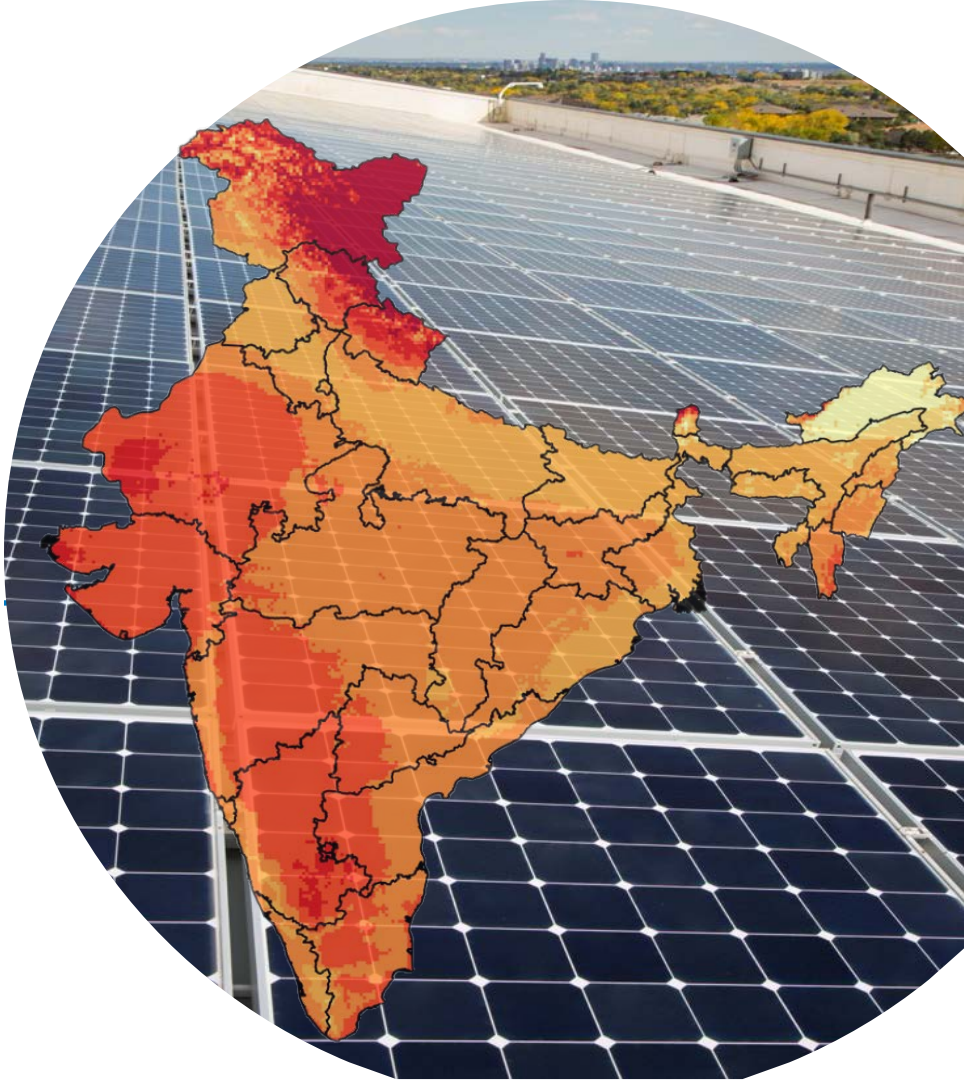
Unlocking the Full Potential of Rooftop PV In India Using Consumer Adoption Modeling

Paritosh Das, Sam Koebrich, Ashwin Ramdas, Amy Rose, David Palchak – NREL

April 2022 | NREL/PR-7A40-80751



Disclaimer

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding was provided by U.S. Department of Energy Office of International Affairs.

Modeling results developed through this study should be considered as projections instead of literal forecasts. Future technology costs, current policies, incentives, and retail rates and assumptions regarding those have been considered in this analysis to provide a baseline projection and would change depending on changing future market/policy conditions.

