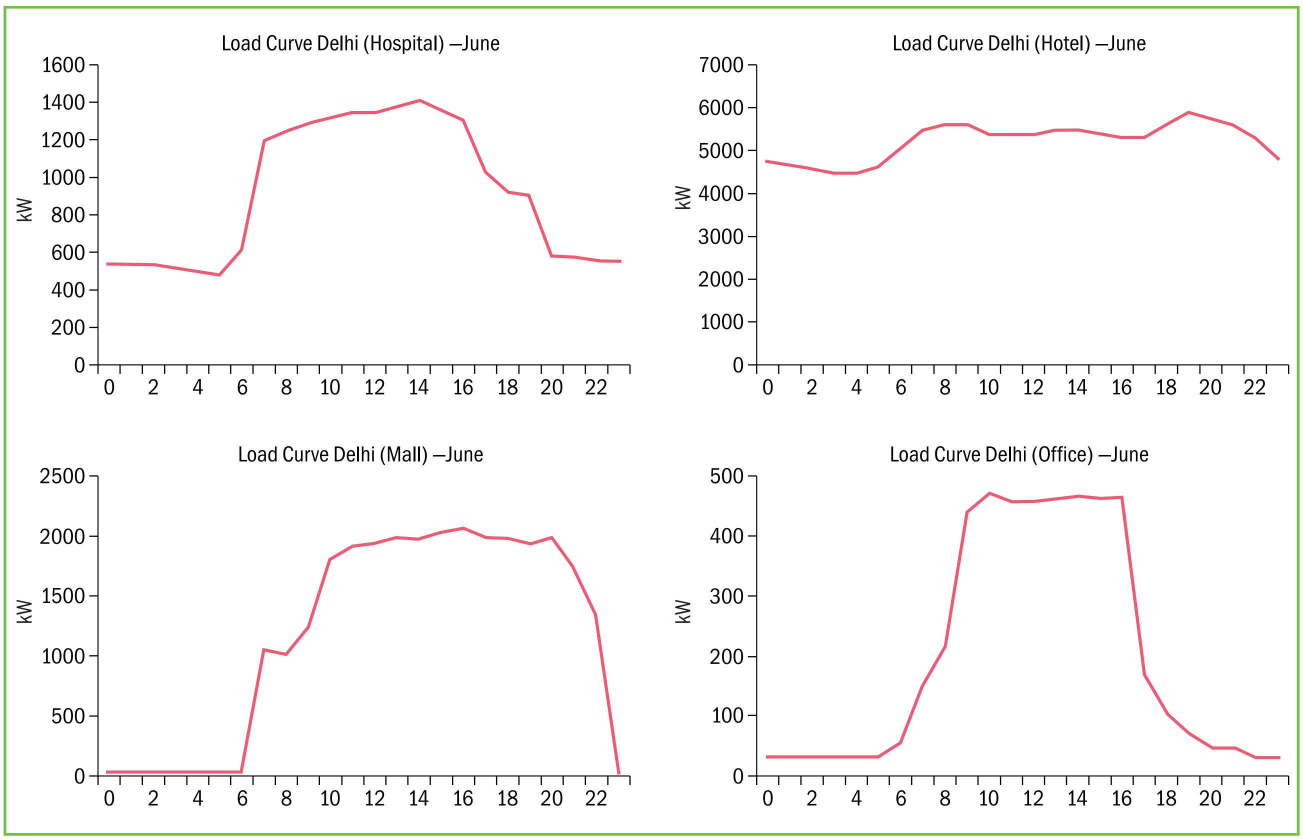


Figure 5.1: Hourly load curves for different building types

In the initial stage, typical load curves for selected commercial buildings have been reviewed. Over 400 buildings with a roof area suitable for a PV system have been assessed and the maximum coverage rates calculated.

The hourly load curves were calculated for a hotel, a hospital, an office building, and a shopping mall (Figure 5.1). For each month, daily load curves with an average hourly consumption were calculated.

The load curve comprises the entire energy consumption of the building for each application including lighting, electrical equipment and the heating, ventilation, and air conditioning (HVAC) system. For each month, the average hourly value for each application was determined and aggregated to calculate total hourly consumption.

The analysis of the buildings load curves shows that a large part of the building load originates from the HVAC system. The profiles of the various building load curves are therefore relatively similar. The greatest load occurs during day time, essentially because the HVAC system usually begins operation when the building becomes occupied. Accordingly, the starting point of the peak load varies slightly between building types. The shape of the load curve for the hotel deviates from that of the other buildings, where the peak is not as significant.

5.1.1 Load Curves and PV Production

After comparing hourly load curves with PV production curves, a PV system size with an AC power output of around 80 per cent of the buildings connected load has been considered. For each month, an hourly average PV production curve has been developed and compared with the hourly load curves of the buildings.

When comparing the production curve with the load curves for January and June (Figure 5.2), it becomes apparent that the profile of the load curves for both the office and hospital buildings corresponds well to the peak production curve. For these buildings, a high coverage rate can be expected.

For a mall building, the relationship between the load curve and the production curve changes between January and June. This will cause production losses because at some points along the curves there will be excess PV production compared to the building load curve. It can therefore be expected that the coverage rate will be slightly lower than that of the office and hospital buildings. To reduce the losses and increase the coverage rate, a battery may be desirable, depending on the cost of battery systems.

The comparison between load curves and production curves for a hotel building shows that PV can cover part of the buildings day time load, but the coverage rate is expected to be lower than that of the other building types.

5.1.2 Review of Rooftop Availability

The roof area of around 400 buildings has been analysed to determine what PV system size would be feasible. To calculate the feasible size of a PV system, the following assumptions have been made:

- Equipment installations, such as cooling towers, ventilation, etc., normally use part of the roof space. It is therefore assumed that around 40 per cent of the roof can be used for the installation of a PV system;
- The average PV power that can be installed per square metre of rooftop is around 100 W/m²;
- A performance ratio of 80 per cent can be assumed for a PV system installed on a flat roof in India.

The analysis of the various building types shows that most roofs are those of either institutions or offices, with a small number of buildings that are either hotels or industrial facilities (Figure 5.3).

The analysis shows that 66 per cent of buildings will support a PV system size up to 100 kW, whilst around 25 per cent of buildings could accommodate a medium-to-large-sized rooftop solar PV system of 100 kW to 500 kW (Figure 5.4).

5.1.3 PV Output for Self-Consumption and Coverage Rates

For the 400 buildings that had their rooftops analysed, annual consumption data was also available. With this information, it was possible to compare the consumption of buildings together with their PV production. This enabled the calculation of the coverage rate, defined as the ratio of PV production to building consumption. Around

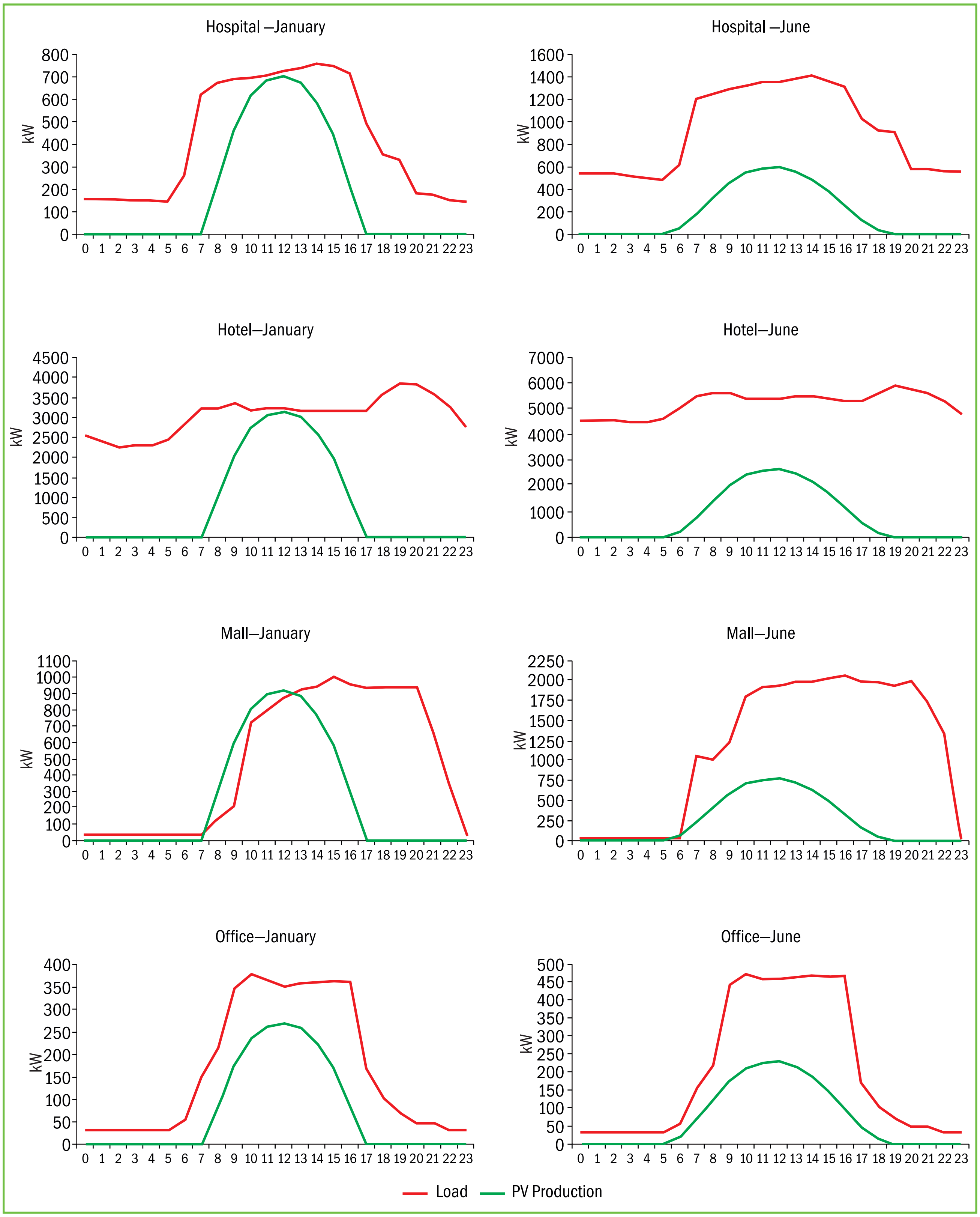


Figure 5.2: Comparison of building load with PV output

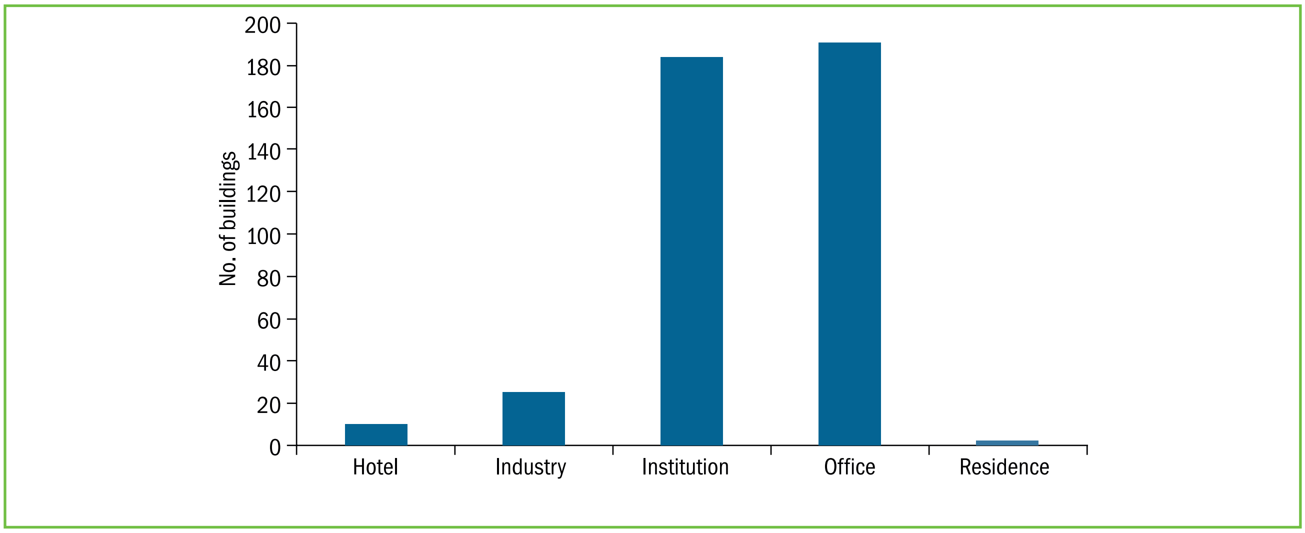


Figure 5.3: Distribution of building types

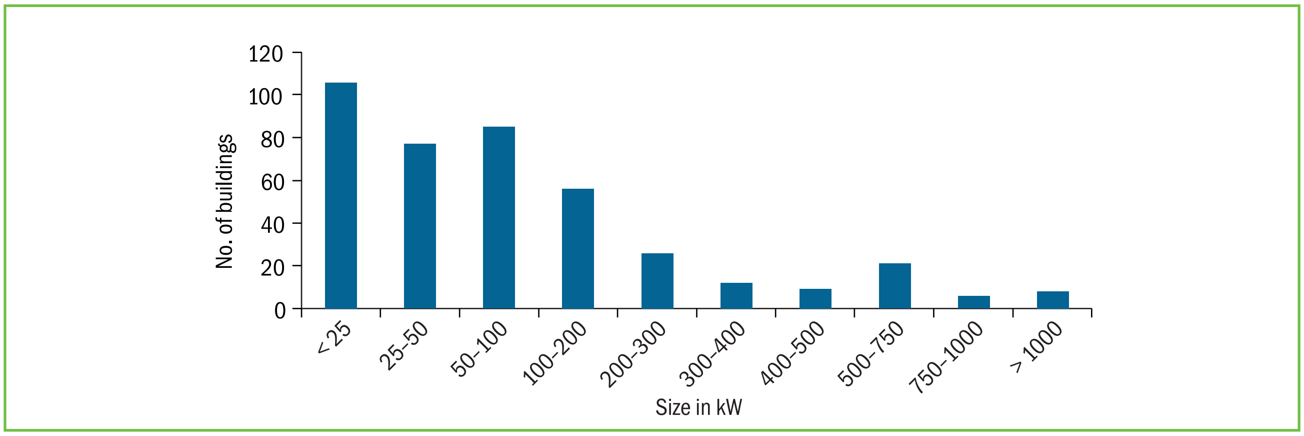


Figure 5.4 Estimated size (kW) of rooftop PV system

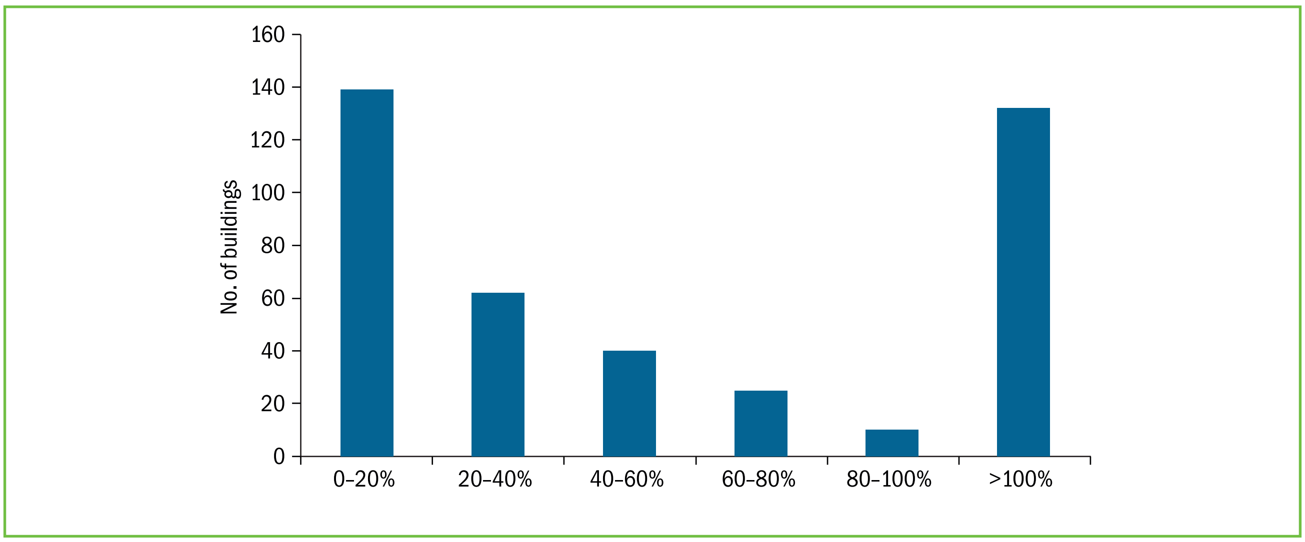


Figure 5.5: Percentage of building's annual energy consumption met by PV

35 per cent of the buildings were found to have a PV coverage rate of up to 20 per cent. A similar proportion of buildings had coverage rates greater than 100 per cent (Figure 5.5).

5.2 PV System Optimization for Different Applications

In this section, the results of the HOMER simulations are discussed to define potential applications for SPV systems. The applications are:

- **Self-consumption:** All of the PV production is used for meeting the building load. Most of the PV production is consumed at the time of production, and the excess energy generated is minimal.
- **Self-consumption and grid feed in**: Most of the PV production is used to cover the building load and the excess PV output is fed into the grid.
- **Multi-user application**: A PV system where a large fraction of the energy produced exceeds the on-site requirements and is transferred to other consumption sites.

To find criteria to differentiate the applications, HOMER simulations using different PV sizes have been performed. In India, many commercial and industrial buildings are equipped with diesel generators (DGs) for supplying power during grid outages. Therefore, simulations have also been carried out for hybrid systems with PV and DGs.

5.2.1 PV Only—Criteria for Applications

The first simulation with HOMER aimed to determine the optimal size of the PV system for the various load curves. The optimal PV size obtained from the simulation, with the exception of office buildings, is lower than the connected load of a building. On average, the difference between PV size and building connected load is around 14 per cent for Delhi and 17 per cent for Chennai (Table 5.1). Due to the variation in load curve profiles, the ratio between PV size and connected load can be used to determine the most appropriate application for each building.

The HOMER simulations also aim to understand the effects of different PV sizes on coverage rates and PV losses. For this purpose, several simulations for each building type have been carried out. The load curve for the building type is set as the fixed parameter, with varied building connected loads of 80 per cent, 100 per cent, 150 per cent, 250 per cent, and 500 per cent. The results of the simulation are shown in Table 5.2. Excess PV energy is defined as the amount of electricity produced by the PV system, which exceed the on-site consumption requirement at the time of production.

Table 5.1: PV System size and coverage rate—HOMER simulation results

Delhi	Hospital	Hotel	Mall	Office
Connected Load (kW)	1,610	6,700	2,360	520
Total Energy Consumption (kWh)	6,405,708	40,826,396	9,177,289	1,715,773
100% Load (kW)	1,610	6,700	2,360	520
HOMER Optimum PV Size (kW)	1,680	7,635	2,275	695
Annual Energy PV Production (kWh)	2,540,953	11,546,233	3,440,871	1,051,169
PV Coverage rate	39.8%	28.2%	38.3%	60.3%
Chennai				
Connected Load (kW)	1,610	6,700	2,360	520
Total Energy Consumption (kWh)	6,405,708	40,826,396	9,177,289	1,715,773
100% Load (kW)	1,610	6,700	2,360	520
HOMER Optimum PV Size (kW)	1,205	5,275	2,170	600
Annual Energy PV Production (kWh)	1,743,299	7,631,468	3,139,395	868,034
PV Coverage rate	28.0%	18.9%	35.0%	50.8%

Results show that a PV system that is 80 per cent of the connected load causes negligible PV excess production (PV energy not consumed) of around 1 per cent, with a coverage rate of between 20 per cent and 39 per cent. For a PV size that is 100 per cent of the connected load, excess generation increases to 6.4 per cent. It is therefore recommended that when the PV system is intended only for self-consumption, the PV system size should not exceed 80 per cent of the buildings connected load.

PV sizes above 80 per cent are suitable for both self-consumption and feeding into the grid. To avoid technical risks, it is recommended the PV system size is limited to 150 per cent of the connected load. To allow for this, installation of a battery is required, allowing an increased coverage rate.

Table 5.2: Effects of different PV sizes on coverage rates

Delhi				
	Hospital	**Hotel**	**Mall**	**Office**
Connected Load (kW)	1,610	6,700	2,360	520
Total energy consumption (kWh)	6,101,525	39,724,288	8,614,391	1,630,781
PV Size 80% of connected load (kW)	**1,290**	**5,360**	**1,890**	**420**
Total energy production (kWh)	6,242,038	40,351,504	8,814,486	1,675,915
Annual energy production by PV (kWh)	19,51,088	81,05,807	28,58,571	6,35,238
Percentage of total Energy Production	31.3%	20.1%	32.4%	37.9%
Annual PV power consumed (kWh)	1,933,509	8,052,335	2,820,900	635,115
Percentage of total energy consumption	31.7%	20.3%	32.7%	38.9%
Excess PV energy (kWh)	17,579	53,471	37,671	123
Percentage of total PV production	0.9%	0.7%	1.3%	0.0%
PV Size 100% of connected load (kW)	**1,610**	**6,700**	**2,360**	**520**
Total energy production (kWh)	6,242,038	40,351,504	8,814,486	1,675,915
Annual energy production by PV (kWh)	2,438,860	10,132,258	3,573,213	794,047
Percentage of total energy production	39.1%	25.1%	40.5%	47.4%
Annual PV power consumed (kWh)	2,318,789	9,813,229	3,345,063	789,112
Percentage of total energy consumption	38.0%	24.7%	38.8%	48.4%
Excess PV energy (kWh)	120,071	319,029	228,150	4,935
Percentage of total PV production	4.9%	3.1%	6.4%	0.6%
PV Size 150% of connected load	**2,415**	**10,050**	**3,540**	**780**
Total energy production (kWh)	6,242,038	40,351,504	8,814,486	1,675,915
Annual energy production by PV (kWh)	3,658,290	15,198,387	5,359,820	1,191,071
Percentage of total energy production	58.6%	37.7%	60.8%	71.1%
Annual PV power consumed (kWh)	2,973,539	12,919,474	4,192,693	1,057,312
Percentage of total energy consumption	48.7%	32.5%	48.7%	64.8%
Excess PV energy(kWh)	684,751	2,278,914	1,167,127	133,759
Percentage of total PV production	18.7%	15.0%	21.8%	11.2%
PV Size 250% of connected load	**4,025**	**16,750**	**5,900**	**1,300**
Total energy production (kWh)	6,242,038	40,351,504	8,814,486	1,675,915
Annual energy production by PV (kWh)	6,097,150	25,330,646	8,933,033	1,985,119
Percentage of total energy production	97.7%	62.8%	101.3%	118.4%

Delhi				
	Hospital	Hotel	Mall	Office
Annual PV power consumed (kWh)	3,562,012	15,760,648	4,881,793	1,253,694
Percentage of total energy consumption	58.4%	39.7%	56.7%	76.9%
Excess PV energy (kWh)	2,535,138	9,569,998	4,051,241	731,424
Percentage of total PV production	41.6%	37.8%	45.4%	36.8%
PV Size 500% of connected load	**8,050**	**33,500**	**11,800**	**2,600**
Total energy production (kWh)	6,242,038	40,351,504	8,814,486	1,675,915
Annual energy production by PV (kWh)	12,194,300	50,661,291	17,866,067	3,970,237
Percentage of total energy production	195.4%	125.5%	202.7%	236.9%
Annual PV power consumed (kWh)	4,023,139	18,145,523	5,444,311	1,373,745
Percentage of total energy consumption	65.9%	45.7%	63.2%	84.2%
Excess PV energy(kWh)	8,171,161	32,515,768	12,421,756	2,596,492
Percentage of total PV production	67.0%	64.2%	69.5%	65.4%

PV systems with a size above 150 per cent of the connected load are suitable for multi-user applications. For this system application, it can be expected that the grid connection has to be reworked to be able to carry the additional load or that a second grid connection has to be set up.

Considering the criteria above, the buildings can be sorted and assigned to an appropriate PV application. As shown in Figure 5.6, around 53 per cent of the PV systems have a capacity that is lower than 80 per cent of the connected load and are therefore ideal for self-consumption.

Around 32 per cent of buildings have a roof size that can accommodate PV systems with a capacity of more than 150 per cent of the buildings connected load. These buildings are therefore ideal for supplying power to third parties. However, regulations may prevent full utilization of building roof space if they do not allow connection of such systems to the grid to sell the electricity. Batteries can help to increase the PV system to a useful size but require additional investments.

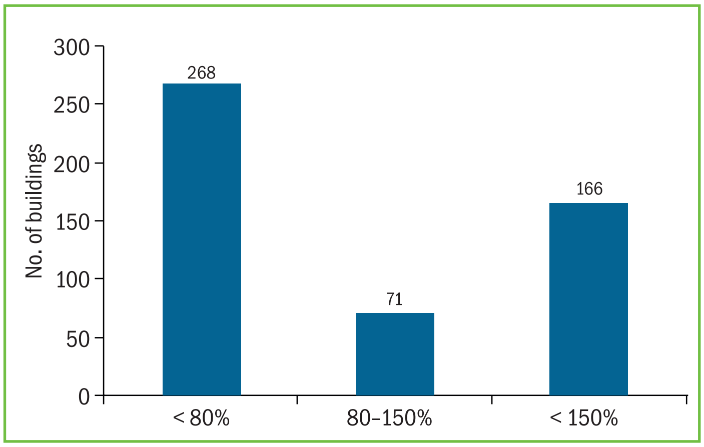


Figure 5.6: PV size as percentage of building-connected load

5.2.2 PV and DG with Grid Outage

In India, many cities experience frequent grid outages. Commercial and industrial facilities consequently use DGs as a backup system. To get some indication about the possible savings on diesel, a hybrid system with PV and DG has been simulated with HOMER. One simulation uses the load curve of a hospital with the PV system size taken as 80 per cent of the connected load. A second simulation was performed using the load curve of a mall building.

To understand the change in diesel consumption, each simulation has been carried out twice. The first run only uses the DG, whilst the second uses a DG plus PV system. Daily grid outages of four hours duration are assumed. The power of the DG corresponds with the connected load. For the simulation, the minimum part load of the DG is considered to be 30 per cent.

Table 5.3: PV and diesel hybrid system

Delhi		
Grid Outage—1 to 5 pm		
one DG—1 unit + PV		
	Hospital	Mall
Connected load (kW)	1,610	2,360
Total energy produced (kWh)	6,246,079	8,828,829
Total energy consumed (kWh)	6,094,557	8,604,130
PV size rate of connected load	80.00%	80.00%
Energy produced by PV (kWh)	1,951,088	2,858,571
Coverage rate of PV	31.24%	32.38%
Excess PV energy (kWh)	24,622	54,070
Excess PV energy [%]	1.26%	1.89%
DG power (kW)	1,610	2,360
Energy produced by DG (kWh)	998,664	1,615,645
Coverage rate of DG	15.99%	18.30%

The analysis shows that for a PV and diesel hybrid system, there is reduced operation of the DG (Table 5.3). We also consider integration of battery systems and PV. The capacity of the battery calculated with HOMER can provide power supply for around 20 minutes for a hospital and 16 minutes for a mall, assuming a fully charged battery and maximum consumption. Despite its small capacity, there is a clear impact on the PV system, with excess PV energy falling to nearly 0 per cent and allowing almost all the PV production to be used for self-consumption (Table 5.4).

Table 5.4: PV, battery, and diesel hybrid system

Delhi		
Grid Outage—1 to 5 pm		
DG—1 unit + PV +Battery		
	Hospital	Mall
Connected load (kW)	1,610	2,360
Total energy produced (kWh)	6,246,079	8,828,829
Total energy consumed (kWh)	6,094,557	8,604,130
PV size rate of connected load	80.00%	80.00%
Energy produced by PV (kWh)	1,951,088	2,858,571
Coverage rate of PV	31.24%	32.38%
Excess PV energy (kWh)	745	8,606
Excess PV energy	0.04%	0.30%
DG power (kW)	1,610	2,360
Energy produced by DG (kWh)	1,015,365	1,625,835
Coverage Rate of DG	16.26%	18.42%
Nominal capacity of battery (kWh)	1,142	1,276
Energy input to battery (kWh/yr)	96,347	128,625

Production of the DG slightly increases when a battery is added to the system. This is caused when the part load of DG is close to the minimum load ratio and the battery is charged by the DG itself.

5.3 Conclusions

In India, a large proportion of the electricity used in commercial buildings is consumed by the HVAC system. The daily electricity consumption pattern follows the irradiation levels and therefore, the PV output.

Whilst the load curves of office and hospital buildings are generally similar to the PV production curve, this is not always the case. Hotels do not have a distinct day time peak and the load curve for a shopping mall is shifted more to the afternoon. This difference between load curves leads to different proportions of consumption being covered by PV energy production.

The optimum size of a PV system for self-consumption is around 80 per cent of the building's connected load. In this case, between 20 per cent and 40 per cent of electricity consumption will be provided by the PV system. Around 50 per cent of the roofs of the reviewed buildings are suitable for PV systems with a maximum generator size of 80 per cent of the connected load or less.

PV systems that exceed the 80 per cent criteria will produce excess PV energy, which is not directly usable for on-site consumption. For PV systems that are greater than 150 per cent of the connected load, additional costs for strengthening the grid connection are required.

In India, a greater number of grid outages take place during the summer, so several commercial and office building run DGs for backup. PV systems can offer additional savings by substituting diesel power, which is more expensive than PV power.

For optimizing the coverage rate, battery systems can help to increase the self-consumption ratio.

Rooftop Solar Systems: Costs and Designs

6.1 Rooftop SPV Costs

To assess the cost of different sizes of rooftop solar photovoltaic (SPV) systems, a market survey was conducted among a sample of over 300 project developers. Seventy-one responses were received and aggregated. The aim of the survey was to obtain market information about the current cost of small to large rooftop SPV systems, as well as the expected cost of SPV systems over the next two to five years.

As shown in Figure 6.1, there is a large cost differential associated with the size of rooftop SPV system. A small system of 5 kW or less costs over 100 Rs/Wp while for a large system of 500 kW or more, the system cost is 64.5 Rs/Wp, showing around a 35 per cent cost difference between small to large rooftop SPV system.

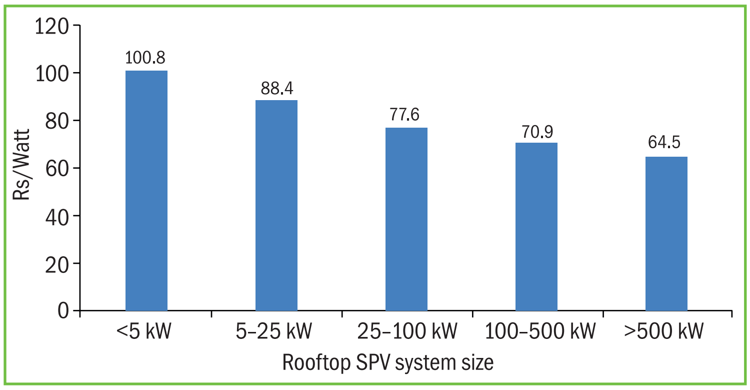


Figure 6.1: Rooftop SPV system cost for different system sizes

SPV costs have seen a dramatic decline in recent years. Further price reductions are expected over the next two to five years. According to the market survey, there is the possibility of around a 14.7 per cent price drop by 2017 and a decline in costs of 25.9 per cent by 2020 (Figure 6.2).

A rooftop SPV system consists of several components such as solar panels, inverters, mounting structures, cables wires and accessories, balance of system including metre and data monitoring equipment, design and project management including civil works, and project insurances.

The cost breakdown for six mid-to-large-sized projects installed over the past two years have been analysed. As shown in Table 6.1, solar panels constitute over half (54 per cent) of the SPV system cost. Inverters and mounting structures consist of

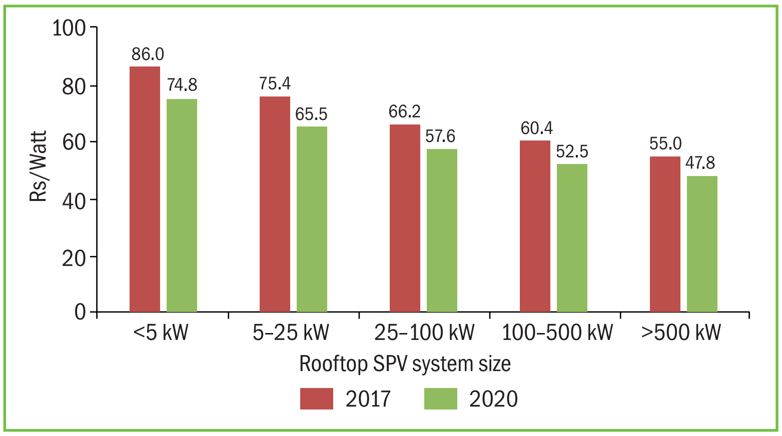


Figure 6.2: Expected Rooftop SPV System cost by 2017 and 2020

Table 6.1: Breakdown of rooftop SPV system cost across components

Rooftop SPV System Size	60 kW	100 kW	180 kW	200 kW	250 kW	500 kW	Average	Average
Components	**Price (Rs/W)**	**Price (Rs/W)**	**Price (Rs/W)**	**Price (Rs/W)**	**Price (Rs/W)**	**Price (Rs/W)**	**Price (Rs/W)**	**Percentage**
Solar Modules Including Freight	36.5	36.5	36.5	36.5	36.5	36.5	36.5	54%
Inverters (String Inverters)	10.0	9.5	8.5	8.0	8.0	7.0	8.5	13%
Mounting Structure	6.0	5.5	5.5	5.5	5.5	4.5	5.4	8%
Cables, Wire Ties, Accessories	3.0	3.0	3.0	3.0	3.0	3.0	3.0	4%
Balance of System Including Metre, Data Monitoring	7.0	6.5	6.0	6.0	5.5	5.5	6.1	9%
Design, Project Management, Installation, Loading, Unloading, Civil	8.0	8.0	7.0	6.5	6.5	6.0	7.0	10%
Project Insurances	0.4	0.7	1.2	1.3	1.6	3.1	1.4	2%
Total	71	70	68	67	67	66	68	100%

an additional 20 per cent of the cost. Overall, solar panels, inverters, and mounting structures add up to two-third (75 per cent) of the total cost of a rooftop SPV system.

The remaining 25 per cent of the system cost consists of components such as the cables, wires, and accessories along with balance of system costs, which include metre and data monitoring equipment, design, and project management (civil works and project insurances).

For PV systems provided with battery backup, the cost of the battery can add substantial cost. A study conducted by TERI in 2014 for solar mini-grids for off-grid applications showed that for six hours of power backup, the additional cost of the battery is in the range of 30 per cent to 25 per cent of the total system cost as shown in Table 6.2.

Table 6.2: Battery cost as percentage of total system cost

Company	PV System Cost (Rs/Wp)	Battery Cost (Percentage of system cost)
ADS Projects, New Delhi	170	25%
Deepa Solar System, Bengaluru	170	25%
Luminous Power, Gurgaon	180	30%
Onergy Systems Pvt. Ltd, Kolkata	180	25%
Sunsource Energy Pvt. Ltd, New Delhi	160	25%
Vikram Solar Pvt. Ltd, Kolkata	170	30%
Average	172	27%

Additionally, HOMER simulations were performed for an office building load (Chapter 5) with a 400 kW PV system. A battery capacity suitable for a maximum of three hours grid outage has been considered, from 12 noon to 3 pm. The HOMER simulation estimated that to serve the buildings load, 33 battery strings would be required, with each battery string being of 48 V, 1400 Ah capacity. A market assessment obtained the cost of batteries for this capacity, which is around Rs 601,759 per battery string, meaning the total cost of 33 battery strings is

Rs 19,858,048. The PV system cost is 70.9 Rs/Wp (Figure 6.1). The total cost of a 400-kW system including the battery is therefore Rs 49,068,848, with the cost of the battery constituting 40.5 per cent of the total system cost.

6.2 PV System Design

PV System Configurations

Designing a PV System is a multistage process that includes site selection, preliminary design, detailed design, installation, and inspections tests. For rooftop applications, typically three types of rooftop PV systems configurations are:

- Grid + PV only
- Grid + PV + diesel generator (DG)
- Grid + PV + Battery

Grid + PV only

For this type of SPV configuration, the PV system is connected to the low tension panel of the building, which is connected to the grid. The inverters prioritize the PV power over the grid power and supply the power generated by the PV module to connected loads, with any shortfall being met by the grid. If the electrical load is less than that of the power generated by PV, the excess power is fed to the grid. A sample single line diagram is shown in Figure 6.3.

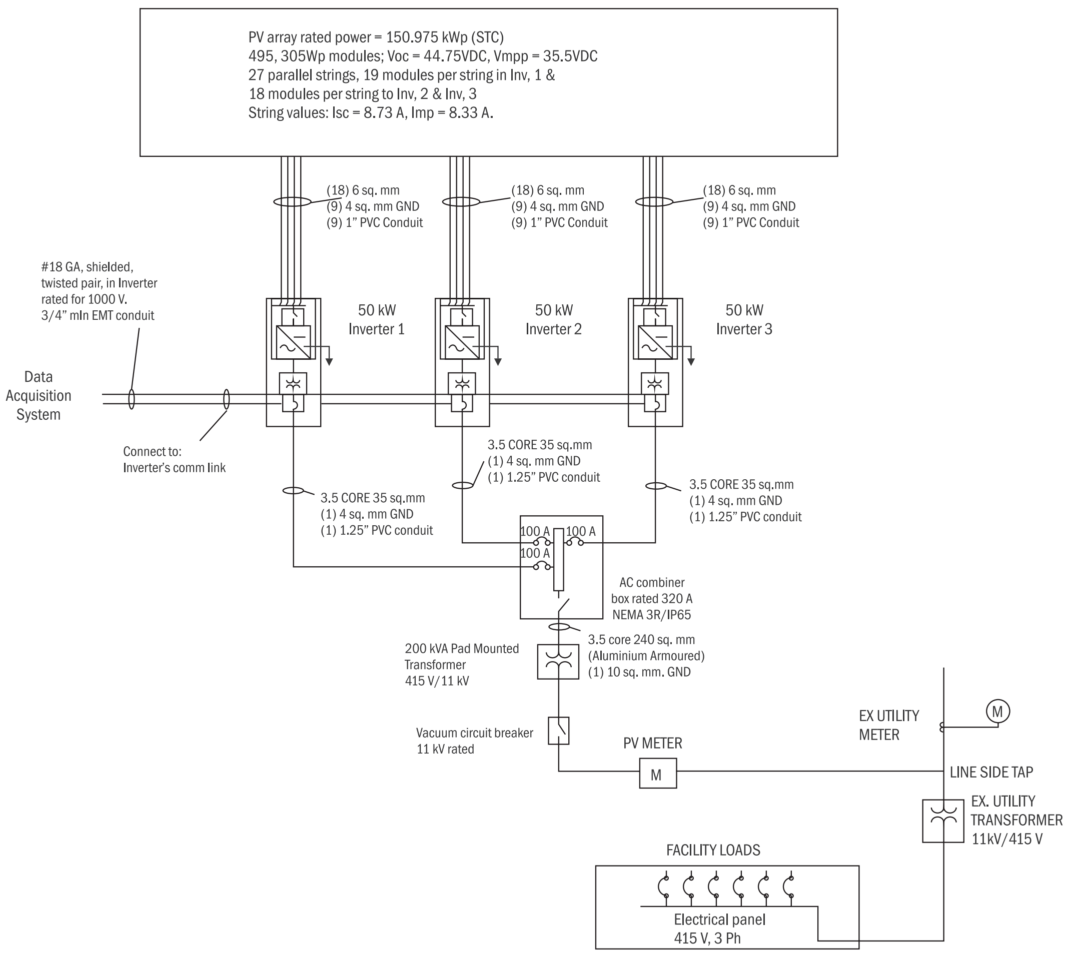


Figure 6.3: Single line diagram for a 150 kWp Grid + PV only system

In this diagram, a system of 150 kWp uses three 50-kW string inverters. The combined output of the inverters is then stepped up to 11 kV and connected to the building load using supply side tap. Equipment standards are discussed in Section 6.2.4.

Figure 6.4 is an example of a grid-connected system which is below 100 kW and does not need to be connected at 11 kV. This system is connected to the buildings main distribution panel and serves the building load directly.

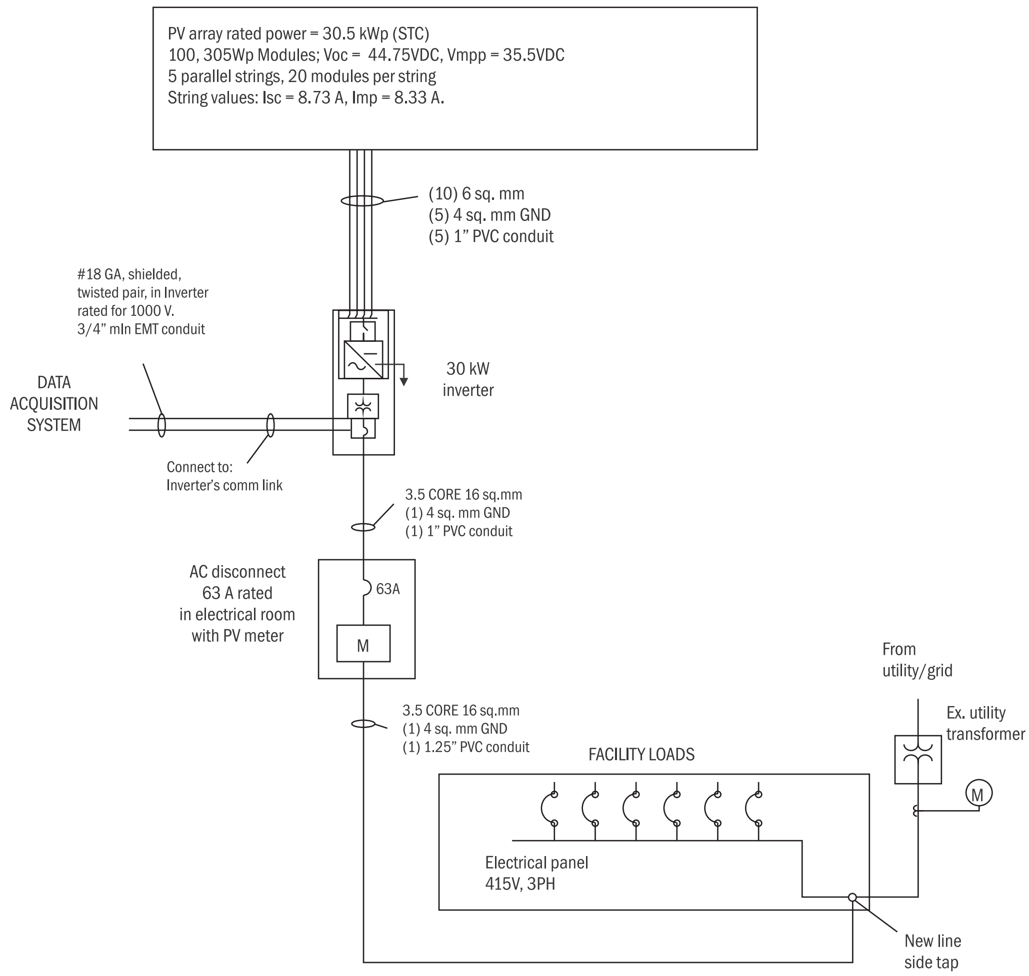


Figure 6.4: Single line diagram for a 30 kWp Grid + PV only system

Grid+ PV + DG

DG serves as the backup power when the grid is out. When the DG is running along with the PV, DG provides the reference power along with any additional power to bridge any shortfall in supply (when the facility loads are greater than that generated from PV). A situation known as 'DG Backfeeding' can occur if the excess power from the PV system feeds back into the DG. In order to prevent this, a smart controller is installed that controls the PV output in cases where the connected load is less than the output from the PV system. A single line diagram for such a situation is given in Figure 6.5.

Grid+ PV + Battery

For this type of system, either the battery or grid can be prioritized for SPV output. If it is set to Solar > Grid > Battery, the operating mechanism will be as follows:

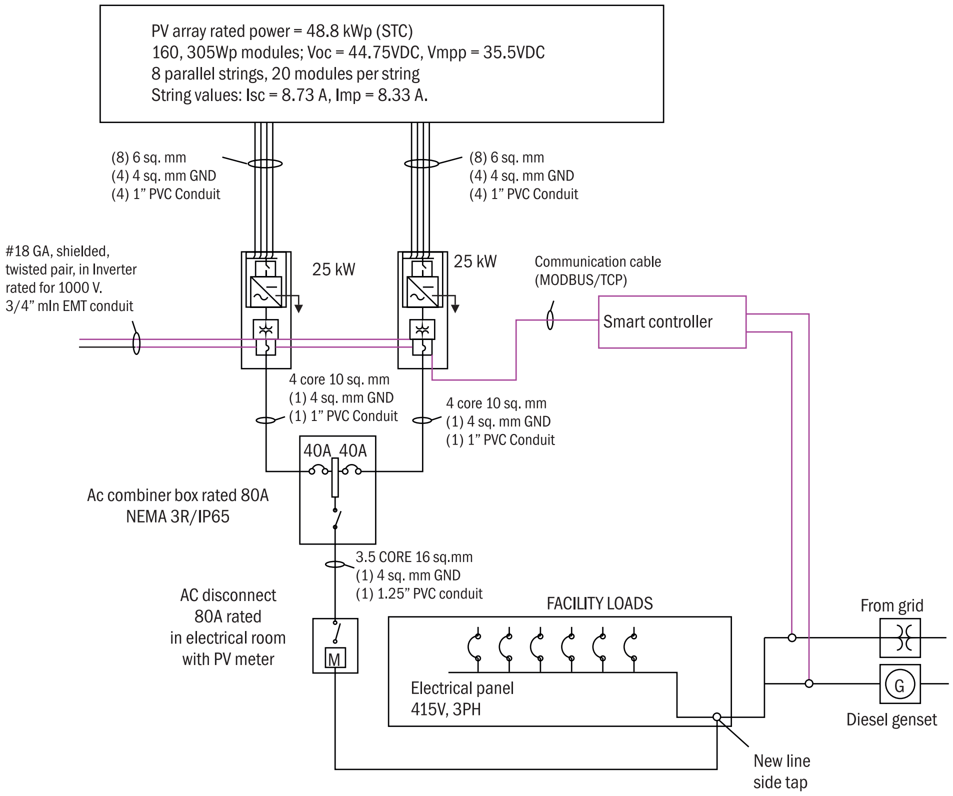


Figure 6.5: Single line diagram for a Grid + PV + DG system

- When solar power output is sufficient to meet the facility loads, it will operate on solar through maximum power point tracker (MPPT) and Inverter. Excess solar power will charge batteries;
- When solar output is weak, the inverter takes direct current (DC) source from solar and the remaining balance from the grid;
- When solar output is not available, the entire load relies on the grid via grid charger;
- When the grid is not available, the load will work off the system batteries until the grid energy resumes. In which case, the load will be shifted back to the grid. During this sequence, any discharge of batteries will be replenished via the grid and available solar;
- The operational logic will work with a zero transfer time for sensitive loads.

If the priority is set to Solar > Battery > Grid, then the operating mechanism will be as follows:

- When solar output is sufficient, then total operational load will operate on solar through MPPT and inverter. Excess solar power will charge batteries;
- When solar energy is weak, then inverter is takes DC source from solar and balance from batteries;
- When batteries reach a discharge level of 75 per cent (25 per cent kept as buffer), the operational load switches to the grid without any change over time;
- After shifting the load to the grid, the batteries are charged from solar energy. If solar energy is not sufficient to charge the batteries; the remaining DC power is taken from the grid charger. Once the batteries are fully charged, the load switches back onto battery backup from grid;

- When the load switches from battery backup to grid supply (i.e., 75 per cent battery discharged) and if grid supply is not available, the load shifts to the inverter to use the buffer battery backup (i.e., balance 25 per cent);
- When grid power returns, during which inverter is working on buffer battery backup, the load shifts to the grid and the batteries are charged through either solar power or from the grid;
- Single line diagram for such a system is given below in Figure 6.6.

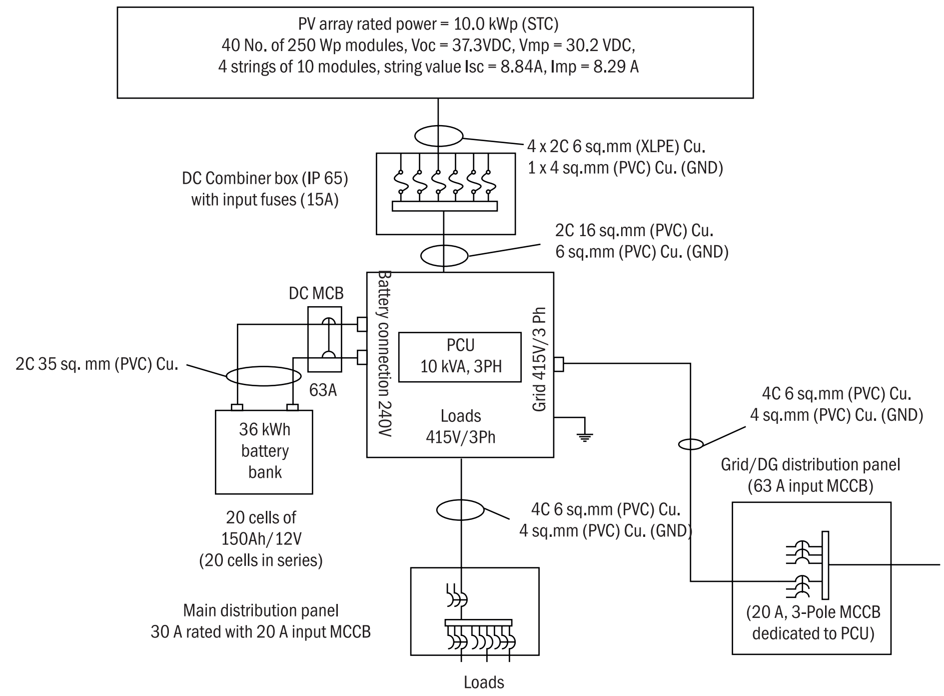


Figure 6.6: Single line diagram for a Grid + PV + battery system

6.2.1 Site Selection

Site Audit

A site audit is an important first step towards developing a robust PV system design. The process involves:

- Filling out the detailed site survey form, which includes a rough sketch of the roof of the building with all the dimensions and all the obstructions marked out. A sample site survey form is presented in Annexure A 6.1;
- Photographs should be taken from all the directions so that all the existing structures can be related to the sketches;
- For industrial sheds, an analysis should be done for checking the roof strength and stability;
- For reinforced cement concrete (RCC) roofs, a drill test should be performed to determine the depth of the RCC slab of the building. This will help to determine the length of fasteners to be used to anchor the mounting structure into the rooftop. Also, one should know the age and condition of the rooftop to ensure the structural integrity of a facility;
- Information regarding interconnection points and the distance from the SPV plant should be gathered. There shall be sufficient space in the electrical panel for SPV interconnection. Ratings of the existing electrical equipment should be taken to avoid any compatibility issues.

Roof Selection

Roof selection should include the following parameters:

- Load bearing capacity of the roof;
- Surrounding obstructions;
- The pitch angle, and the south-facing portion of the shed (industrial sheds);
- Location of the interconnection point; and
- Access to the roof for operation and maintenance.

6.2.2 Preliminary Design

Before designing the layout, it is important to estimate the optimum tilt angle for the solar modules, which will result in maximum generation. Typically, the optimum tilt is equal to the latitude of the location at which the SPV system is installed. The optimum tilt angle can alternatively be obtained through simulation with use of software packages like PVSyst, and HOMER. The inter-row space is calculated with the same procedure as shading analysis. It is ensured that one row of panels does not cast a shadow on the other row for the peak generating period in the day. With use of all the above information, a preliminary layout is produced. A typical layout for a rooftop solar system is given in Figure 6.7.

Figure 6.7: Typical rooftop SPV system layout

6.2.3 Mounting Systems

There are several types of mounting system that are suitable for different types of rooftop SPV installations.

Penetrating roof mount

This type of mounting system is generally anchored onto the roof with the help of fasteners (chemical or mechanical). The fasteners are connected to the RCC slab of the building and the mounting structure legs. A typical penetrating roof mount structure is shown in Figure 6.8.

Figure 6.8: Penetrating roof mounting system

Ballasted Systems

This type of mounting system is used to prevent drill holes in the roof and is used when there are water seepage issues or a waterproofing layer on the roof which cannot be damaged. On the mounting structure, counter weights are designed and placed to hold the SPV structure to the roof in case of high winds (using the wind zone classification). A typical ballasted mounting system is shown in the Figure 6.9.

Figure 6.9: Ballasted roof mounting System

Mountings for Industrial Sheds

This type of mounting typically uses rails, brackets for holding modules and attachments for integrating the system to roof purlins. A typical shed mount system is shown in Figure 6.10.

Rooftop Canopies

This type of mounting system is used for instances such as mounting solar modules on open parking lot roofs and roofs of parking garage buildings. However, it must be insured that these canopy type solar installations comply with local building codes. A typical canopy mount system is shown in Figure 6.11.

In India, several organizations are engaged with the manufacture and supply of mounting systems, notably:

- SNS Corporation
- Ganges Internationale
- SAPA
- Arctech Solar
- Schletter Inc.
- Smartrac
- Nuevosol
- NEPC India
- Solar Cube
- Mecasolar

Figure 6.10: Mounting system for industrial sheds

Figure 6.11: Canopy type mounting system

6.2.4 Detailed Design

The detailed design of a rooftop SPV system includes selection of system components such as PV modules, inverters, mountings, cables, and wires. The components need to adhere to established standards and codes. In this section, the selection criteria for the various rooftop SPV system components is described:

SPV Module

- The PV modules must qualify to International Electrotechnical Commission (IEC) 61215 for crystalline silicon modules and IEC 61646 in case of thin film modules;
- In addition, PV modules must qualify to IEC 61730 for safety qualification testing. For the PV modules to be used in a highly corrosive atmosphere throughout their lifetime, they must qualify to IEC 61701;
- SPV module conversion efficiency should be as per IEC specification and the cell should have a minimum fill factor of 0.7 for crystalline technology module;

- The module frame shall be made of corrosion resistant materials, preferably having an aluminium anodized finish in case of crystalline modules;
- The rated output power of any supplied module shall have a tolerance of –0/+3 per cent;
- The module shall be provided with an IEC approved junction box that either has an external screw terminal connection or is sealed with arrangement for the provision of a by-pass diode. The box shall have a hinged, weather proof lid with captive screws, and cable gland entry points or may be of a IP-65 rated sealed type;
- Modules deployed must use a RF identification tag. The following information must be mentioned in the RFID used on each module (this can be inside or outside the laminate, but must be able to withstand harsh environmental conditions);
  - Name of the manufacturer of the PV module;
  - Name of the manufacturer of solar cells;
  - Month and year of manufacture (separate for solar cells and modules);
  - Country of origin (separately for solar cells and module);
  - I-V curve for the module Wattage, Imp, Vmp, Voc, Isc, and FF for the module;
  - Unique serial no. and model no. of the module;
  - Date and year of obtaining IEC PV module qualification certificate;
  - Name of the test lab issuing IEC certificate; and
  - Other relevant information on traceability of solar cells and module as per ISO 9001 and ISO 14001;
- The module manufacturer must follow the test procedures laid out in the IEC guidelines. To ensure superior quality of PV modules, several manufactures of Tier-1 PV modules adopt testing protocols that exceed the IEC guidelines (Table 6.3).

Table 6.3: Testing protocols for few superior quality PV modules

	Module manufacturers			
Testing items	**IEC guidelines**	**Manufacturer I**	**Manufacturer II**	**Manufacturer III**
Damp heat (85°C /85% RH)	1000 Hrs	2000 Hrs	1500 Hrs	2000 Hrs
Temperature cycles (–40°C to 85°C)	200 Cycles	400 Cycles	300 Cycles	400 Cycles
Humidity freeze	10 Cycles	20 Cycles	15 Cycles	20 -40 Cycles
IEC UV+60	15 kWh/m^2	30 kWh/m^2	60 kWh/m^2	30 kWh/m^2
Mechanical load	2400 Pa	5400 Pa	5400 Pa	10000 Pa
Reverse current	135%	NA	200%	135%

Inverter

Since a SPV array produces DC electricity, it is necessary to convert this DC into alternating current (AC) and adjust the voltage levels to match the grid voltage. This is achieved through an electronic inverter and the associated control and protection devices. These system components are termed 'Power Conditioning Unit (PCU)'. In addition, the PCU shall also house MPPT, an interface between the SPV array and the inverter, and the power conditioning unit/inverter should also be DG set interactive. Typical technical features of the inverter shall be as follows:

- Switching devices: IGBT/MOSFET
- Control: Microprocessor/DSP
- Nominal AC output voltage and frequency: 415V, 3 Phase, 50 Hz
- Output frequency: 50 Hz
- Grid Frequency Synchronization range: +3 Hz or more
- Ambient temperature considered: –20°C to 50°C

- Humidity: 95 per cent non-condensing
- Protection of Enclosure: IP-20 (minimum) for indoor and IP-65 (minimum) for outdoor.
- Grid Frequency Tolerance range: 3 per cent or more
- Grid Voltage tolerance: –20 per cent and +15 per cent
- No-load losses: Less than 1 per cent of rated power
- Inverter efficiency(minimum): >93 per cent
- Total harmonic distortion: <3 per cent
- Power factor: >0.9

Inverters should adhere to the following codes and standards:

- Anti-islanding protection/grid regulation: IEC 61727; IEC 62116; Indian standard are equivalent to IEC, German versions are DIN VDE 0124-100; DIN VDE V 0126-1-1;
- EMC/EMI Filters: IEC 61000, IS (Equivalent to IEC 61000), German version is EN 61000;
- Safety: IS/IEC 62109/EN 62109 for protection against Electric shock, Fire, Mechanical and other hazards;
- Environmental testing : IEC 60068-2-1; IEC 60068-2-2; IEC 60068-2-14; IEC 60068-2-30; IEC 60068-2-6; IEC 60068-2-21 (Indian and German standards are equivalent to above mentioned IEC codes for environmental safety and these codes are applicable to charge controller and MPPT units); and
- Ingress protection: IEC 60529: 1989/A1:1999 for low power inverters, IEC 60529 EDITION 2.1 2001-02 for high power inverters. IS (Equivalent to IEC 60529) and German version for same is EN 60529:1999+A1.

Mounting System

Hot dip galvanized MS mounting structures can be used for mounting the modules, panels and arrays. Each structure should have an angle of inclination as per the site conditions to make maximum use of the available insolation. However, to accommodate more capacity the angle inclination may be reduced until the plant meets the specified performance ratio requirements. The Mounting structure shall be designed to withstand the speed for the wind zone of the location where a PV system is proposed to be installed.

- A suitable fastening arrangement such as grouting and calming should be provided to secure the installation against the specific wind speed;
- The mounting structure steel shall be as per latest IS 2062: 1992 and galvanization of the mounting structure shall be in compliance of latest IS4759;
- The structural material shall be corrosion resistant and electrolytically compatible with the materials used in the module frame, including fasteners, nuts, and bolts. Aluminium structures also can be used which can withstand the wind speed of respective wind zone. Necessary protection towards rusting need to be provided either by coating or through anodization;
- The fasteners used should be made of stainless steel. The structures shall be designed to allow easy replacement of any module. The array structure shall be so designed that it will occupy minimum space without sacrificing the output from the SPV panels;
- Civil structures shall be designed to account for the load baring capacity of the roof;
- The total load of the structure (when installed with PV modules) on the terrace should be less than 60 kg/m^2.

Cables and Cable Joints

All the cables used in outdoor conditions should be XLPE/XLPO insulated. Cables of appropriate size to be used in the system shall have the following characteristics:

- Meet IEC 60227/IS 694, IEC 60502/IS1554 standards;
- Temperature range: –10°C to +80°C;
- Voltage rating: 1000 V;

- Excellent resistance to heat, cold, water, oil, abrasion, UV radiation;
- Flexibility;
- The size of the cables between array interconnections, array to junction boxes, junction boxes to inverter, etc. shall be sufficient to keep the voltage drop (power loss) of the entire SPV system to a minimum. The cables (as per IS) should be insulated with a special grade PVC compound formulated for outdoor use;
- Cable Routing/Marking: All cable/wires are to be routed in a GI cable tray and suitably tagged and marked with proper manner by good quality ferule or by other means so that the cable easily identified;
- The cable should be so selected that it should be compatible up to the life of the SPV panels, that is, 25 years;
- Multi-strand, annealed high conductivity copper conductor PVC type 'A' pressure extruded insulation or XLPE insulation. Overall PVC/XLPE insulation for UV protection armoured cable for underground laying. All cable trays including covers to be provided. All cables conform to latest edition of IEC/equivalent BIS Standards: BoS item / component Standard Description Standard Number Cables General Test and Measuring Methods, PVC/XLPE insulated cables for working Voltage up to and including 1100 V, UV resistant for outdoor installation IS /IEC 69947;
- The size of each type of DC cable selected shall be based on minimum voltage drop; however, the maximum drop shall be limited to 1 per cent;
- The size of each type of AC cable selected shall be based on minimum voltage drop however; the maximum drop shall be limited to 2 per cent.

Conduits/Cable trays

When using conduits in outdoor conditions, UV protected conduits and cable trays should be used. Conduit material should be PVC Sch.40/Sch.80 for longer life span. Cable trays should be made of galvanized iron or aluminium, so that they are rust free and have longer life span.

Combiners and Junction boxes

For outdoor conditions, boxes should be IP65/NEMA 3R rated, so that all the electrical/electronic components are safe from environmental factors. All the electrical/ electronic equipment should be rated appropriately with regard to the temperature derating factors. Below are the standards which these boxes should adhere to:

IEC 529: For ingress tolerance of enclosures (IP 65 protection) and IEC 61439.

DIN EN 50548 (VDE 0126-5): 2012-02 (Germany)—Junction boxes for PV Modules.

IS 2148 & IS 6381: For flame proof and increased safety junction box.

Overcurrent and overvoltage protection equipment

- IS 3106—Code of practice for selection and installation and maintenance of fuses;
- IS 60947/IEC 60947 9 Part(I, II, III)—Code of practice for over voltage and over current protection;
- EN 50521 (German version)—For over voltage and over current protection;
- DIN EN 62305-3 (German Version)—For lightening and overvoltage protection of PV power supply;

Metering

HT connections (11 kV and above)—the applicable meter can be a bidirectional meter (Category B) and has to comply with the existing IS-14697 and IS 15959 standards.

LT connections (below 11kV)—the applicable meter shall comply with the existing meter standards IS-13779 and IS-15959 (Indian Standards for Data Exchange for electricity meters).

The meters shall adhere to the standards for consumers specified by the Central Electricity Authority (Installation and Operation of Meters) Regulations, 2006, and Central Electricity Authority (Installation and Operation of meters) Amendment Regulations, 2010.

Electrical Plans

Electrical plans include wiring and equipment layouts. Wiring includes typical arrangement of series and parallel strings of modules, their connections to inverters or junction boxes, and the wiring up to interconnection points. A typical electrical wiring layout is shown in Figure 6.12.

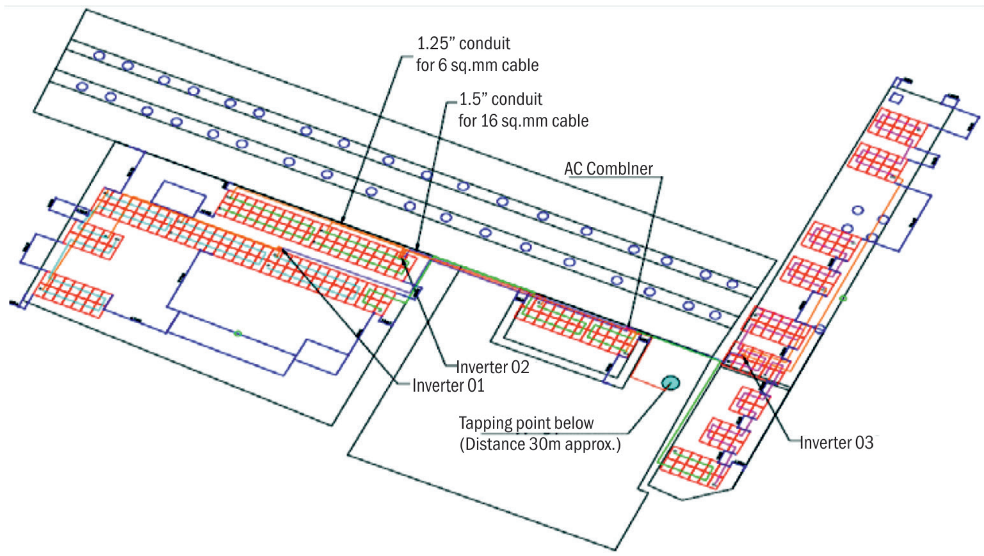


Figure 6.12: Typical electrical layout of a rooftop SPV system

Structural drawings and analysis

Drawings for the mounting structure are produced depending upon the roof conditions and environmental conditions. The different types of mounting structures are discussed in the section on preliminary design. A typical mounting structure drawing is shown in Figure 6.13.

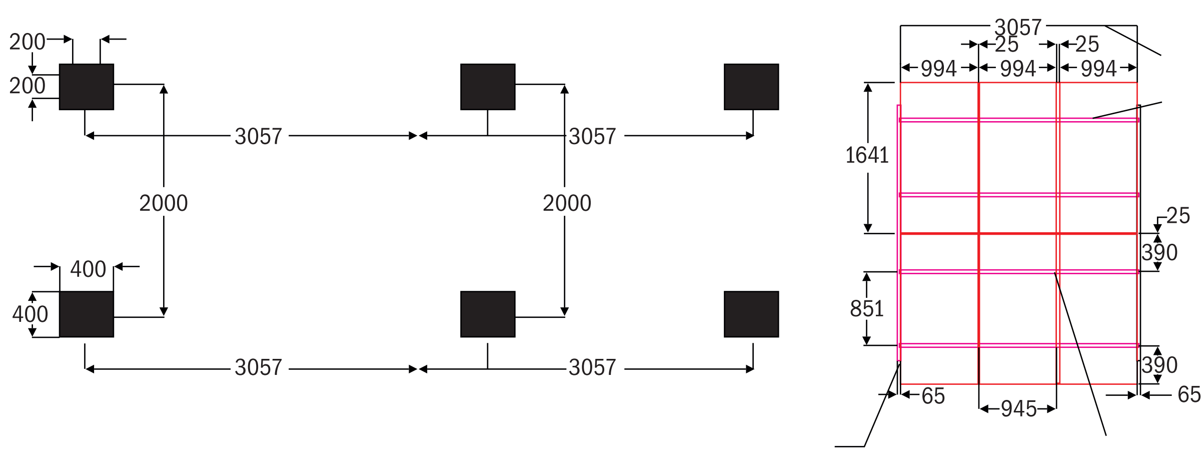


Figure 6.13: Structural layout of a rooftop SPV system

Structural simulations are conducted with the help of software packages to find out whether the structure can actually take the load of design wind speed, dead load, and other environmental factors. Multiple software packages are used such as (STAAD Pro and ANSYS. Most commonly used structure materials are galvanized iron and aluminium. Figure 6.14 shows a sample structural analysis simulation.

Voltage drop calculations over cable lengths

Cable sizing is done based upon the current carrying capacity of the cables and the lengths across the runs. The power loss due to cables should be limited to 2 per cent to 15 per cent at the DC and 0.5 per cent at AC for the whole system. A sample calculation for estimation of cable length and voltage drop is shown in Annexure A 6.2.

Structure Design

Introduction

Silicon Crystalline Module mounting structure is analysed on software Staad proV8i for a basic wind speed of 41 m/sec.

General Arrangement

The structure consists of 4 supports to mount 4 module of size 1640 mm x 992 mm x 40 mm. The modules are placed in landscape orientation in four rows.

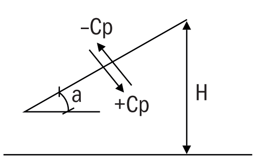
Load Calculation

Dead Load:

- Size of solar panel = 1640 mm x 992 mm.
- Solar panel is kept at an inclination of 15 degrees.
- Weight of single solar panel = 20 kg (as per data sheet of the module)
- Force due to one solar panel of 20 kg = 0.2 kN.
- The dead weight of the modules acts in vertically downward direction.
- Force per metre on C purlins = 0.2 / (2x0.992) = 0.101 kN/m

Wind Load:

- The structure is designed for Vb = 41 m/sec.



SIGN CONVENTION
+VE TOWARDS STRUCTURE
–VE DISTANCE AWAY FROM STRUCTURE

- Design wind speed = Vz = Vb x k1 x k2 x k3
- k1 (Probability factor) = 0.9
- k2 (Terrain, height and structure size factor) = 1.0
- k3 (Topography factor) = 1 (as the site is levelled. Topography is only considered in the regions where the slope is more than 3 degrees such as cliff of hills, mountains and valleys.)
- Vz = 36.9 m/s
- Wind pressure intensity Pz = 0.6 (Vz)2 = 0.816 kN/m^2

Pressure Coefficient:

- For calculating the force on the panels from the pressure calculated above we need pressure coefficient. The current structure falls under mono-slope free roofs.
- The pressure coefficients for a mono-slope free roof of 15 degrees tilt angle, with a solidarity ratio of 0.2:
  - o 1.16 when wind is trying to lift the structure.
  - o 0.8 when wind is trying to push the structure.

Force per metre calculation:

Wind Load trying to uplift the structure

- Total upward force due to wind on each module
  = Pressure coeff. x pressure x exposed area
  = 1.16 x 0.816 x 1.640 x 0.992 = 1.539 kN.
- Force on purlins normal to the plane of module
  = 1.16 x 0.816 x (1.640/2) = 0.736 kN/m.

Wind load trying to push the structure downward

- Total downward force due to wind on each module
  = Pressure coefficient x pressure x exposed area
  = 0.8 x 0.816 x 1.640 x 0.992 = 1.062 kN.
- Force on the purlins normal to the plane of the module
  = 0.8 x 0.816 x (1.640/2) = 0.535 kN/m.

Load combination – to be used for structural analysis

a) DL + WL1   b) DL + WL2

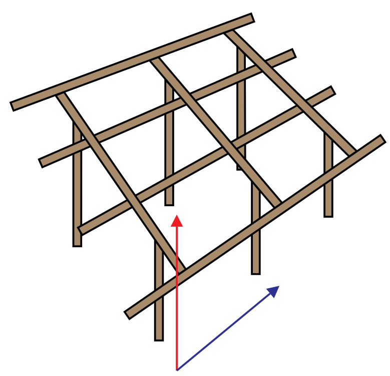


Figure 6.14: Structural simulation analysis of a rooftop SPV system

Interconnection

According to CEA, SPV should be connected at the low voltage end for capacities of less than 100 kW and at medium voltage end for capacities of more than 100 kW. But generally, systems with a capacity of up to 500 kW are connected on the LV side if the power is used for captive consumption. This helps in reducing the costs as well as increasing plant efficiency.

Monitoring

Monitoring is very important to ascertain the plants performance. Several online monitoring platforms options are available, which help in analysing the plant performance and can be used to identify any issues. Parameters such as power, DC and AC voltage, DC and AC current, cumulative energy, irradiance, temperature, etc. can be seen on an hourly, daily, monthly, or yearly basis. Screenshot of such a monitoring platform with a running plant is shown in Figure 6.15.

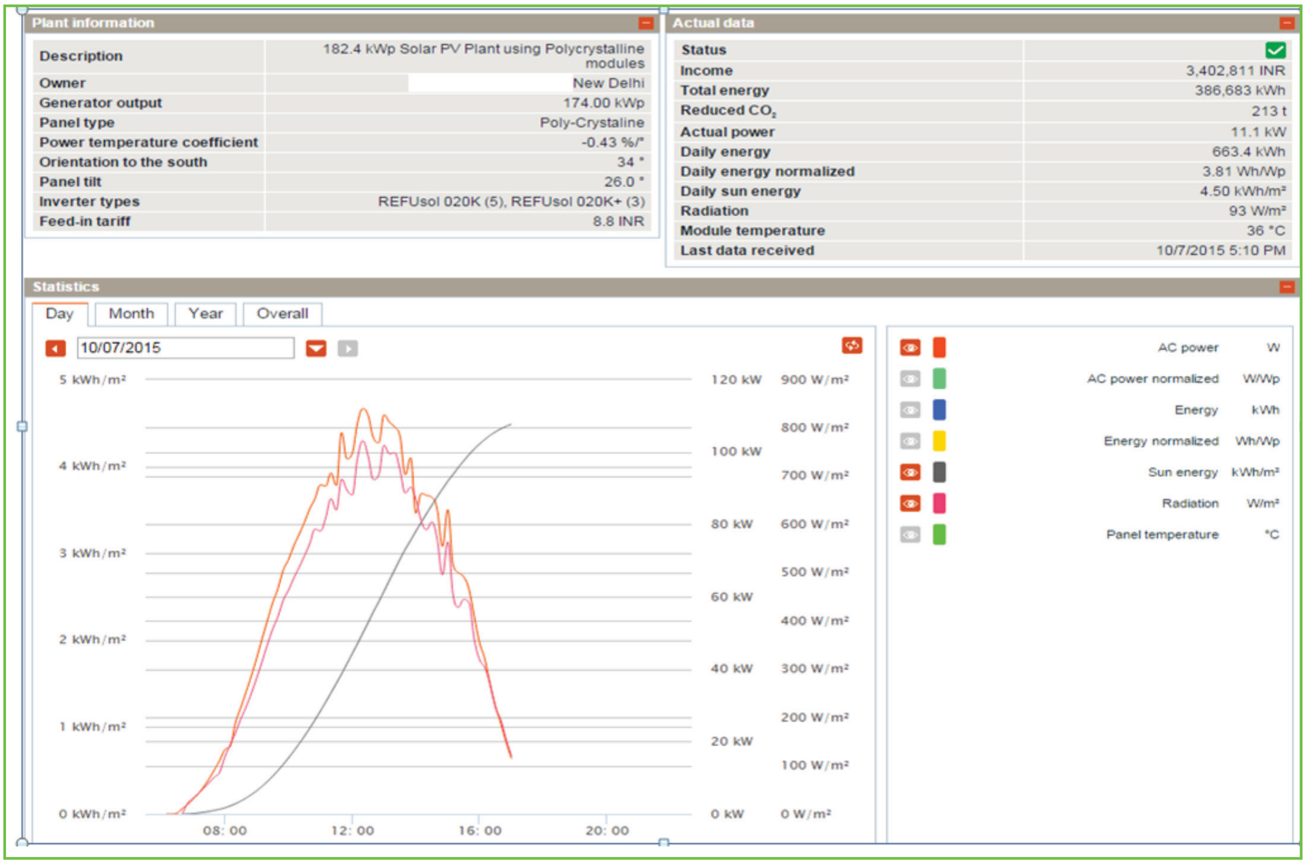


Figure 6.15: SPV plant monitoring system

Bill of Quantity

Design drawings enable the estimation of the quantities of material that needs to be procured for the project, whilst also allowing prediction of the projects cost. A detailed bill of quantity for a 100 kW project is given in Table 6.4.

Table 6.4: Bill of quantity for a 100 kW Rooftop SPV project

100 kWp On-grid system		
Items	**Technical specifications**	**Quantity required**
Solar modules	255 Wp	396
Mounting structure	Fabricated (100.98 kWp), supports for inverter mounting at mounting structure	
Inverter	20 kW	4
Data logger and sensor	Refusol in-built data logger	1 each
DC cables	4 sq.mm single core multi strand (PVC) (earthing) class-2	425 metre
	6 sq.mm single core multi strand XLPE class-2	850 metre
AC cables	16 Sq.mm 4 core multi strand XLPE class-5	160 metre
	4 Sq.mm single core multi strand (PVC) (earthing) class-5	160 metre
	120 Sq.mm 4 core aluminium (armoured)	55 metre
AC combiner box	3 Ph,415 V 160A rated with (4)40A MCBs	1
AC disconnect switch	3 Ph,415 V 160A rated with PV meter	1
Grounding and lightning arrester	Grounding system with MS bar and lightening arrestor	1
Lugs	4-6 Sq.mm lugs ring type Cu	850
	16 Sq.mm lugs pin type/ring type Cu	12
	120 Sq. mm lugs ring type/pin type	10
Conduit	1.25″ Conduit fitting C clamp	250
	1.5″ Conduit fitting C clamp	250
	L-bend 1.25 inch schedule 40	50
	T-bend 1.25 inch schedule 40	10
	L-bend 1.5 inch schedule 40	30
	Conduit (1.25 inch) schedule 40	425 metre
	Conduit (1.5 inch) schedule 40	160 metre
Communication cable	CAT5 shielded communication cable	200 metre
	RJ 45 connectors for communication cables with one Ethernet switch	10
Cable tie	100 mm UV resistance	500
	200 mm UV resistance	500
	300 mm UV resistance	500
MC4 connector pair	MC4 connector pair	55
Electrical tape	R,Y,B,G,Blk	2 each

6.3 Conclusions

- The per watt cost of larger PV systems can be 25–30 per cent less than the smaller sized PV systems, thus the payback time for larger systems will be shorter;
- SPV costs have declined in the past few years. Grid parity has been attained in the case of commercial and industrial customers in some areas;
- Solar modules consist of around 55 per cent of the total project cost;
- In urban areas, grid connected systems are most popular (due to lower costs), whereas systems with battery backup are more popular in rural or semi urban areas (due to lack of regular electricity supply);
- Roof selection is a very important factor as it determines the cost of mounting structures, cabling, integrity, and durability of the system;
- Proper shading analysis and optimum design considerations must be taken into account as they would govern the power generation and ultimately the financials of the project;
- Mounting systems should take into account the following things:
  - Structural integrity of the roof;
  - Adherence of the mounting structure to the roof with the help of fasteners or counter weights;
  - It must be able to withstand the wind load according to the wind zone map;
- Solar modules and other BOS should adhere to IEC codes and other relevant Indian codes. These should be tested for going beyond the international standards;
- Wires should be sized appropriately whilst also taking the overcurrent and temperature factors into consideration;
- Interconnection for up to 100 kW should be done on LV side and above 100 kW on HV side.

7 Chapter

Overview of the Market Potential

Estimates of the market potential for rooftop solar photovoltaics (SPV) in India have been made in several studies over the past two years. In 2013, TERI conducted a study to estimate the rooftop solar power potential across India for the residential, commercial, and industrial sectors. This analysis was carried out through market surveys conducted in six metropolitan cities in the country. TERI estimates a total market potential for rooftop solar for the three sectors of 124 GW. 'Bridge to India' also conducted a market potential assessment for rooftop solar power, estimating potential of between 26 to 35 GW for the commercial and industrial sectors and 31 to 41 GW for the residential sector. The National Institute of Solar Energy (NISE) estimates potential for around 42 GW of rooftop solar power across all the states in India. In this study, the estimation of the market potential has been made by administering a survey among solar PV (SPV) project developers.

7.1 Market Survey Approach

The Ministry of New and Renewable Energy (MNRE) has developed a 'Channel Partners' programme, wherein SPV project developers register as Channel Partners. More than 500 developers are currently registered under this programme. A market survey questionnaire was developed and sent to around 250 project developers of which 71 developers sent responses. Not all participants respond to each question. The questionnaire was designed to seek information on the following aspects:

- **Markets and deployment**
  - Years of experience in SPV
  - Projects installed, under construction, and under contract
  - Targeted market segment
  - Targets for rooftop SPV
  - Geographic preference
- **Cost and business models**
  - Average installation cost per Watt
  - Rate of interest and loan tenure
  - Preferred business model
  - Government support
  - Debt equity ratio
- **Operation and maintenance (O&M)**
  - Cleaning of PV modules

  - Service requests from customers
  - Annual maintenance
  - Monitoring the system
  - Downtime of SPV systems
- **Workforce and organization capabilities**
  - Organization capacity
  - Training and experience of staff
  - Lack of experienced workforce

7.2 Market Survey Results

7.2.1 Deployment Status and Market Expansion

Since March 2015, 5,518 rooftop solar projects have been deployed with a cumulative capacity of 221 MW. Over 75 per cent of the projects installed are more than 25 kW in size. Of the total projects installed, 72 per cent were deployed in the industrial and commercial sectors. Around 60 per cent of the project developers perceive that the investment in rooftop solar is driven by the ability to save electricity bills for end-users. Another 21 per cent project developers mentioned that the reduced carbon foot-print is a driver for implementation of rooftop solar PV (Figure 7.2b).

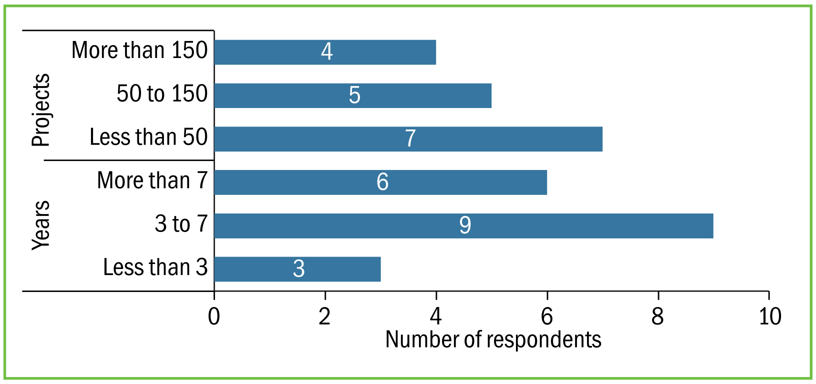


Figure 7.1: Experience in SPV sector

Project developers indicated they already have a degree of experience in the installation of solar projects. Of 60 respondents, 49 indicated more than two years' experience with implementation of solar projects and around 50 per cent have four or more years of experience in the solar sector (Figure 7.1).

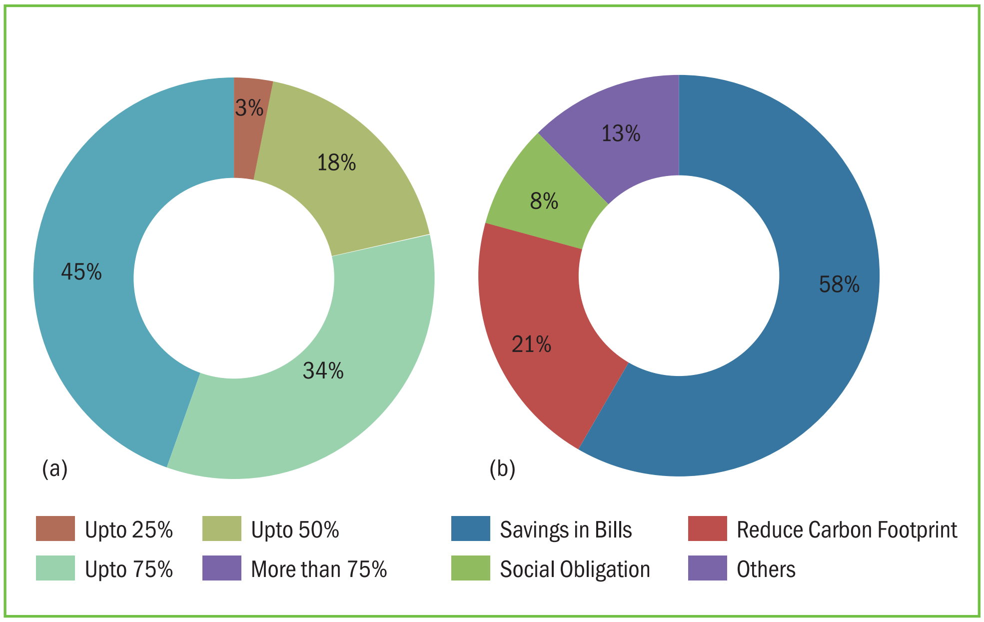


Figure 7.2: (a) Likely share of commercial and industrial sectors in rooftop solar deployments. (b) Investment criterion for rooftop SPV

The rooftop solar market segment is braced for significant expansion. Sixty developers indicated a combined target of 802.5 MW for rooftop solar by 2017–18, which is expected to reach 3,222 MW by 2020.