Acknowledgements

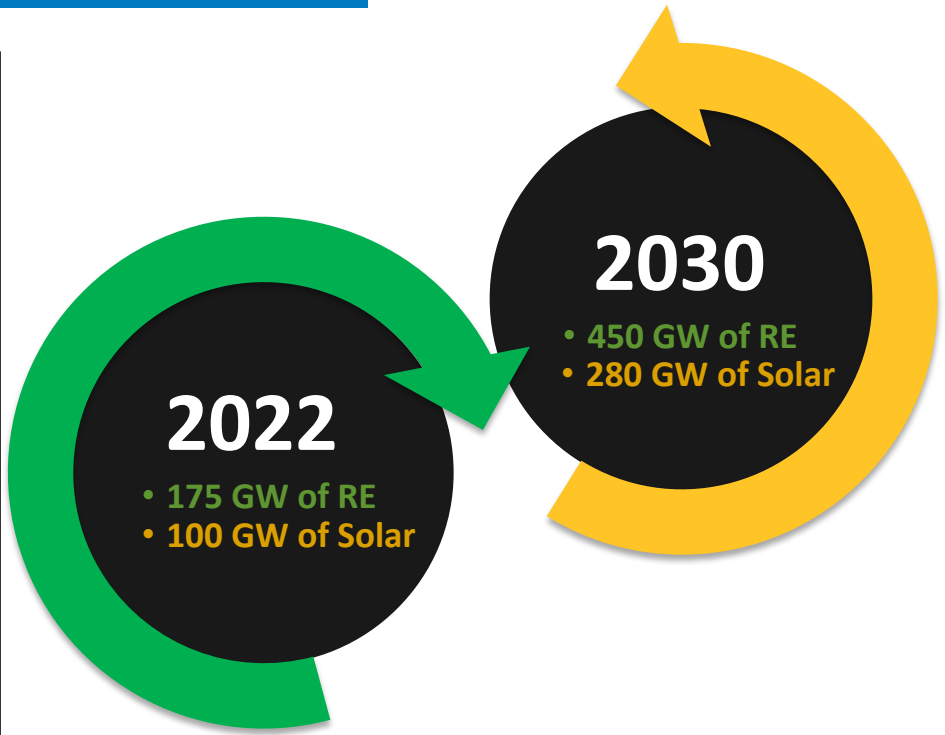
The authors are greatly indebted to several individuals for their thoughtful feedback and guidance, including Elena Thomas-Kerr (U.S. Department of Energy), Jai Asundi, Abhishek Nath, Saptak Ghosh (Center for Study of Science, Technology and Policy - CSTEP), and Arjun Gupta, Jagabanta Ningthoujam (Rocky Mountain Institute - RMI).

Contents

Overview of Distributed PV in India

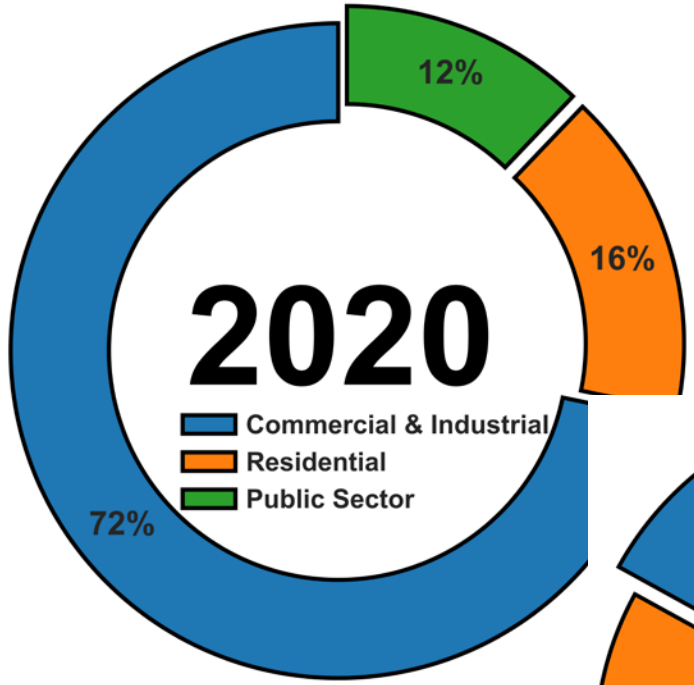
- **Policy Regime:** India's national renewable energy commitment calls for the development of **175 GW** and **450 GW** of **Renewable Energy** (RE) resources by **2022** and **2030** respectively
  - These include **100 GW** and **280GW** of **solar capacity** by the year **2022** and **2030** respectively
- **Resource Potential:** India offers **high solar resource potential**, with many rooftop systems achieving higher than 18% capacity factors
- **Unlike utility-procured solar, deployment of customer-adopted solar, is uncertain**, requiring advanced bottoms-up consumer solar adoption forecasting methods

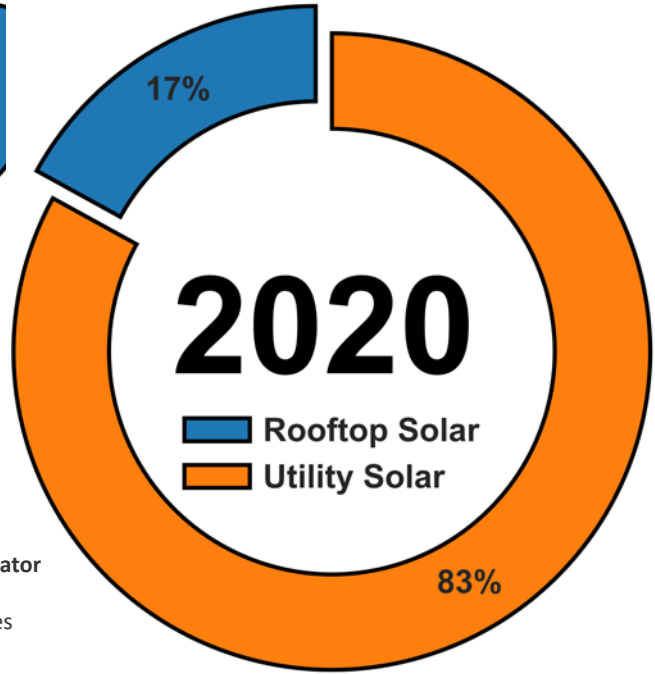
National RE Targets



- **Commercial and Industrial (C&I)** customers accounted for close to **72% (4.8GW)** of the total **6.8GW** cumulative rooftop solar installed by 2020
- By end of 2020, **Utility-scale Solar** continued to dominate India's solar sector with a market-segment of **83% (34GW)**
- **India's** cumulative **total** solar installed capacity reached **40GW*** by 2020

* Considers only commissioned projects and doesn't account for projects in pipeline

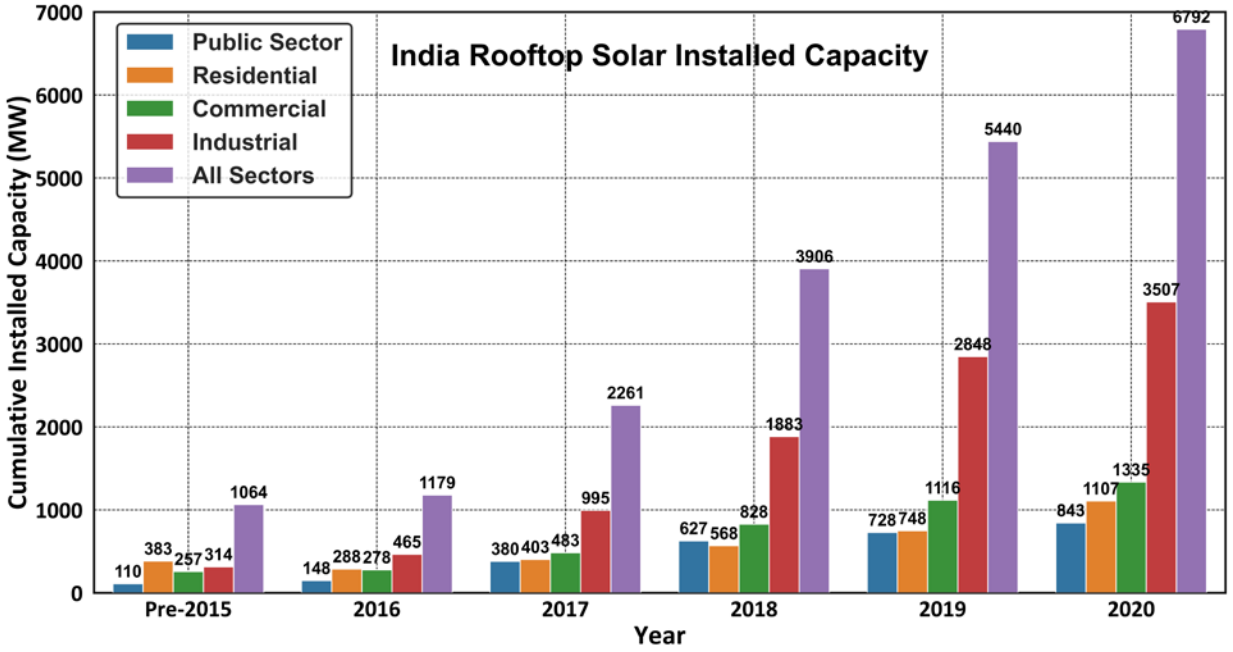




Sources: Data compiled and analyzed from **India RE Navigator** (Bridge To India); **Mercom** (Q4 Annual 2020 India Solar Market Update; **BloombergNEF** (2H 2021 India Renewables Market Outlook)

Rooftop Solar – India

- **India's** cumulative **total** rooftop solar installed capacity reached **6.8 GW** by 2020
- **Rooftop Solar** installations grew at a modest rate of **25% in 2020** as compared to **39% in 2019**
- **Commercial and Industrial** sub-sectors continued to lead due to **high electricity tariffs**
- **Residential sector** has tremendous growth capabilities as **technology costs** continue to decrease and **financing** options become more readily available