The industrial and commercial sectors are likely to emerge as the prime drivers for rooftop solar projects. More than 80 per cent of respondents indicated that over 75 per cent of the rooftop solar target will be implemented in the commercial and industrial sectors. Another 20 per cent will deploy up to 50 per cent of the target in the industrial and commercial sectors (Figure 7.2).

The questionnaire sought to identify the geographical regions where there was most activity in the market. The majority of solar project developers have focussed their operations in the North and South of India whereas there are relatively low levels of activity in the East and North-East of India (Figure 7.3).

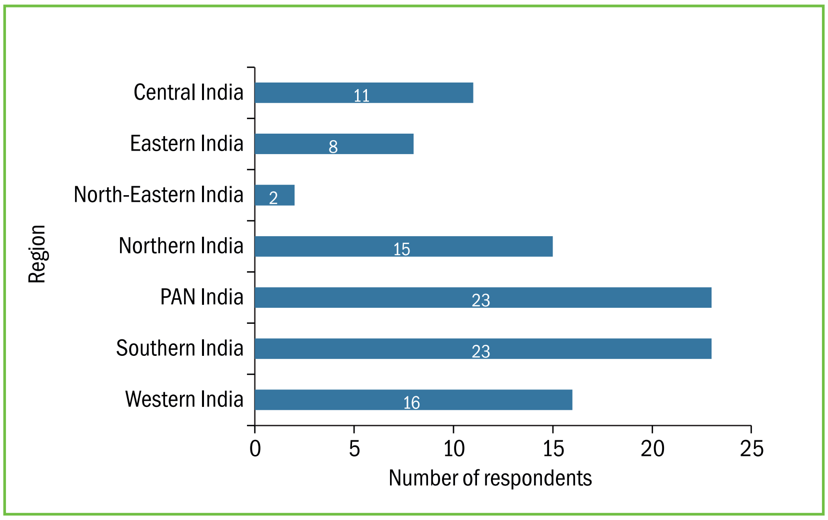


Figure 7.3: Preferred geographic spread for rooftop SPV deployments

7.2.2 Cost and Business Models

The cost components associated with SPV systems are provided in Chapter 6. The preferred business models are briefly described in this section. The preference for third-party financing Opex (Operational expenditure) and internal financing, and Capex (capital expenditure) business models was solicited in the questionnaire, for which a similar level of support was found for each. Thirty-seven per cent of respondents preferred a Capex model, while 35 per cent indicated preference for internal financing based Opex model. Another 28 per cent indicated third-party financing as the preferred business model (Figure 7.4).

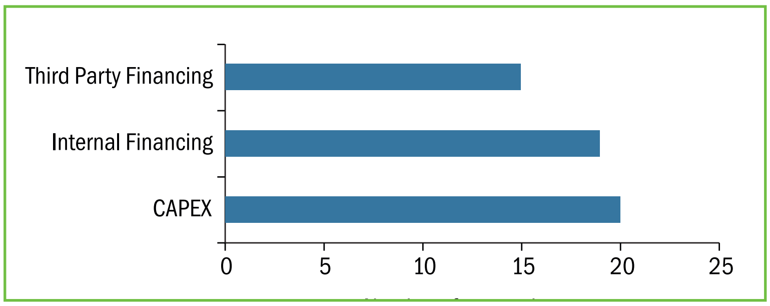


Figure 7.4: Preferred business models

The questionnaire asked project developers for their preferred form of government support, with most respondents (55 responses) identifying multiple preferences. Low-interest loans stood out as the most preferred mechanism for government support. Accelerated depreciation (44 responses) and exemption on excise/import duty on system components were also expressed as important support measures

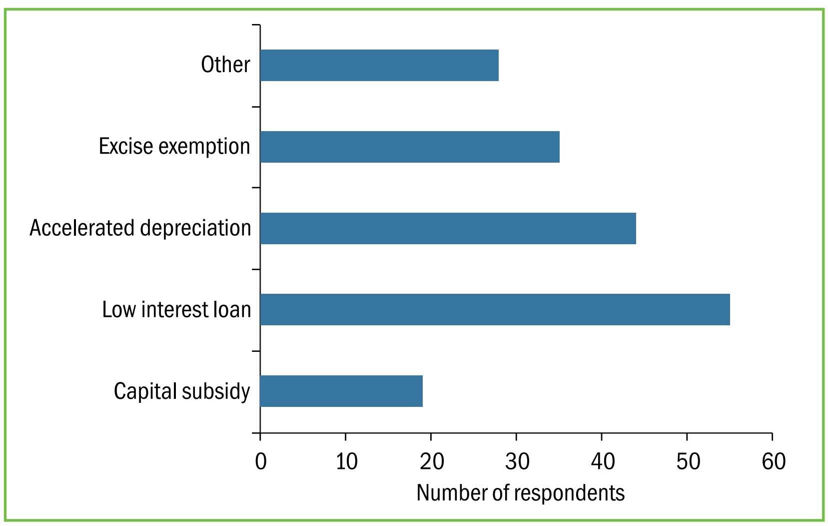


Figure 7.5: Preferred government support

(35 responses). The capital subsidy appeared to receive relatively low levels of support amongst developers (19 responses) (Figure 7.5).

Most developers currently receive project loans at an interest rate of between 12–14 per cent, whilst another 22 per cent of respondents indicated that the cost of their loan is less than 12 per cent. For 17 per cent of the respondents, the interest on loan appears to be very high, at more than 14 per cent. The typical loan tenure is 10 years or less for the majority of project developers (71 per cent) (Figure 7.6). Solar projects are generally funded at a debt-equity ratio of 70:30 per cent.

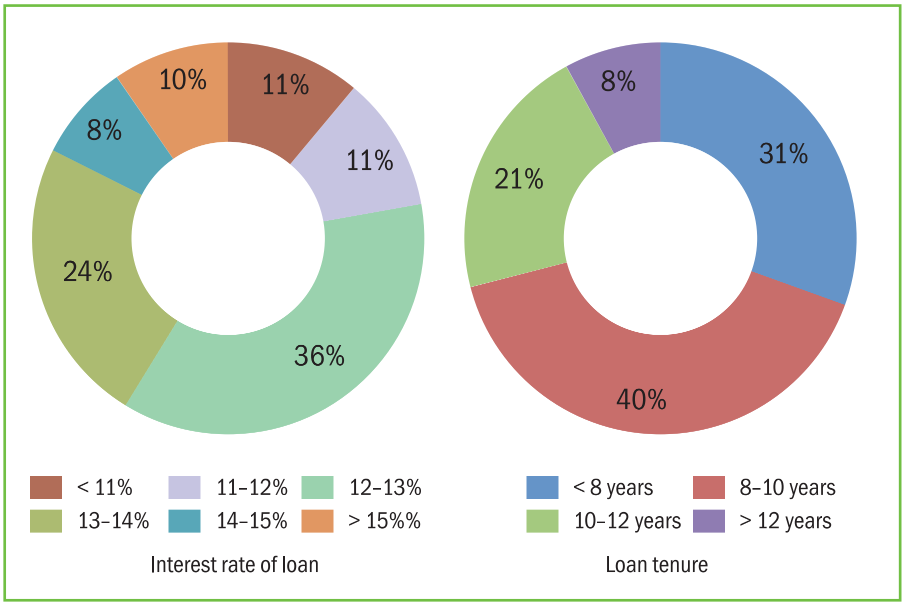


Figure 7.6: Borrowing criterion for PV projects

7.2.3 Operation and Maintenance (O&M)

The O&M of rooftop PV systems is highly important in ensuring adequate energy output from the system. Solar developers often also offer O&M services through annual maintenance contracts (AMC). Around 64 per cent of developers indicated that AMC's were profitable, with 89 per cent or respondents indicating that they generate additional business opportunities.

Newly installed systems could potentially breakdown. In this context, we asked how many service requests were received in the first year since the rooftop SPV system was installed. The majority of respondents (62 per cent) indicated receiving less than two service requests in the first year since installation, with another 24 per cent indicated receiving two to four service requests (Figure 7.7). Most service requests have been related to inverter failures, followed by generation-related issues. Most of the systems faced less than 10 per cent down-time in the first year of operation, with only 5 per cent of

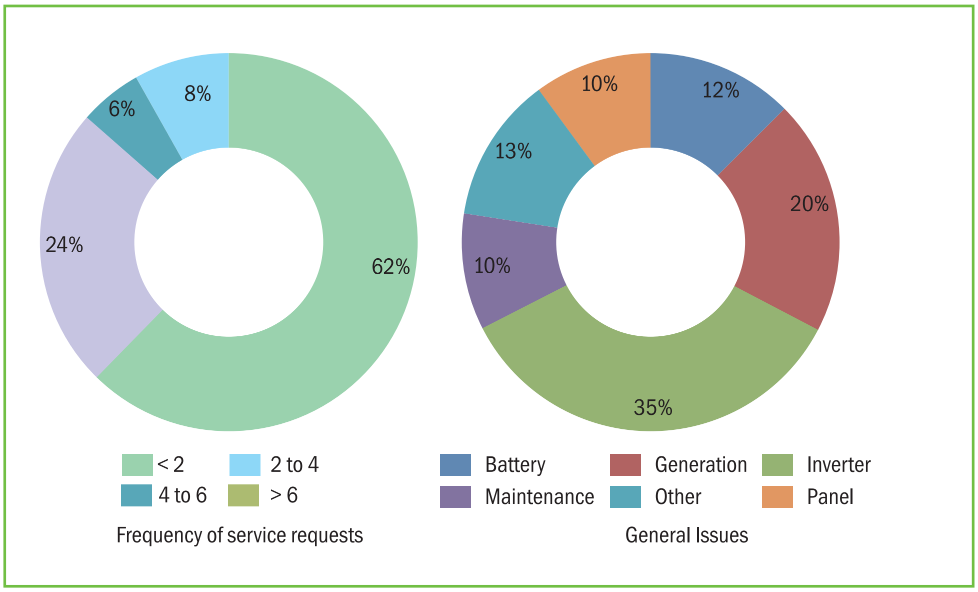


Figure 7.7: O&M service requirements

systems experiencing down-time of more than 20 per cent in the first year since installation (Figure 7.8). Inverter failure and issues related to system maintenance were the main reasons for a system to break-down.

Frequent cleaning of the PV modules is important, especially in India due to the amount of dust and aerosols in the atmosphere. Of the developers providing AMC services, 80 per cent indicated either a once in two weeks or once in a week cleaning schedule of the PV modules. Most developers indicated that they provide training to facility managers for cleaning of PV modules. Only 39 per cent AMC service providers include PV module cleaning as a service (Figure 7.9).

7.2.4 Workforce and Organization Capabilities

The questionnaire sought responses on the organization capability of project developers in terms of their ability to provide services for preliminary detailed design, system installation, and O&M. Most developers appear to have

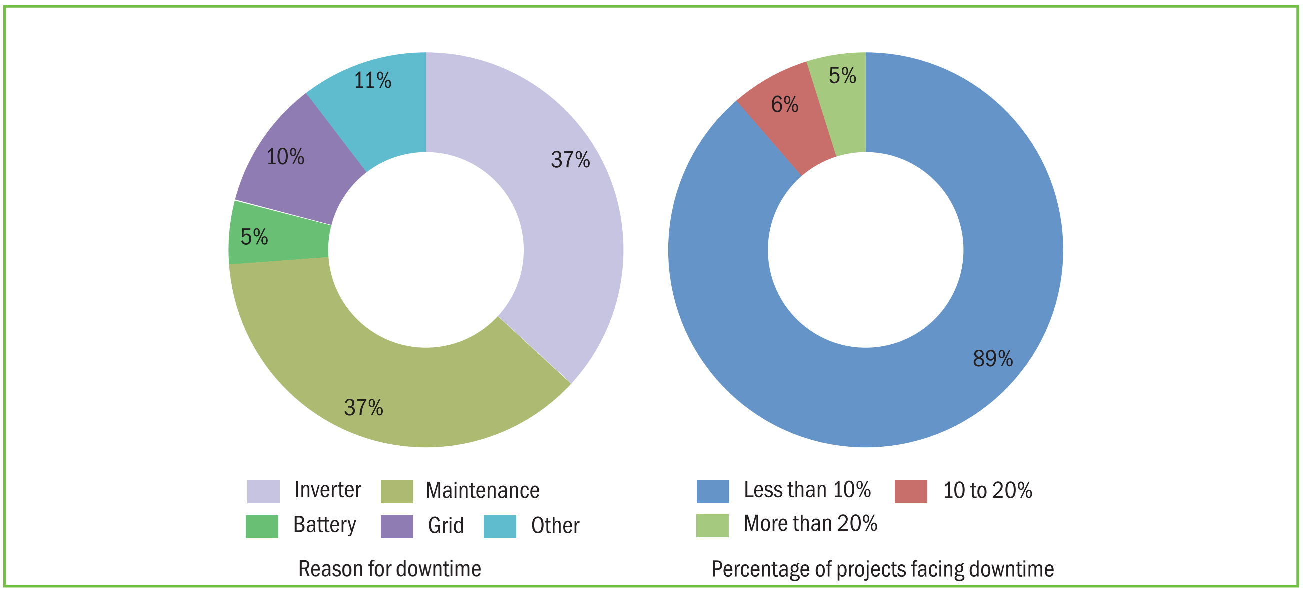


Figure 7.8: Downtime in projects

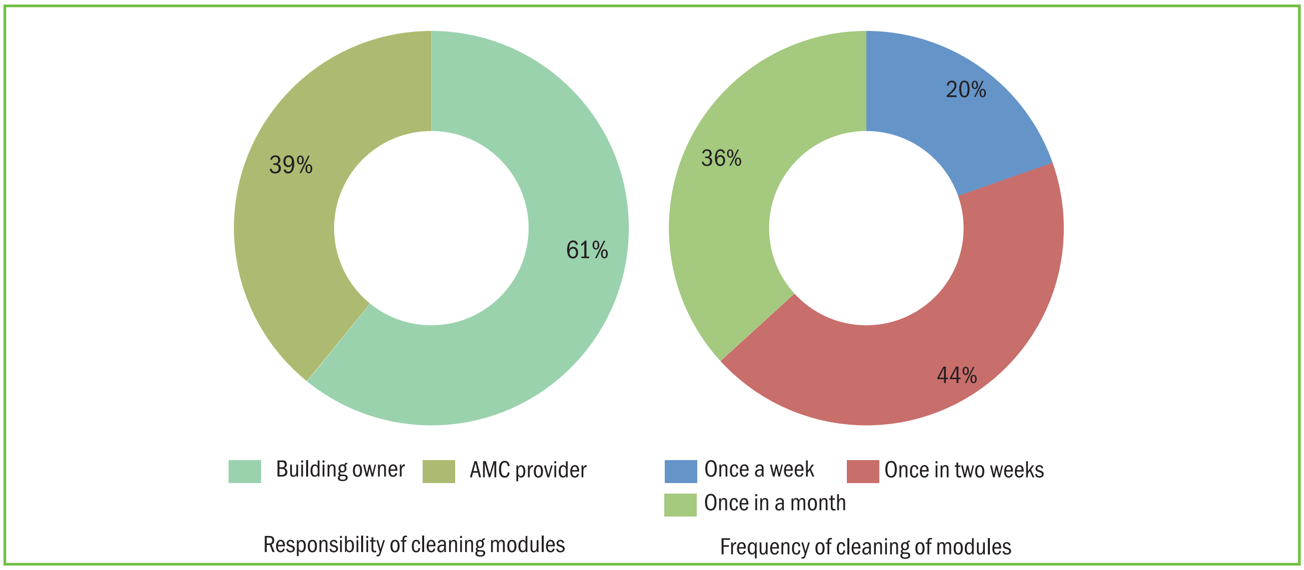


Figure 7.9: Cleaning of PV modules

in-house capabilities for all these service categories, although system installation and detailed design services can often also be outsourced (Figure 7.10). In general there is an expressed shortage of skilled labour in the market, with 62 per cent of respondents indicating they faced a shortage of professionals (Figure 7.11). This is more apparent for system designers, electricians, technicians and marketing professionals.

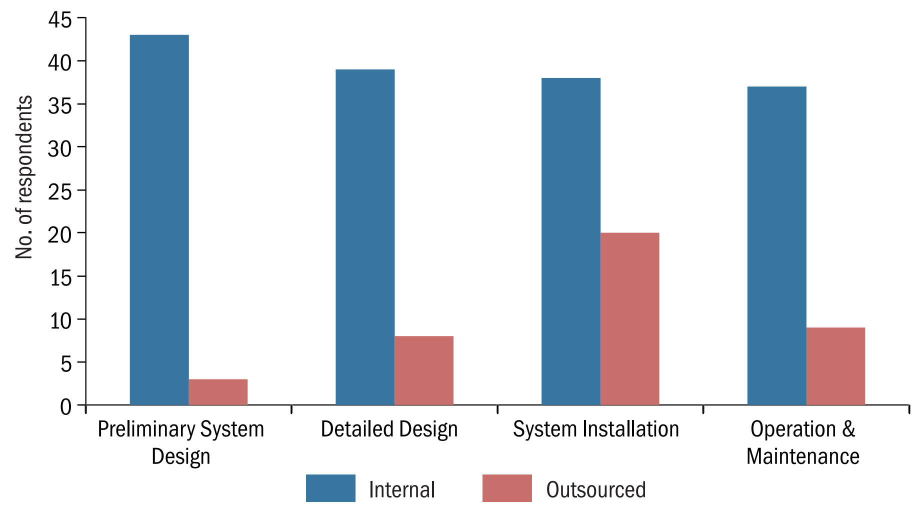


Figure 7.10: Organizational capacity of skilled workforce

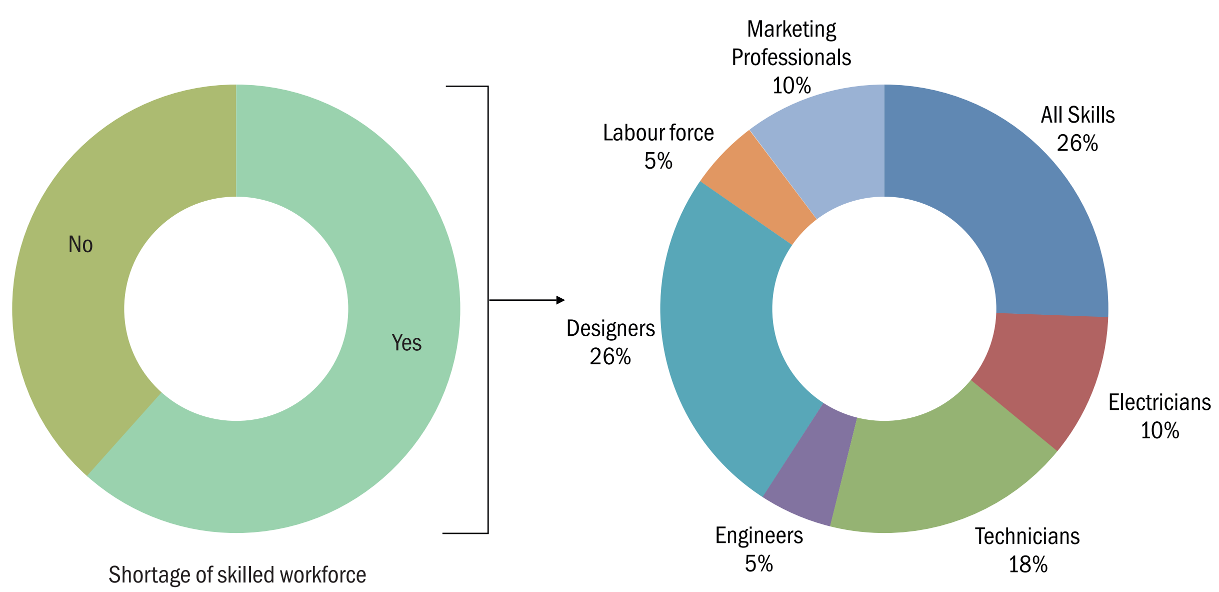


Figure 7.11: Shortage of skilled workforce in industry

7.3 Conclusions

A market assessment has been made to capture the status of the rooftop SPV development and future expectations. A questionnaire-based survey was administered among a sample of around 250 solar project developers, of which 71 developers participated in the survey. The key findings of the market assessment are:

- The solar market is poised for significant growth in the next five years. The current survey participants indicated that they have deployed more than 200 MW of rooftop solar and their target for rooftop solar is around 800 MW by 2017 and more than 3,000 MW by 2020.
- The industrial and commercial sectors are expected to emerge as the most promising sectors for expansion of the rooftop SPV market.
- Low interest loan, accelerated depreciation, and exemption on import/excise duty on PV system components are preferred incentive mechanisms to promote the rooftop solar market.
- For most solar project developers, O&M services and issues related to malfunctioning of inverters are the main reasons for system down time.
- Most project developers have in-house skilled manpower to conduct preliminary design, detailed design, and installation services.
- There is an expressed shortage of skilled labour, mostly associated with designing SPV systems. It is anticipated that the Solar Energy Training Network skills development programme aimed at providing technical skills on solar to more than 400,000 technicians will help in filling this gap.

MNRE along with TERI is currently offering 10 capacity development awareness workshops for utilities, banks, project developers, and state agencies. An additional 15 capacity building programmes are scheduled in 2016. Currently, awareness of rooftop SPV among commercial and industrial users is limited. Targeted awareness campaigns will have to be mobilized for this consumer category to spur the market.

8

Chapter

Rooftop Solar PV: Cost of Energy

This chapter analyses the levelized cost of electricity (LCOE) for different solar photovoltaic (SPV) system configurations for the commercial and industrial sectors across 10 states in India. The LCOE is compared with the cost of grid electricity for different categories of commercial and industrial tariffs. The analysis offers insights into the financial viability of a standalone PV system, a PV system combined with battery, and a PV system with an accompanying diesel generator for periods of power outages, as well as the financial viability of these PV configurations under a financial incentive regime. A comparison of these cost-of-supply differentials is made in current conditions, and also considers future changes in costs in both the short term (2–3 years) and medium term (5 years). The model follows standard cash flow based textbook methodology, considering operational cash flows with investment costs to calculate the financial performance indicators. These financial performance indicators include LCOE, internal rate of return (IRR), net present value (NPV), and payback period and are calculated for all the PV system/incentive combinations to make an assessment of where efforts for future PV deployment should be focussed.

8.1 Model Approach

The overall methodology adopted for the financial framework is shown Figure 8.1, which is followed by a more detailed explanation of each stage. The analysis is made with use of a set of assumptions based

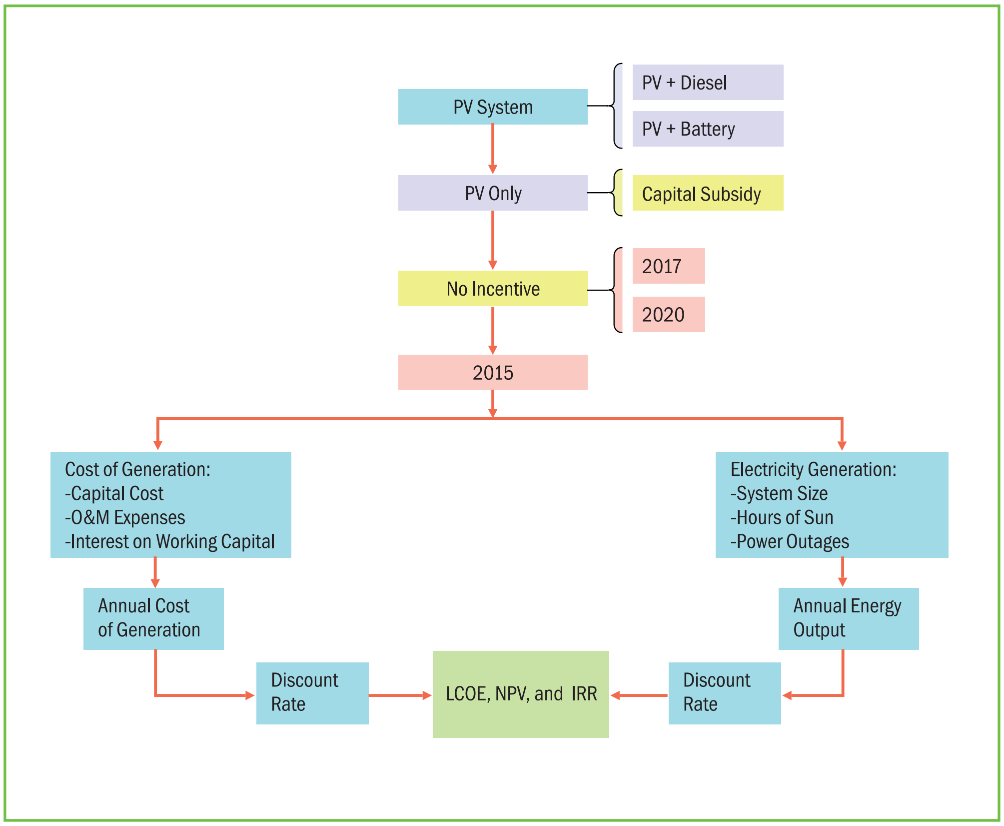


Figure 8.1: Process flow chart outlining methodology for financial analysis

on currently available market data and research, as well as the assumptions outlined in the most recent guidelines provided by the Central Electricity Regulatory Commission.

8.1.1 Solar Electricity Generation

The PV system capacities considered in this analysis are 25 kWp, 150 kWp, and 1,000 kWp and are considered for both the commercial and industrial sectors. These capacities are selected based on the need for a small, medium, and large system size to be included in the analysis. The effective sunshine hours data for each state is taken from the NASA RETScreen database (Table 8.1). The analysis assumes a 20 per cent loss of PV system energy generation, reflecting losses in the conversion process of sunlight from DC to AC. The PV system lifetime is considered to be 25 years. There is also a further degradation factor of 10 per cent attributed to PV module efficiency over a period of 20 years.

Table 8.1: Assumptions for estimation of solar electricity generation

Solar resource	Units	Value	Data source
Delhi	Hours	5.06	NASA RET-Screen
Haryana	Hours	5.44	NASA RET-Screen
Gujarat (Ahmedabad)	Hours	5.22	NASA RET-Screen
West Bengal (Kolkata)	Hours	4.67	NASA RET-Screen
Chhattisgarh	Hours	4.93	NASA RET-Screen
Punjab	Hours	5.44	NASA RET-Screen
Karnataka (Bengaluru)	Hours	5.26	NASA RET-Screen
Rajasthan	Hours	5.21	NASA RET-Screen
Andhra Pradesh	Hours	5.02	NASA RET-Screen
Maharashtra (Mumbai)	Hours	5.94	NASA RET-Screen
Power generation			
PV system losses	Percentage	20%	PVSyst Simulation
Module degradation factor	Percentage	10%	KfW
PV system life	Years	25	CERC SO 243 2015
Days in a year	No	365	

Power outage: Estimates of energy loss from power outages in the grid are used to calculate net energy generation from the SPV system. Based on a TERI study, the average power outage for six major cities is 1.3 hours per day in the summer months and 0.8 hours per day in the winter months (Table 8.2). Fifty per cent of the power outage is assumed to take place in the day time when the PV system is in operation. The power outage calculation is only applied to the PV only analysis, since for systems without storage or diesel generator backup, an operational reference grid is required to use the power output generated from the PV only system. PV + battery configurations on the other hand, can utilize the power stored in the battery for times of power outage, whilst the PV + diesel configuration can utilize the backup diesel generator.

Electricity cost: Industrial and commercial tariffs for the 10 states have been included in this analysis. Future tariff rate rises have been estimated by calculating the compound annual growth rate (CAGR) for each tariff, based on tariff rates over the last 10 years. An average is then taken of all commercial CAGRs across all states (CAGR—5.44 per cent) and all industrial CAGRs (5.26 per cent) separately to provide a long-term estimate of future tariff rates over the 25 year lifetime of a PV system. There are three base years, which are 2015, 2017, and 2020.

Table 8.2: Grid power outage assumptions

Power outage	Unit	Value	Data source
Summer Season	Hours	1.3	TERI
Non-Summer Seasons	Hours	0.8	TERI
No. of Months in Summer Season	Month	4	TERI
No. of Months of Non-Summer Season	Month	8	TERI
Power Outage During Day Time	Percentage	50%	TERI

Net Energy Generation and Revenue Estimate: Net energy generation is achieved by subtracting power outages from PV energy generation. For PV-only, the analysis considers power outages. For PV + Battery and PV + Diesel configurations, no power loss due to grid outage is considered.

The discount rate is then applied to net energy generation in accordance with standard textbook methodology for calculation of the LCOE metric. The revenue generated from the PV system is calculated by multiplying the net energy generation for each tariff of each state by the respective projected tariff rate for each year over the lifetime of the PV system.

8.1.2 Financial Parameters

The following operational cash flow components are applicable to the commercial and industrial sectors:

Operation and maintenance (O&M): The standard O&M charge is assumed at 4 per cent of the capital cost of the PV system. This includes the cost of the inverter replacement required every 10 years. The battery replacement cost for the PV plus battery system configuration is additional and explained later in the chapter. The O&M charges are considered to increase each year, with an escalation rate of 5.72 per cent (Table 8.3).

Table 8.3: O&M cost assumptions

O&M	Units	Value	Data source
O&M expenses (percentage of capital cost)	Percentage	4.0%	Developers' Survey
Escalation of O&M prices	Percentage	5.72%	CERC SO 243 2015
Inverter replacement	Years	10	Typical

Interest on working capital: The working capital cost component is calculated as 13.5 per cent of the sum of maintenance spares and one month's O&M charges. Maintenance spares are estimated at 15 per cent of the O&M expense. Assumptions for this cost component are all taken from CERC's guidelines (Table 8.4).

Table 8.4: Assumptions for calculating interest on working capital

Interest on working capital	Units	Value	Data source
O&M charges	Month	1	CERC SO 243 2015
Maintenance spares (percentage of O&M)	Percentage	15%	CERC SO 243 2015
Interest on working capital	Percentage	13.5%	CERC SO 243 2015

Financing costs: These are not included as cost components since they are results rather than inputs to the financial performance indicators. Loan repayment and return on equity costs are not therefore considered. The sum of the operating cash flow cost components are discounted annually using a weighted average cost of capital of

10.81 per cent to reflect the change in value over time. The annual rate of inflation is assumed to be 6.8 per cent (Table 8.5).

Table 8.5: Assumptions for discounting and inflation

	Units	Value	Data source
Annual average inflation rate	Percentage	6.8%	World Bank
WACC	Percentage	10.8%	CERC SO 243 2015
Capital subsidy	Percentage	15.0%	MNRE

8.1.3 PV System Capacity Sizes and Configurations

PV system size: The analysis models the cost of supply differentials between different PV system capacities for all system configurations (Table 8.6). System costs are anticipated to reduce with increasing system size, taking into account the improved economies of scale associated with larger systems. In addition, there is an expected reduction in PV system costs of future systems for all capacities, in anticipation of an increasingly mature PV market.

Table 8.6: System configuration cost assumptions

		2015	2017	2020	Data source
25kWp PV system					
PV only	Rs/Wp	78	66	58	Developers' survey
PV + battery	Rs/Wp	97	83	72	Battery cost is 40% of the PV system cost
PV + diesel	Rs/Wp	78	66	58	Diesel generator capital not considered
150 kWp PV System					
PV only	Rs/Wp	71	60	53	Developers' survey
PV + battery	Rs/Wp	89	76	66	Battery cost is 40% of the PV system cost
PV + diesel	Rs/Wp	71	60	53	Diesel generator capital not considered
1,000 kWp PV System					
PV only	Rs/Wp	65	55	48	Developers' survey
PV + battery	Rs/Wp	81	69	60	Battery cost is 40% of the PV system cost
PV + diesel	Rs/Wp	65	55	48	Diesel generator capital not considered

PV + battery: There is a clear cost difference between PV only and PV + battery systems, owing to the additional requirement of a battery (Table 8.7). The initial cost for the PV + battery configuration is therefore estimated at an additional 40 per cent of the cost of the standard PV only system cost. A battery replacement is required every five years, calculated at 40 per cent of the initial capital cost of the system and adjusted for inflation for replacement years.

PV + diesel: For the PV + diesel system configuration, it is assumed that the diesel generator exists prior to the installation of the SPV system, with the system capital cost therefore remaining equal to that of the PV only configuration. There is however an additional cost for diesel consumption, which is estimated at 50 Rs/litre of diesel consumed and 0.45 litres[1] of diesel consumed per kWh, based on HOMER simulations. It is assumed the diesel generator is required for 0.47 hours per day, taking into account the average power outages for both the summer and winter months. Due to the PV system, the diesel generator will operate at part load, assumed at 25 per cent of full load capacity. The part load diesel consumption is 40 per cent compared to full load consumption. Continued operation of the diesel generator is required to provide a technical grid necessary for the PV system to be

1 Obtained from HOMER simulations

operational during a power outage. In the analysis, a special case will also be applied, whereby the diesel generator supplies the full load during a power outage. Whilst the future cost of diesel is difficult to estimate, considering the currently low oil price, it is assumed to rise annually in line with inflation.

Table 8.7: Diesel cost and battery cost assumptions

Diesel Generator Costs	Units	Value	Data Source
Cost of Diesel	Rs/l	50	Representative market price for diesel fuel
Diesel Generator Consumption	l/kWh	0.45	
Diesel Price Escalation Rate (Equal to Inflation Rate)	Percentage	6.8	
Battery Replacement—Percentage of Capital Cost	Percentage	40	
Diesel Consumption Ratio at One-Fourth Part Load	Percentage	40	

8.1.4 Financial Incentives

All PV system configurations and capacity sizes in this analysis are evaluated assuming no additional financial support. In addition, the benefits of a subsidy on the capital cost of the PV system are also considered.

Capital cost subsidy: A 15 per cent capital cost subsidy is included in the system cost calculations. It is applied to the initial capital cost investment with the aim of reducing the gap between total cost and revenue generated, improving the financial viability of the PV system. Capital cost subsidy is only available to projects undertaken in the commercial sector, not in the industrial sector.

8.2 Model Outputs

The revenue and cost components discussed previously in this chapter have been combined to produce various financial performance indicators of the viability of SPV systems in the commercial and industrial sectors in 10 states in India. The following metrics were calculated:

8.2.1 Levelized Cost of Energy (LCOE)

There is considerable variation in the LCOE values across the different states and tariffs, with LCOE values ranging from as high as 17.7Rs/kWh for a 25 kWp PV + battery system configuration in 2015 for West Bengal (Figure 8.2A), down to 4.8 Rs/kWh for a 1,000 kWh PV only system with incentive in Maharashtra in 2020 (Figure 8.2C).

The PV + battery configuration has the highest LCOE of all the system configurations due to initial capital costs involved as well as the battery replacements required every five years. The additional costs associated with PV + battery configuration add substantially to the LCOE of a PV only system, with an average increase of 5.9Rs/kWh increase for a small size system, representing a 60 per cent increase compared to a PV only system in 2015 (Figure 8.2A).

The PV only and PV + diesel configurations exhibit comparable LCOE metrics in 2015, with diesel costs only increasing the LCOE marginally initially. However in 2017 and 2020, the PV only configuration becomes increasingly competitive versus the PV + diesel, as the cost of diesel increases compared to the falling PV system capital cost (Figure 8.2A). PV + battery system therefore also becomes increasingly competitive with PV + diesel, although still markedly more costly in 2020.

Operation of the diesel generator is required during a power outage to ensure a technical grid necessary for the operation of the PV system. The standard analysis therefore assumes that during a power outage, the diesel generator operates at 25 per cent of capacity with diesel consumption at 40 per cent compared to full load capacity. To determine the benefit of the addition of a PV system in terms of reduced diesel consumption, a special case has also been evaluated as part of this analysis. Under this scenario, the diesel generator generates at full load capacity

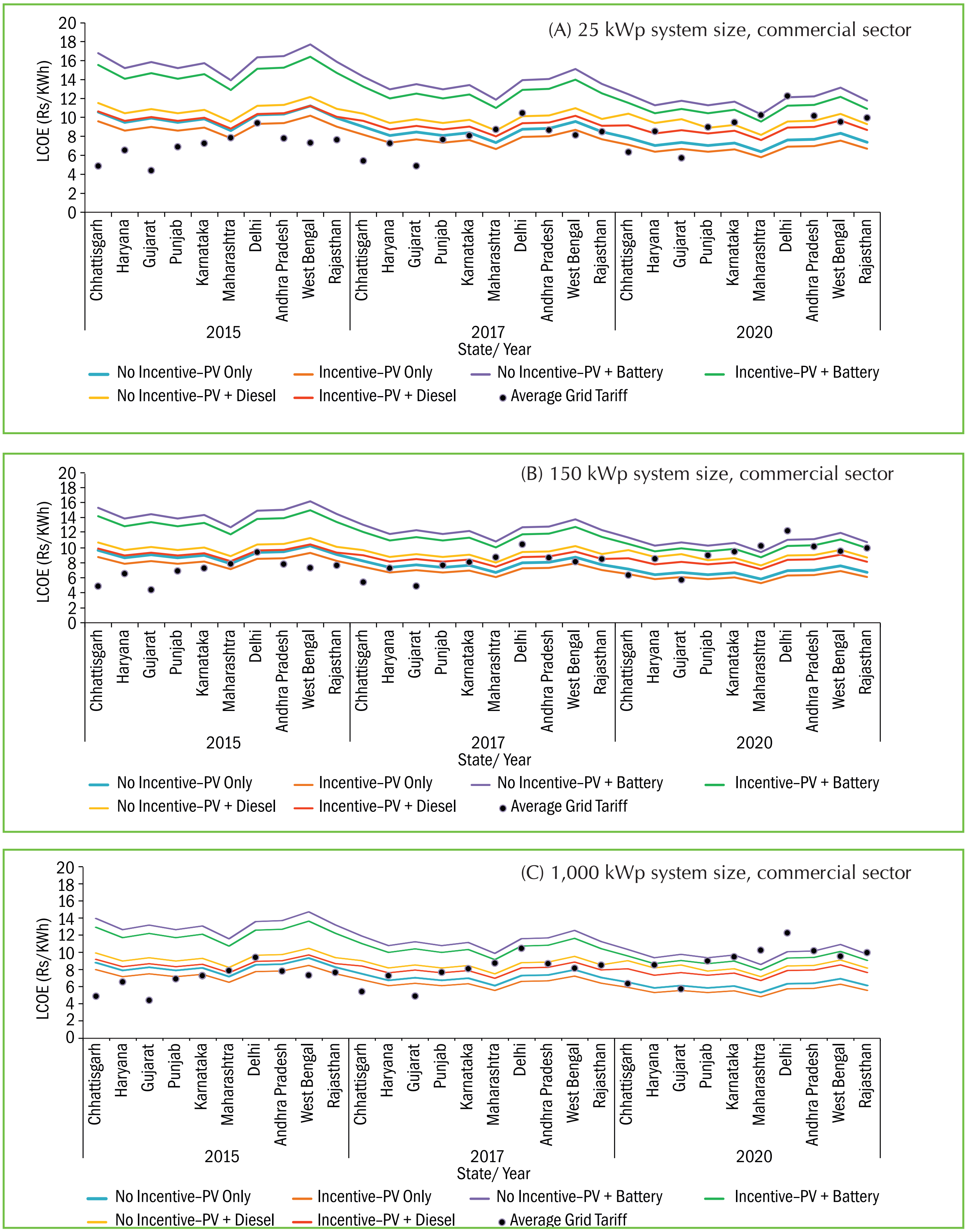


Figure 8.2: Grid parity: commercial sector

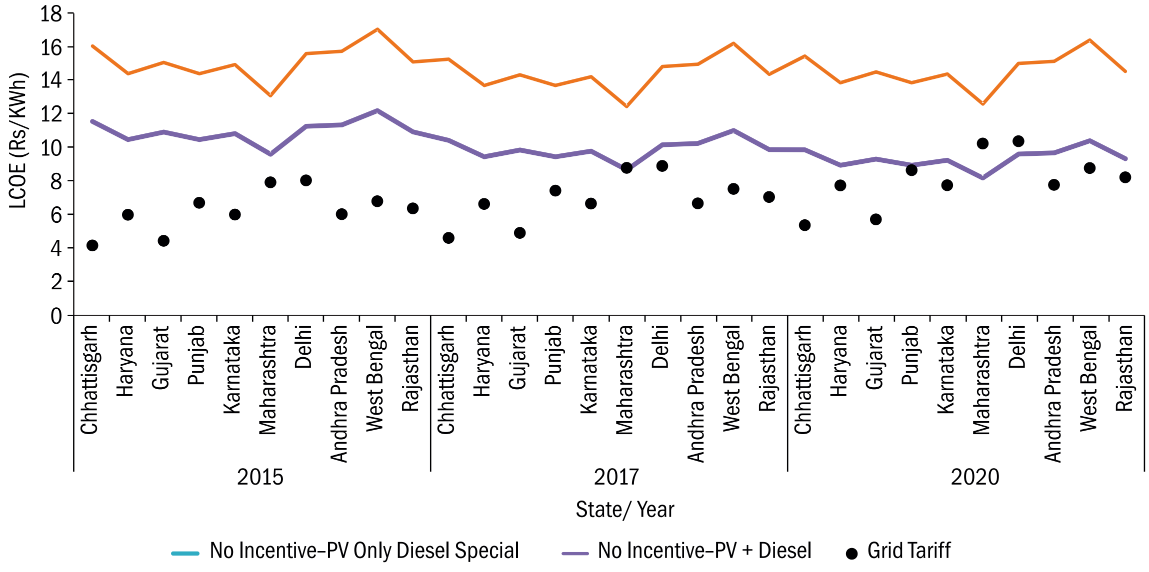


Figure 8.3: Grid parity, PV + diesel and PV + diesel special case, 25 kWp system size, commercial sector

during a power outage, thus also increasing diesel consumption significantly, from 40 per cent to 100 per cent. This has a significant impact on the LCOE for the PV + diesel system configuration. The LCOE in the special case increases by 39 per cent by an average of 4.2 Rs/kWh for a small scale PV + diesel system in 2015, compared to the PV + Diesel standard assumption (Figure 8.3). In the special case, the LCOE of the ten states range from Rs13.1/kWh in Maharashtra up to Rs17/kWh in West Bengal. Only under this scenario does the PV + Diesel configuration show a higher LCOE than an equivalent PV + battery system. The difference between the LCOE for the standard PV + diesel and special case PV + diesel systems highlights the avoided diesel cost during power outages that the PV system brings.