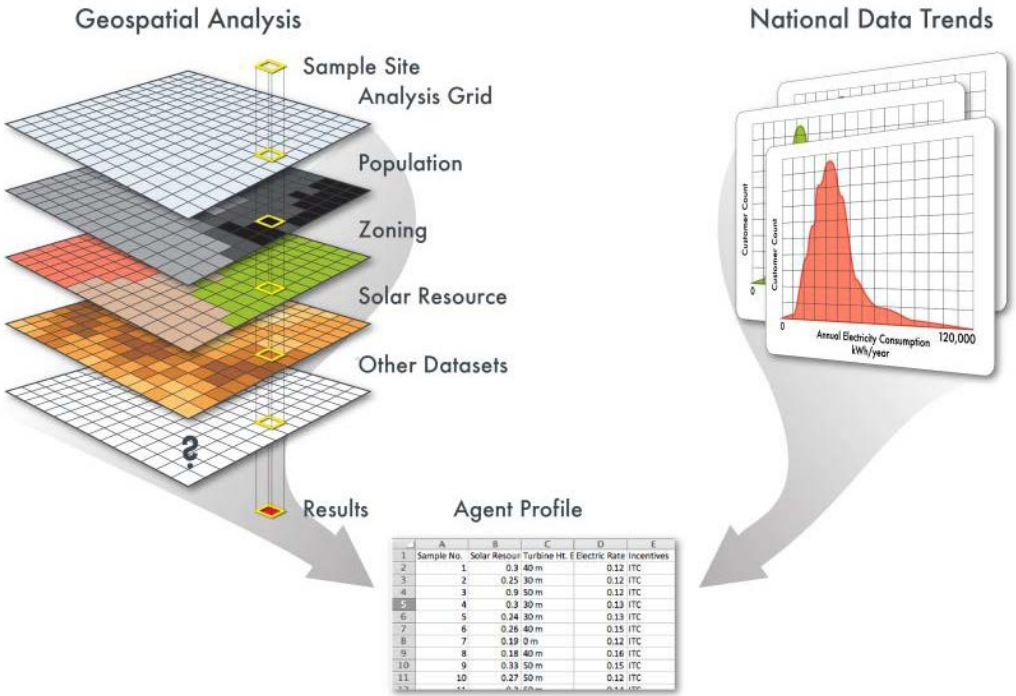


Sources: Data compiled and analyzed from **India RE Navigator (Bridge To India)**;

Methodology and Data

dGen™ Model

- **Agent-Based Model** simulating **consumer decision-making**
- Forecasts adoption of **distributed sola** by sector and state through 2050
- Incorporates detailed **spatial data** to understand **geographic variation**
- **Agent characteristics** derived from population-weighted sampling to create a **comprehensive** and **representative** database of the analysis population

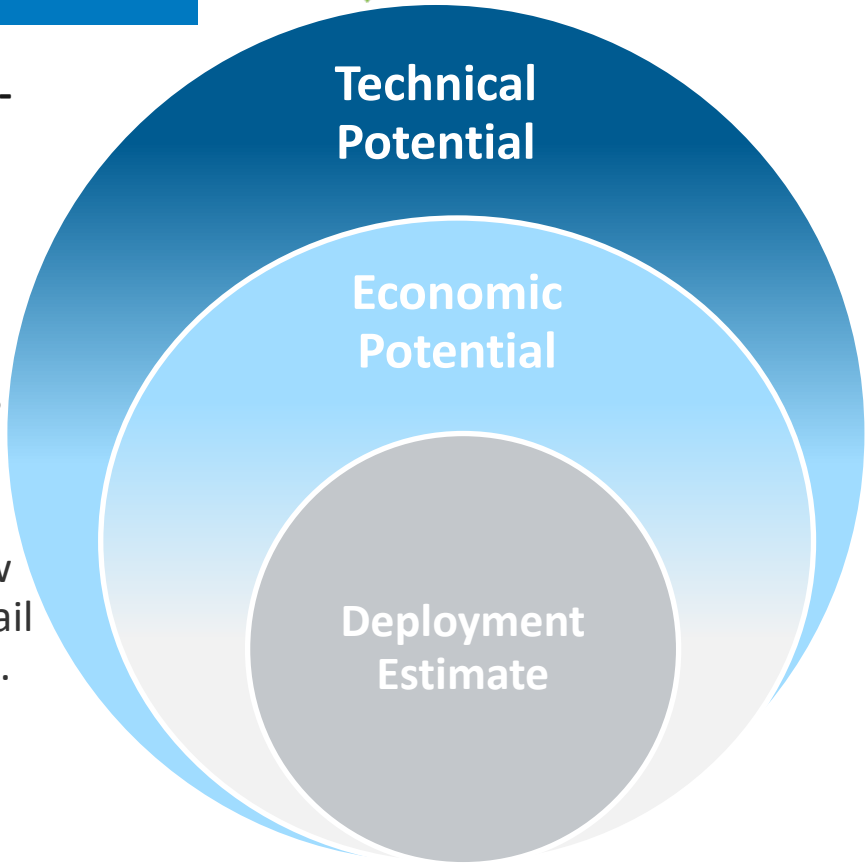


Website: www.nrel.gov/analysis/dgen/
Documentation: www.nrel.gov/docs/fy16osti/65231.pdf

Modeling Methodology

Adoption of rooftop solar is modeled through an agent-based approach that includes four steps:

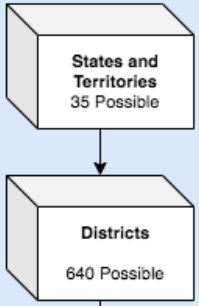
1. **Generating agents** (i.e., potential customers) and assigning them attributes based on a probabilistic representation of individual customer types
2. Applying **technical and siting restrictions**, such as resource quality, rooftop availability (solar), and quality for each agent
3. Performing **economic calculations** using cash flow analysis incorporating project costs, prevailing retail rates, incentives, and net metering considerations.
4. Estimate total rooftop solar deployment by applying **market diffusion estimates** (i.e., not all sites with economic potential will be deployed)



India Model Level

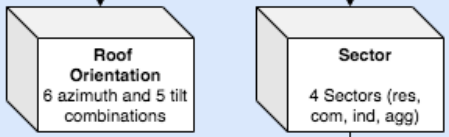
Geography: 35 States & Territories / 640 Districts

- Data from the *2011 Census* and *19th EPS Survey* is used to associate **consumption**, **number of households**, and **population** by district/state. (Note that Telangana was not included in 2011 Census).



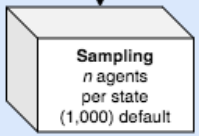
Building Characteristics:

- Sector impacts financing availability, tariff, tariff escalation, Bass Diffusion parameters, and roof size.

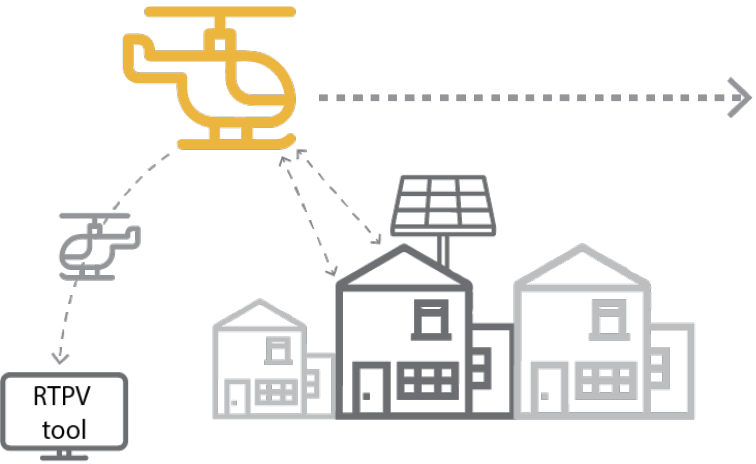


Agent Sampling: 1000 Agents per State

- Sampling based on available attributes, distributions of consumption by tariff class and state, and rooftop attributes.



Roof Characteristics Using LiDAR Methodology



Source: CSTEP's CREST Model;

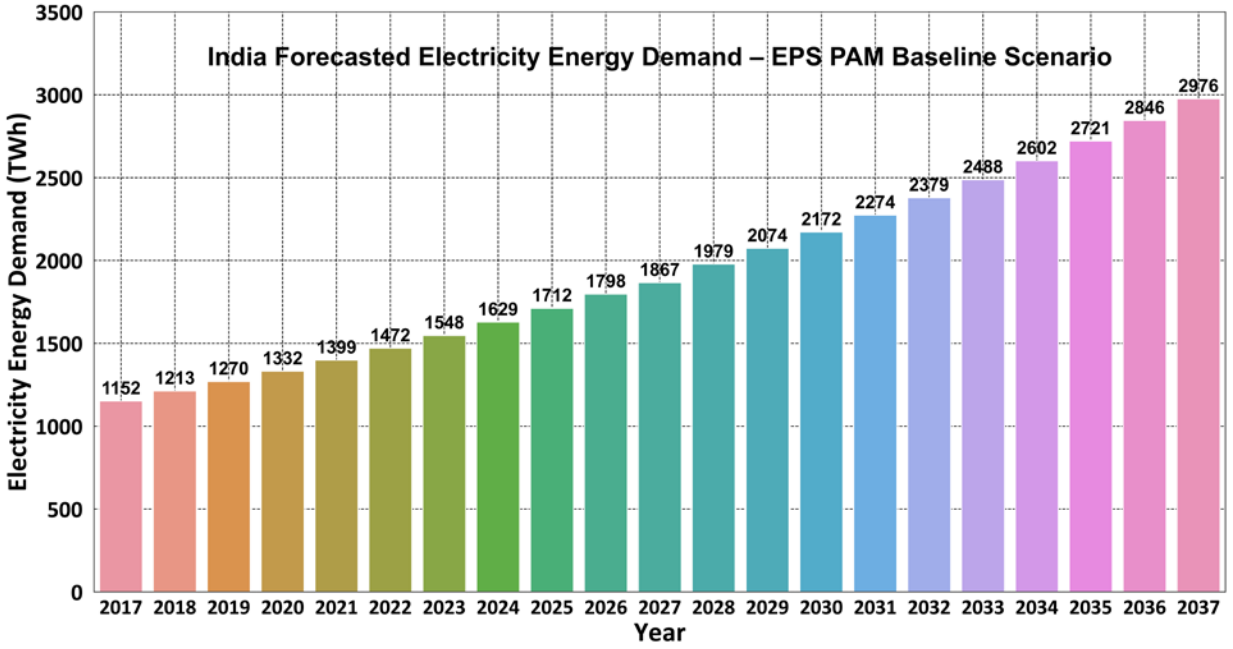
Airborne Light Detection and Ranging (LiDAR) technology is used to obtain detailed 3D city models and maps, the system consists of:

- LiDAR laser sensors/ scanners
- Global Positioning System (GPS)
- Inertial measurement units (IMU)
- Digital Camera
- Data Recorder / External Storage Device

- **LiDAR datasets** developed from **CSTEP's RTPV Estimation Tool: CREST** for Bengaluru City under Bangalore Electricity Supply Company (BESCOM) were used to **develop distributions of roof size by sector** that can be **sampled** as **representative** for all of India
- LiDAR data is used to **detect attributes of each roof plane** based on developable roof area, tilt angle, and azimuth
- These were passed to **NREL's PVWATTS** model to simulate **annual and hourly generation** for each roof plane

Electricity Energy Demand

- Incorporated forecasted state-level **electricity energy demand** from CEA's **19th Electric Power Survey (EPS)** Long Term Electricity Demand Forecasting Report
- Used the **Partial Adjustment Model (PAM) Baseline Scenario** for forecasted electricity consumption
- **For 2035**, India's total **Electricity Energy and Peak Demand** was forecasted to be **2976 TWh** and **398 GW** respectively



Sources: Data compiled and analyzed from **CEA 19th Electric Power Survey (EPS) Report**; **CEA 19th EPS Long Term Electricity Demand Forecasting Report;**

Solar Resource Characteristics

System Configuration

Azimuth: 180 Degrees (South)