Increasing the capacity of the PV system has a significant positive impact on the LCOE metric of all system configurations, with a LCOE of 9.5 Rs/kWh for a 25 kWp PV only configuration in Punjab in 2015, falling to 7.9 Rs/kWh with a 1,000 kWp PV only system. The lower LCOE associated with larger capacity systems actually plays a significantly greater role in improving PV system viability than a capital subsidy, with the LCOE for a 25 kWh standalone PV system in 2015 falling only to 8.6 Rs/kWh with a capital subsidy applied. Due to the higher capital cost associated with the PV + battery systems, the capital cost subsidy has a greater impact on the viability of this configuration.

In 2015, the LCOE of all PV only system sizes remains higher than the grid tariff in most states. For a 25 kWp system size, only selected tariffs in Mumbai, Delhi, and Andhra Pradesh have a LCOE that is competitive with the grid tariff in the commercial sector and only if a capital subsidy is considered. Due to higher tariffs versus the commercial sector, small scale systems in the industrial sector are largely unviable even with a capital subsidy in 2015 (Figure 8.4A). When considering a larger 150 kWp (Figure 8.4B) and 1,000 kWp system size (Figure 8.4C), PV system, the LCOE in several states becomes competitive with the grid tariff in the commercial and industrial sectors in 2017 and 2020. The PV only configuration in Maharashtra is also competitive in the industrial sector in 2015 at 150 kWp system size.

In 2017 and 2020, PV systems become increasingly viable due to falling system costs over time as the technology reaches maturity, particularly in states with higher grid tariffs. In 2020, several states have a lower LCOE for a 25 kWp PV only system than the grid tariff. At no point do Gujarat and Chhattisgarh, which have exceptionally low grid tariffs, surpass the point of grid parity with the PV only system configuration at 25 kWP system size. Even for a 1,000 kWp size, the LCOE for Chhattisgarh and Gujarat are only viable compared to two tariffs in 2020.

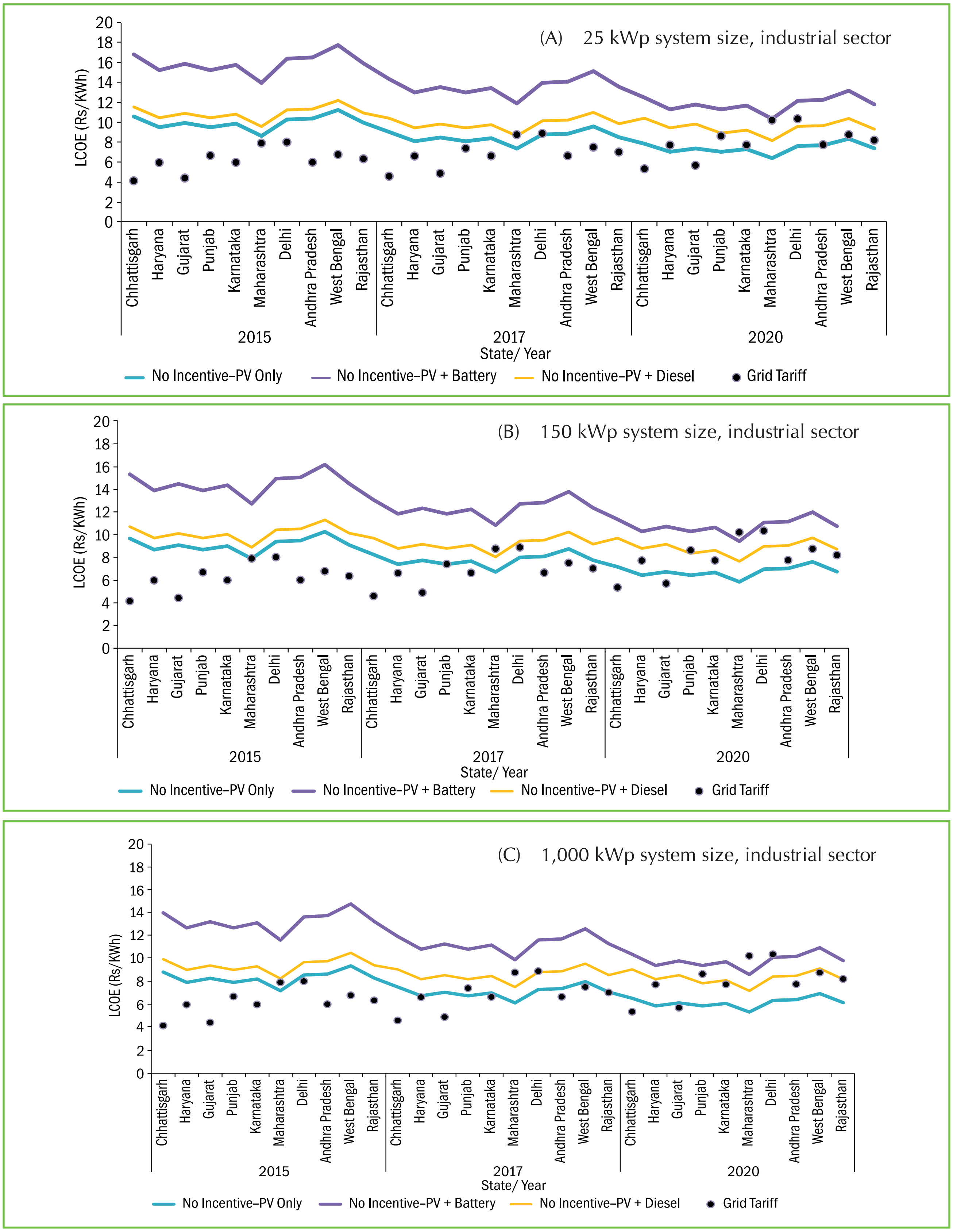


Figure 8.4: Grid parity, industrial sector

The PV + battery system remains comparatively unattractive compared to the PV + diesel and PV only configurations, with only one tariff in Maharashtra being higher than the PV + battery configuration at 25 kWp capacity.

However, despite the benefits on the LCOE metric of higher capacity systems, falling system costs over time, and capital subsidy, tariff rate rises are the biggest factors in the improving viability of SPV, with an anticipated increase in tariffs of around 30 per cent by 2020. For all LCOE data outputs from this analysis, refer to Annexure A8.1.

8.2.2 Payback Period

There is a large variation in the payback period for different system sizes, configurations, and incentives, ranging from 2.4 years in Maharashtra for a 1,000 kWp stand-alone system in 2020 (with incentive) (Figure 8.5), to as high as 13.5 and 12.3 years for Chhattisgarh and Gujarat, respectively, in 2015, with the small scale PV + battery configuration (Figure 8.6).

Haryana and West Bengal have relatively high payback periods of around seven years in 2015 for a small scale system in the commercial sector (Figure 8.7A), falling to a more attractive four years in 2020, with the industrial sector having slightly higher paybacks of nearly eight years in 2015, falling to around five years in 2020. When upscaling to a large size system, these payback periods fall to around six years in 2015 and less than four years in 2020 (Figure 8.7C).

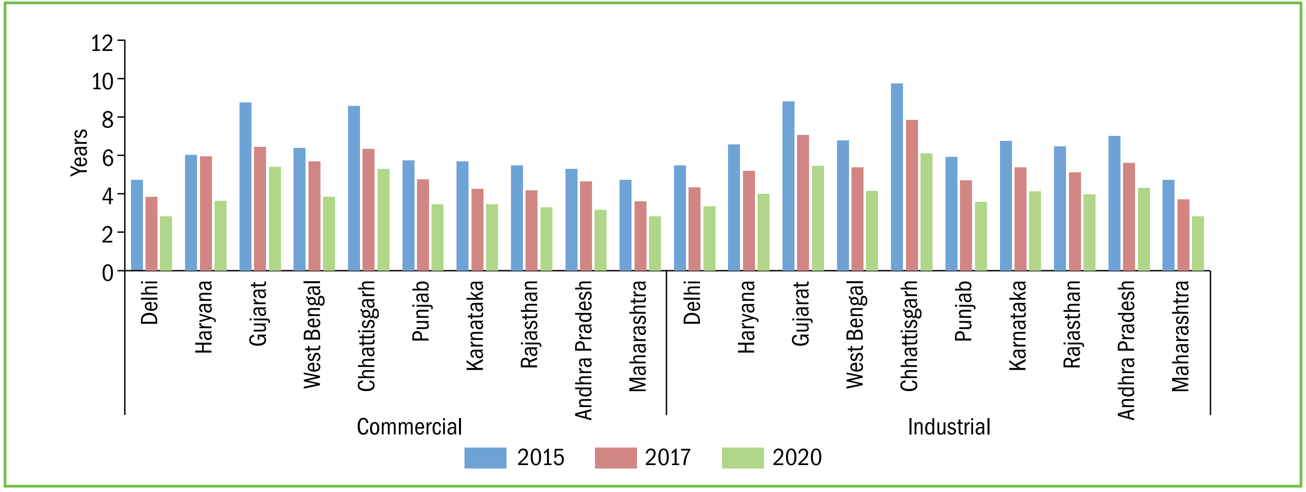


Figure 8.5: Payback period for 1,000 kWp, PV only, with incentive

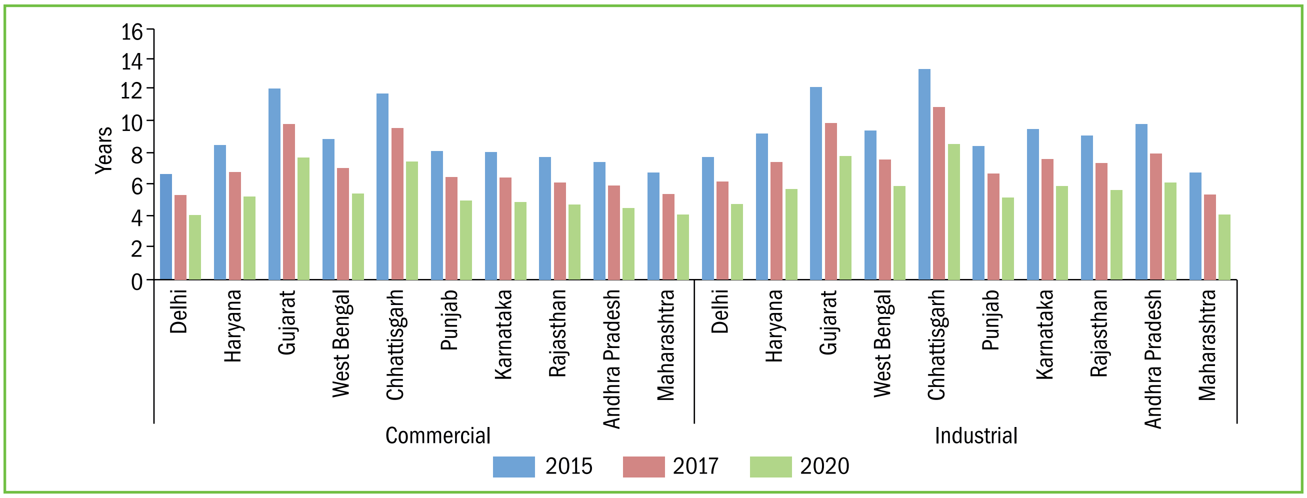


Figure 8.6: Payback period for 25 kWp, PV + battery, no incentive

The payback period for PV + diesel configuration (Figure 8.8) is equal to the payback period of a PV only system of the same size (Figure 8.7B), since the payback calculation does not consider the additional running costs of using a PV + diesel configuration. This factor should be considered when analysing payback periods of different system configurations.

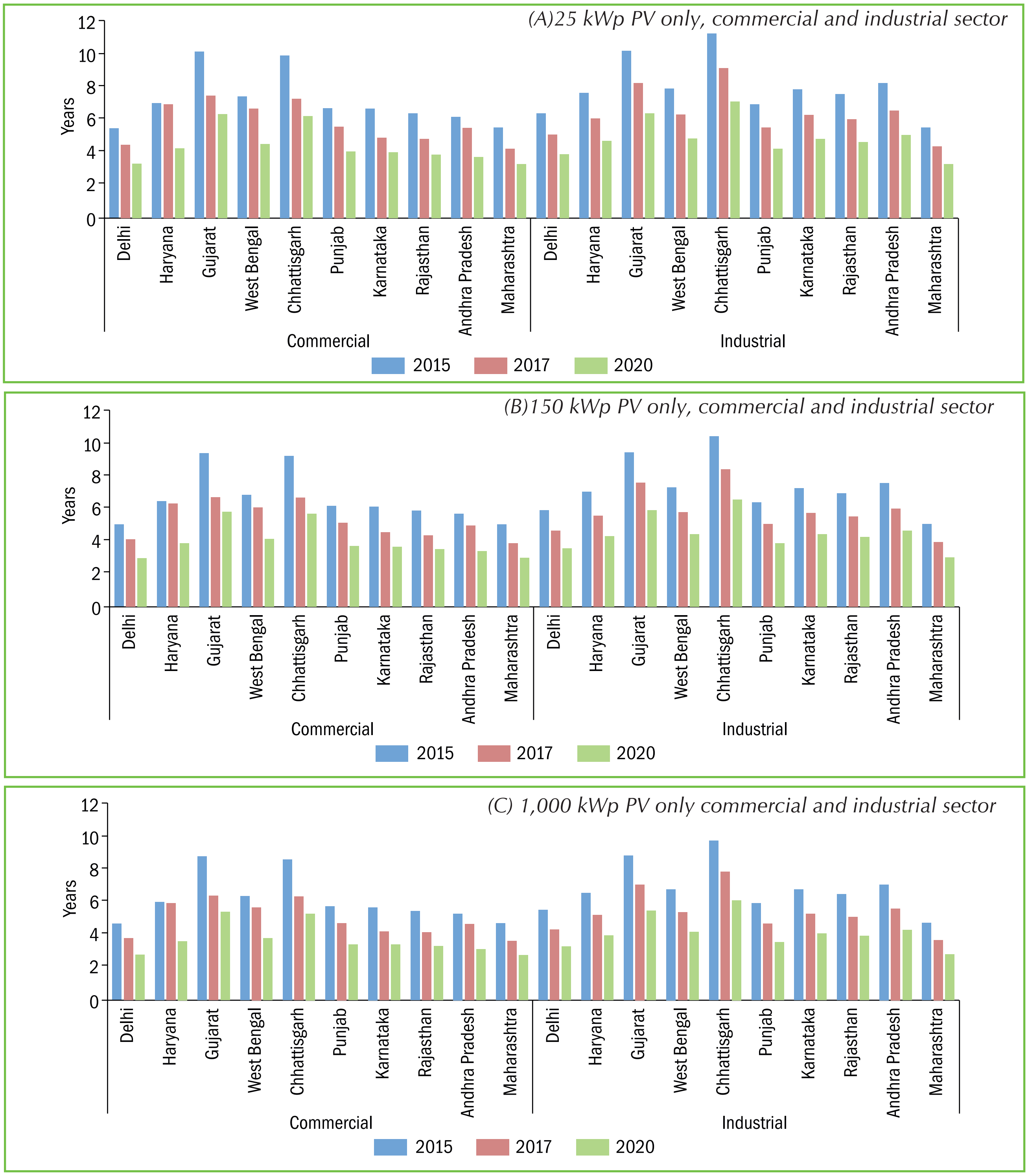


Figure 8.7: Payback period, PV-only, no incentive

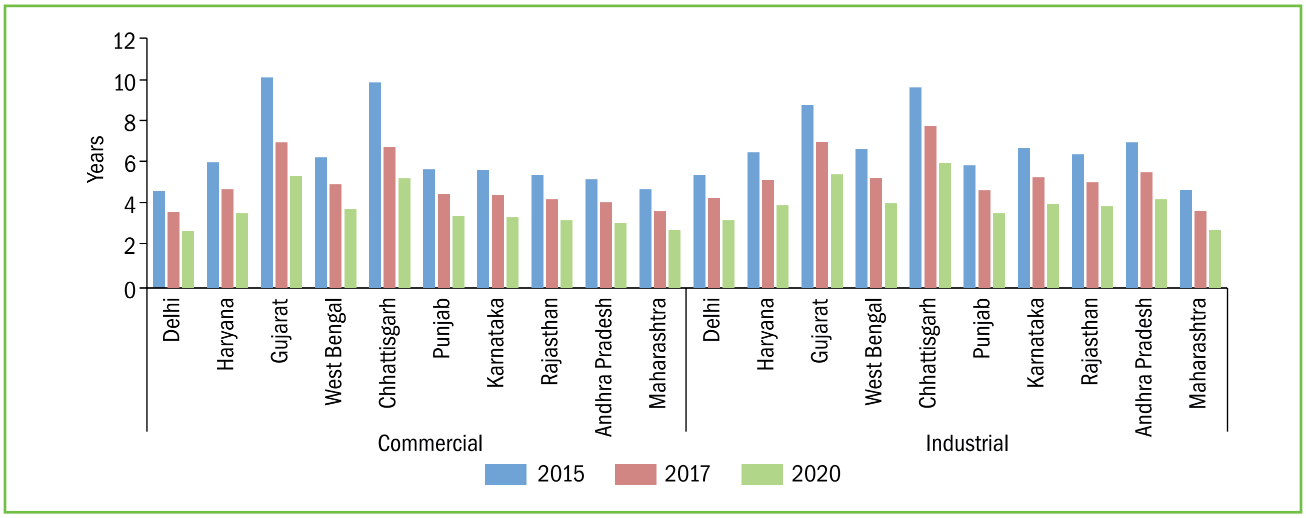


Figure 8.8: Payback period for 150 kWp, PV + diesel, no incentive

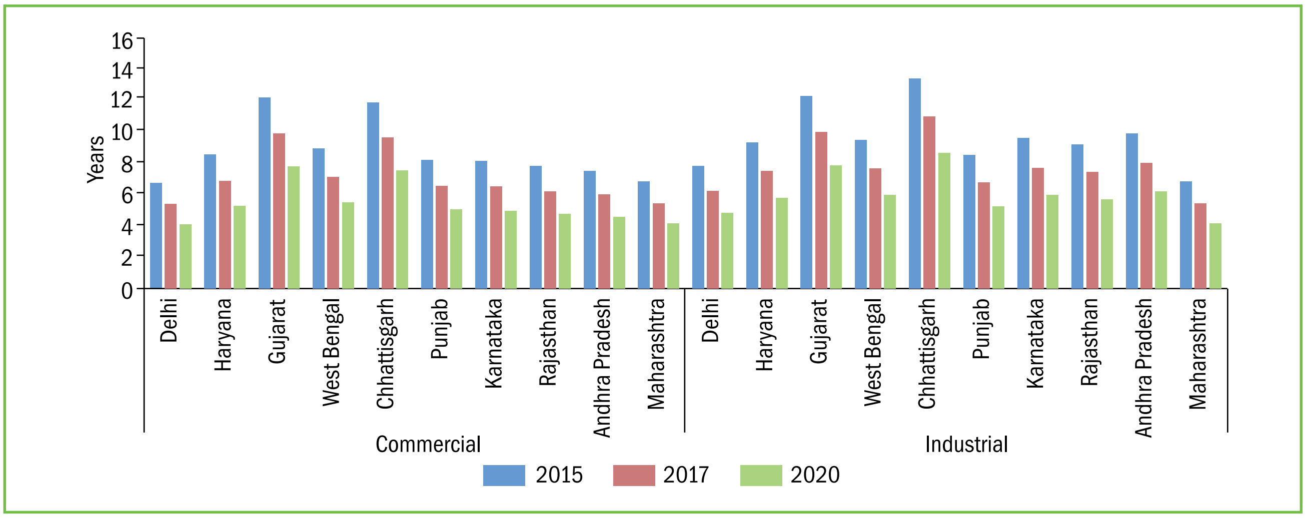


Figure 8.9: Payback period for 25 kWp, PV + battery, no incentive

As anticipated, the payback period for a stand-alone PV system is the lowest compared to a PV + battery configuration. The payback period for a small PV + battery in the industrial sector in Rajasthan in 2015 is 9.2 years (Figure 8.9), compared to 7.6 years for a stand-alone system (Figure 8.7A). In 2015, many states have a payback period of over nine years for a small scale PV + battery system, making any investment appear relatively unattractive, with the payback period only falling to around six years in 2020.

There is a reduction in the payback period of 13 per cent for a stand-alone PV system, when availing the capital subsidy incentive. Payback periods of between three and four years in 2020 for a small capacity system are common for most states with a capital subsidy (Figure 8.10), with payback periods in 2017 also appealing at between four and five years for most states. For all payback data outputs from this analysis, refer to Annexure A8.2.

8.2.3 Net Present Value (NPV)

In 2015, Delhi and Maharashtra show significant positive NPVs, with several other states also showing a modest positive NPV value for a 25 kWp stand-alone PV system in the commercial sector, before considering incentives.

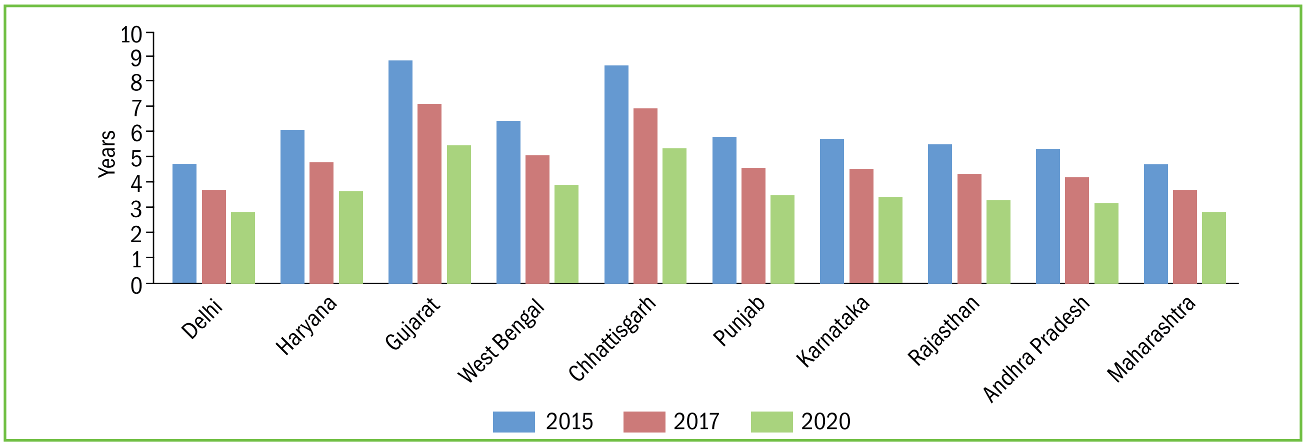


Figure 8.10: Payback period for 25 kWp, PV only, capital subsidy (commercial)

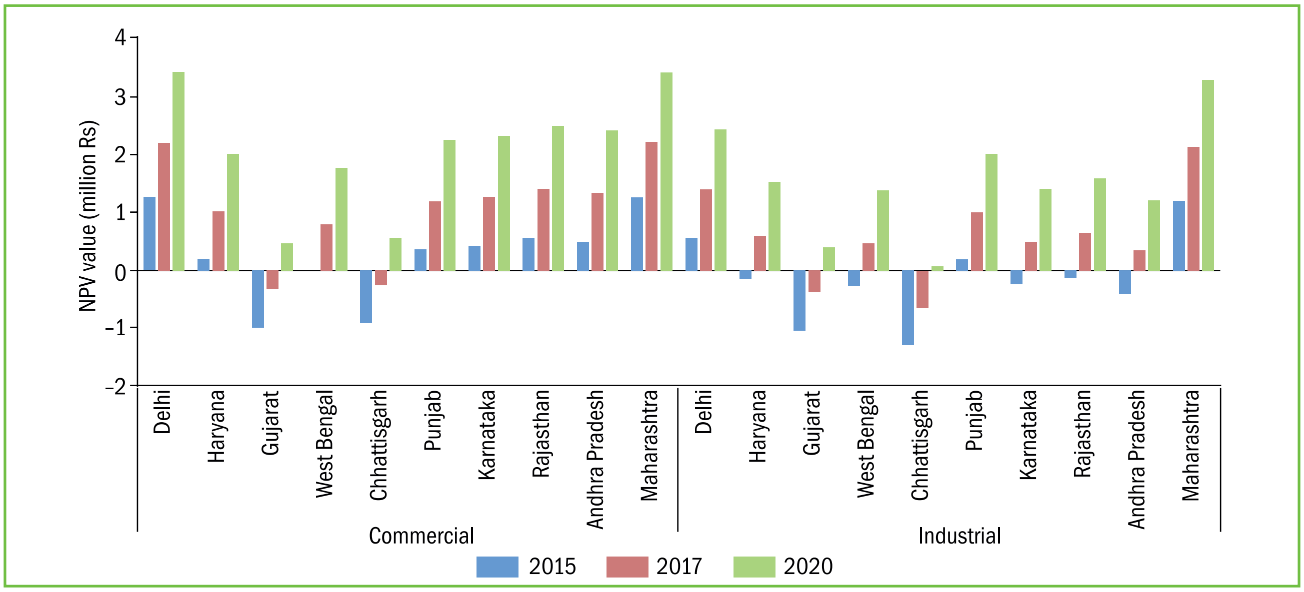


Figure 8.11: NPV for 25 kWp, PV only—no incentive

The number of states with a positive average NPV value increases significantly in 2017 and by 2020, eight states are showing substantial positive NPV values (Figure 8.11). The two exceptions are Chhattisgarh and Gujarat, which show only marginally positive NPVs in 2020 due to the particularly low grid tariff rates in those states. They are therefore likely to be unviable without any support from government financial incentives.

The observations on NPVs contrast markedly with the findings of the LCOE analysis discussed previously, which show a 25 kWp stand-alone system being far from competitive with grid tariffs in 2015 and several tariffs still failing to achieve grid parity even by 2020. Therefore, despite the LCOE being substantially above current grid tariff rates, a trend of increasing grid tariff's over the lifetime of the PV system enables the PV project to offset its current relatively high costs through higher revenues, even after discounting.

In addition to providing a contrasting assessment on project profitability, the NPV metric also deviates from the LCOE findings with regard to the level of benefit financial incentives bring.

There is a much more significant benefit from the capital subsidy on the project NPV metric than on the LCOE metric. Whilst the impact of the capital subsidy show a relatively minor benefit on the LCOE, the average NPV values are greatly improved by government financial support (Figure 8.12). By 2020, even Gujarat and Chhattisgarh, with

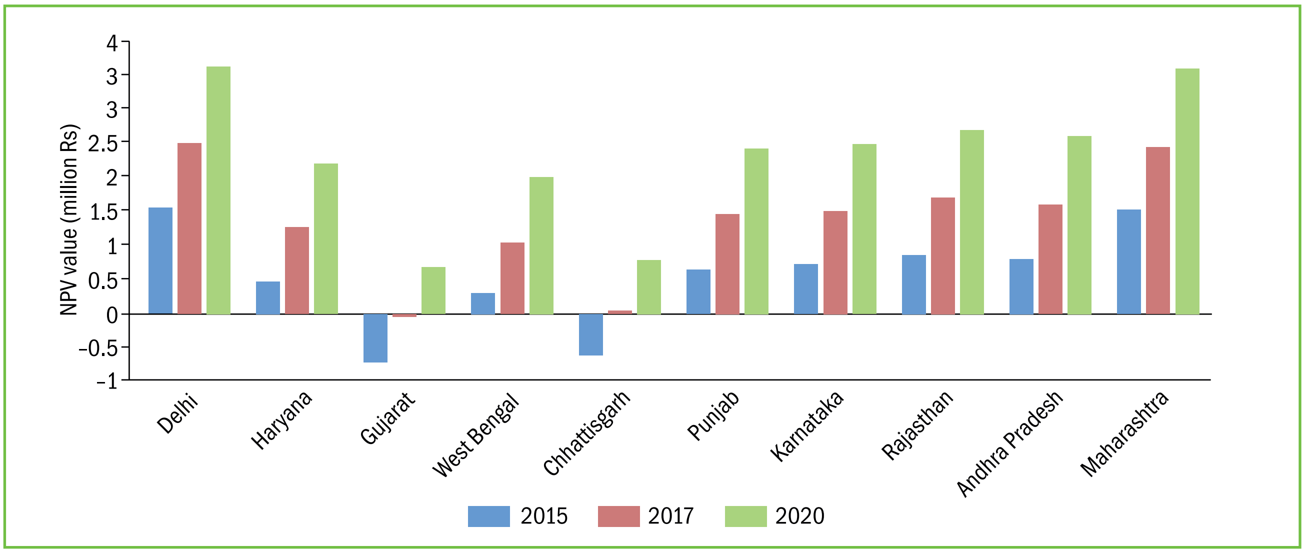


Figure 8.12: NPV for 25 kWp, PV only, capital subsidy (commercial)

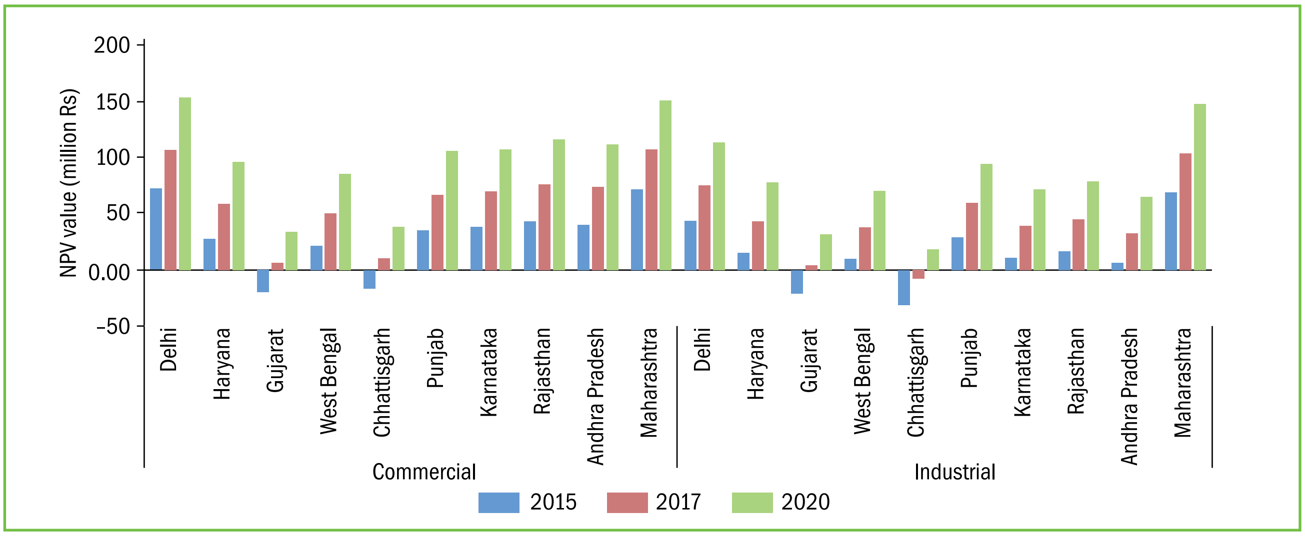


Figure 8.13: NPV for 1,000 kWp, PV only—no incentive

very low tariffs, small scale PV systems are showing a more significantly positive NPV in 2020, when availing of the capital subsidy. For projects that already have a positive NPV, the benefit of the capital subsidy is that it returns a substantially more positive NPV than without incentive, which may be crucial in ensuring earlier PV deployment.

Average NPV values for the industrial sector are significantly lower than for the commercial sector for most states, highlighting the different tariff regimes generally used between sectors. The exception here is Maharashtra, which has similar tariff levels for the commercial and industrial sectors. It may therefore be preferable to prioritize the commercial sector, especially as it can utilize the capital subsidy incentive.

As with the findings of the LCOE analysis, larger PV projects (Figure 8.13) are more profitable than smaller ones, with both Chhattisgarh and Gujarat showing positive NPVs in 2017 for a 1,000 kWp capacity system, although probably not substantial enough to make the project worthwhile. Despite the benefit of larger systems, PV + battery configurations may be financially unviable at all system capacities, even by 2020 (Figure 8.14).

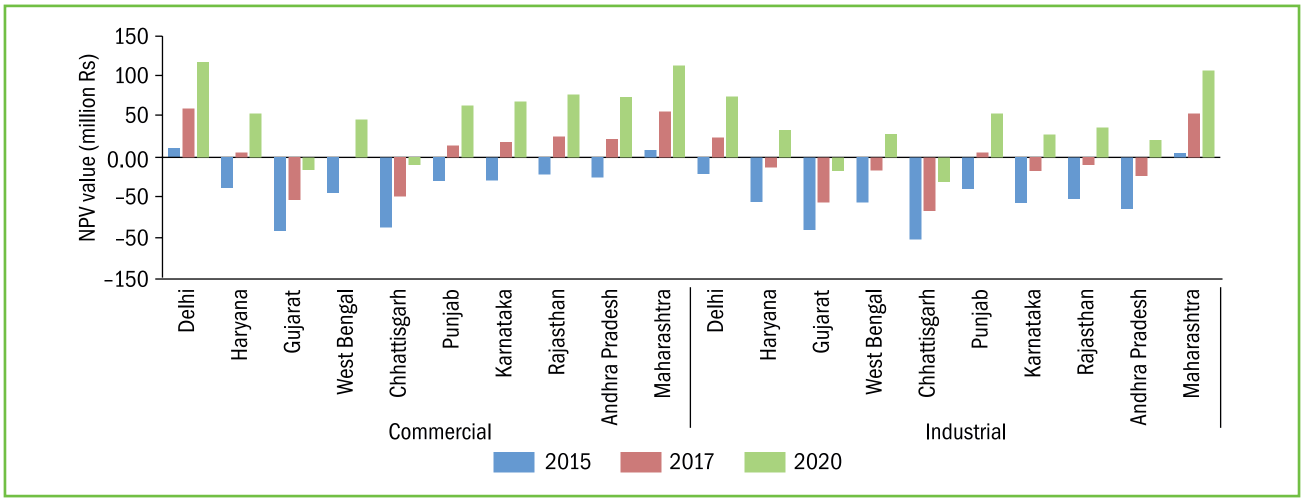


Figure 8.14: NPV for 1,000 kWp, PV + battery—no incentive

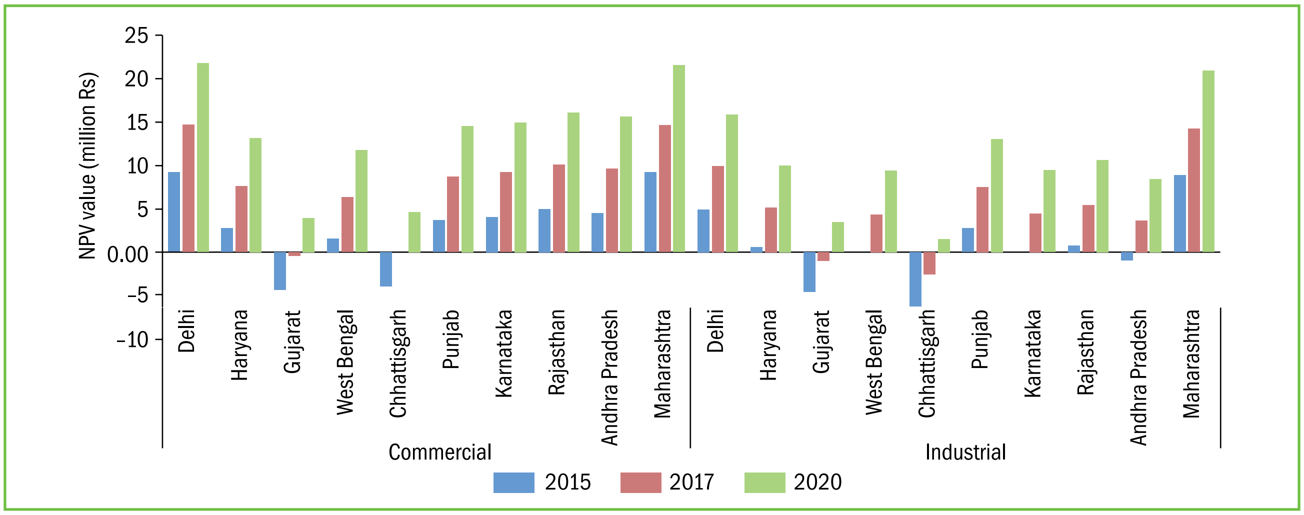


Figure 8.15: NPV for 150 kWp, PV only—no incentive

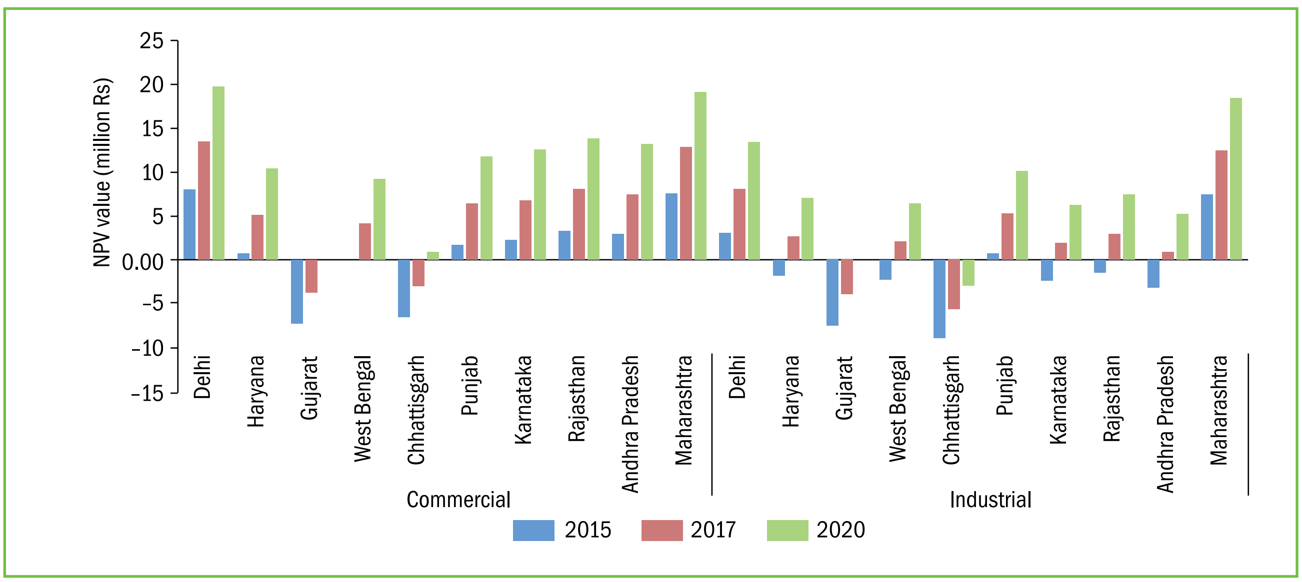


Figure 8.16: NPV for 150 kWp, PV + diesel—no incentive

The LCOE analysis highlighted the slight divergence in competitiveness of the PV only configuration compared to the PV + diesel configuration in 2017 and 2020. From comparing the NPV metrics of a PV only system (Figure 8.15) with an equally sized PV + diesel system (Figure 8.16), it is clear that the NPVs remain comparable, with PV only maintaining only slightly high values. This therefore indicates that the lack of a power outage associated with the diesel system providing adequate compensation for the slightly higher cost.

For all NPV data outputs from this analysis, refer to Annexure A8.3.

8.2.4 Internal Rate of Return (IRR)

The IRR has been calculated to provide an easy comparison with other potential projects of their investment potential. The IRR metrics largely mirror the findings of the NPV analysis, with even a small scale PV only system in the states of Delhi and Maharashtra offering very high rates of return, even from 2015. The IRR of a small-scale PV system in both Gujarat and Chhattisgarh remains low in 2015 (3 per cent and 3.5 per cent, respectively) and are likely to be unappealing compared with other investment opportunities until 2017. The IRR for all other states in 2015 is likely to be highly competitive compared to other investment opportunities (Table 8.8).

Table 8.8: IRR for a 25 kWp capacity standalone PV system—no incentive

PV Only—No Incentive			2015	2017	2020
25 kWp	Commercial	Delhi	16%	21%	29%
		Haryana	11%	15%	22%
		Gujarat	3%	8%	13%
		West Bengal	10%	14%	20%
		Chhattisgarh	4%	8%	13%
		Punjab	12%	16%	23%
		Karnataka	12%	17%	23%
		Rajasthan	13%	18%	24%
		Andhra Pradesh	12%	17%	24%
		Maharashtra	16%	21%	29%
	Industrial	Delhi	12%	17%	24%
		Haryana	9%	13%	19%
		Gujarat	3%	7%	12%
		West Bengal	8%	13%	18%
		Chhattisgarh	0%	5%	10%
		Punjab	11%	15%	22%
		Karnataka	8%	13%	18%
		Rajasthan	9%	14%	19%
		Andhra Pradesh	7%	12%	17%
		Maharashtra	16%	21%	29%

For the larger, 1,000 kWp system capacity, several states are already showing exceptional rates of returns in 2015, with even Rajasthan and Andhra Pradesh having IRRs of 16 per cent and 15.5 per cent, respectively, in 2015 for a stand-alone system without incentive (Table 8.9).

Whilst the IRR metric provides similar findings to the NPV metric, they both invariably provide a slightly different result since the IRR does not consider a discount rate. Therefore, while the IRR may show a positive return, the NPV may be negative (Figure 8.17). These two metrics should both therefore be considered together when evaluating investment decisions. For all IRR data outputs from this analysis, refer to Annexure A8.4.

Table 8.9: IRR for a 1,000 kWp capacity PV system, no incentive

PV Only—No Incentive			2015	2017	2020
1,000 kWp	Commercial	Delhi	20%	26%	35%
		Haryana	14%	19%	26%
		Gujarat	6%	11%	16%
		West Bengal	13%	18%	25%
		Chhattisgarh	7%	11%	17%
		Punjab	15%	20%	28%
		Karnataka	15%	21%	28%
		Rajasthan	16%	22%	29%
		Andhra Pradesh	15%	21%	29%
		Maharashtra	19%	26%	35%
	Industrial	Delhi	16%	22%	29%
		Haryana	12%	17%	23%
		Gujarat	6%	10%	16%
		West Bengal	11%	16%	22%
		Chhattisgarh	4%	8%	13%
		Punjab	14%	19%	26%
		Karnataka	11%	16%	23%
		Rajasthan	12%	17%	24%
		Andhra Pradesh	11%	15%	21%
		Maharashtra	19%	26%	34%

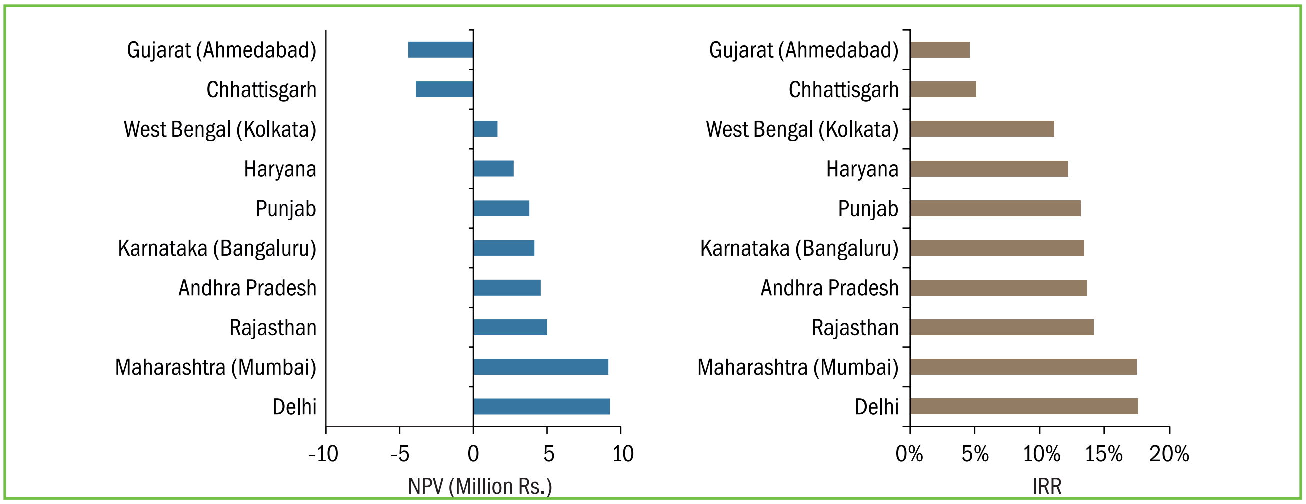


Figure 8.17: 2015 NPV and IRR comparison for 150 kWp, commercial, PV only—no incentive

8.2.4 Sensitivity Analysis—System Losses of 30 per cent

A sensitivity analysis will determine how a change in the PV system losses variable from 20 per cent to 30 per cent will impact the four financial performance indicators used in this analysis and provide a useful insight into project viability even with higher than anticipated system losses.

Levelized Cost of Electricity (LCOE)

Increasing system losses from 20 per cent to 30 per cent leads to less electricity generation for the same overall cost, therefore resulting in higher LCOE values for all system configurations and capacities. Therefore, since it is the PV net generation that is impacted from an increase in system losses, there is a 14 per cent increase in the levelized cost across all system capacities and configurations when system losses of 30 per cent are assumed. For a 25 kWp PV only system, levelized costs in 2015 range from 9.9 Rs/kWh in Maharashtra to 12.8 Rs/kWh in West Bengal (Figure 8.19), approximately a 1.4 Rs/kWh increase in LCOE compared to PV system losses of 20 per cent (Figure 8.18).

For a 150 kWp PV only system, LCOE metrics range from 9 Rs/kWh to 11.7 Rs/kWh when assuming PV system losses of 30 per cent, an average additional LCOE of 1.3 Rs/kWh.

The PV + battery configuration experiences the highest absolute increase in LCOE with an average of 2.3 Rs/ kWh per state for a small size system in 2015, with the LCOE for the ten states ranging from 15.9 Rs/kWh to 20.2 Rs/kWh. PV + diesel therefore becomes increasingly more cost competitive versus the PV + battery configuration due to the lower initial investment cost of the PV + diesel system.

Payback

An increase in the system losses to 30 per cent results in lower PV output and a subsequent reduction in annual revenue generation. It therefore takes a longer period of time to pay back the initial investment cost, resulting in an increase in the payback period of 12 per cent across all system capacities and configurations. The payback periods

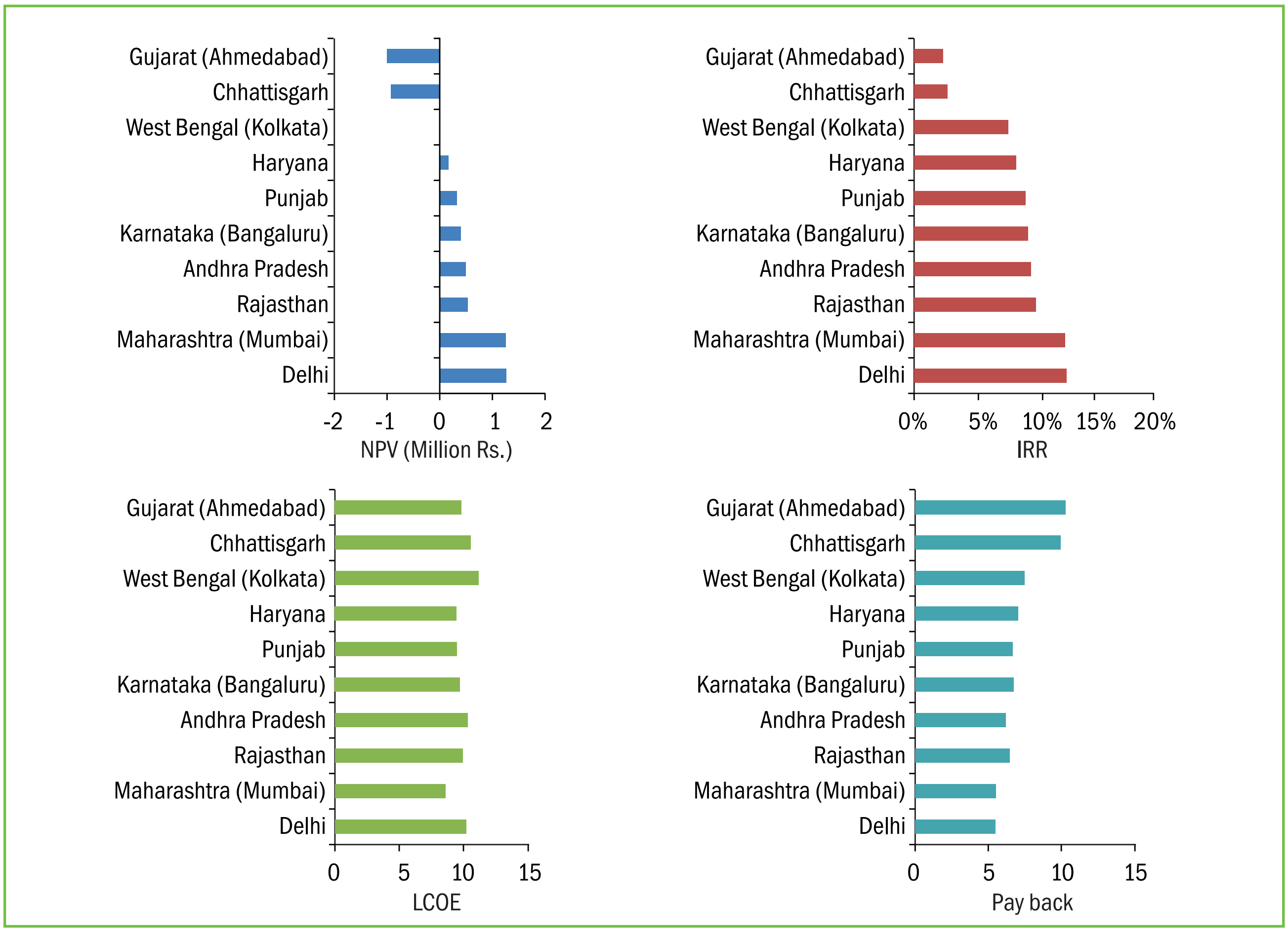


Figure 8.18: 20 per cent system losses, PV only 25 kWp, commercial, no incentive

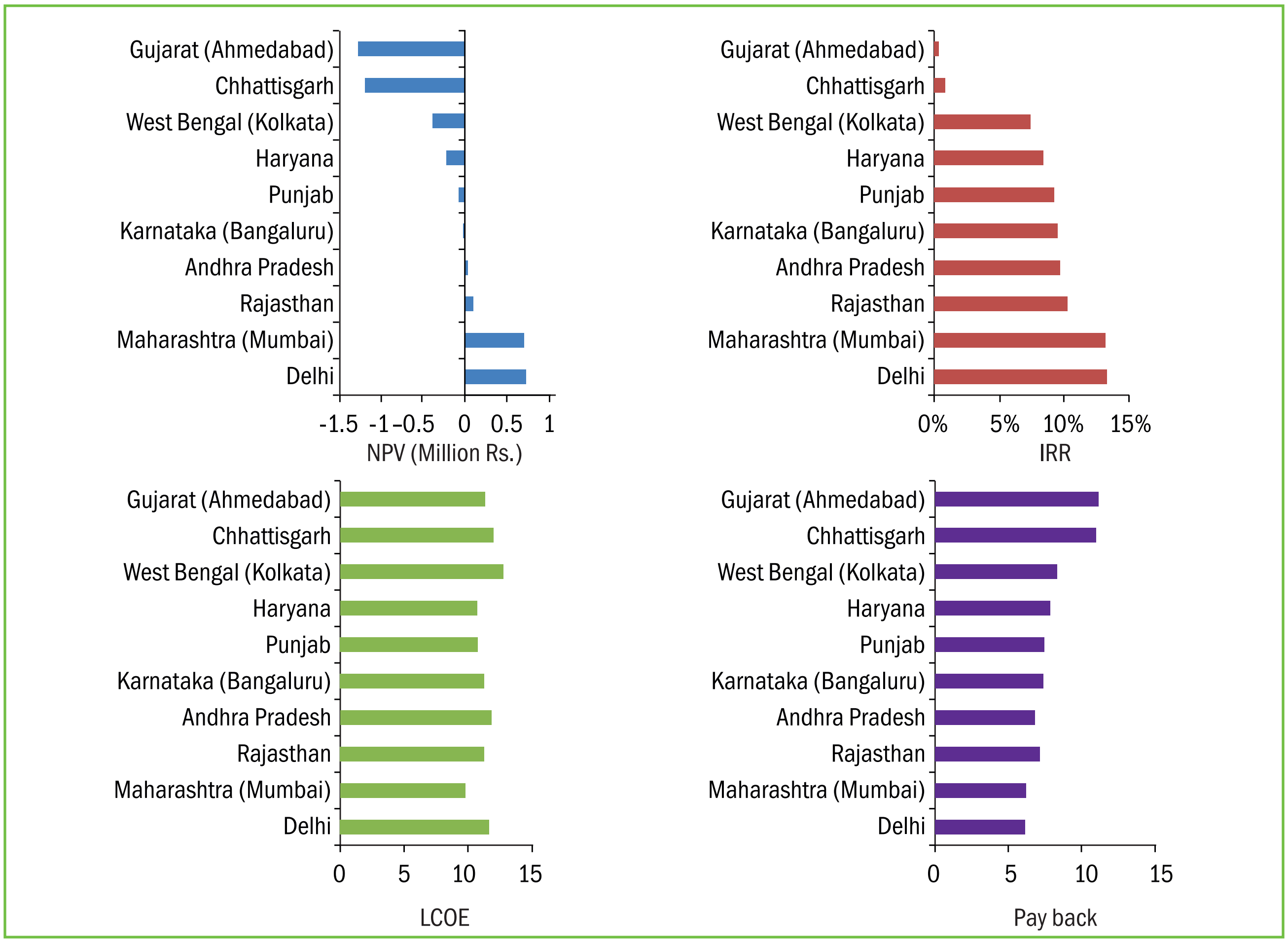


Figure 8.19: 30 per cent system losses, PV only 25 kWp, commercial, no incentive

for Chhattisgarh and Gujarat therefore increase to 10.3 and 10.5 years in 2015 (Figure 8.20), compared to 9.3 and 9.5 years, respectively, when assuming system losses of 30 per cent for a 150 kWp PV only system (Figure 8.21). The range in average payback periods for the 10 states increases to between 5.7 and 10.5 years in the commercial sector in 2015, an average increase of 0.8 years. When using the 15 per cent capital subsidy, paybacks in the commercial sector in 2015 are between 5.4 years and 9.7 years.

Net Present Value (NPV)

There is a significant swing from positive to negative NPVs when increasing system losses by 10 per cent for a small scale PV project, with the states of West Bengal, Haryana, Punjab, Karnataka, and Andhra Pradesh switching from being profitable to indicating a negative NPV. Delhi and Maharashtra maintain an attractive NPV, whilst Rajasthan maintains a marginally positive NPV, but that is likely not to represent an attractive investment.

For large 1,000 kWp PV only systems, there is no change in the number of states with positive NPVs, although the reduction in this metric makes the projects much less profitable. When availing the capital subsidy, only small scale PV only projects in Chhattisgarh and Gujarat return a negative NPV in 2015 with system losses assumed at 30 per cent, whereas the majority of states show a negative NPV without a capital subsidy. This again shows the potential importance of the capital subsidy in ensuring project viability.

Internal Rate of Return (IRR)

The IRR for small scale PV only systems for all states, including Gujarat and Chhattisgarh remains positive when adjusting to a 30 per cent system loss. This deviates from the sensitivity analysis for the LCOE metric, which shows

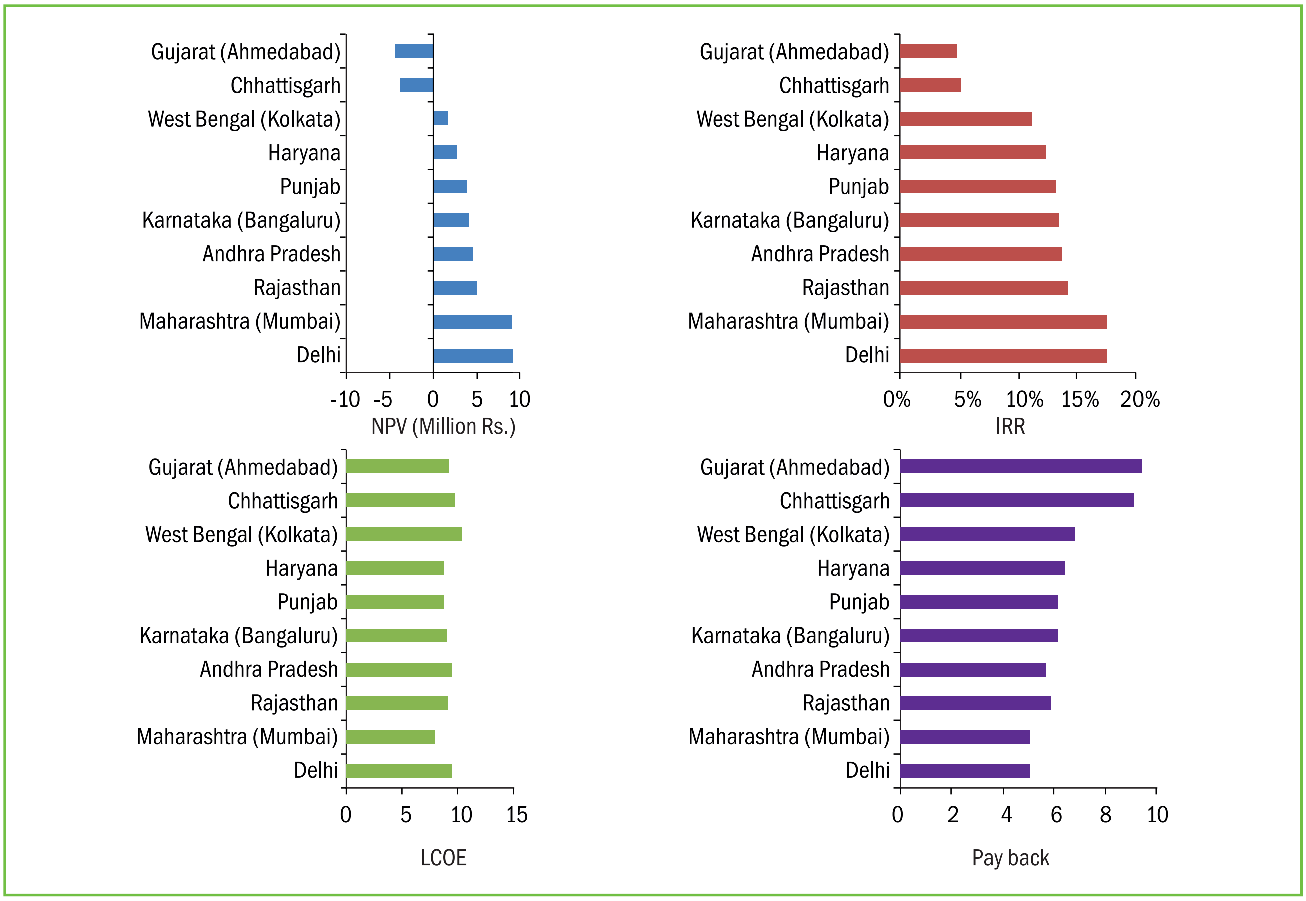


Figure 8.20: 20 per cent system losses, PV only 150 kWp, commercial, no incentive

a swing from profitability to non-profitability for several states and again highlights the importance of evaluating both metrics together when making an investment decision.

When assuming a PV system loss of 30 per cent, IRRs are in the range of 0.4 per cent in Gujarat to 13.3 per cent for Delhi for a small scale PV only system, a reduction of around 2 per cent compared to system losses of 20 per cent.

With the use of a capital subsidy, the majority of states (excluding Gujarat and Chhattisgarh) show an IRR of more than 10 per cent when system losses are assumed at 30 per cent indicating an attractive investment.

8.3 Conclusions

The financial framework developed to analyse the viability of different PV system configurations and capacities across the commercial and industrial sectors in 10 states in India has provided some useful insights. This chapter has quantified all the different cost components required when conducting analysis according to a capital cost/ operational cash flow methodology. The key findings from this modelling exercise are as follows.

Grid Tariffs

- Projected tariff rate rises are the most significant factor affecting the viability of PV projects, with current grid tariffs ranging from 3.8 Rs/kWh for Chhattisgarh to 10.6 Rs/kWh for Delhi;

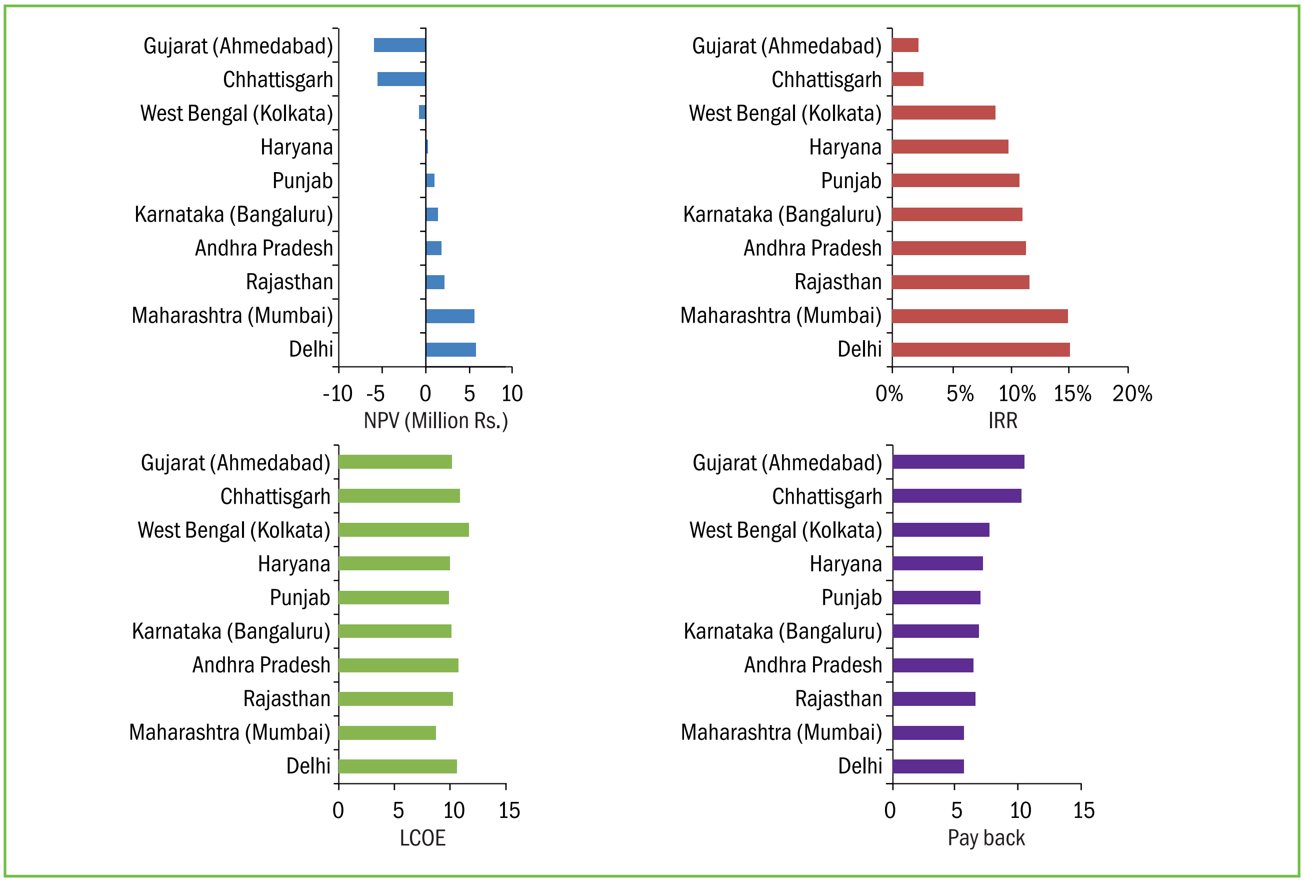


Figure 8.21: 30 per cent system losses, PV only 150 kWp, commercial, no incentive

- The states of Delhi and Maharashtra should be the initial focus of PV deployment. Due to their particularly high average tariff rates of 8.8 Rs/kWh and 7.9 Rs/kWh in 2015, respectively, with all financial indicators in this analysis suggesting that PV deployment in these states is already competitive with the grid;
- The commercial sector offers marginally more competitive tariffs than the industrial sector. PV projects in the commercial sector will therefore be viable sooner and requiring fewer incentives than the industrial sector.

Grid Parity

- The levelized cost of energy varies significantly depending on the choice of system configuration, system capacity, and financial incentives. For instance, LCOE values range from 4.8 Rs/kWh for a 1,000 kWp PV only configuration with capital subsidy in Maharashtra in 2020, up to 17.7 Rs/kWh for a 25 kWp PV + battery system in West Bengal 2015;
- The PV + diesel configuration represents a more cost-effective option than PV + battery configuration even in 2020, despite relatively increasing costs of diesel;
- In 2015, the LCOE for all PV system sizes remains higher than the grid in most states. Despite this, most states already exhibit positive NPV metrics in 2015, becoming increasingly more attractive in 2017 and 2020. A 25 kWp stand-alone PV system may therefore represent an attractive investment as early as 2015 despite not reaching grid parity on a LCOE basis;
- Larger capacity PV systems offer a significant improvement on LCOE metrics than smaller capacity systems owing to their improved economies of scale and are therefore likely to be viable earlier than other system capacities. Larger PV systems should therefore be a focus of early PV deployment. By 2020, costs are expected to fall to a level below the current capital subsidy LCOE level;

- The LCOE of a 150 kWp standalone PV systems surpasses grid parity without capital incentive for selected tariffs in Delhi, Andhra Pradesh, and Maharashtra in 2015.

Payback Period

- Payback periods for a 25 kWp PV only system with incentive are as low as 4.8 years in Delhi and Maharashtra currently in 2015, falling to 4.5 years with a 1,000 kWp system;
- The payback period is significantly higher when incorporating a battery into the PV system. For a mid-size PV system + battery in the industrial sector in Rajasthan, payback is currently 8.6 years, compared to 7 years for a stand-alone system;
- All states, with the exception of Gujarat and Chhattisgarh, offer a payback period of less than 6 years for a small standalone PV system in 2020; and
- Government incentives may be crucial for encouraging earlier PV deployment in some states with marginally positive NPVs. Capital subsidy will also be more beneficial for PV + battery configuration, due to capital cost of that configuration.

Net Present Value (NPV)

- Despite the LCOE being substantially above current grid tariff rates, a trend of increasing tariff's over the lifetime of the PV system enables the PV project to offset its currently high costs through higher revenues, resulting in a positive NPV;
- Punjab, Karnataka, Rajasthan, and Andhra Pradesh offer attractive NPVs as early as 2017 in the commercial sector with the larger 1,000 kWp PV system;
- The use of a capital subsidy has a significant positive effect on the NPV value, and may be effective at bringing forward PV projects within an earlier time scale;
- Delhi, Mumbai, and Punjab offer particularly attractive NPVs for the industrial sector in 2020; and
- Small scale PV projects in Gujarat and Chhattisgarh are likely to be uncompetitive even in 2020.

Internal Rate of Return (IRR)

- The internal rates of return mirror the findings from the NPV analysis, with Delhi and Mumbai offering highly attractive rates of return, particularly from 2017;
- The commercial sector offers particularly high IRRs when compared to the industrial sector;
- Most states, including Karnataka, Rajasthan, and Andhra Pradesh offer attractive rates of return in 2015 even for small stand-alone PV systems at 11.8 per cent, 12.6 per cent, and 12.1 per cent, respectively; and
- Whilst the IRR may indicate a potentially attractive investment, a potential project should be evaluated against both IRR and NPV metrics to gain a full understanding of project viability.

Supply Infrastructure

The existence of an adequate supply infrastructure is a prerequisite for a sustained uptake of the small solar photovoltaic (PV) sector. Poor workmanship due to a lack of a trained workforce and a lack of quality products can potentially stall expansion of the PV market.

The solar power sector, particularly the rooftop PV sector, has significant potential for job creation, which will require the training of a skilled workforce. With the rooftop solar PV market being relatively new and having its own specific skill requirements, there is a need for well-trained workers with the required skill set. Various training institutes offer a variety of courses, a summary of which is presented in this chapter.

9.1 Training Institutes and Survey of Courses Offered

A screening of the market is carried out in this study to understand the institutes that offer training on solar rooftop PV, the contents of the training, the target audience, the duration of the training, and the training cost.

In addition to the market screening, a survey of the courses offered by the training institutes has been conducted, and sent via email. The training institutes were asked to fill out a table with information pertinent to their courses. The table included, among other information, the number of participants already trained by them and the feedback received from the trainees. Many training institutes took part in the survey and provided the information. A summary of these training institutes, the courses offered by them, and the results of the survey are as follows.

9.1.1 National Institute of Solar Energy (NISE)—Solar Energy Training Network (SETNET)

The National Institute of Solar Energy (NISE) under the Ministry of New and Renewable Energy (MNRE) has established the Solar Energy Training Network (SETNET) with the aim of providing skilled labour to work towards the highly ambitious targets for rooftop grid connected and off-grid solar PV plants. SETNET has been developed in collaboration with the United States Agency for International Development (USAID) under the US–India Partnership to Accelerate Clean Energy Deployment technical assistance (PACE-D Program).

A standardized curriculum will be developed under the SETNET programme, which will be used by all of its members. The trainers of SETNET will also be accredited. These procedures will help to fulfil the programmes aim to build skills and capacities amongst solar energy professionals. The SETNET curriculum includes not only rooftop grid connected projects but also off-grid, micro-grid, rooftop solar, stand-alone systems and high technology areas such as solar process interventions. Four types of training programmes have been identified and development of the curricula has been started for a few programmes. An overview of the SETNET training programmes is given in Table 9.1.

Table 9.1: Overview of the four major courses developed at SETNET

Course name	Aryabhatt Certificate for Project Managers	Konark Graduate Engineer Certificate	Bhaskar Business Certificate	Suryan Installation, Operation Management Professional
Content of the training	Design (rooftop to UMPP), Solar Project Management	Basic solar engineering and management	Business and technical courses	Rooftop; heater; micro-grid; house hold applications; street-light, and charging stations
Target profile	Senior design engineers	Graduate engineers	Entrepreneurs	Diploma/ITI Graduates
No. of trainees estimated	3,000 (market mode)	10,000 (market mode)	10,000 (market mode)	400,000 (mix of sponsored and market mode)
Course fees	INR 10,000	INR 10,000	INR 10,000	INR 8,000
Course duration	30 days (120 h)	30 days (120 h)	30 days (120 h)	20 days (90h)
No. of professionals already trained	Few hundreds are already trained			

Aryabhatta Certificate (for high level designers)

This course is intended for engineers who already have some experience in the solar sector. The aim of this course is to enable the participants to effectively plan, design, and operate solar power systems for a range of project sizes, from rooftop systems to ultra-megawatts solar power plants.

Konark (graduate engineer course)

This course is meant for engineers who seek employment as solar engineers.

Suryan (for solar field technicians)

The Suryan Programme is intended for participants dealing with home lighting system, rooftop solar, street lighting, solar water heaters, inverters and batteries, charging stations, and solar cookers.

Bhaskar (for business/financial programmes)

Bhaskar provides training in several different areas including policy and regulation, business models, finance, appraising solar projects supply chain management, solar entrepreneurship development, and micro finance. There are three Bhaskar course programmes under the Bhaskar certificate:

- The Bhaskar Course I is titled "Rooftop Solar PV Technology, Design, Engineering, and Energy Yield Assessment" and is aimed at new entrepreneurs, Engineering, Procurement and Construction (EPC) contractors, project developers, officials from state government and research students.
- The Bhaskar Course II is titled "Best Practices: Procurement and Tendering Procedures" and is designed for officials from State Governments, state nodal agencies (SNAs), corporates, banks, co-operative societies, and municipal bodies.
- The Bhaskar Course III under the name "Grid Integrated Rooftop Solar PV Technology and Design" is intended for new entrepreneurs, EPC contractors, project developers, officials from State Government, SNAs, PSUs, and research students and distribution companies.

A detailed list of training institutes under the SETNET programme is given in Annexure A9.1

9.1.2 NISE—Suryamitra

NISE is organizing 'Suryamitra' skill development programmes, in collaboration with state nodal agencies at various locations around the country. The duration of this skill development programme is 600 hours. It is a free of cost programme sponsored by the MNRE and is suitable for candidates. The candidate must be of graduate grade (cleared class XII) and not below 18 years of age. Candidates with an ITI, Diploma in Electrical, Mechanical, and Electronics shall be given preference. Candidates with an electrician certificate and relevant experience shall also be given preference. Special emphasis will be given to people from a rural background, unemployed youth, women, and SC/ST candidates.

Persons with higher qualifications such as a degree (in any discipline) are not eligible for this Programme.

Upon successful completion of the course, a certificate will be issued. The Suryamitra Programme is also designed to prepare the candidate for an entrepreneurial career in the solar energy sector.

9.1.3 Gujarat Energy Research and Management Institute (GERMI)

The Gujarat Energy Research and Management Institute (GERMI) is promoted by the Gujarat State Petroleum Corporation Ltd, an undertaking of the Gujarat Government. GERMI, located in the capital of Gujarat, Gandhinagar has provided training in the field of solar power plants since 2011. GERMI offers a comprehensive technical workshop for design and O&M engineers working in the field of solar PV energy. The details of the training workshop are as follows (Table 9.2):

Table 9.2: Overview of the course offered at GERMI

Course name	Solar PV power plant design , installation, and its O&M
Contents	Hands on, software design, theory lectures, and practical session
Target profile	Engineers, start-ups organization, project manager, owner of the organization, entrepreneurs
Course duration (hours / days)	5/6 days. 7 hours /day
Fees (INR)	Rs48,000 (plus tax)
Number of professionals already trained	More than 500

9.1.4 Global Sustainable Energy Solutions (GSES)

Global Sustainable Energy Solutions (GSES) is a private limited company based out of Delhi, India, and provides consultancy services and training related to solar PV power plants. GSES is an industry leader in accredited solar training for the safe design and installation of grid connected SPV systems. GSES offers solar training and renewable energy courses to cater for a broad range of clients. (Table 9.3).

Table 9.3: Overview of the course offered at GSES.

Course name	Professional advantage Technical advantage Business advantage
Target profile	Engineers Project managers Entrepreneurs Project developers Consultants Engineering students pursuing renewable energy courses
Course duration (hours / days)	Professional advantage: 3–6 months Technical advantage: 3–5 days Business advantage: 2–3 days
Fees (INR)	Rs15000–35000
Number of professionals already trained	About 500

9.1.4 Arbutus/University of Pune

Arbutus Consultants, in cooperation with the University of Pune, offer training courses on solar power plant design, installation, and O&M. Theoretical lectures are coupled with practical hands on experience in the training courses. The details of the course at Arbutus are given in Table 9.4:

Table 9.4: Overview of the course offered at Arbutus/University of Pune

Course name	Various courses have been completed; presently conducting 100 hours Certificate Course In Design, Installation, and Commissioning of Solar PV System
Contents	Overview of industry and systems Principles and technologies Design of grid-connected systems Case study of grid-connected systems design and case study of off-grid systems installation, commissioning and engineering practices Project management Experiments- on roof top PV system entrepreneur awareness Group discussion Site visit to large scale solar power plant
Target profile	* Diploma/ITI pass—Installers/supervisors * Engineers—Design graduates of PV plants/supervisors * Project managers—Project due diligence and project management * Entrepreneurs—Project appraisal
Course duration (hours)	100 hrs.
Fees	Rs 29,000
Number of professionals already trained	Under present course—40; Overall – 400+

9.1.5 Steinbeis Academy

Steinbeis Academy for Advanced Technology Training and Entrepreneurship, a Network Centre of Steinbeis Foundation, Germany, provides training in the areas of renewable energy, solar PV, automotive, machine tools, automation, and robotics (Table 9.5).

Table 9.5: Overview of the course offered at Steinbeis Academy

Entry level	Project engineers	Technical executives	Project managers
Entry level	+ Additional practical subject	+ Techno-commercial level	+ Commercial level + on-site projects
Basic knowledge on installation, functioning, commissioning, and maintenance	Solar rooftop installation process, safety precautions, domestic power estimation	Technical training and practical information, business practice tactics industry	Technical training and practical information, complete exposure on on-site projects

9.1.6 National Centre for Photovoltaic Research and Education (NCPRE)

The National Centre for Photovoltaic Research and Education (NCPRE) at IIT Bombay was launched in 2010 as a part of the Jawaharlal Nehru National Solar Mission of the Government of India. Various short-term courses consisting of two to three days of training and long-term courses consisting of ten days of training are being carried out at NCPRE.

9.2 Standards and Codes Relevant for Rooftop PV in India

This section discusses the various technical codes relevant for rooftop solar PV in India.

9.2.1 Central Electricity Authority (CEA) Code

The Central Electricity Authority (CEA) of India is the national agency that determines the technical regulations within the country for grid-connected solar rooftop PV systems. The technical and safety requirements for rooftop solar PV generation are outlined in the following CEA regulations/guidelines:

- Technical Standards for Connectivity of the Distributed Generation Resources' Regulations, 2013
- Installation and Operation of Meters' Regulation 2006 (draft amendment in 2013 includes distributed solar generation) that regulates metering standards.
- Measures of Safety and Electricity Supply Regulations, 2010' govern safety for generators.

'Technical Standards for Connectivity of the Distributed Generation Resources' Regulations, 2013, are applicable to any solar system that is connected at voltage level below 33 kV. The roles and responsibilities of the developer/system owner and the distribution company are defined in the CEA regulations (Table 9.6) and cover areas including the equipment standards and codes of practice for safety, and the system requirements for safe voltage, frequency, and harmonics.

- **Voltage band:** To ensure that the PV system remains connected to the grid when it is beneficial for the operation of the grid and disconnects when system connection is detrimental to the grid, voltage–time operating bands are defined in the CEA regulations. If the voltage of the grid exceeds or falls below the operational range of 80–110 per cent of the nominal voltage, the rooftop solar PV power plant should be disconnected from the grid in 2 seconds according to the CEA regulations. Reconnection with the grid is allowed only when the voltage falls within the prescribed limits and is stable for 60 seconds.
- **Frequency band**: If the grid frequency deviates from the standard frequency of 50 Hz, that is, reaches 50.5 Hz or 49.5 Hz, the rooftop solar PV system should be disconnected from the grid within 0.2 seconds. As a result, the rooftop solar PV system has to be equipped with protective functions for over and under frequency trip functions. As with voltage, reconnection to the grid is only allowed when the frequency falls within the prescribed limits and is stable for 60 seconds.
- **Harmonics:** CEA follows the Institute of Electrical and Electronics Engineers (IEEE) 519 standard on harmonics. The limitations for current and voltage harmonic contaminations through individual harmonic limits and

total harmonic distortion (THD) limits are defined in IEEE 519. The voltage distortion limit established by the standard for general systems is 5 per cent THD. In this standard, the total demand distortion (TDD) is used as the base number to which the limits are applied. There are specific limits mentioned for various harmonics for different TDD values.

- **Flicker:** CEA follows IEC 61000-3-3,-3-11 standards to control flicker. The standards state that
  - The perception of light flicker in the short term, observed over 10-minute intervals (Pst) value shall not be greater than 1.
  - The perception of light flicker in the long term, observed over 2 hours of 12 Pst samples (Plt) value shall not be greater than 0.65. P is the number of voltage changes per minute versus the percentage of voltage change.
- **DC injection in AC grid:** The CEA regulated current DC injection limit is in line with the IEEE 1547 standard, wherein the maximum permissible level of DC injection is 0.5 per cent of the full rated output at the interconnection point.
- **Anti-islanding:** The CEA mandates prevention of unintentional islands in all inverters according to 'Technical Standards for Connectivity of the Distributed Generation Resources', 2013. The MNRE currently mandates the UL1741 68 / IEEE1547 for anti- islanding protection for utility scale projects commissioned under the National Solar Mission.

Table 9.6: Overview of codes and standards

Parameter	Code/Standard
Voltage band Frequency	V < 80% (<2 s) and V > 110% (<2 s) f ≥ 50.5 Hz (0.2 s) and f < 49.5 Hz (0.2s)
Harmonics	IEEE 519
Flicker	IEC 61000-3-3 and IEC 61000-3-11
DC Injection	<0.5% of full rated output current
Anti-islanding	UL1741/ IEEE1547

A comparison is made between the technical requirements for rooftop solar PV laid out by CEA with those in countries which have a large amount of distributed solar PV generation, such as Germany, the USA, and Australia. A comparison of voltage and frequency limits between countries is given in Table 9.7.

Table 9.7: Comparison of voltage and frequency limits for different countries

Parameter	CEA/India	Germany	USA	Australia
Voltage	V < 80% (<2 s) V > 110% (<2 s)	V < 80% (<0.1 s) V > 110% (<0.1 s) for low voltage, <0.15 s to 1.5 s for medium voltage	V <50% (≤0.16 s) 50% ≤ V < 88% (≤2 s) 110% < V < 120% (≤1 s) V ≥ 120% (0.16 s)	V < 216 V (-) V > 253 V(<3 s) as per AS 60038 81
Frequency	f ≥ 50.5 Hz (0.2s) f < 47.5 Hz (0.2s)	47.5 Hz < f < 50.2Hz 50.2 Hz < f < 51.5Hz [droop function]	f > 60.5 Hz or f < 59.3 Hz (≤0.16 s) [DER ≤ 30 kW] f > 60.5 Hz or f < 57.0 Hz (≤0.16 s) [DER > 30 kW]	f > 55Hz (<2 s) f < 45Hz (<2 s)

From Table 9.7, it can be seen that the technical requirements laid out by the CEA for rooftop solar PV power plants are comparable with other international practices for the proper functionality of the rooftop PV systems.

9.2.2 Metering Arrangement

The technical requirements of meters are laid out by the CEA through the regulation 'Installation and Operation of Meters, 2006', which was amended in 2013 to include renewable energy meters for distributed solar generation. The standards mentioned in the regulation are:

- IS 13779 is applicable to static Watt-hour meters of class 1 and 2.
- IS 14697 provides the standards for static transformer operated Watt-hour and VAR- hour meters, of accuracy class 0.2 S and 0.5 S.

Since meters have different accuracy classes, the CEA in its amendment of the regulation (installation and operation of meters) in 2010 specifies the accuracy class for different voltage levels:

- ≤ 650 V—class 1.0 or better
- 650 V and ≤ 33 kV—class 0.5 S or better

These standards are equivalent to the IEC 62052-11 and 62053-21/22 standards. The metering arrangements in various countries are shown in Table 9.8. It is clear that the accuracy of the meters required by the CEA regulation is consistent with international standards.

Table 9.8 Comparison of metering arrangements for different countries

Voltage connection	CEA	Germany	USA
No. of meters	2	1	1/2
Type of meters	Not specified	Bi-directional	Bi-directional/2 meters
Metering arrangement	Net-metering	FiT	FiT
Accuracy class	650 V–class 1 or better > 650 V and ≤ 33kW – class 0.5S	< 1 kV – class 1 > 1 kV < 72.5 kV – class 0.5S	0.2 S & 0.5S
FiT = Feed in Tariff.			

However, for metering arrangements that have either a single net-meter or two meters consisting of one generation meter and one load meter, the regulations are not adequate when compared to other countries. Most of the countries use bi-directional net-meters, which simplify the installation, O&M, and processing of energy produced, billing, etc. Moreover the requirements related to the metering arrangement are different to state policies from several Indian states, which do not conform to the CEA regulations. This is mainly due to the limited availability of bi-directional net meters in India.