Ground Coverage Ratio (GCR): 0.4

Losses: 14%

Tilt: Angle equal to Latitude

Module Type: Standard

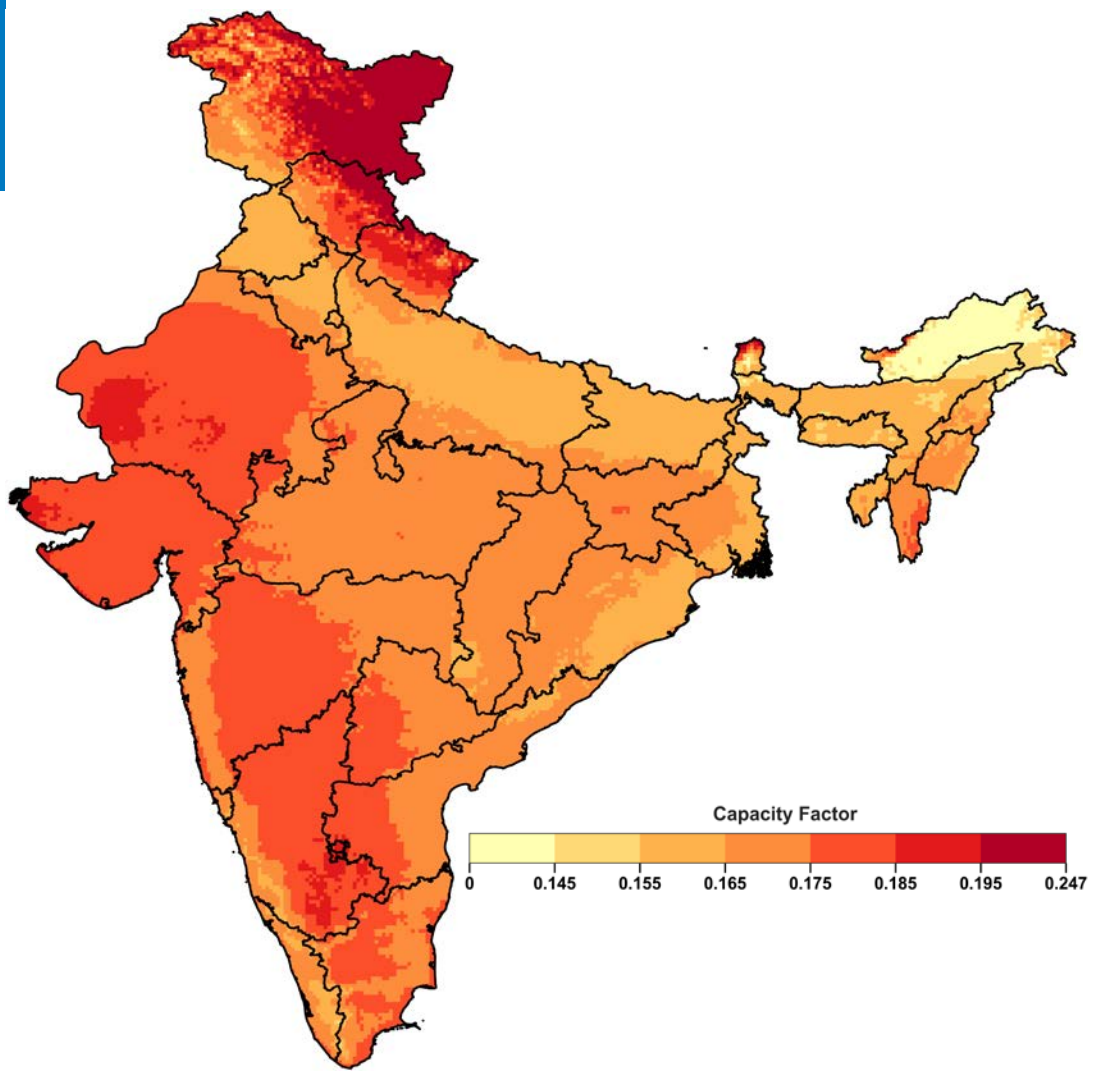
DC/AC Ratio: 1.3

Array Type: Fixed

Observation Year: 2014

Temporal Resolution: Hourly

Spatial Resolution: 10x10 km Grid



Rooftop PV Financial Assumptions

Financial - Assumptions

Financial Modeling

- Each agent completes a discounted cash flow analysis in each model year
  - Uses hourly solar generation and electricity consumption profiles
- Cash flows include capital and O&M costs, revenue from bill savings and incentives, and tax considerations

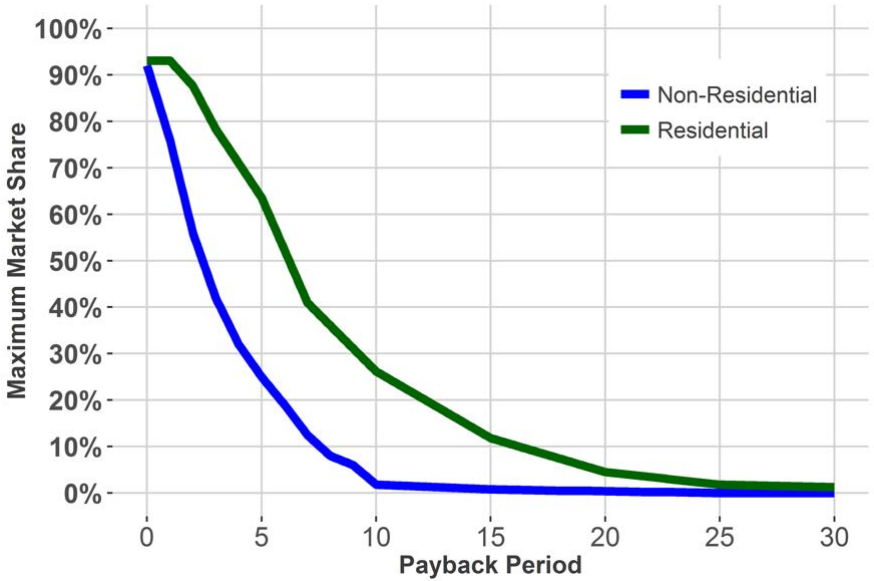
Baseline Retail Rates

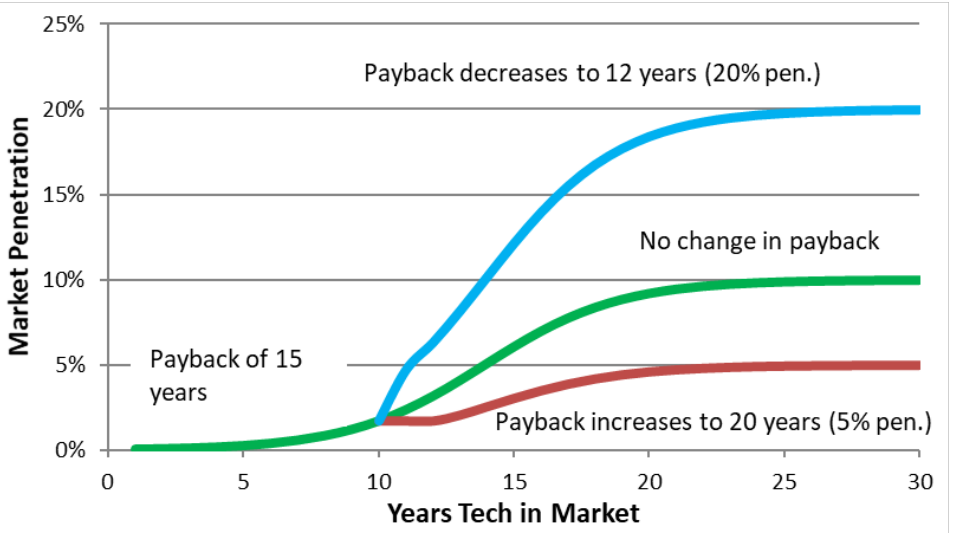
- Agents assigned appropriate tariff (w/ net metering) based on geographic and energy/demand consumption constraints
- Retail tariffs included tiers of consumption and prices by sector and state
- Representative DISCOMs are used for each state

Financing and Incentives:

- Incentives and financing options available by state and sector were implemented
- Assumes all consumers have access to financing