9.2.3 Interconnectivity

The voltage level at which the distributed energy generation systems should feed the power generated into the grid, (interconnection voltage) depends on the size of the rooftop solar PV plant. The CEA regulation that governs this is the 'Report of subgroup-I Grid interactive Rooftop solar PV system'. According to this regulation, rooftop solar PV plants smaller than 10 kW can feed at 230 V single phase line, whereas plants greater than 10 kW and less than 100 kW should feed at 415 V three phase line. For rooftop solar PV plants greater than 100 kW and less than 1,500 kW, the inter-connection should be at 11 kV 3-phase line, whereas for plants greater than 1,500 kW the interconnection should be either at 11kV or at 33 kV or at 66 kV 3-phase line.

As with the net metering arrangement, the interconnection voltage requirement varies from one state to another, mostly guided by the respective state solar net metering policies. A summary of the interconnection voltage level for different rooftop solar PV sizes in three states is given in Table 9.9. However, this difference doesn't affect the implementation of rooftop solar PV power plants.

Table 9.9 Interconnection voltage requirements for different PV sizes

Voltage connection	System Size	Voltage level
CEA Report of subgroup-I Grid interactive Rooftop solar PV system	< 10 kW > 10 kW < 100 kW > 100 kW < 1500 kW > 1500 kW	230 V, 1 Phase, L.T. 415 V, 3 Phase, L.T. 11 kV, 3 Phase, H.T. 11 kV/33 kV/66 kV, 3 Phase, H.T.
Delhi	< 10 kW > 10kW < 100 kW >100 kW	240 V, 1 Phase, L.T./ 415 V, 3 Phase, L.T. 415 V, 3 Phase, L.T. H.T./E.H.T.
Gujarat	< 6 kW > 6 kW < 100 kW > 100 kW	240 V, 1 Phase, L.T. 415 V, 3 Phase, L.T. 11 kV, 3 Phase, H.T.
Tamil Nadu	<4 kW > 4kW < 112 kW >112 kW	240 V, 1 Phase, L.T./ 415 V, 3 Phase, L.T. 415 V, 3 Phase, L.T- H.T./E.H.T.

9.3 Building Code

9.3.1 Earthquake Resistant Structures

In India, about 57 per cent area is in a highly seismically active zone, including Delhi, the capital of the country. Engineering intervention in buildings and structures is needed to make them strong enough to withstand the impact of earthquake.

The Bureau of Indian Standards has produced a number of national standards in the field of design and construction of earthquake resistant structures. A brief description of Indian Standards in the area of mitigation of natural hazard of earthquake that are relevant to the design of buildings with rooftop solar PV is provided. There are mainly three relevant codes as follows:

- IS 1893:1984: Criteria for Earthquake Resistant Design of Structures
- IS 1893(Part 1): 2002 'General Provisions and Buildings'
- IS 1893(Part 4): 2005 'Industrial Structures Including Stack Like Structures'
- IS 4326: 1993 'Earthquake Resistant Design and Construction of Buildings - Code of Practice'
- IS 1893 (Part 1): 2002: Criteria for Earthquake Resistant Design of Structures 'General Provisions and Buildings'

This standard contains provisions that are general in nature and applicable to all structures and is relevant to the design of commercial and residential buildings. It also contains provisions that are specific only to buildings. It covers general principles and design criteria, combinations, design spectrum, the main attributes of buildings, dynamic analysis, as well as a seismic zoning map and seismic coefficients of important towns, map showing epicentres, map showing tectonic features, and lithological map of India (Figure 9.1).

IS 1893(Part 4): 2005 'Industrial Structures Including Stack Like Structures'

This standard deals with earthquake resistant design of the industrial structures (plant and auxiliary structures), including stack-like structures such as process industries, power plants, textile industries, off-shore structures, and marine/port/harbour structures.

In addition to the above, stack-like structures covered by this standard include transmission and communication towers, chimneys, and silos (including parabolic silos). This standard specifies design requirements for structures standing on rocks or soils, which do not settle, liquefy, or slide due to loss of strength during vibrations.

The design approach adopted in this standard is to ensure that

- Structures possess sufficient strength to withstand minor earthquakes (Design Basis Earthquake [DBE]) that occur frequently, without damage;
- Structures resist moderate earthquakes (DBE) without significant structural damage though some non-structural damage may occur; and
- Structures withstand a major earthquake (MCE) without collapse.

IS 4326: 1993 'Earthquake Resistant Design and Construction of Buildings - Code of Practice'
This standard provides guidance in selection of materials, special features of design, and construction for earthquake-resistant buildings including masonry construction, timber construction, prefabricated construction, etc. In this standard, it is intended to cover the specified features of design and construction for earthquake resistance of buildings of conventional types. The general principles to be observed in the construction of such earthquake-resistant buildings as specified in this standard are lightness, continuity of construction, avoiding the use of or reinforcing projecting and suspended parts, building configuration, strength in various directions, stable foundations, ductility of structure, connection to non-structural parts, and fire safety of structures.

Special construction of features has been elaborated in this standard, such as separation of adjoining structures, crumple sections, foundation design, roofs and floors, and staircases.

9.3.2 Wind Load on Rooftop Structures

Wind loading on the rooftop solar PV power plant must be considered in the design of the mounting structures. In all the solar rooftop policies released by various Indian states, there is no reference to any requirement of wind loading on the rooftop structures and its effect on the floor of the building. The standard, "IS: 875(Part 3): Wind Loads on Buildings and Structures", provides guidelines for the design of rooftop structures by taking into consideration the load due to wind. The main parameters that should be included in the design of the rooftop structures are: design wind speed and design pressure at the site. The design wind speed at the site must consider the terrain, height, and size of the structure as well as the local topography. Extreme wind conditions must also be taken into consideration while designing the maximum wind loading on the building.

9.3.3 Fire Safety

Care should be taken in designing a rooftop solar PV system to prevent the outbreak of fire due to, or during the installation and operation of a rooftop solar PV system. During outbreak of fire on a building with rooftop solar PV, the solar PV components should not increase the intensity of fire, that is, the solar PV components should not be made from easily inflammable products. The solar panels themselves typically contain limited plastics, but it is the frames, mounting systems, cables, and boxes that can add to the combustible loading of an installation and eventually lead to increased combustibility of the entire roof. Standards for testing the performance of solar panels have been developed at an international level. The international and Indian standard for module safety qualification IS/IEC 61730-1: 2004 Photovoltaic (PV) Module Safety Qualification includes information on the fire safety of the PV modules. Another code that can be of use for the design of rooftop solar PV systems is IEC 60695-1-1: Fire Hazard Testing—Part 1-1: Guidance for Assessing the Fire Hazard of Electro-Technical Products—General Guidelines.

Additionally, necessary precautions should be taken to ensure that the safety of the fire fighters is not compromised in the event of a fire on a building with rooftop solar PV. The disconnection of the roof top solar PV systems is not possible since the PV system inverter can hold a charge and send electricity back up to the solar panels. The panels themselves will continue to produce power as long as the sun is shining and possibly even at night when bright lights are present. Thus, the conduit leading from the PV panels to an inverter remains live with direct current even after the main service panel has been shut-off. This means that fire fighters are at risk of getting an electric shock, as they have to fight a fire in the presence of high DC voltage and current. Furthermore, DC cable insulation is likely to melt during the course of a fire on a building with a PV system. DC arcs are not only an ignition source themselves, but an additional life safety threat to fire fighters, as such, the following is suggested:

It should be possible to safely disconnect the PV system in the event of a fire,

- A so called 'fireman's switch', as is already in use in the German market, should be used;
- Additional isolators should be installed between strings/arrays and the inverter at roof top level to at least de-energize the main conduit leading from the roof to the inverter. These switches can be remotely actuated from a safe location;
- The layout of the solar panels should be such that it does not block key locations and pathways that the fire fighter would use otherwise on a roof;
- The added weight of a solar panel array should not lead to roof collapse, if the integrity of the structure is already compromised by fire;
- The decomposed products of the panels may not emit toxic fumes.

9.4 Conclusions

In this chapter, the enabling supply infrastructure required to ensure the quality of rooftop solar PV installations has been analysed with a focus on skills development, technical and electrical codes and standards, and building codes. The main conclusions of the study are:

- Training courses on rooftop solar PV are available in the Indian market. Of the four training institutes that took part in our survey, it is reported that more than 2,000 participants have already received training on solar PV systems. The SETNET Programme of NISE has developed four types of training programme and is aiming to provide training on solar PV systems to 400,000 skilled to semi-skilled labours. With the formation of the SETNET and enlistment of 35 training institutes as partner organizations that are located in different geographies in India, the supply of trained rooftop solar PV installers/technicians is going to increase in the future.
- The CEA regulations relating to the technical requirements for rooftop solar PV are very detailed and are on a par with international standards. However, availability of net-meters in India is a concern. The interconnection voltage for connecting different sizes of solar PV systems to the grid has been specified by CEA and at the same time by all the state agencies. There is some discrepancy between the interconnection requirements laid down by the CEA and that from the state agencies.

The solar rooftop policies launched by various states define the technical and other requirements for the rooftop solar PV systems. None of the state policies define the requirements for checking the earthquake resistance of the structures/buildings, wind loading, and fire safety norms that should be followed. The policies should take these important aspects into consideration.

10

Chapter

Environmental and Social Impacts

10.1 Screening of Environmental and Social Impacts

This study analyses the technical, economic, and market potential of rooftop solar power in the commercial and industrial sectors in India. This chapter maps the environmental and social impacts from rooftop solar projects using guidelines issued by the Indian Government as well as the project appraisal matrix of the KfW Development Bank's Sustainability Guidelines. We also believe that an assessment of the PV recycling aspects should be conducted to address any environmental impact associated with the afterlife of rooftop PV projects.

Ministry of Environment and Forests (MoEF) Guidelines for Environmental and Social Impact Assessment

In recent decades, execution of development projects and programmes has been conducted at an increasing pace. There are various impacts of such development projects. While society benefits significantly, there is the potential for exploitation of natural resources and other environmental risks and hazards. Such interventions may significantly alter the existing social and cultural fabric, and people within the project area often bear the brunt of adverse impacts, where they may even be forced to relocate in order to make way for such interventions. Therefore, there is a need to understand and evaluate any potential adverse environmental and social impacts so that mitigation plans can be put in place. Environmental Impact Assessments (EIA) and Social Impact Assessments (SIA) are now generally accepted as integral components of policy and decision making. Since the current study involves analysing the feasibility of rooftop potential for solar power in the commercial and industrial facilities, it becomes imperative to assess the environmental and social impacts of such interventions.

India's Ministry of Environment and Forests (MoEF) has launched several policy initiatives and enacted environmental and pollution control legislations designed to integrate environmental concerns into development projects. The Environmental Protection Act of 1986 was heralded as a progressive initiative and the EIA Notification of 1994 further accelerated this act. An SIA is generally carried out as a part of the EIA clearance process. The EIA encompasses three major components: (i) Physical Environment, (ii) Biological Environment, and (iii) Social Environment. In 2006, the EIA Notification amendment declared such an assessment within a radius of 10 km of the proposed project site as a compulsory exercise.

The majority of projects in India where an EIA is required are large developmental projects such as nuclear power, river valley's and thermal power plants. The government has played an important role by making an EIA mandatory for 30 categories of development project (Annexure A10.1). The agencies, which are primarily responsible for certain sectors, are involved in preparing the guidelines. SIA's, which are carried out as part of an EIA, have increased in importance in the recent years. The National Rehabilitation and Resettlement Policy, issued in 2007, recognizes the need to carry out an SIA as part of the resettlement planning and implementation processes and is a legal requirement. For any new project or expansion of an existing project that involves involuntary displacement of 400 or more families, in plain areas, or 200 or more families in tribal or hilly areas, conducting an SIA is deemed mandatory. As per the EIA Notification issued in 2006 by the MoEF, all projects and activities are broadly categorized into two categories (Category A and Category B) based on the spatial extent of potential impacts and potential impacts on human health and natural and human made resources. Table 10.1 depicts the impact category and examples of projects/programmes.

Table 10.1: Environmental and social impact category and examples of projects

Impact category	Potential environmental and social impacts on	Examples of projects
A	▪ Air ▪ Water ▪ Forests ▪ Flora and fauna ▪ Hazardous waste ▪ Landscape ▪ Land use ▪ Soil ▪ Drainage pattern ▪ Transport systems ▪ Displacement of people ▪ Livelihood ▪ Health	▪ Mining and hydro-electric ▪ Offshore and onshore oil and gas exploration ▪ Nuclear power projects and processing of nuclear fuel ▪ Ports, harbours, airports ▪ Petroleum refineries including crude and product pipelines ▪ Chemical pesticides/fertilizers ▪ Oil and gas transportation pipe line
B	▪ Air ▪ Land ▪ Soil ▪ Water ▪ Landscape ▪ Drainage pattern ▪ Hazardous waste ▪ Displacement of people ▪ Livelihood ▪ Health	▪ Township and area development projects ▪ Solid waste management facility ▪ Cement plants—standalone grinding units ▪ Fibbers manufacturing and synthetic chemical industry ▪ Integrated pain industry ▪ Sugar industry ▪ Industrial estate/parks/special economic zone

Environmental and Social Screening Requirements—Rooftop PV Systems

Small-scale PV projects are not listed in the category of 30 development projects identified by the government, which require an EIA and SIA. Such projects are likely to qualify as a low-impact development project in terms of having any adverse environmental or social impact due to the following reasons

- It does not involve involuntary displacement of people as no lands are required to implement this project
- It is not undertaken in any ecological fragile areas;
  - It does not involve any submergence of lands/forests;
- There are no major construction activities that are involved;
- It does not deal with any hazardous/radioactive materials;
- Operating PV systems make no noise and do not pollute;
- PV panels don't produce any polluted emissions (A 100 W solar module is estimated to prevent over two tons of carbon dioxide emissions over its lifetime).

Compliance with KfW 'Sustainability Guidelines'

The KfW Sustainability Guidelines identify and classify development projects under three categories—A, B, or C—depending on their potentially negative environmental and social impact. The implementation of small rooftop solar PV (SPV) systems may not qualify under any of the projects identified by KfW's guidelines for environmental and social screening. It would at best qualify under the category C since there are no major adverse social or environmental impact and the implementation and operation of the project does not require any particular protection, compensation, or monitoring measures. Table 10.2 depicts the impact category and examples of projects/programmes.

Table 10.2: Impact category and examples of projects

Impact category	Potential environmental and social impacts	Examples of projects
a	Projects have potentially negative impact on the environment and on social conditions. It is mandatory to analyse the impacts and identify measures that need to be taken to avert, mitigate, and offset any negative consequences	▪ Large dams ▪ Irrigation and drainage projects ▪ Geological mining ▪ Infrastructure projects
B	The potential consequences of projects are limited to the local area, are in most cases reversible, and are easier to mitigate through appropriate measures	▪ Waste management ▪ Infrastructure projects ▪ Industrial activities
C	Projects have no or only minor negative environmental and social consequences and the implementation and operation of the project does not require any particular protection, compensation, or monitoring measures	▪ Small scale PV projects

Further, after mapping the impacts of small scale SPV projects against the appraisal standards of the KfW guidelines; it clearly shows that the negative impacts of such projects are negligible (Table 10.3).

Table 10.3: Impacts of rooftop SPV projects mapped against project appraisal standards

Project appraisal standards	Impact from rooftop PV projects
Preventing, reducing, or limiting environmental pollution or degradation, including greenhouse gas emissions and other burdens	There are no emissions from rooftop SPV systems during the operating life.
Protecting and preserving biodiversity and tropical forests and managing natural resources in a sustainable manner	Rooftop SPV does not have any impact tropical forests and natural resources
Consideration of probable and foreseeable consequences of climate change	Rooftop SPV helps in mitigating climate change impacts.
Avoiding any adverse impact on community life, particularly of indigenous people and other vulnerable communities, and safeguarding the rights, living conditions, and values of indigenous communities	Not applicable
Avoiding or minimizing involuntary resettlement and forced eviction of communities and mitigating the negative social and economic consequences arising from changes in the use of land and soil by restoring the original living conditions of the communities concerned	Rooftop SPV does not involve involuntary displacement of people as no lands are required to implement such projects
Promoting health and safety at work and industrial safety for all project staff	Not applicable
Outlawing forced labour and the worst forms of child labour, banning discrimination in professional life and at the workplace, and promoting the freedom of association and the right to collective bargaining	Not applicable

Protecting and preserving cultural heritage	Not applicable
Assisting the executing agency in managing and monitoring potentially negative environmental, climate, and social consequences arising from the implemented project	Not applicable

10.2 Recycling of PV Modules

PV modules make up over 50 per cent of the total investment cost of a large scale PV power plant. All other components of the PV power plant including the inverters and balance of plant (BOP) costs are marginal. PV modules contain substances such as glass, aluminium, and semiconductor materials that can be successfully recovered and reused, either in new PV modules or other products. With the rapid expansion of PV technology, the amount of waste generated by PV products in the future is set to increase, making it essential to manage this waste for recycling. Strong growth and high price pressure in the industry also necessitates new, low-cost sources of solar silicon.

In 2008, the amount of PV waste generated by the EU was around 3 800 tonnes (corresponding to 51 MWp). By 2030, this is expected to rise to 130,000 tonnes.[1] By means of recycling, valuable raw materials can be recovered from the PV modules, thus reducing the demand for primary raw materials. Recycling also reduces the environmental impact. In addition to saving energy and resources, it is also important to prevent the loss or release of scarce or poisonous elements and compounds. The recycling process of different monocrystalline/polycrystalline modules and thin-film modules is described as follows.

10.2.1 Recycling Process

The recycling process of PV modules depends on their type and composition. The composition of various types of PV modules is shown in Table 10.4.

Table 10.4: Composition of c-Si and thin-film modules (corresponding to the respective technology)[a]

	c-Si (crystalline silicon cells)	a-Si (amorphous silicon cells)	CIS (copper indium diselenide cells)	CdTe (cadmium telluride cells)
Proportion (Percentage)				
Glass	74	80	85	95
Aluminium	10	10	12	<0.01
Silicon	ca. 3	<0.1		
Polymers	ca. 6.5	10	6	3.5
Zinc	0.12	<0.1	0.12	0.01
Lead	<0.1	<0.1	<0.1	<0.01
Copper (cables)	0.6		0.85	1.0
Indium			0.02	
Selenium			0.03	
Tellurium				0.07
Cadmium				0.07
Silver	<0.006			<0.01

[a] Recycling of solar modules—potential and requirements of a future material flow/PV CYCLE study 2007

From this table, it can be seen that most of the modules are predominantly composed of glass, varying between 74 per cent for crystalline silicon modules to 95 per cent for CdTe thin-film modules. The next most significant

1 Recycling PV modules BINE Infomationsdienst

component used in most type of modules is aluminium, which is used in the frames of the modules. The amount of aluminium used varies from $<$0.01 per cent to 10 per cent. The amount of silicon used is less, between 0.1 per cent for amorphous Silicon modules to up to 3 per cent for crystalline Silicon modules. Polymers used in the modules for the junction box and cables vary between 3.5 per cent to up to 10 per cent. The thin-film modules (both copper indium diselenide and cadmium telluride type) use very small proportions of metals depending on the cell type.

There is a wide range of materials used in producing PV modules. Recycling of most of these materials uses established technologies, for example, recycling of glass, aluminium, and polymers. Recycling of PV modules to reclaim the raw materials used for crystalline silicon and thin-film type of modules is described as follows:

Crystalline Modules

The recycling process of both mono and poly crystalline modules is shown in Figure 10.1. The first step is disassembly, where the glass and metal are separated from the module. Various mechanical, chemical, thermal and incineration techniques are used for the separation of glass and metal from the modules. Once separated, glass and metals can be recycled for further use.

The silicon solar cell array is then passed through thermal and chemical processing through which silicon wafers can be produced. These wafers can then be used for producing new solar cells for new PV modules. Sometimes, after thermal processing, if broken wafers can be separated easily, they are processed in ingot form, from which silicon wafers can be cut. These wafers can be used for solar cells for new PV modules.

The SPV module recycling process used by crystalline PV module manufacturer SolarWorld is described as follows:

- Firstly, the rack-mount modules are incinerated at 600°C in a process that burns the plastic components in a semiconductor-protecting process;
- The remaining materials such as solar cells, glass, and metals are then separated manually;
- The glass and metals are then sent for recycling;
- The solar cells are re-etched onto the wafer;
- The recovered glass could be suitable as raw material for float glass recycling;
- According to PV CYCLE's 2007 study, both recycled and new wafers are of equal value electrically after having undergone solar cell processing;
- SolarWorld's recycling process tries to keep as much of the original wafer thickness as possible.

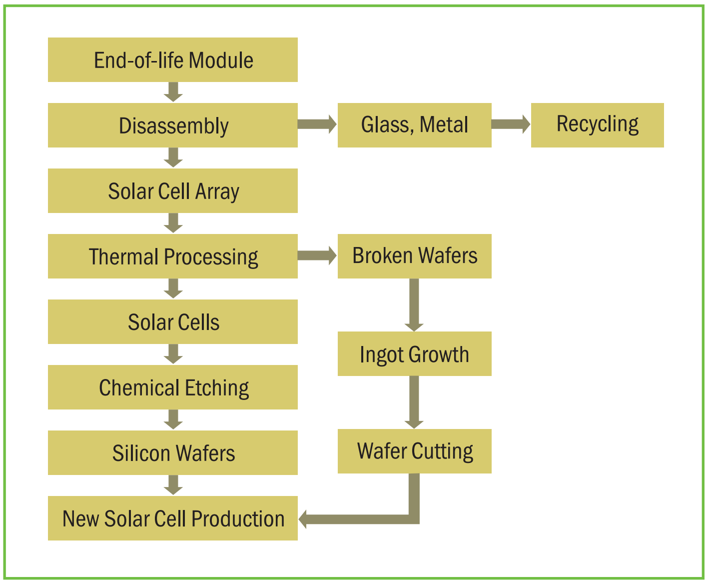


Figure 10.1 Recycling process of crystalline modules

Recovery/Efficiency of SolarWorld's Recycling Process

- SolarWorld's recycling process can recover more than 84 per cent of the input module weight;
- More than 90 per cent of the recovered glass can be used in new products;
- After re-melting, about 95 per cent of the semiconductor materials can be used in new solar modules;
- The energy of the polymer incineration could be used in other processes or for pre-heating new charges in future productions;
- Depending on prior damage to the modules, type of module structure and the solar cell used, the thermal process recovers 0–98 per cent intact.

Cadmium-Telluride (CdTe) Thin Film Modules

The recycling process of CdTe modules is shown in Figure 10.2

- Firstly, lamination bonds are broken. This is achieved when the modules are shredded into large pieces before being further crushed by a hammer mill into pieces typically smaller than 5 mm;
- Next, the semiconductor films are removed in a slow rating leach drum in a process that takes 4–6 hours. A mixture of weak sulphuric acid and hydrogen peroxide is added to the glass so as to achieve an optimal solid-liquid ratio. The films are then etched from the glass during the leach cycle;
- A classifier is then used to separate the glass from the liquids;
- The glass is then further separated from the larger ethylene vinyl acetate (EVA) pieces when both materials are put through a vibrating screen. During this process, the glass falls through the screen and onto a chute where it is then cleaned. The EVA is deposited onto another conveyer and collected;
- Once cleaned, the glass is deposited into containers for recycling and the water used for rinsing is pumped to a precipitation system for metal recovery;
- Sodium hydroxide is used to precipitate the metal compounds in three stages by increasing pH levels. Once the solids form a metal rich filter cake, the settled solids are sent off to be processed into semiconductor grade raw materials that are used in the manufacture of new solar modules.

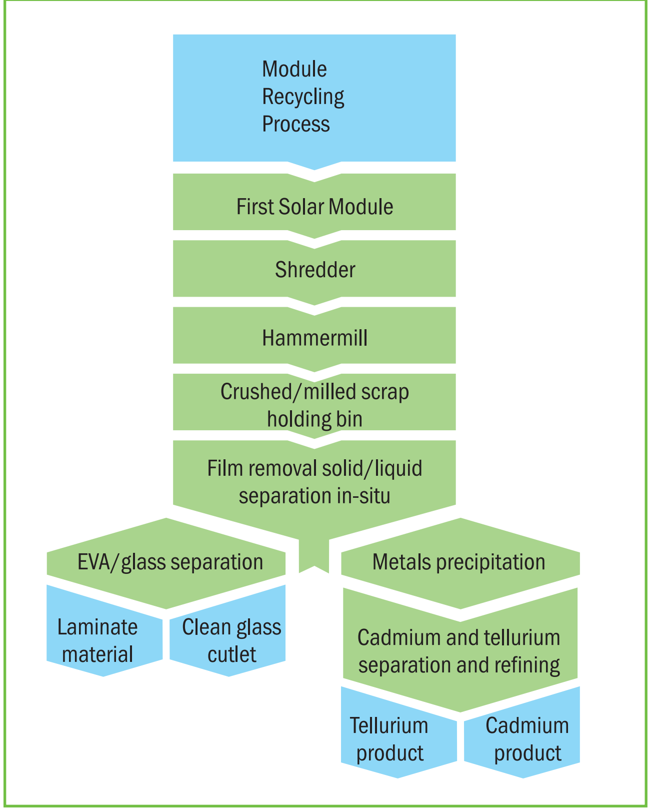


Figure 10.2: Recycling process of Cadmium-Telluride (CdTe) thin film modules produced by First Solar (Source: First Solar)

Success Rate

- The process can recover 90 per cent of the glass for use in new products;
- Ninety-five per cent of the semiconductor materials for use in new solar modules;
- At least 80 per cent of the tellurium is recovered and can be sold at commercial grade (99.7 per cent Te);

10.2.2 Advantages of Recycling.

By adapting recycling of PV modules, the requirement of raw materials needed for production of PV modules will be reduced. This would reduce the energy required in procurement/processing of these raw materials and also the emissions associated. Modules with solar cells made solely from newly produced silicon require three times as much energy for manufacturing as solar cells of equal capacity made using recycled material. Wafers of which a proportion of recycled material is used in their manufacture are also significantly more cost-effective than new ones. Thus, recycling of PV modules improves the ecological and economic characteristics of PV systems.

After recycling, it is possible to use silicon of previously unusable quality, whilst glass from PV module recycling can be used in glass fibre or insulation products and glass packaging products. Metals and plastics can be used for new raw materials in other industries.

10.2.3 Market Status

There are various companies in the market that offer recycling of PV modules. Many PV module manufacturers have started their own module recycling processes wherein they collect their own used/damaged modules and recycle them. First Solar, SolarWorld are among them.

In July 2007, eight companies in the PV industry founded the PV CYCLE association. The objective of PV CYCLE was to establish a voluntary industry-wide PV module take-back and recycling programme for old modules in Europe. Currently, there are over 60 members, and the association represents around 85 per cent of the European PV market, and it undertakes to reclaim and depose PV waste, free of charge. As shown in Figure 10.3, PV CYCLE has collected and treated PV modules totalling 12,425 tonnes in the years from 2010 to September 2015.

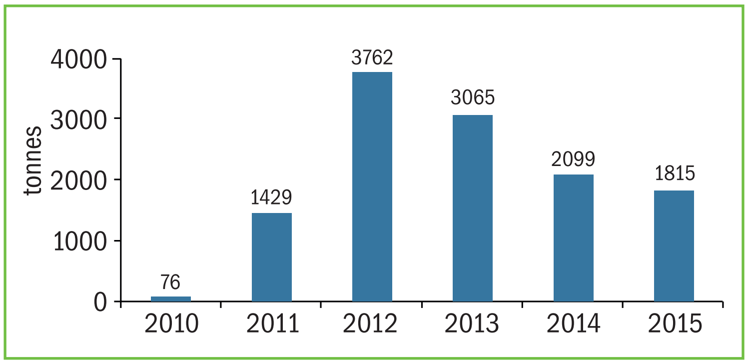


Figure 10.3: PV modules (in tonnes) collected over the years in Europe

The distribution of the total treated waste PV modules in Europe is shown in Figure 10.4. In addition to having the highest installed SPV capacity, Germany is also leading in recycling of PV modules with 7,074 tonnes of modules already treated. Italy and Spain follow Germany in the treatment of waste PV modules.

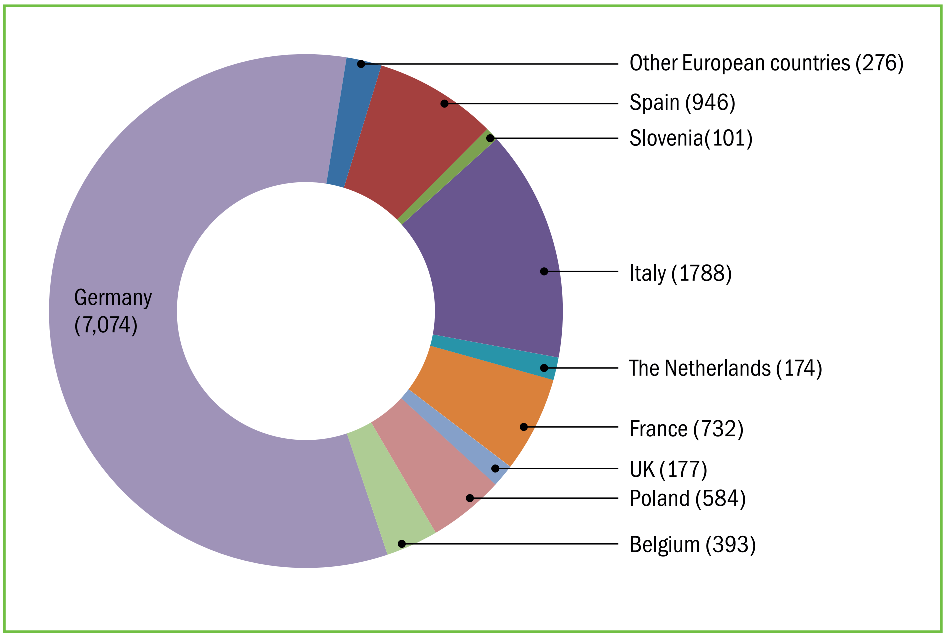


Figure 10.4: The distribution of total treated PV modules in tonnes in various European countries

Based on the PV technology, silicon-based PV modules constitute the highest share amongst the treated PV modules with about. 81.3 per cent of modules. CI(G)S thin film modules are second on the list of modules being treated, followed by CdTe type thin film modules (Figure 10.5).

10.2.4 Waste and Recycling Legislations

European Union: Waste Electrical and Electronic Equipment (WEEE) Directive

The Waste Electrical and Electronic Equipment Directive (WEEE) was launched in 2003 to regulate the treatment of electronic and electronic waste at the end of their cycle. The WEEE directive was twice amended ("recast") in 2008 and 2012, resulting in an enlarged scope to include many new additional products. PV panels were introduced in the revision of 2012. The WEEE set fundamental legal rules and obligations for collecting and recycling PV panels in the European Union. The WEEE also established minimum collection and recovery targets.

The recast WEEE directive of August 13, 2012 (2012/19/EU) provides a legislative framework for extended producer responsibility of PV modules throughout Europe. As of February 14, 2014, collection, transport, and treatment (recycling) of PV panels in every European Union (EU) countries is regulated.

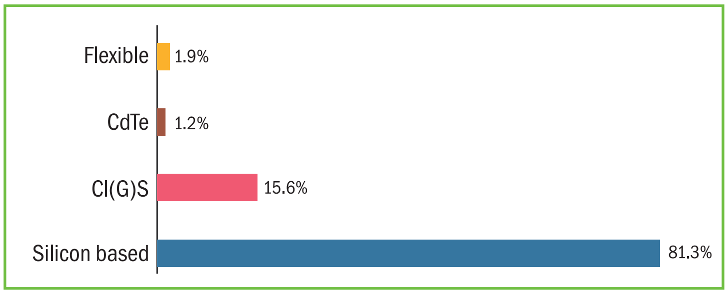


Figure 10.5: Percentage of the types of modules according to technology collected and recycled in Europe until September 2015

In an attempt to prevent waste, legislations established through the WEEE directive require producers (national manufacturers/importers) to ensure waste management of their discarded product(s) in each country of the EU where they are active, through comprehensive waste management solutions.

European countries are mandated to adopt PV waste management programmes that incorporate tracking, recollection, storage, and recycling of PV modules. The producers must factor the cost of collection and end-of-life treatment. This legislative directive encourages products that are easier to recycle and that use fewer raw materials.

Since February 14, 2014, legislation developed under the recast WEEE mandated PV manufacturers to collect 85 per cent of the solar modules sold in the EU, and of that 80 per cent must be recycled.

Germany: "Electrical and Electronic Equipment Act Elektrogesetz/ElektroG"

On October 24, 2015, the German WEEE law, ElektroG was adapted into law, therefore bringing PV modules under the scope of mandatory producer responsibility. The classification of PV modules as household equipment results in a legally binding financial guarantee on yearly sold PV modules in Germany.

Apart from the provision of an annual financial guarantee, the German law also requires financing of current waste either collected by the municipal network, a dedicated industry scheme, or the Producer directly.

10.2.5 Legislation in India

Until now there has been no legislations in India that governs the end-of-life treatment of PV modules.

10.3 Recycling of Batteries

PV batteries have a limited lifetime and the issue of proper disposal is vital to the sustainability of SPV systems as well as the environment. Proper disposal of batteries is essential to ensure they do not interfere with the environment on expiration of their life span. Battery recycling technology has matured since batteries are used for many purposes. Moreover, waste management of batteries is also well organized and a routine operation. The relevant laws for recycling of batteries in the EU, Germany and India are described as follows.

10.3.1 Legislation in EU/Germany

EU: Batteries Directive

The 2006/66/EU Directive on Batteries and Accumulators and Waste Batteries and Accumulators aims to contribute to the protection, preservation, and improvement of the environment by minimizing the negative impact of batteries and accumulators during and after their useful life. By balancing requirements with regard to the placing on the market of batteries and accumulators, the directive ensures smooth functioning of the internal market. With some exception, the directive applies to all batteries and accumulators, regardless of their chemical nature, size, or design.

The Directive not only prohibits the marketing of batteries containing some hazardous substances, but it also defines measures to establish schemes aiming at a high level of collection and recycling, and fixes targets for collection and recycling activities. The Directive also sets out provisions on labelling of batteries and their removability from equipment.

The Directive goes further to improve the environmental performance of all operators involved in the life cycle of batteries and accumulators. This includes producers, distributors, end users and in particular, those operators directly involved in the treatment and recycling of waste batteries and accumulators. Producers of batteries and accumulators and other products incorporating a battery or accumulator are given responsibility for the waste management of the batteries and accumulators that they place on the market.

Germany

The Batteries Act [Batteriegesetz]-(BattG) was enacted into law on June 30, 2009, superseding the Batterieverordnung (battery regulation) and transposing Directive 2006/66/EC into German law. The Act lays down product stewardship requirements for battery manufacturers and distributors. The law places additional restrictions on the use of cadmium in battery and accumulator manufacturing. Proven recycling mechanisms have largely been retained, whereas labelling requirements have changed. Reporting and notification obligations have been added, as well as recovery objectives for waste portable batteries.

Goals of the Batteries Act [Batteriegesetz]-(BattG)

The Batteries Act [Batteriegesetz]-(BattG) is aimed at manufacturers, distributors, consumers, and public sector garbage collection companies. The law aims to reduce battery waste pollutant input, increase recovery rates, and ensure that waste batteries that fall within the scope of battery manufacturer and retailer product stewardship obligations are disposed of properly, the goal being to minimize environmental pollution attributable to waste batteries. Under this scheme, producers are responsible for both take-back and recycling of used batteries and accumulators. Every producer must therefore record and announce his presence on the market in a register for battery producers and state how he will meet his disposal responsibilities.

10.3.2 Legislation in India

In 2001, the MoEF issued the Indian Battery Management and Handling Rules that require lead battery manufacturers to collect a minimum of 90 per cent of the batteries they sell through dealers. The main objective of these rules is to provide for tracking and canalization of the lead acid batteries to ensure that used batteries are collected and recycled in an environmentally sound manner. The manufacturers, importers, assemblers, etc. have been entrusted with specific responsibilities under these rules. The system of filing half-yearly returns provides for the tracking of the used lead acid batteries. Recyclers are also required to be registered by state-level pollution control boards.

The salient features of the Rules are as follows:

- Consumers to return used batteries;
- Manufacturers/assemblers/reconditioners/importers are responsible for collection of batteries and transport to registered recyclers;
- Auction of used batteries only in favour of registered recyclers;
- Dealers are also responsible for collection;
- Level playing field;
- Filing of half-yearly returns.

The act of 2001 was amended in 2010 and the new act is called **'Batteries (Management and Handling) Amendment Rules 2010'.**

10.3.4 Guideline for Disposal of PV Modules

To ensure complete disposal and recycling of PV modules, the manufacturer should be responsible for recycling of PV modules. A central body should be established to monitor and register PV module production and take back old/damaged modules from the market. All PV module manufacturers should be registered with this central body with frequency of reporting to be determined. Annual reporting of sold PV modules is recommended. This is shown in Figure 10.6.

The manufacturer must ensure a definite framework for organizing take back and waste management for SPV modules, which should be registered with the central monitoring body. All manufacturer modules/products must be tagged or marked accordingly, to ensure easier tracking. The manufacturer must also take into consideration the costs of organizing take-back and waste management in its pricing of the PV modules.

A proper information system should be put in place so to inform the central monitoring body and end customer as to the status of their PV modules. The responsibility of the central monitoring body is to make sure that the mandatory collection and recycling targets laid out by the relevant national regulations are being achieved by the registered PV module manufacturers.

Figure 10.6: Recommended disposal of PV modules

10.4 Conclusions

The environmental and social impacts associated with the implementation of rooftop solar projects are either negligible or none. Taking back and recycling PV waste free of charge makes sense both ecologically and economically. Based on present technology, around 90 per cent of the materials in a PV module can be recycled. In future, automated recycling processes will make it possible to achieve recycling rates of over 95 per cent and to recover raw materials without cost, or even at a profit. It is recommended that a mandatory PV modules and batteries waste management regulation is established, which should be implemented and monitored regularly.

Annexure

Annexure A2.1: Commercial and Industrial Tariff

Table A2.1: Delhi—Commercial/Non-Domestic

S. No	Commercial Categories (hostels/ schools/ colleges, hospitals, lawyer chambers, hotels, restaurants, cinemas, banks, petrol pumps)	2005–06 (NDPL)	2006–07 (NDPL)	2007–08[1] (NDPL)	2008–09 (NDPL)	2009–10 (NDPL)	2010–11[1] (NDPL)	2011–12 (NDPL)	2012–13 (TPDDL)	2013–14 (TPDDL)	2014–15 (TPDDL)	10 years CAGR
		[[1] in Rs /kWh else in Rs/kVAh]										
1	Up to 10kW (NDLT) (NDLT I)	5.35	5.35	5.35	5.4	5.4	5.4	6.5	7.6	7.9	8.8	5.69%
2	Between 10 kW(11 kVAh) and 100kW(108 kVAh) (NDLT) (NDLT I)	4.87	4.87	4.87	4.92	4.92	4.92	6.1	7.25	7.6	8.5	6.38%
3	Greater than 100 kW (108 kVA) (NDLT) (MLHT)	5.64	5.64	5.64	5.69	5.69	5.69	7	8.5	8.9	9.95	6.51%
4	For supply at 11 kV and above (for load greater than 108 kVA) (NDHT) (MLHT)[2]	4.9	4.9	4.9	4.95	4.95	4.95	5.9	7.15	7.5	8.4	6.17%

5	Non-Domestic Light/Power on 11 kV Single Delivery Point for Commercial Complexes (NDHT) (NDLT II)[2]	4.14	4.87	4.87	4.92	4.92	4.92	4.92	7.15	7.5	8.4	8.18%

[1] No order was issued this year therefore taking tariff schedule of previous year

[2] Additional rebate of 2.5% on the energy charges for supply above 11 kV rates, for supply at 33/66 kV and 4% for supply at 220 kV

Table A2.2: Delhi—Industrial

S.No	Industrial Categories	2005–06 (NDPL)	2006–07 (NDPL)	2007–08[1] (NDPL)	2008–09 (NDPL)	2009–10 (NDPL)*	2010–11[1] (NDPL)	2011–12 (NDPL)	2012–13 (TPDDL)	2013–14 (TPDDL)	2014–15 (TPDDL)	10 years CAGR
		[1 in Rs/kWh else in Rs/kVAh]										
1	Up to 10kW (SIP)	5	5	5	5.05	4.95	5	6	7.25	7.6	8.45	6.00%
2	Between 10 kW (11 kVA) and 100 kW (108 kVA) (SIP)	4.35	4.35	4.35	4.4	4.3	4.35	5.5	6.6	7	7.9	6.85%
3	Greater than 100 kW (108 kVA) (400 volts) No supply on LT for load >215 kVA (SIP)	4.95	4.95	4.95	5	4.9	4.95	6.5	8	8.5	9.5	7.51%
4	Industrial Power on 11 kV Single Point Delivery for Group of SIP Consumers[2]	3.7	3.7	3.7	3.75	3.65	3.7	4.8	6	6.3	7.1	7.51%
5	Large Industrial Power (LIP)* (Supply at 11 kV and above) (above 100kW)[2]	4.3	4.3	4.3	4.35	4.05	4.2	5.3	6.3	6.6	7.4	6.22%

[1] No order was issued this year therefore taking tariff schedule of previous year

[2] Additional rebate of 2.5% on the energy charges for supply above 11 kV rates, for availing supply at 33/66 kV and 4% for supply at 220 kV

NDLT = 230 volts(single phase), 400volts(three phase)
NDHT = above 11kV
SIP = less than 200kW/215 kVA
LIP = load above 100 kW
*Tariffs revised from October 2009 (these tariffs applicable for half year)
*Cross subsidy; taxes; (surcharge) to be included

Table A2.3: Haryana—Commercial/Non-Domestic

Commercial Categories (business houses, cinemas, clubs, public/corporate offices, schools, hospitals, hotels, etc.)	2005–06	2006–07	2007–08	2008–09	2009–10*	2010–11	2011–12	2012–13	2013–14	2014–15	CAGR 10 years
	(in Rs/Unit)						(in Rs/kWh)				
Up to 5 kW (LT)	4.19	4.19	4.19	4.19	4.19	4.4	4.5	5.25	5.85	5.85	3.78%
Above 5 kW and Up to 20 kW (LT)	4.19	4.19	4.19	4.19	4.19	4.4	4.5	5.5	6.1	6.1	4.26%
Above 20 kW up to 50 kW (LT)	4.19	4.19	4.19	4.19	4.19	4.6	4.7	5.5	6	6.5	5.00%
Existing consumers above 50 kW up to 70 kW (LT)	4.19	4.19	4.19	4.19	4.19	4.6	4.7	5.75	6.25	6.75	5.44%
Consumers above 50 kW (HT)	4.19	4.19	4.19	4.19	4.19	4.6	4.7	5.25	5.85	6.35	4.73%

*Last hearing was on March 9, 2010 and on September 13, 2010 tariff order of 2010–11 was issued, that is, no order was issued for this financial year. Hence, tariff for previous year continued

Table A2.4: Haryana—Industrial

Industrial Categories	2005–06	2006–07	2007–08	2008–09	2010–11	2011–12	2012–13	2013–14	2014–15	CAGR 10 Years
	(in Rs/unit)				(in Rs/kVAh)					
HT Industry	**(above 70kW)**				**(above 50kW)**					
Supply at 11 KV	4.09	4.09	4.09	4.09	4.15	4.15	4.7	5.3		3.77%
Supply at 33 KV	4.09	4.09	4.09	4.09	4.03	4.03	4.6	5.2		3.49%
Supply at 66 kV or 132 kV	4.09	4.09	4.09	4.09	3.91	3.91	4.5	5.1	5.6	3.55%
Supply at 220 kV	4.09	4.09	4.09	4.09	3.83	3.83	4.4	5	5.5	3.35%
Supply at 400 kV	4.09	4.09	4.09	4.09	–	–	4.35	4.95	5.45	3.24%
Arc furnaces/ Steel Rolling Mills if supply is at 11 kV	4.09	4.09	4.09	4.09	–	4.3	4.88	5.5	6	4.35%
LT Industry	**(up to 70 kW) (in Rs/unit)**				**(up to 50kW) (in Rs/kWh)**					
Up to 10 KW	4.28	4.28	4.28	4.28	4.3	4.4	5.35	5.85	6.35	4.48%
Above 10 KW and up to 20 KW	4.28	4.28	4.28	4.28	4.3	4.4	5.35	6.1	6.6	4.93%
Above 20 KW and up to 50 KW	4.28	4.28	4.28	4.28	4.3	4.4	5.1	5.85	6.35	4.48%
Existing consumers above 50 kW up to 70 kW (LT)	4.28	4.28	4.28	4.28	4.3	4.4	4.98	5.5	6	3.82%

LT = 230 volts (single phase) or 400 volts (three phase)
HT = above 11kV

Table A2.5: Gujarat Tariff Schedule (UGVCL)

Category		2005–06*	2006–07	2007–08	2008–09	2009–10	2010–11	CAGR			2011–12	2012–13	2013–14	2014–15	2015–16	CAGR
Low and Medium Voltage (up to 400 volts)		(in Rs/unit)														
LTP-II		4	4	4	4	4	4.1	0.50%	GLP		3.45	3.55	3.8	3.8	3.9 3.11%	
LFD-III		3	3	3	3.1	3.1	3.2	1.30%								
LTP-I (per month)	Up to 10 BHP:	3.5	3.5	3.5	3.6	3.6	3.7	1.12%	Non-RGP	Up to 10kW	3.9	4	4.25	4.25	4.35	
	Above 10 BHP	3.75	3.75	3.75	3.85	3.85	4	1.30%								
LFD-II (per month)	First 50 units	3.6	3.6	3.6	3.6	3.6	3.7	0.55%								2.77%
	Next 100 units	4.2	4.2	4.2	4.2	4.2	4.3	0.47%		Between 10 kW and 40 kW	4.2	4.3	4.55	4.55	4.65	
	Next 150 units	–	–	–	4.8	4.8	-									
	Remaining units	4.7	4.7	4.7	4.9	4.9	4.9	0.84%								2.58%
LTP-III		3.95	3.95	3.95	4.05	4.05	4.05	0.50%	LTMD (above 40 kW and up to 100 kW) LTP-III		4.25	4.35	4.6	4.6	4.7	2.55%
LTP-IV (up to 125 BHP and used during 10 PM to 6 AM)		2.25	–	–	2	2	2	−2.33%	Non-RGP night (up to 40 kW and using electricity exclusively during 10 PM-6 AM)		2.2	2.3	2.5	2.5	2.6	4.26%
LTP-IV A (between 15 kW and up to 100 kW and used during 10 PM to 6 AM)		2.25	–	–	2	2	2	−2.33%	LTMD night (above 40 kW and using electricity exclusively during 10 PM–6 AM)		2.2	2.3	2.5	2.5	2.6	4.26%

*No order was issued by UHBVNL in 2005 and 2004; therefore, the data is of 2003–04

Table A2.6: Gujarat Tariff Schedule (UGVCL)

Category		2005–06*	2006–07	2007–08	2008–09	2009–10	2010–11	CAGR			2011–12	2012–13	2013–14	2014–15	2015–16	CAGR
At High (3.3 kV or above)/Extra High Tension																
Up to 1000 kVA billing demand	HTP-II(A)	4.1	4.1	4.1	4.2	4.2	3.9	−1.00%	100 kVA and above (HTP-I)	Up to 500 kVA	3.9	4	4.25	4.25	4.35	2.77%
For 1001 kVA to 2500 kVA billing demand							4.1	–		500 kVA–2500 VA	4.1	4.2	4.45	4.45	4.55	2.64%
Above 2500 kVA billing demand							4.2	–		above 2500kVA	4.2	4.3	4.55	4.55	4.65	2.58%
HTP-III		6.2	6.2	6.2	6.3	6.3	6.3	0.32%	100 kVA and above for temporary period (HTP-III)		6.3	6.4	6.5	6.5	6.6	1.17%
HTP-IV		2.25	2.25	2.25	2	2	2	−2.33%	100kVA and above during 10.00 PM to 06.00 AM (HTP-IV)		2	2.1	2.3	2.3	2.4	4.66%

*No order was issued by UHBVNL in 2005 and 2004; therefore, the data is of 2003–04

Time of Use Charges (for HT consumers) [Peak Hours 7:00 AM to 11:00 AM and 06.00 PM to 10.00 PM] for 2014–15 in Paisa/unit (2014-15)		
Category		Tariff
100 kVA and above (HTP-I)	For Billing Demand up to 500 kVA	35
	For Billing Demand above 500 kVA	75
100 kVA and above for temporary period (HTP-III)		75

Places Included	
LTP-I	Commercial/industrial premises.
LTP-II	Educational institutions and research and development laboratories
LTP-III	Commercial/industrial/office/institutional premises
LFD-II	Shops, workshop, hotels, restaurants, showrooms, offices, etc.
LFD-III	Educational and other institutions registered with the Charity Commissioner
GLP	LTP-II + LFD-III (Educational and other institutions registered with Charity Commissioner and R&D laboratories)
Non-RGP	LTP-I + LFD-II (shops, offices, banks, distribution pumping stations, hostels, laboratories, hospitals, telephone exchanges, training centres, public gardens, theatre, recreation places, multiplexes, malls, workshop, hotels, restaurants, educational institutes)
LTMD	Commercial/industrial/office/institutional premises

Table A2.7: West Bengal—Commercial/Non-Domestic

Category		2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	CAGR
Low and Medium Voltage		(in Rs/kWh)								
Commercial (Rural) (quarterly)	First 180 kWh	2.82	2.89	3.03	4.35	5.45	5.45	5.46	5.9	11.12%
	Next 120 kWh	3.99	4.07	4.21	5.53	6.63	6.63	6.64	7.1	8.58%
	Next 150 kWh	4.25	4.4	4.54	6.18	7.29	7.29	7.29	7.75	8.96%
	Next 450 kWh	4.65	4.74	4.9	6.57	7.68	7.68	7.68	8.18	8.40%
	Above 900 kWh	5.5	5.7	5.88	6.99	8.1	8.1	8.12	8.67	6.72%
Commercial (Urban) (quarterly)	First 180 kWh	2.87	2.94	3.08	4.4	5.5	5.5	5.51	5.92	10.90%
	Next 120 kWh	4.04	4.12	4.26	5.58	6.68	6.68	6.6	7.12	8.43%
	Next 150 kWh	4.25	4.4	4.54	6.18	7.29	7.29	7.29	7.75	8.96%
	Next 450 kWh	4.65	4.74	4.9	6.57	7.68	7.68	7.68	8.18	8.40%
	Above 900 kWh	5.5	5.7	5.88	6.99	8.1	8.1	8.12	8.67	6.72%
Private Educational Institutions and Hospitals		3.75	3.86	4.01	5.03	6.14	6.14	6.19	6.8	8.87%
Commercial (11 KV)		3.88	3.95	4.06	5.56	6.67	6.67	6.72	6.68	8.07%
Commercial (33 KV)		3.7	3.75	3.86	5.35	6.46	6.46	6.51	6.63	8.69%
Commercial (132 KV)		3.48	3.57	3.68	5.18	6.29	6.29	6.34	6.59	9.55%
Private Educational Institutions		3.8	3.8	3.9	5.4	6.51	6.51	5.57	7.32	9.82%

Table A2.8: West Bengal—Industrial

Category	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	CAGR
At High/Extra High Tension	(in Rs/kWh)								
Industries (11 KV)	3.66	3.72	3.86	5.37	6.47	6.47	6.48	6.86	9.39%
Industries (33 KV)	3.45	3.48	3.59	5.09	6.17	6.17	6.18	6.67	9.88%

Industry (Rural) (monthly)	first 500kWh	2.79	2.88	3.03	4.51	5.62	5.62	5.62	6	11.56%
	next 1500 kWh	3.91	4	4.16	5.66	6.77	6.77	6.77	7.2	9.11%
	above 2000 kWh	4.12	4.21	4.37	5.87	6.98	6.98	6.98	7.45	8.83%
Industry (Urban) (monthly)	first 500 kWh	2.94	3.03	3.18	4.63	5.74	5.74	5.74	6.1	10.99%
	next 1500 kWh	4.06	4.15	4.31	5.81	6.92	6.92	6.92	7.35	8.85%
	above 2000 kWh	4.32	4.41	4.57	6.07	7.18	7.18	7.18	7.65	8.51%
Data for 2005–06 and 2006–07 not available, WBSEB data										

Table A2.9: Chhattisgarh—Commercial/Non-Domestic

S. No	Non–Domestic			2006–07	2007–08	2008–09 (no order)	2009–10	2010–11 (no order)	2011–12		2012–13	2013–14	2014–15	CAGR
		[in Rs/kWh]												
1	LT (230 volts or 400 volts)*	Normal Tariff	0–100 units	–	–	–	2.75	2.75	1.5	0–100 units	1.5	1.5	4	
2			0–500 units	3.75	3.7	3.7	3.25	3.25	1.65	101–500 units	1.8	1.8	4.5	
3			0–above 500	4.25	4	4	3.75	3.75	1.9	501 and above	2.1	2.1	6	4.40%
4		Demand Based Tariff	Demand of 15 to 75 kW	–	–	–	3.5	3.5	3.8	Demand of 15 to 75 kW	4.5	4.5	5	7.39%
5	HT (11 or 33 kV)**	33 kV		3.5	3.35	3.35	3.25	3.25	3.65		4.1	4.1	4.2	2.31%
6		11 kV		3.6	3.45	3.45	3.35	3.35	3.75		4.2	4.2	4.3	2.25%

* Shops, show rooms, business houses, offices, educational institutions, public buildings, town halls, clubs, gymnasium and health clubs, meeting halls, places of public entertainment, circus, hotels, etc.
** Hospitals, offices, hotels, shopping malls, educational institutions

Table A2.10: Chhattisgarh—Industrial

S.No	Industry			2005–06	2006–07	2007–08	2008–09 (no order)	2009–10	2010–11 (no order)	2011–12	2012–13	2013–14	2014–15	CAGR
		[in Rs/kWh]												
1	LT (230 volts or 400 volts)	Up to 25 HP		2.3	2.5	2.5	2.5	2.5	2.5	2.8	3.15	3.15	3.4	
2		Above 25 HP up to 100 HP		3.3 (25–75 HP) 3.4 (75–100 HP) 3.6 (100–150 HP)	3.25	3	3	3	3	3.4	3.75	3.75	3.8	0.92%
3		Demand–based tariff for contract demand of 15 kW to 75 kW		3.4	3.4	3	3	3	3	3.4	3.85	3.85	4	1.82%
4	HT (11 or 33 kV)	33 kV	Steel Industries		2.5	2.3	2.3	2.3	2.3	2.75	3.5	3.5	3.6	
5			Mines/ Cement	3.35 /3.6	3.35/ 3.55	3.35	3.35	3.35	3.35	3.6	3.95	3.95	4.2	
6			Other Industries	3.15	3	2.9	2.9	2.8	2.8	3.2	3.5	3.5	4.2	3.25%
7			Working between 6 am and 6 pm	–	3.3	3.3	3.3	3.2	3.2	3.5	3.75	3.75	4.2	3.06%
8		11 kV	Steel Industries	–	–	–	–	2.4	2.4	2.85	3.6	3.6	3.7	
9			Mines/ Cement	–	–	–	–	3.45	3.45	3.7	4.05	4.05	4.3	
10			Other Industries	3.2	3.1	3	3	2.9	2.9	3.3	3.6	3.6	4.3	3.34%
11			Working between 6 am and 6 pm	–	3.4	3.4	3.4	3.3	3.3	3.6	3.85	3.85	4.3	2.98%

Time of Day Tariff applicable on all HT consumers (2014-15)

Time	Increase and Decrease in Energy Charges
5 am–6 pm	Normal tariff
6 pm–11pm	130% of normal tariff
11 pm–5 am	85% of normal tariff

Table A2.11: Punjab - Commercial/Non Domestic

NON–DOMESTIC		2005–06	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	CAGR
	(in Rs/kW)												
Load up to 100 kW	Up to 100 kWh	4.23	4.23	4.53	4.49	4.91	5.19	5.56	6.03	6.45	6.57	6.53	
	Above 100 kWh										6.71	6.75	
Exceeding 100 kW	Up to 100 kVAh									6.58	6.71	6.68	
	Above 100 kVah										6.86	6.9	5.01%
* Non-domestic includes business houses, cinemas, clubs, offices, hotels/motels, departmental stores, shops, guesthouses.													

Table A2.12: Punjab—Industrial

Industrial			2005–06	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	CAGR (11 years)
	(in Rs/kW)													
Large (more than 100 kVA; 11 kV or higher)	General		3.72	3.72	3.98	3.95	4.33	4.58	4.95	5.61	6.33	6.14	6.82	6.25%
	Arc/PIU		3.72	3.72	3.98	3.95	4.33	4.58	4.95	5.61	6.33	6.33	7.03	6.58%
	Seasonal	Season	3.72	3.72	3.98	3.95	4.33	4.58	4.95	5.61	6.33	6.14	6.82	6.25%
		Off-Season	4.28	3.72	4.58	4.54	4.97	5.25	5.67	6.44	7.27	7.4	8.22	6.75%
	Ice Factories		3.72	3.72	3.98	3.95	4.33	4.58	4.95	5.61	6.33	6.14	6.82	6.25%
Medium (20 kW–100 kVA; 400 V or 11 kV	General		3.72	3.72	3.98	3.95	4.33	4.58	4.95	5.61	6.26	6.52	6.52	5.78%
	Seasonal	Season	3.72	3.72	3.98	3.95	4.33	4.58	4.95	5.61	6.26	6.52	6.52	5.78%
		Off-Season	4.31	3.72	4.61	4.54	4.97	5.25	5.67	6.44	7.19	8.12	8.12	6.54%
	Ice Factories		3.72	3.72	3.98	3.95	4.33	4.58	4.95	5.61	6.26	6.52	6.52	5.78%
Small (up to 20 kW; 230 V or 400 V)	General		3.37	3.37	3.61	3.58	3.92	4.14	4.47	5.1	5.74	6.50	5.85	5.67%
	Seasonal	Season	3.37	3.37	3.61	3.58	3.92	4.14	4.47	5.1	5.74	6.50	5.85	5.67%
		Off-Season	4	3.37	4.28	4.24	4.64	4.91	5.3	6.03	6.79	7.67	6.9	5.60%
	Ice Factories		3.37	3.37	3.61	3.58	3.92	4.14	4.47	5.1	5.74	5.85	5.85	5.67%

- Arc furnaces and power intensive units include induction furnaces, chloroalkaline units, billet heaters, surface hardening machines & electrolytic process industries
- Seasonal industries are all cotton ginning, pressing, and bailing plants; all rice shellers; all rice bran stabilization units; kinnow grading, and waxing centres.
- Power factor for 2015–16 and 2014–15 is 0.9 for LS and MS and non-domestic (above 100 kW)

Table A2.13: Karnataka—Commercial/Non-Domestic

Commercial		2005–06	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	CAGR 11 years
	(in Rs/unit)												
HT2 (b)	First Two Lakh Units	4.85	4.85	4.7	4.7	5.6	6	6.3	6.7	6.75	7.15	7.35	4.24%
	Balance Units	5.15	5.15	4.9	4.9	5.95	6.3	6.6	7	7.05	7.45	7.65	4.04%
HT2 (c) (i) Govt	First One Lakh Units	3.8	3.65	3.55	3.55	4.3	4.6	4.9	5.1	5	5.4	5.6	3.95%
	Balance Units	4.3	4.15	3.95	3.95	4.6	4.9	5.2	5.4	5.5	5.9	6.1	3.56%
HT2 (c) (ii) Pvt	First One Lakh Units	4.85	4.85	4.7	4.7	5.6	6	6.3	6.7	6	6.4	6.6	3.13%
	Balance Units	5.15	5.15	4.9	4.9	5.95	6.3	6.6	7	6.5	6.9	7.1	3.26%
LT2 (b) under ULBs	0–100 units	4.15	4.15	4.1	4.1	4.65	4.95	5.5	5.7	5.7	6	6	3.76%
	100–200 units	4.65	4.65	4.6	4.6	5.25	5.55	6.5	6.7	6.7	7.2	7.2	4.47%
	200–400 units	4.9	4.9	4.8	4.8	5.6	5.9						
	Above 400 units	5.25	5.25	5.15	5.15	6.05	6.35						
LT3 under ULBs	First 50 units	5.05	4.95	4.95	4.95	5.15	5.6	6	6.2	6.45	6.75	6.95	3.25%
	Balance Units	6	5.9	5.9	5.9	6.5	6.8	7	7.2	7.45	7.75	7.95	2.85%

Table A2.14: Karnataka—Industrial

Industrial			2005–06	2006–07	2007–08	2008–09[1]	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	CAGR 11 years
	(in Rs/unit)													
HT	First One Lakh Units		3.8	3.65	3.55	3.55	4.3	4.6	4.9	5.1	5.35	5.7	5.85	4.41%
	Balance Units		4.3	4.15	3.95	3.95	4.6	4.9	5.2	5.4	5.65	6	6.15	3.64%
LT	Areas under Municipal Corporations	First 500 units	3.3	3.15	3.15	3.15	3.3	3.6	3.8	4	4.25	4.55	4.75	3.71%
		Next 500 units	3.8	3.8	3.65	3.65	3.9	4.2	4.5	4.7	4.95	5.35	5.55	3.86%
		Balance units	4.05	4.05	3.9	3.9	4.25	4.6	4.8	5	5.25	5.65	5.85	3.75%
	Other than Above Areas	First 500 units	3.3	3.3	3.15	3.15	3.3	3.6	3.8	4	4.25	4.55	4.7	3.60%
		Next 500 units	3.8	3.8	3.65	3.65	3.9	4.2	4.5	4.7	4.95	5.35	5.5	3.77%
		Balance units	4.05	4.05	3.9	3.9	4.25	4.6	4.8	5	5.25	5.65	5.8	3.66%

Table A2.15: Rajasthan Tariff Schedule (JVVNL)—Non-Domestic

Non–Domestic			2011–12	2012–13	2013–14	2014–15	CAGR
Sanctioned Load	Consumption per Month		in Rs/Unit				
Up to 5 kW	Up to 100 units	First 100	5.1	5.6	5.6	6.75	9.79%
	Between 100 and 200 units	First 100	5.1	5.6	5.6	6.75	9.79%
		Above 100 and up to 200	5.5	6	6	7.15	9.14%
	Between 200 and 500 units	First 100	5.1	5.6	5.6	6.75	9.79%
		Above 100 and up to 200	5.5	6	6	7.15	9.14%
		Above 200 and up to 500	5.9	6.25	6.25	7.45	8.09%
	Above 500 units	First 100	5.1	5.6	5.6	6.75	9.79%
		Above 100 and up to 200	5.5	6	6	7.15	9.14%
		Above 200 and up to 500	5.9	6.25	6.25	7.45	8.09%
		Above 500 units	5.9	6.6	6.6	7.85	9.99%
Above 5 kW	LT supply	First 100 units	5.1	5.6	5.6	6.75	9.79%
		Above 100 and up to 200 units	5.5	6	6	7.15	9.14%
		Above 200 and up to 500 units	5.9	6.25	6.25	7.45	8.09%
		Above 500 units	5.9		6.6	7.85	9.99%
	HT supply (Contract demand over 50kVA)	All	5.9	6.25	6.25	7.45	8.09%

Table A2.16: Rajasthan—Industrial

Industrial		2011–12		2012–13	2013–14	2014–15	CAGR
	in Rs/Unit						
Small Industries (up to 18.65 kW (25HP))	Up to 5kW	4	First 500 units	4.5	4.5	5.35	10.18%
	Above 5 and up to 18.65kW	4.35	Above 500 units	4.85	4.85	5.75	9.75%
Medium Industries (Above 18.65 and up to 112 kW)	Max Demand 50 kVA (LT)	4.75	Max Demand 50kVA (LT)	5.25	5.25	6.25	9.58%
	Max Demand 125 kVA (HT)	4.75	Max Demand 125kVA (HT)	5.25	5.25	6.25	9.58%
Bulk Supply for Mixed Load	Up to 50 kVA (LT)	4.75	LT	5.25	5.25	6.25	9.58%
	above 50 kVA (HT)	4.75	HT	5.25	5.25	6.25	9.58%
Large Industries (above 125 kVA (150 HP))		5		5.5	5.5	6.5	9.14%

Table A2.17: Andhra Pradesh—Commercial

Commercial Categories			2005–06	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15*	2015–16\	CAGR
	in Rs/Unit													
LT	Up to 50 Units a Month (LT) (53/ kW)		3.95	3.95	3.95	3.85	3.85	3.85	3.85	3.85	5.4	5.4	5.4	3.18%
	Above 50 units a month	First 50 units	3.95	3.95	3.95	3.85	3.85	3.85	3.85	3.85	6.63	6.63	6.63	5.32%
		50–101 units	6.25	6.25	6.25	6.2	6.2	6.2	6.2	6	7.38	7.38	7.38	1.68%
		101–300	6.25	6.25	6.25	6.2	6.2	6.5	6.5	7	8.13	8.13	8.54	3.17%
		301–500	6.25	6.25	6.25	6.2	6.2	6.5	6.5	7	8.63	8.63	9.06	3.78%
		Above 500	6.25	6.25	6.25	6.2	6.2	6.5	6.5	7	9.13	9.13	9.59	4.37%
HT	11 kV		4.4	4.4	4.4	4.3	4.3	4.8	4.8	5.97	6.9	6.9	7.25	5.12%
	33 kV		–	3.9	3.9	3.8	3.8	4.3	4.3	5.35	6.28	6.28	6.59	5.39%

Table A2.18: Andhra Pradesh—Industrial

Industrial Categories*		2005–06	2006–07		2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	CAGR
	in Rs/Unit													
LT	Industry (General) LT	3.75		3.75	3.75	3.75	3.75	4.13	5	5	6.08	6.08	6.38	5.46%
	Seasonal Industries (off season)	4.4		4.4	4.4	4.4	4.4			5.67	6.75	6.75	7.09	4.89%
	Pisciculture/ Prawn Culture	0.9		0.9	0.9	0.9	0.9	0.9	2.12	2.12	4.63	4.63	4.63	17.80%
	Sugarcane Crushing	0.5		0.5	0.5	0.5	0.5	0.5	1.62	1.62	4.63	4.63	4.63	24.93%
	Poultry Farms	3.75		3.75	3.75	3.75	3.75	4.13	5	5	5.63	5.63	5.63	4.15%
	Mushroom and Rabbit Farms	3.75		3.75	3.75	3.75	3.75	4.13	5	5	5.63	5.63	5.63	4.15%
	Floriculture in Green House	3.75		3.75	3.75	3.75	3.75	4.13	5	5	5.63	5.63	5.63	4.15%
	Cottage Industries up to 10 HP	1.8		1.8	1.8	1.8	1.8	1.8		2.67	3.75	3.75	3.75	7.62%
	Agro-Based Activity up to 10 HP	1.8		1.8	1.8	1.8	1.8	1.8		2.67	3.75	3.75	3.75	7.62%
HT	Industry (General) HT	11kV	3.35	3.3	3.3	3.25	3.2	3.52	3.52	4.8	5.73	5.73	6.02	5.88%
		33kV	4.4	3.1	3.1	3	2.95	3.25	3.25	4.37	5.3	5.3	5.57	5.22%
	Seasonal Industries	11kV	–	4.4	4.4	4.3	4.3	4.8	4.8	5.9	6.9	6.9	7.25	5.12%
		33kV		3.9	3.9	3.8	3.8	4.3	4.3	5.35	6.28	6.28	6.59	5.39%

* No order was issued in 2014–15 and the schedule for 2013–14 was followed for that financial year as well.

Table A2.19: Mumbai TATA Power—Commercial

Commercial		2006–07		2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	CAGR
	(in Rs/kWh)											
LT	< 11.2 kW	4.6	0–20kW	4.25	3.85	4.25	4.25	4.25	5.1	5.75	7.5	8.45%
	> 11.2 kW	3.5	> 20 kW and ≤ 50 kW	5.2	4.3	4.8	4.8	4.8	5.31	5.91	6.01	2.09%
			> 50 kW	6.2	4.65	5.05	5.05	5.05	5.86	6.46	7.62	2.99%
HT		3.15		4.95	4.35	5.2	5	5	6.49	7.29	8.11	7.31%

Table A2.20: Mumbai TATA Power—Industrial

Industrial		2006–07		2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	CAGR
	(in Rs/kWh)											
LT	< 11.2 kW	4.6	0–20 kW	3.6	4.1	4.5	4.5	4.5	4.65	7.38	6.9	9.74%
	> 11.2 kW	3.5	above 20 kW	4.6	4.6	5.1	5.1	5.1	5.52	8.2	7.35	6.92%
HT		3.15		4.35	4.1	5	5.2	5.2	6.2	8.02	8.44	9.93%

Annexure A6.1:Site survey and roof inspection template

General Information							
Site Type, e.g., School, Industry, etc.						Date	
Client Name							
Client Address (Detailed)							
Client's Contact Person			Designation				
Contact Details	Contact. No		Mail ID			Website	
Site Latitude, Longitude , Altitude & Google Pic	Latitude	Longitude	Altitude	Google map Pic		Ambient Temperature in °C	
		Yes ☐	No ☐	___Min	___Max	___ Avg.	
Suggested area for SPV	Ground ☐	Area	________	Sq.Mtr.	Photographs	Y ☐ N ☐	BIPV Y ☐ N ☐
	Roof P	Area	Sq.Mtr.	Photographs	Y P N ☐		
Suggested type of SPV by client P	On-grid ☐	Off-Grid	Hybrid	Autonomy	Backup Hours		
		Wind ☐	Biogas ☐	Any ☐ ________	Days ____	Hrs.	
Existing SPV details	Y ☐ N P	Type of system		System Size		If Off-grid then Battery Bank capacity and SPV Array	
		On-grid ☐	Off-Grid ☐	________	KW	________ Ah	_____ KW
Other suggestion from Client						General Energy Rate	

			Range (KWH/Unit)	Rate Rs/KWh					

Electrical Information

Power provider company/ organisation	BSES 1 Ph ________ 3 Ph	
Sanctioned Load (kW)		KW

Last 6 month unit consumed (KWH)					
Month-1	Month-2	Month-3	Month-4	Month-5	Month-6
April	Mar	Feb	Jan	Dec	Nov

Last 6 month Elect. Bill (Rs/month)					
Month-1	Month-2	Month-3	Month-4	Month-5	Month-6
April	Mar	Feb	Jan	Dec	Nov
Average Rs22000 per month					

Does the Energy Rate Change during Peak Hours					▯
If Y, Please Provide Peak time & regular Energy (Rs/kWh) Rates					
Time		Rate (Rs/ kWh)	Time		Rate (Rs/ kWh)
eg:- 9:0AM	11:00 AM	11.40			

Single line wiring drawing of the site electrical	▯
Floor plan showing electrical Control room / MDP	▯

Connection Type & Voltage					
other	____________				

Average Grid Availability (Hours / 24 Hours)	Variable	Hrs.

Transformer Rating		KVA	3phase

Is Load separation/ divided at Main Distribution Panel (MDP) Light Loads	Heavy loads	
Distance between transformer and MDP	________	Mtr.
Distance between DG and MDP	________	Mtr.
Distance between Proposed SPV and MDP	________	Mtr.

Diesel Generator					
Mfg.By:-	Sudhir	Rating	15	KVA	AGE_3_Y
Average Daily Diesel Consumption(Ltrs)					

Average Monthly Diesel Consumption (Ltrs./Month)(last 6 month detail)							
	Month-1	Month-2	Month-3	Month-4	Month-5	Month- 6	Average
Month	April	Mar	Feb	Jan	Dec	Nov	(Average)
Ltrs	Average 60 lt for 4 months						

Average Monthly cost of Diesel (Rs/Month) (last 6 month detail)							
	Month-1	Month-2	Month-3	Month-4	Month-5	Month- 6	Average
Month	April	Mar	Feb	Jan	Dec	Nov	(Average)
Rs							

Amount Spent on Operations & Maintenance of Diesel Generator Per Year (Rs/Year)	____________

Load Details

S.No.	Name of appliances/load	Qty.	Watt (W)	Hrs. in day	Hrs. in Night	Days of week	Types of Load (e.g., 3 Ph Motors, Star rating ACs etc.)
1							
2							
3							
4							
5							
6							

7							
8							
9							
10							
11							
12							
13							
14							
15							

Civil Information

Type of system proposed to client

Roof top	P	Ground mount	▯	Any other	__________

Photographs of roof	P
Detailed roof drawing if available	▯

Roof Top

Total Roof-top area		Sq. Mtr.	Roof age	__3__

Orientation? i.e., South Y/N :-Y

Type of roof

Tin Shed	▯	Slate	▯
RCC Slab	P		
Albesters roof	▯		

Roof condition

Poor	▯	Fair	▯
Good	▯	Excellent	▯
New	P		

Provided drawings, orientation & dimensions of beams and pillars of roof	▯
Provided Proposed location of inverter on drawing/sketch by client	▯
Estimated length of Suggested location of inverter and MDP (in Mtrs.) by client	▯

Any Shading, than height of objects (in Mtr.) e.g., trees, water tank, etc.

Object	Distance form SPV (M)	Orientation	Height (M)

Ground Mount

Total ground area	________	Sq. Mtr.
Suggested location of SPV & inverter on drawing/sketch	▯	

Any Shading, then height of objects (in Mtr.) e.g., trees, adjacent buildings, etc.

__________	Mtr.
__________	Mtr.
__________	Mtr.

Type of soil

Peaty	▯	Silt	▯
Sandy	▯		
Chalky	▯		
Clay	▯	Loam	▯
Others	______________________		
Availability of soil report	▯		
If Yes , Attach report			

Photographs and Plans:-

Please attach a sketch / diagram of the roof showing key dimension and photos of the exterior of the house showing proposed SPV roof area, internal structure of roof, if visible.

Annexure A6.2:Voltage drop calculations

String Current, Isc	8.23	A	At 50 degree	
Module Vmp	27.1	V		
String Length	19	Nos		
String Voltage	514.9	V		
DC SIDE				
Location	Length(m)	Wire Size(mm^2)	Del_V_DC	Drop (percentage)
String 1 to Inverter 1(Pos + Neg)	10	6	1.157	0.225
String 2 to Inverter 1(Pos + Neg)	42	6	2.132	0.414
String 3 to Inverter 1(Pos + Neg)	34	6	1.888	0.367
String 4 to Inverter 1(Pos + Neg)	36	6	1.949	0.378
String 1 to Inverter 2(Pos + Neg)	56	6	2.558	0.497
String 2 to Inverter 2(Pos + Neg)	8	6	1.096	0.213
String 3 to Inverter 2(Pos + Neg)	32	6	1.827	0.355
String 4 to Inverter 2(Pos + Neg)	38	6	2.010	0.390
String 1 to Inverter 3(Pos + Neg)	50	6	2.375	0.461
String 2 to Inverter 3(Pos + Neg)	30	6	1.766	0.343
String 3 to Inverter 3(Pos + Neg)	34	6	1.888	0.367
String 4 to Inverter 3(Pos+Neg)	52	6	2.436	0.473

Inverter AC current	25	A		
Output voltage	415	V		
Main Combiner AC Current	75	A		
AC SIDE				
Location	Length(m)	Wire Size (mm^2)	Del_V_AC	Drop
Inverter 1 to Combiner	13	10	1.190	0.287
Inverter 2 to Combiner	5	10	0.458	0.110
Inverter 3 to Combiner	16	10	1.464	0.353
Combiner to Interconnection	30	25	3.272	0.788

Annexure A8.1: Levelized Cost of Electricity

PV Only—No Incentive		2015	2017	2020
25	Delhi	10.28	8.77	7.63
	Haryana	9.49	8.10	7.04
	Gujarat	9.93	8.47	7.37
	West Bengal	11.23	9.58	8.34
	Chhattisgarh	10.58	9.02	7.85
	Punjab	9.49	8.10	7.04
	Karnataka	9.85	8.40	7.31
	Rajasthan	9.95	8.49	7.39
	Andhra Pradesh	10.37	8.84	7.70
	Maharashtra	8.62	7.36	6.40
150 kWp	Delhi	9.39	8.00	6.95
	Haryana	8.67	7.39	6.42
	Gujarat	9.07	7.73	6.72
	West Bengal	10.26	8.74	7.60
	Chhattisgarh	9.66	8.23	7.16
	Punjab	8.67	7.39	6.42
	Karnataka	9.00	7.66	6.66
	Rajasthan	9.09	7.75	6.73
	Andhra Pradesh	9.47	8.07	7.01
	Maharashtra	7.88	6.71	5.83
1000 kWp	Delhi	8.54	7.28	6.33
	Haryana	7.89	6.73	5.85
	Gujarat	8.25	7.04	6.12
	West Bengal	9.34	7.96	6.92
	Chhattisgarh	8.79	7.50	6.52
	Punjab	7.89	6.73	5.85
	Karnataka	8.19	6.98	6.07
	Rajasthan	8.27	7.05	6.13
	Andhra Pradesh	8.62	7.35	6.39
	Maharashtra	7.17	6.11	5.31
PV Only—Capital Subsidy		**2015**	**2017**	**2020**
25	Delhi	9.33	7.96	6.92
	Haryana	8.61	7.35	6.39
	Gujarat	9.01	7.69	6.69
	West Bengal	10.19	8.70	7.57
	Chhattisgarh	9.60	8.19	7.12
	Punjab	8.61	7.35	6.39
	Karnataka	8.94	7.62	6.63
	Rajasthan	9.03	7.70	6.70

	Andhra Pradesh	9.41	8.03	6.98
	Maharashtra	7.82	6.68	5.81
150 kWp	Delhi	8.52	7.26	6.31
	Haryana	7.87	6.70	5.83
	Gujarat	8.23	7.01	6.10
	West Bengal	9.31	7.93	6.90
	Chhattisgarh	8.77	7.47	6.49
	Punjab	7.87	6.70	5.83
	Karnataka	8.16	6.96	6.05
	Rajasthan	8.25	7.03	6.11
	Andhra Pradesh	8.60	7.32	6.37
	Maharashtra	7.15	6.09	5.29
1000 kWp	Delhi	7.75	6.61	5.74
	Haryana	7.16	6.10	5.31
	Gujarat	7.49	6.39	5.55
	West Bengal	8.47	7.22	6.28
	Chhattisgarh	7.98	6.80	5.91
	Punjab	7.16	6.10	5.31
	Karnataka	7.43	6.33	5.50
	Rajasthan	7.51	6.40	5.56
	Andhra Pradesh	7.82	6.67	5.80
	Maharashtra	6.50	5.55	4.82
PV + Battery—No Incentive		2015	2017	2020
25	Delhi	16.35	13.95	12.14
	Haryana	15.21	12.97	11.29
	Gujarat	15.85	13.52	11.76
	West Bengal	17.72	15.11	13.15
	Chhattisgarh	16.78	14.32	12.46
	Punjab	15.21	12.97	11.29
	Karnataka	15.73	13.42	11.67
	Rajasthan	15.88	13.55	11.79
	Andhra Pradesh	16.48	14.06	12.23
	Maharashtra	13.93	11.88	10.34
150 kWp	Delhi	14.94	12.73	11.06
	Haryana	13.90	11.84	10.29
	Gujarat	14.48	12.34	10.72
	West Bengal	16.19	13.79	11.99
	Chhattisgarh	15.33	13.06	11.35
	Punjab	13.90	11.84	10.29
	Karnataka	14.37	12.24	10.64
	Rajasthan	14.51	12.36	10.74
	Andhra Pradesh	15.06	12.83	11.15

	Maharashtra	12.73	10.84	9.42
1000 kWp	Delhi	13.59	11.59	10.07
	Haryana	12.64	10.78	9.37
	Gujarat	13.17	11.23	9.76
	West Bengal	14.73	12.56	10.91
	Chhattisgarh	13.95	11.89	10.34
	Punjab	12.64	10.78	9.37
	Karnataka	13.07	11.15	9.69
	Rajasthan	13.20	11.25	9.78
	Andhra Pradesh	13.70	11.68	10.15
	Maharashtra	11.58	9.87	8.58
PV + Battery—Capital Subsidy		2015	2017	2020
25	Delhi	15.14	12.92	11.24
	Haryana	14.09	12.02	10.46
	Gujarat	14.68	12.52	10.90
	West Bengal	16.41	14.00	12.18
	Chhattisgarh	15.54	13.26	11.54
	Punjab	14.09	12.02	10.46
	Karnataka	14.57	12.43	10.81
	Rajasthan	14.71	12.55	10.92
	Andhra Pradesh	15.26	13.02	11.33
	Maharashtra	12.90	11.01	9.58
150 kWp	Delhi	13.84	11.79	10.25
	Haryana	12.87	10.96	9.53
	Gujarat	13.41	11.43	9.93
	West Bengal	14.99	12.77	11.10
	Chhattisgarh	14.20	12.10	10.52
	Punjab	12.87	10.96	9.53
	Karnataka	13.31	11.34	9.86
	Rajasthan	13.44	11.45	9.95
	Andhra Pradesh	13.95	11.88	10.33
	Maharashtra	11.79	10.04	8.73
1000 kWp	Delhi	12.59	10.73	9.33
	Haryana	11.71	9.98	8.68
	Gujarat	12.20	10.40	9.04
	West Bengal	13.64	11.63	10.11
	Chhattisgarh	12.92	11.02	9.57
	Punjab	11.71	9.98	8.68
	Karnataka	12.11	10.33	8.97
	Rajasthan	12.22	10.42	9.06
	Andhra Pradesh	12.69	10.82	9.40

	Maharashtra	10.72	9.14	7.95
PV + Diesel—No Incentive		2015	2017	2020
25	Delhi	11.23	10.13	9.58
	Haryana	10.45	9.43	8.91
	Gujarat	10.89	9.82	9.29
	West Bengal	12.17	10.98	10.38
	Chhattisgarh	11.53	10.40	9.83
	Punjab	10.45	9.43	8.91
	Karnataka	10.81	9.75	9.21
	Rajasthan	10.91	9.84	9.30
	Andhra Pradesh	11.32	10.21	9.66
	Maharashtra	9.57	8.63	8.16
150 kWp	Delhi	10.43	9.44	8.97
	Haryana	9.70	8.78	8.34
	Gujarat	10.11	9.15	8.69
	West Bengal	11.30	10.23	9.72
	Chhattisgarh	10.70	9.69	9.20
	Punjab	9.70	8.78	8.34
	Karnataka	10.03	9.08	8.63
	Rajasthan	10.13	9.17	8.71
	Andhra Pradesh	10.51	9.51	9.04
	Maharashtra	8.88	8.04	7.64
1000 kWp	Delhi	9.66	8.79	8.40
	Haryana	8.99	8.18	7.82
	Gujarat	9.36	8.52	8.15
	West Bengal	10.47	9.52	9.10
	Chhattisgarh	9.91	9.02	8.62
	Punjab	8.99	8.18	7.82
	Karnataka	9.29	8.46	8.08
	Rajasthan	9.38	8.54	8.16
	Andhra Pradesh	9.74	8.86	8.47
	Maharashtra	8.23	7.49	7.16
PV + Diesel—Capital Subsidy		2015	2017	2020
25	Delhi	10.37	9.40	8.94
	Haryana	9.65	8.74	8.31
	Gujarat	10.05	9.11	8.67
	West Bengal	11.24	10.18	9.69
	Chhattisgarh	10.64	9.65	9.18
	Punjab	9.65	8.74	8.31
	Karnataka	9.98	9.04	8.60
	Rajasthan	10.07	9.13	8.68

	Andhra Pradesh	10.45	9.47	9.01
	Maharashtra	8.83	8.01	7.62
150 kWp	Delhi	9.64	8.77	8.38
	Haryana	8.97	8.15	7.80
	Gujarat	9.35	8.50	8.13
	West Bengal	10.45	9.50	9.08
	Chhattisgarh	9.90	9.00	8.60
	Punjab	8.97	8.15	7.80
	Karnataka	9.27	8.43	8.07
	Rajasthan	9.36	8.51	8.14
	Andhra Pradesh	9.72	8.84	8.45
	Maharashtra	8.21	7.47	7.14
1000 kWp	Delhi	8.94	8.18	7.87
	Haryana	8.32	7.61	7.32
	Gujarat	8.67	7.93	7.63
	West Bengal	9.69	8.86	8.53
	Chhattisgarh	9.18	8.39	8.08
	Punjab	8.32	7.61	7.32
	Karnataka	8.60	7.87	7.57
	Rajasthan	8.69	7.94	7.65
	Andhra Pradesh	9.02	8.24	7.93
	Maharashtra	7.62	6.97	6.71

Annexure A8.2: Payback Period

PV Only—No Incentive			2015	2017	2020
25	Commercial	Delhi	5.5	4.5	3.3
		Haryana	7.04	6.99	4.3
		Gujarat	10.2	7.4	6.4
		West Bengal	7.4	6.7	4.6
		Chhattisgarh	9.9	7.4	6.2
		Punjab	6.7	5.6	4.1
		Karnataka	6.7	5.0	4.1
		Rajasthan	6.4	4.9	3.9
		Andhra Pradesh	6.2	5.5	3.8
		Maharashtra	5.5	4.3	3.3
	Industrial	Delhi	6.5	5.1	3.9
		Haryana	7.7	6.1	4.7
		Gujarat	10.2	8.27	6.45
		West Bengal	7.9	6.34	4.90
		Chhattisgarh	11.3	9.14	7.16
		Punjab	7.0	5.54	4.26

		Karnataka	7.9	6.31	4.87
		Rajasthan	7.6	6.05	4.66
		Andhra Pradesh	8.2	6.59	5.10
		Maharashtra	5.5	4.39	3.36
150 kWp	Commercial	Delhi	5.1	4.2	3.1
		Haryana	6.5	6.4	3.9
		Gujarat	9.5	6.8	5.9
		West Bengal	6.9	6.1	4.2
		Chhattisgarh	9.2	6.7	5.7
		Punjab	6.2	5.2	3.8
		Karnataka	6.2	4.6	3.7
		Rajasthan	5.9	4.4	3.6
		Andhra Pradesh	5.7	5.0	3.5
		Maharashtra	5.1	4.0	3.1
	Industrial	Delhi	6.0	4.7	3.6
		Haryana	7.1	5.6	4.3
		Gujarat	9.5	7.7	5.9
		West Bengal	7.3	5.9	4.5
		Chhattisgarh	10.5	8.5	6.6
		Punjab	6.4	5.1	3.9
		Karnataka	7.3	5.8	4.5
		Rajasthan	7.0	5.6	4.3
		Andhra Pradesh	7.6	6.1	4.7
		Maharashtra	5.1	4.0	3.1
1000 kWp	Commercial	Delhi	4.7	3.8	2.8
		Haryana	6.0	6.0	3.6
		Gujarat	8.8	6.4	5.4
		West Bengal	6.4	5.7	3.8
		Chhattisgarh	8.6	6.3	5.3
		Punjab	5.7	4.7	3.4
		Karnataka	5.7	4.3	3.4
		Rajasthan	5.5	4.2	3.3
		Andhra Pradesh	5.3	4.7	3.2
		Maharashtra	4.7	3.6	2.8
	Industrial	Delhi	5.5	4.3	3.3
		Haryana	6.5	5.2	4.0
		Gujarat	8.8	7.1	5.5
		West Bengal	6.8	5.4	4.1
		Chhattisgarh	9.7	7.8	6.1
		Punjab	5.9	4.7	3.6
		Karnataka	6.7	5.4	4.1
		Rajasthan	6.5	5.1	3.9

		Andhra Pradesh	7.0	5.6	4.3
		Maharashtra	4.7	3.7	2.8
PV Only—Capital Subsidy			2015	2017	2020
25	Commercial	Delhi	4.8	3.8	2.9
		Haryana	6.1	4.8	3.7
		Gujarat	8.9	7.2	5.5
		West Bengal	6.5	5.1	3.9
		Chhattisgarh	8.7	7.0	5.4
		Punjab	5.8	4.6	3.5
		Karnataka	5.8	4.6	3.5
		Rajasthan	5.6	4.4	3.3
		Andhra Pradesh	5.4	4.3	3.2
		Maharashtra	4.8	3.8	2.9
150 kWp	Commercial	Delhi	4.4	3.5	2.6
		Haryana	5.7	4.5	3.4
		Gujarat	8.3	6.6	5.1
		West Bengal	6.0	4.7	3.6
		Chhattisgarh	8.1	6.5	5.0
		Punjab	5.4	4.3	3.2
		Karnataka	5.4	4.2	3.2
		Rajasthan	5.1	4.1	3.1
		Andhra Pradesh	5.0	3.9	3.0
		Maharashtra	4.4	3.5	2.6
1000 kWp	Commercial	Delhi	4.1	3.2	2.4
		Haryana	5.2	4.1	3.1
		Gujarat	7.7	6.1	4.7
		West Bengal	5.5	4.4	3.3
		Chhattisgarh	7.5	6.0	4.6
		Punjab	5.0	3.9	3.0
		Karnataka	4.9	3.9	2.9
		Rajasthan	4.7	3.7	2.8
		Andhra Pradesh	4.6	3.6	2.7
		Maharashtra	4.1	3.2	2.4
PV + Battery – No Incentive			2015	2017	2020
25	Commercial	Delhi	6.8	5.4	4.1
		Haryana	8.6	6.9	5.3
		Gujarat	12.2	10.0	7.8
		West Bengal	9.0	7.2	5.6
		Chhattisgarh	11.9	9.7	7.6
		Punjab	8.3	6.6	5.1
		Karnataka	8.2	6.6	5.0
		Rajasthan	7.9	6.3	4.8

		Andhra Pradesh	7.6	6.1	4.7
		Maharashtra	6.9	5.5	4.2
	Industrial	Delhi	7.9	6.3	4.9
		Haryana	9.4	7.6	5.9
		Gujarat	12.3	10.1	7.9
		West Bengal	9.6	7.7	6.0
		Chhattisgarh	13.5	11.0	8.7
		Punjab	8.6	6.9	5.3
		Karnataka	9.6	7.8	6.0
		Rajasthan	9.2	7.4	5.8
		Andhra Pradesh	10.0	8.1	6.3
		Maharashtra	6.9	5.5	4.2
150 kWp	Commercial	Delhi	6.3	5.0	3.8
		Haryana	8.0	6.4	4.9
		Gujarat	11.4	9.3	7.2
		West Bengal	8.4	6.7	5.1
		Chhattisgarh	11.1	9.0	7.0
		Punjab	7.7	6.1	4.7
		Karnataka	7.6	6.0	4.6
		Rajasthan	7.3	5.8	4.4
		Andhra Pradesh	7.0	5.6	4.3
		Maharashtra	6.4	5.0	3.9
	Industrial	Delhi	7.3	5.8	4.5
		Haryana	8.7	7.0	5.4
		Gujarat	11.5	9.3	7.3
		West Bengal	8.9	7.1	5.5
		Chhattisgarh	12.6	10.3	8.1
		Punjab	7.9	6.3	4.9
		Karnataka	8.9	7.2	5.6
		Rajasthan	8.6	6.9	5.3
		Andhra Pradesh	9.3	7.5	5.8
		Maharashtra	6.4	5.1	3.9
1000 kWp	Commercial	Delhi	5.8	4.6	3.5
		Haryana	7.4	5.9	4.5
		Gujarat	10.6	8.6	6.7
		West Bengal	7.7	6.2	4.7
		Chhattisgarh	10.3	8.4	6.5
		Punjab	7.1	5.6	4.3
		Karnataka	7.0	5.6	4.3
		Rajasthan	6.7	5.3	4.1
		Andhra Pradesh	6.5	5.2	3.9

		Maharashtra	5.9	4.6	3.5
	Industrial	Delhi	6.8	5.4	4.1
		Haryana	8.1	6.4	5.0
		Gujarat	10.7	8.7	6.8
		West Bengal	8.2	6.6	5.1
		Chhattisgarh	11.7	9.5	7.5
		Punjab	7.3	5.8	4.5
		Karnataka	8.3	6.6	5.1
		Rajasthan	7.9	6.3	4.9
		Andhra Pradesh	8.6	6.9	5.3
		Maharashtra	5.9	4.7	3.6
PV + Battery—Capital Subsidy			2015	2017	2020
25	Commercial	Delhi	5.9	4.7	3.6
		Haryana	7.5	6.0	4.6
		Gujarat	10.8	8.7	6.8
		West Bengal	7.9	6.3	4.8
		Chhattisgarh	10.5	8.5	6.6
		Punjab	7.2	5.7	4.4
		Karnataka	7.1	5.7	4.4
		Rajasthan	6.9	5.5	4.2
		Andhra Pradesh	6.6	5.3	4.0
		Maharashtra	6.0	4.7	3.6
150 kWp	Commercial	Delhi	5.5	4.3	3.3
		Haryana	7.0	5.6	4.3
		Gujarat	10.1	8.1	6.3
		West Bengal	7.3	5.8	4.5
		Chhattisgarh	9.8	7.9	6.1
		Punjab	6.7	5.3	4.1
		Karnataka	6.6	5.2	4.0
		Rajasthan	6.4	5.0	3.8
		Andhra Pradesh	6.1	4.8	3.7
		Maharashtra	5.6	4.4	3.3
1000 kWp	Commercial	Delhi	5.0	4.0	3.0
		Haryana	6.4	5.1	3.9
		Gujarat	9.3	7.5	5.8
		West Bengal	6.7	5.3	4.1
		Chhattisgarh	9.1	7.3	5.6
		Punjab	6.2	4.9	3.7
		Karnataka	6.1	4.8	3.7
		Rajasthan	5.9	4.6	3.5
		Andhra Pradesh	5.6	4.5	3.4

		Maharashtra	5.1	4.0	3.0
PV + Diesel—No Incentive			2015	2017	2020
25	Commercial	Delhi	5.1	4.0	3.0
		Haryana	6.5	5.2	4.0
		Gujarat	9.4	7.6	5.9
		West Bengal	6.8	5.4	4.1
		Chhattisgarh	9.2	7.4	5.7
		Punjab	6.2	4.9	3.8
		Karnataka	6.2	4.9	3.7
		Rajasthan	5.9	4.7	3.6
		Andhra Pradesh	5.7	4.5	3.4
		Maharashtra	5.1	4.1	3.1
	Industrial	Delhi	5.9	4.7	3.6
		Haryana	7.1	5.7	4.3
		Gujarat	9.5	7.6	5.9
		West Bengal	7.2	5.8	4.4
		Chhattisgarh	10.4	8.4	6.6
		Punjab	6.4	5.1	3.9
		Karnataka	7.3	5.8	4.5
		Rajasthan	7.0	5.6	4.3
		Andhra Pradesh	7.6	6.0	4.7
		Maharashtra	5.2	4.1	3.1
150 kWp	Commercial	Delhi	4.7	3.7	2.8
		Haryana	6.0	4.8	3.6
		Gujarat	8.7	7.0	5.4
		West Bengal	6.3	5.0	3.8
		Chhattisgarh	8.5	6.8	5.3
		Punjab	5.7	4.5	3.5
		Karnataka	5.7	4.5	3.4
		Rajasthan	5.5	4.3	3.3
		Andhra Pradesh	5.3	4.1	3.1
		Maharashtra	4.7	3.7	2.8
	Industrial	Delhi	5.5	4.3	3.3
		Haryana	6.6	5.2	4.0
		Gujarat	8.8	7.1	5.5
		West Bengal	6.7	5.3	4.1
		Chhattisgarh	9.7	7.8	6.1
		Punjab	5.9	4.7	3.6
		Karnataka	6.7	5.4	4.1
		Rajasthan	6.5	5.1	3.9
		Andhra Pradesh	7.0	5.6	4.3
		Maharashtra	4.8	3.7	2.8

1000 kWp	Commercial	Delhi	4.3	3.4	2.5
		Haryana	5.5	4.4	3.3
		Gujarat	8.1	6.5	5.0
		West Bengal	5.8	4.6	3.5
		Chhattisgarh	7.9	6.3	4.8
		Punjab	5.3	4.2	3.2
		Karnataka	5.2	4.1	3.1
		Rajasthan	5.0	4.0	3.0
		Andhra Pradesh	4.8	3.8	2.9
		Maharashtra	4.4	3.4	2.6
	Industrial	Delhi	5.0	4.0	3.0
		Haryana	6.0	4.8	3.7
		Gujarat	8.1	6.5	5.0
		West Bengal	6.2	4.9	3.8
		Chhattisgarh	9.0	7.2	5.6
		Punjab	5.5	4.3	3.3
		Karnataka	6.2	4.9	3.8
		Rajasthan	6.0	4.7	3.6
		Andhra Pradesh	6.5	5.1	3.9
		Maharashtra	4.4	3.4	2.6
PV + Diesel – Capital Subsidy			2015	2017	2020
25	Commercial	Delhi	4.4	3.4	2.6
		Haryana	5.7	4.5	3.4
		Gujarat	8.2	6.6	5.1
		West Bengal	5.9	4.7	3.6
		Chhattisgarh	8.0	6.4	4.9
		Punjab	5.4	4.3	3.2
		Karnataka	5.3	4.2	3.2
		Rajasthan	5.1	4.0	3.1
		Andhra Pradesh	4.9	3.9	2.9
		Maharashtra	4.4	3.5	2.6
150 kWp	Commercial	Delhi	4.0	3.2	2.4
		Haryana	5.2	4.1	3.1
		Gujarat	7.6	6.1	4.7
		West Bengal	5.5	4.3	3.3
		Chhattisgarh	7.4	5.9	4.6
		Punjab	5.0	3.9	3.0
		Karnataka	4.9	3.9	2.9
		Rajasthan	4.7	3.7	2.8
		Andhra Pradesh	4.6	3.6	2.7

		Maharashtra	4.1	3.2	2.4
1000 kWp	Commercial	Delhi	3.7	2.9	2.2
		Haryana	4.8	3.8	2.9
		Gujarat	7.1	5.6	4.3
		West Bengal	5.0	4.0	3.0
		Chhattisgarh	6.9	5.5	4.2
		Punjab	4.6	3.6	2.7
		Karnataka	4.5	3.6	2.7
		Rajasthan	4.3	3.4	2.6
		Andhra Pradesh	4.2	3.3	2.5
		Maharashtra	3.8	2.9	2.2

Annexure A8.3: Net Present Value

PV Only—No Incentive			2015	2017	2020
25	Commercial	Delhi	1273861	2229650	3424243
		Haryana	185231	1019359	2005501
		Gujarat	–1006913	–306013	451856
		West Bengal	1819	815450	1766472
		Chhattisgarh	–920856	–210339	564009
		Punjab	363168	1217182	2237395
		Karnataka	419757	1280095	2311143
		Rajasthan	564336	1440831	2499564
		Andhra Pradesh	489998	1358186	2402685
		Maharashtra	1256355	2210187	3401428
	Industrial	Delhi	553676	1415244	2445519
		Haryana	–159863	624614	1523356
		Gujarat	–1039646	–350222	386343
		West Bengal	–283232	487916	1363917
		Chhattisgarh	–1288061	–625477	65296
		Punjab	194318	1017061	1981093
		Karnataka	–262023	511416	1391327
		Rajasthan	–121062	667607	1573502
		Andhra Pradesh	–399706	358858	1213388
		Maharashtra	1205499	2137491	3287922
150 kWp	Commercial	Delhi	9272275	14788171	21785525
		Haryana	2740492	7526427	13273071
		Gujarat	–4412370	–425806	3951203
		West Bengal	1640023	6302975	11838900
		Chhattisgarh	–3896028	148241	4624119
		Punjab	3808118	8713366	14664439
		Karnataka	4147648	9090841	15106928
		Rajasthan	5015123	10055260	16237452
		Andhra Pradesh	4569097	9559389	15656175

		Maharashtra	9167235	14671393	21648634
	Industrial	Delhi	4951162	9901737	15913181
		Haryana	669930	5157955	10380206
		Gujarat	–4608766	–691059	3558127
		West Bengal	–70282	4337770	9423571
		Chhattisgarh	–6099259	–2342587	1631845
		Punjab	2795016	7512639	13126623
		Karnataka	56970	4478770	9588028
		Rajasthan	902734	5415912	10681077
		Andhra Pradesh	–769127	3563420	8520397
		Maharashtra	8862101	14235221	20967599
1000 kWp	Commercial	Delhi	72189580	107341221	152855547
		Haryana	28644364	58929594	96105852
		Gujarat	–19041385	5914707	33960066
		West Bengal	21307904	50773245	86544713
		Chhattisgarh	–15599101	9741685	38446175
		Punjab	35761870	66842519	105381642
		Karnataka	38025406	69359018	108331564
		Rajasthan	43808568	75788479	115868390
		Andhra Pradesh	40835065	72482671	111993214
		Maharashtra	71489316	106562699	151942937
	Industrial	Delhi	43382161	74764996	113706585
		Haryana	14840617	43139783	76820082
		Gujarat	–20350693	4146352	31339558
		West Bengal	9905872	37671880	70442519
		Chhattisgarh	–30287312	–6863834	18497675
		Punjab	29007856	58837671	95129530
		Karnataka	10754215	38611879	71538900
		Rajasthan	16392645	44859494	78825892
		Andhra Pradesh	5246901	32509547	64421361
		Maharashtra	69455093	103654886	147402706
PV Only—Capital Subsidy			2015	2017	2020
25	Commercial	Delhi	1564861	2477900	3640243
		Haryana	476231	1267609	2221501
		Gujarat	–715913	–57763	667856
		West Bengal	292819	1063700	1982472
		Chhattisgarh	–629856	37911	780009
		Punjab	654168	1465432	2453395
		Karnataka	710757	1528345	2527143
		Rajasthan	855336	1689081	2715564
		Andhra Pradesh	780998	1606436	2618685
		Maharashtra	1547355	2458437	3617428
150 kWp	Commercial	Delhi	10867525	16147171	22966775
		Haryana	4335742	8885427	14454321

		Gujarat	–2817120	933194	5132453
		West Bengal	3235273	7661975	13020150
		Chhattisgarh	–2300778	1507241	5805369
		Punjab	5403368	10072366	15845689
		Karnataka	5742898	10449841	16288178
		Rajasthan	6610373	11414260	17418702
		Andhra Pradesh	6164347	10918389	16837425
		Maharashtra	10762485	16030393	22829884
1000 kWp	Commercial	Delhi	81864580	115591221	160025547
		Haryana	38319364	67179594	103275852
		Gujarat	–9366385	14164707	41130066
		West Bengal	30982904	59023245	93714713
		Chhattisgarh	–5924101	17991685	45616175
		Punjab	45436870	75092519	112551642
		Karnataka	47700406	77609018	115501564
		Rajasthan	53483568	84038479	123038390
		Andhra Pradesh	50510065	80732671	119163214
		Maharashtra	81164316	114812699	159112937
PV + Battery—No Incentive			2015	2017	2020
25	Commercial	Delhi	–644900	710892	2256185
		Haryana	–1872376	–653762	656493
		Gujarat	–3168844	–2095116	–1033110
		West Bengal	–2018183	–815863	466473
		Chhattisgarh	–3059738	–1973818	–890920
		Punjab	–1677456	–437058	910521
		Karnataka	–1602672	–353916	1007982
		Rajasthan	–1439897	–172950	1220117
		Andhra Pradesh	–1506471	–246964	1133355
		Maharashtra	–737446	608004	2135576
	Industrial	Delhi	–1439517	–187684	1176309
		Haryana	–2250407	–1086183	128332
		Gujarat	–3204845	–2143740	–1105165
		West Bengal	–2335432	–1180395	18446
		Chhattisgarh	–3466002	–2433113	–1442679
		Punjab	–1862422	–656279	629755
		Karnataka	–2351970	–1198719	–2926
		Rajasthan	–2193888	–1023557	201375
		Andhra Pradesh	–2488936	–1350483	–179938
		Maharashtra	–792711	529005	2012228
150 kWp	Commercial	Delhi	–1009719	6740895	15713881
		Haryana	–8374581	–1447029	6115728
		Gujarat	–16153384	–10095156	–4021889
		West Bengal	–9249420	–2419636	4975607
		Chhattisgarh	–15498752	–9367365	–3168749
		Punjab	–7205057	–146805	7639893

		Karnataka	–6756351	352047	8224663
		Rajasthan	–5779701	1437843	9497469
		Andhra Pradesh	–6179145	993759	8976900
		Maharashtra	–1564995	6123565	14990226
	Industrial	Delhi	–5777426	1349441	9234621
		Haryana	–10642763	–4041555	2946759
		Gujarat	–16369394	–10386899	–4454220
		West Bengal	–11152916	–4606825	2287448
		Chhattisgarh	–17936334	–12123134	–6479302
		Punjab	–8314853	–1462133	5955303
		Karnataka	–11252140	–4716769	2159213
		Rajasthan	–10303649	–3665802	3385023
		Andhra Pradesh	–12073937	–5627354	1097140
		Maharashtra	–1896587	5649571	14250137
1000 kWp	Commercial	Delhi	11479424	60304737	118132826
		Haryana	–37619650	5718577	54145143
		Gujarat	–89478342	–51935601	–13438972
		West Bengal	–43451910	–765469	46544332
		Chhattisgarh	–85114128	–47083663	–7751372
		Punjab	–29822829	14386736	64306242
		Karnataka	–26831453	17712413	68204710
		Rajasthan	–20320452	24951053	76690081
		Andhra Pradesh	–22983411	21990495	73219617
		Maharashtra	7777589	56189202	113308461
	Industrial	Delhi	–20305284	24361711	74937763
		Haryana	–52740868	–11578261	33018681
		Gujarat	–90918406	–53880556	–16321183
		West Bengal	–56141887	–15346731	28623275
		Chhattisgarh	–101364675	–65455455	–29821726
		Punjab	–37221465	5617881	53075638
		Karnataka	–56803381	–16079694	27768373
		Rajasthan	–50480109	–9073246	35940440
		Andhra Pradesh	–62282027	–22150261	20687884
		Maharashtra	5566974	53029246	108374536
PV + Battery—Capital Subsidy			2015	2017	2020
25	Commercial	Delhi	–237500	1058442	2558585
		Haryana	–1464976	–306212	958893
		Gujarat	–2761444	–1747566	–730710
		West Bengal	–1610783	–468313	768873
		Chhattisgarh	–2652338	–1626268	–588520
		Punjab	–1270056	–89508	1212921
		Karnataka	–1195272	–6366	1310382
		Rajasthan	–1032497	174600	1522517
		Andhra Pradesh	–1099071	100586	1435755
		Maharashtra	–385311	955554	2437976

150 kWp	Commercial	Delhi	1223631	8643495	17367631
		Haryana	–6141231	455571	7769478
		Gujarat	–13920034	–8192556	–2368139
		West Bengal	–7016070	–517036	6629357
		Chhattisgarh	–13265402	–7464765	–1514999
		Punjab	–4971707	1755795	9293643
		Karnataka	–4523001	2254647	9878413
		Rajasthan	–3546351	3340443	11151219
		Andhra Pradesh	–3945795	2896359	10630650
		Maharashtra	336763	8026165	16643976
1000 kWp	Commercial	Delhi	25024424	71854737	128170826
		Haryana	–24074650	17268577	64183143
		Gujarat	–75933342	–40385601	–3400972
		West Bengal	–29906910	10784531	56582332
		Chhattisgarh	–71569128	–35533663	2286628
		Punjab	–16277829	25936736	74344242
		Karnataka	–13286453	29262413	78242710
		Rajasthan	–6775452	36501053	86728081
		Andhra Pradesh	–9438411	33540495	83257617
		Maharashtra	19111974	67739202	123346461
PV + Diesel—No Incentive			2015	2017	2020
25	Commercial	Delhi	1082926	1998681	3119550
		Haryana	–144551	634028	1519858
		Gujarat	–1441018	–807327	–169745
		West Bengal	–290357	471926	1329837
		Chhattisgarh	–1331913	–686029	–27555
		Punjab	50370	850731	1773885
		Karnataka	125154	933873	1871347
		Rajasthan	287929	1114839	2083481
		Andhra Pradesh	221355	1040825	1996719
		Maharashtra	990380	1895793	2998941
	Industrial	Delhi	288309	1100106	2039673
		Haryana	–522581	201607	991696
		Gujarat	–1477019	–855951	–241801
		West Bengal	–607606	107395	881811
		Chhattisgarh	–1738176	–1145323	–579314
		Punjab	–134596	631510	1493120
		Karnataka	–624144	89071	860438
		Rajasthan	–466062	264232	1064740
		Andhra Pradesh	–761110	–62693	683426
		Maharashtra	935115	1816794	2875592
150 kWp	Commercial	Delhi	8126665	13402361	19957365
		Haryana	761804	5214437	10359213
		Gujarat	–7017000	–3433689	221595
		West Bengal	–113035	4241830	9219091

		West Bengal	9620851	37032283	69079317
		Chhattisgarh	–32041367	–9285911	14783614
		Punjab	23249932	52184487	86841228
		Karnataka	26241307	55510165	90739695
		Rajasthan	32752309	62748805	99225067
		Andhra Pradesh	30089350	59788247	95754603
		Maharashtra	60850350	93986953	135843447
	Industrial	Delhi	32767477	62159463	97472748
		Haryana	331893	26219491	55553667
		Gujarat	–37845645	–16082804	6213803
		West Bengal	–3069126	22451021	51158260
		Chhattisgarh	–48291914	–27657703	–7286740
		Punjab	15851296	43415633	75610624
		Karnataka	–3730620	21718058	50303359
		Rajasthan	2592652	28724506	58475426
		Andhra Pradesh	–9209266	15647491	43222870
		Maharashtra	58639735	90826998	130909521
PV + Diesel—Capital Subsidy			2015	2017	2020
25	Commercial	Delhi	1373926	2246931	3335550
		Haryana	146449	882278	1735858
		Gujarat	–1150018	–559077	46255
		West Bengal	643	720176	1545837
		Chhattisgarh	–1040913	–437779	188445
		Punjab	341370	1098981	1989885
		Karnataka	416154	1182123	2087347
		Rajasthan	578929	1363089	2299481
		Andhra Pradesh	512355	1289075	2212719
		Maharashtra	1281380	2144043	3214941
150 kWp	Commercial	Delhi	9721915	14761361	21138615
		Haryana	2357054	6573437	11540463
		Gujarat	–5421750	–2074689	1402845
		West Bengal	1482215	5600830	10400341
		Chhattisgarh	–4767118	–1346899	2255985
		Punjab	3526577	7873661	13064627
		Karnataka	3975284	8372513	13649397
		Rajasthan	4951934	9458309	14922203
		Andhra Pradesh	4552490	9014225	14401634
		Maharashtra	9166640	14144031	20414960
1000 kWp	Commercial	Delhi	74227185	106352488	147837812
		Haryana	25128111	51766329	83850129
		Gujarat	–26730581	–5887849	16266014
		West Bengal	19295851	45282283	76249317
		Chhattisgarh	–22366367	–1035911	21953614
		Punjab	32924932	60434487	94011228

		Karnataka	35916307	63760165	97909695
		Rajasthan	42427309	70998805	106395067
		Andhra Pradesh	39764350	68038247	102924603
		Maharashtra	70525350	102236953	143013447

Annexure A8.4: Internal Rate of Return

PV Only—No Incentive			2015	2017	2020
25	Commercial	Delhi	16%	21%	29%
		Haryana	11%	15%	22%
		Gujarat	3%	8%	13%
		West Bengal	10%	14%	20%
		Chhattisgarh	4%	8%	13%
		Punjab	12%	16%	23%
		Karnataka	12%	17%	23%
		Rajasthan	13%	18%	24%
		Andhra Pradesh	12%	17%	24%
		Maharashtra	16%	21%	29%
	Industrial	Delhi	12%	17%	24%
		Haryana	9%	13%	19%
		Gujarat	3%	7%	12%
		West Bengal	8%	13%	18%
		Chhattisgarh	0%	5%	10%
		Punjab	11%	15%	22%
		Karnataka	8%	13%	18%
		Rajasthan	9%	14%	19%
		Andhra Pradesh	7%	12%	17%
		Maharashtra	16%	21%	29%
150 kWp	Commercial	Delhi	18%	23%	32%
		Haryana	12%	17%	24%
		Gujarat	5%	9%	14%
		West Bengal	11%	16%	22%
		Chhattisgarh	5%	10%	15%
		Punjab	13%	18%	25%
		Karnataka	13%	19%	26%
		Rajasthan	14%	19%	27%
		Andhra Pradesh	14%	19%	26%
		Maharashtra	17%	23%	32%
	Industrial	Delhi	14%	19%	27%
		Haryana	10%	15%	21%
		Gujarat	4%	9%	14%
		West Bengal	10%	14%	20%
		Chhattisgarh	2%	7%	12%
		Punjab	12%	17%	24%

		Karnataka	10%	14%	20%
		Rajasthan	11%	15%	22%
		Andhra Pradesh	9%	14%	19%
		Maharashtra	17%	23%	31%
1000 kWp	Commercial	Delhi	20%	26%	35%
		Haryana	14%	19%	26%
		Gujarat	6%	11%	16%
		West Bengal	13%	18%	25%
		Chhattisgarh	7%	11%	17%
		Punjab	15%	20%	28%
		Karnataka	15%	21%	28%
		Rajasthan	16%	22%	29%
		Andhra Pradesh	15%	21%	29%
		Maharashtra	19%	26%	35%
	Industrial	Delhi	16%	22%	29%
		Haryana	12%	17%	23%
		Gujarat	6%	10%	16%
		West Bengal	11%	16%	22%
		Chhattisgarh	4%	8%	13%
		Punjab	14%	19%	26%
		Karnataka	11%	16%	23%
		Rajasthan	12%	17%	24%
		Andhra Pradesh	11%	15%	21%
		Maharashtra	19%	26%	34%
PV Only—Capital Subsidy			2015	2017	2020
25	Commercial	Delhi	18%	24%	33%
		Haryana	13%	18%	25%
		Gujarat	4%	9%	15%
		West Bengal	11%	17%	23%
		Chhattisgarh	5%	10%	16%
		Punjab	14%	19%	26%
		Karnataka	14%	19%	27%
		Rajasthan	15%	20%	28%
		Andhra Pradesh	14%	20%	27%
		Maharashtra	18%	24%	33%
150 kWp	Commercial	Delhi	20%	27%	37%
		Haryana	14%	20%	27%
		Gujarat	6%	11%	17%
		West Bengal	13%	19%	26%
		Chhattisgarh	7%	12%	17%
		Punjab	15%	21%	29%
		Karnataka	16%	21%	29%
		Rajasthan	16%	22%	31%
		Andhra Pradesh	16%	22%	30%

		Maharashtra	20%	27%	37%
1000 kWp	Commercial	Delhi	22%	30%	40%
		Haryana	16%	22%	30%
		Gujarat	8%	13%	19%
		West Bengal	15%	21%	29%
		Chhattisgarh	8%	13%	20%
		Punjab	17%	23%	32%
		Karnataka	18%	24%	32%
		Rajasthan	18%	25%	34%
		Andhra Pradesh	18%	24%	33%
		Maharashtra	22%	30%	40%
PV + Battery—No Incentive			2015	2017	2020
25	Commercial	Delhi	2%	9%	16%
		Haryana	–5%	2%	9%
		Gujarat	#NUM!*	#NUM! *	–2%
		West Bengal	–7%	1%	8%
		Chhattisgarh	#NUM!*	#NUM!*	–1%
		Punjab	–4%	3%	10%
		Karnataka	–3%	4%	11%
		Rajasthan	–2%	5%	12%
		Andhra Pradesh	–3%	4%	11%
		Maharashtra	2%	8%	16%
	Industrial	Delhi	–3%	4%	11%
		Haryana	–10%	–1%	6%
		Gujarat	#NUM!*	#NUM!*	–3%
		West Bengal	–11%	–2%	5%
		Chhattisgarh	#NUM!*	#NUM!*	–6%
		Punjab	–5%	2%	9%
		Karnataka	–11%	–2%	5%
		Rajasthan	–9%	–1%	7%
		Andhra Pradesh	#NUM!*	–3%	4%
		Maharashtra	2%	8%	15%
150 kWp	Commercial	Delhi	5%	11%	19%
		Haryana	–3%	4%	11%
		Gujarat	#NUM!*	–8%	1%
		West Bengal	–4%	3%	10%
		Chhattisgarh	#NUM!*	–7%	2%
		Punjab	–1%	5%	12%
		Karnataka	–1%	6%	13%
		Rajasthan	0%	7%	14%
		Andhra Pradesh	–1%	6%	13%
		Maharashtra	4%	10%	18%
	Industrial	Delhi	0%	6%	14%
		Haryana	–6%	1%	8%
		Gujarat	#NUM!*	#NUM!*	0%

		West Bengal	–7%	1%	8%
		Chhattisgarh	#NUM!*	#NUM!*	–3%
		Punjab	–3%	4%	11%
		Karnataka	–7%	0%	8%
		Rajasthan	–6%	2%	9%
		Andhra Pradesh	–9%	–1%	6%
		Maharashtra	4%	10%	18%
1000 kWp	Commercial	Delhi	7%	13%	21%
		Haryana	0%	6%	13%
		Gujarat	#NUM!*	–5%	3%
		West Bengal	–1%	5%	12%
		Chhattisgarh	#NUM!*	–4%	4%
		Punjab	1%	8%	15%
		Karnataka	2%	8%	15%
		Rajasthan	3%	9%	16%
		Andhra Pradesh	2%	8%	16%
		Maharashtra	6%	13%	21%
	Industrial	Delhi	2%	9%	16%
		Haryana	–3%	4%	11%
		Gujarat	#NUM!*	–6%	2%
		West Bengal	–4%	3%	10%
		Chhattisgarh	#NUM!*	–10%	–1%
		Punjab	0%	6%	13%
		Karnataka	–4%	3%	10%
		Rajasthan	–3%	4%	11%
		Andhra Pradesh	–6%	2%	9%
		Maharashtra	6%	12%	20%
PV + Battery—Capital Subsidy			2015	2017	2020
25	Commercial	Delhi	3%	10%	19%
		Haryana	–5%	3%	10%
		Gujarat	#NUM!*	#NUM!*	–1%
		West Bengal	–7%	2%	9%
		Chhattisgarh	#NUM!*	#NUM!*	0%
		Punjab	–3%	4%	12%
		Karnataka	–3%	5%	12%
		Rajasthan	–1%	6%	13%
		Andhra Pradesh	–2%	5%	13%
		Maharashtra	2%	10%	18%
150 kWp	Commercial	Delhi	6%	13%	22%
		Haryana	–2%	5%	13%
		Gujarat	#NUM!*	–8%	1%
		West Bengal	–4%	4%	12%
		Chhattisgarh	#NUM!*	–7%	2%
		Punjab	0%	7%	14%
		Karnataka	0%	7%	15%

		Rajasthan	1%	8%	16%
		Andhra Pradesh	0%	7%	16%
		Maharashtra	5%	12%	21%
1000 kWp	Commercial	Delhi	8%	15%	25%
		Haryana	1%	8%	16%
		Gujarat	#NUM!*	–5%	4%
		West Bengal	–1%	6%	14%
		Chhattisgarh	#NUM!*	–4%	5%
		Punjab	2%	9%	17%
		Karnataka	2%	9%	18%
		Rajasthan	4%	10%	19%
		Andhra Pradesh	3%	10%	18%
		Maharashtra	7%	15%	24%
PV + Diesel—No Incentive			2015	2017	2020
25	Commercial	Delhi	15%	20%	28%
		Haryana	9%	13%	19%
		Gujarat	#NUM!*	3%	8%
		West Bengal	8%	12%	18%
		Chhattisgarh	–3%	4%	9%
		Punjab	10%	15%	21%
		Karnataka	10%	15%	21%
		Rajasthan	11%	16%	22%
		Andhra Pradesh	11%	16%	22%
		Maharashtra	15%	20%	27%
	Industrial	Delhi	11%	16%	22%
		Haryana	6%	11%	16%
		Gujarat	#NUM!*	2%	7%
		West Bengal	6%	10%	16%
		Chhattisgarh	#NUM!*	–2%	4%
		Punjab	9%	14%	19%
		Karnataka	6%	10%	16%
		Rajasthan	7%	11%	17%
		Andhra Pradesh	5%	9%	14%
		Maharashtra	14%	20%	27%
150 kWp	Commercial	Delhi	17%	23%	31%
		Haryana	10%	15%	21%
		Gujarat	–1%	5%	10%
		West Bengal	9%	14%	20%
		Chhattisgarh	0%	6%	11%
		Punjab	12%	16%	23%
		Karnataka	12%	17%	23%
		Rajasthan	13%	18%	25%
		Andhra Pradesh	12%	17%	24%
		Maharashtra	16%	22%	30%
	Industrial	Delhi	13%	18%	25%

		Haryana	8%	13%	18%
		Gujarat	–2%	4%	9%
		West Bengal	7%	12%	18%
		Chhattisgarh	#NUM!*	0%	6%
		Punjab	10%	15%	21%
		Karnataka	7%	12%	17%
		Rajasthan	8%	13%	19%
		Andhra Pradesh	6%	11%	16%
		Maharashtra	16%	22%	30%
1000 kWp	Commercial	Delhi	19%	25%	34%
		Haryana	12%	17%	24%
		Gujarat	1%	6%	12%
		West Bengal	11%	16%	22%
		Chhattisgarh	2%	7%	13%
		Punjab	13%	18%	25%
		Karnataka	14%	19%	26%
		Rajasthan	15%	20%	27%
		Andhra Pradesh	14%	19%	27%
		Maharashtra	18%	24%	33%
	Industrial	Delhi	15%	20%	27%
		Haryana	10%	14%	20%
		Gujarat	1%	6%	11%
		West Bengal	9%	14%	20%
		Chhattisgarh	#NUM!*	2%	8%
		Punjab	12%	17%	24%
		Karnataka	9%	14%	19%
		Rajasthan	10%	15%	21%
		Andhra Pradesh	8%	13%	18%
		Maharashtra	18%	24%	33%
PV + Diesel—Capital Subsidy			2015	2017	2020
25	Commercial	Delhi	17%	24%	32%
		Haryana	11%	16%	22%
		Gujarat	#NUM!*	4%	10%
		West Bengal	10%	15%	21%
		Chhattisgarh	–2%	5%	11%
		Punjab	12%	17%	24%
		Karnataka	12%	17%	24%
		Rajasthan	13%	19%	26%
		Andhra Pradesh	13%	18%	25%
		Maharashtra	17%	23%	31%
150 kWp	Commercial	Delhi	19%	26%	35%
		Haryana	12%	18%	25%
		Gujarat	0%	6%	12%
		West Bengal	11%	16%	23%
		Chhattisgarh	1%	7%	13%

		Punjab	14%	19%	26%
		Karnataka	14%	20%	27%
		Rajasthan	15%	21%	28%
		Andhra Pradesh	14%	20%	28%
		Maharashtra	19%	25%	35%
1000 kWp	Commercial	Delhi	22%	29%	39%
		Haryana	14%	20%	27%
		Gujarat	3%	8%	14%
		West Bengal	13%	19%	26%
		Chhattisgarh	4%	9%	15%
		Punjab	15%	21%	29%
		Karnataka	16%	22%	30%
		Rajasthan	17%	23%	31%
		Andhra Pradesh	16%	22%	31%
		Maharashtra	21%	28%	38%

* Values are either very high or very low

Annexure A9.1: List of SETNET Training Institutes

Sr. No.	Organization Name
	Gujarat Energy Research and Management Institute
	Institute for Energy Studies, Anna University
	ADS Global Knowledge Academy
	Bhillai Institute of Technology
	Cares Renewable Private Limited
	Everonn Skill Development Ltd.
	IACHARYA Silicon Ltd.
	Indian School of Petroleum & Energy
	MNIT Jaipur
	OMS Power Training and Research Institute
	S.R. Corporate Consultant Pvt. Ltd.
	Surabhi Educational Society (SES)
	Sri Eshwar College of Engineering
	Sunshine Technologies
	The Energy and Resources Institute
	Thapar University Patiala
	Tra International
	University Institute of Engineering and Technology
	University of Lucknow
	University of Agricultural Sciences
	First Green Consulting Private Limited
	Centre for Development of Imaging Technology
	Renewable Energy Centre, Mithradham
	Amity University
	Arbutus Consultants Pvt. Ltd.
	Mangla Smart Energy Solutions Private Ltd.
	GSH India Private Limited
	AnthroPower
	Global Sustainable Energy Solutions India
	Asia Institute of Power Management
	Tamil Nadu Advanced Technical Training Institute
	World Institute of Solar Energy (WISE)
	N B Institute for Rural Technology
	2E Knowledge Ventures Pvt. Ltd.
	Indian Institute of Engineering Science and Technology

Annexure A10.1: List of projects requiring environmental clearance from the central government in India

- Nuclear power and related projects such as Heavy Water Plants, nuclear fuel complex, rare earths
- River valley projects including hydel power, major irrigation, and their combination including flood control
- Ports, harbours, airports (except minor ports and harbours)

- Petroleum refineries including crude and product pipelines
- Chemical fertilizers (Nitrogenous and Phosphatic other than single superphosphate)
- Pesticides (Technical)
- Petrochemical complexes (Both Olefinic and Aromatic) and Petrochemical intermediates such as DMT, Caprolactam, LAB, etc. and production of basic plastics such as LLDPE, HDPE, PP, PVC
- Bulk drugs and pharmaceuticals
- Exploration for oil and gas and their production, transportation, and storage
- Synthetic rubber
- Asbestos and asbestos products
- Hydrocyanic acid and its derivatives
- Primary metallurgical industries (such as production of iron and steel, aluminium, copper, zinc, lead and ferrous alloys)
- Electric arc furnaces (Mini Steel Plants)
- Chloro-alkali industry
- Integrated paint complex including manufacture of resins and basic raw materials required in the manufacture of paints
- Viscose staple fibre and filament yarn
- Storage batteries integrated with manufacture of oxides of lead and lead antimony alloys
- All tourism projects between 200 m to 500 m of high water line and at locations with an elevation of more than 1000 m with investment of more than Rs 5 crores
- Thermal power plants
- Mining projects (major minerals) with leases more than five hectares
- Highway projects except projects relating to improvement work including widening and strengthening of roads with marginal land acquisition along the existing alignments provided it does not pass through ecologically sensitive areas such as national parks, sanctuaries, tiger reserves, reserve forests
- Tarred roads in the Himalayas and or forest areas
- Distilleries
- Raw skins and hides
- Pulp, paper, and newsprint
- Dyes
- Cement
- Foundries (individual)
- Electroplating
- Meta amino phenol