Modeling Solar Adoption

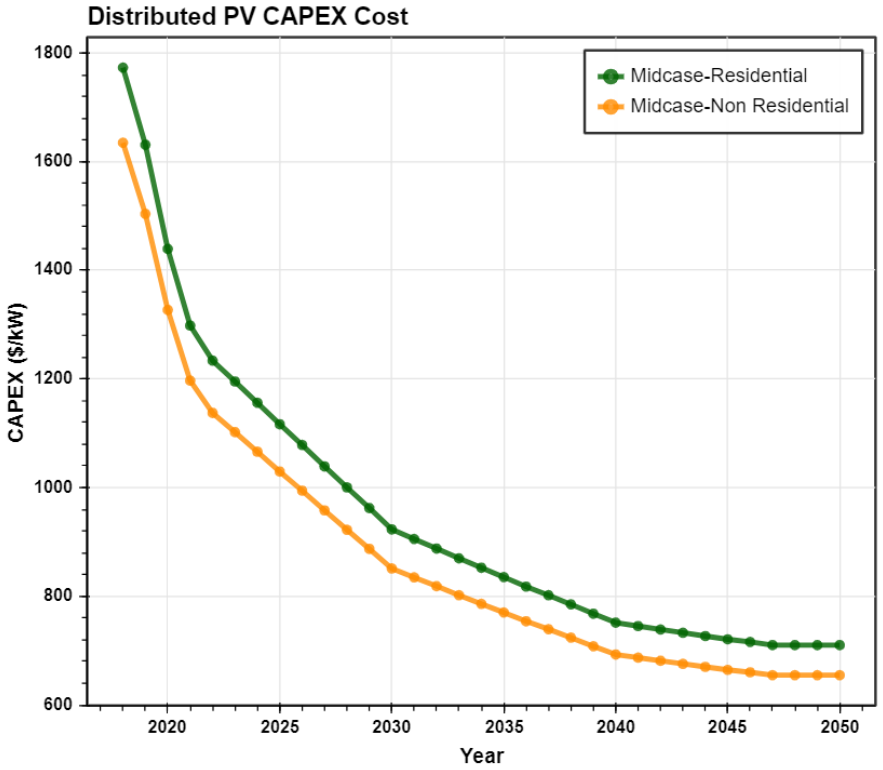


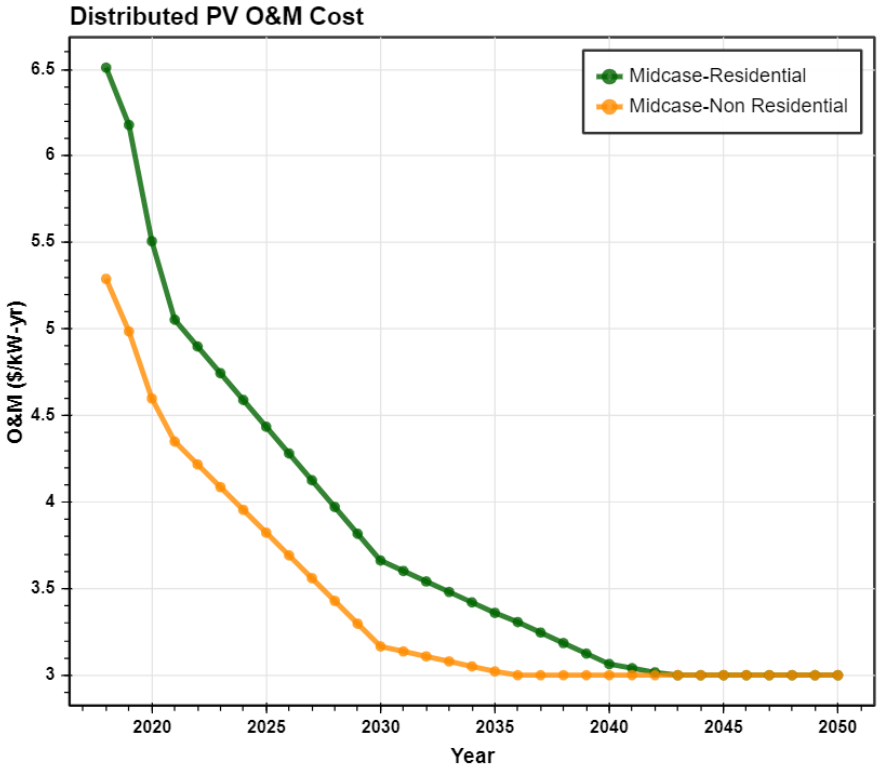


- Using historic consumer surveys, we relate the system payback to the fraction of consumers that would adopt solar
- Evaluate the optimal system size using consumer's energy consumption, solar resource, and economic factors including retail tariffs, incentives, and compensation mechanism
- Use the Bass Diffusion model to simulate adoption over time, using the "Maximum Market Share" as the terminal adoption level

Rooftop PV Costs

- India specific Distributed PV costs were imputed using **ReEDS India's DPV cost** projections, and NREL's **Annual Technology Baseline (ATB) 2020** data
- **Midcase Scenario CAPEX Costs:**
  - **Residential:** $1773/kW (2018), $710/kW (2050)
  - **Non-Residential (C&I):** $1635 (2018), $655/kW (2050)

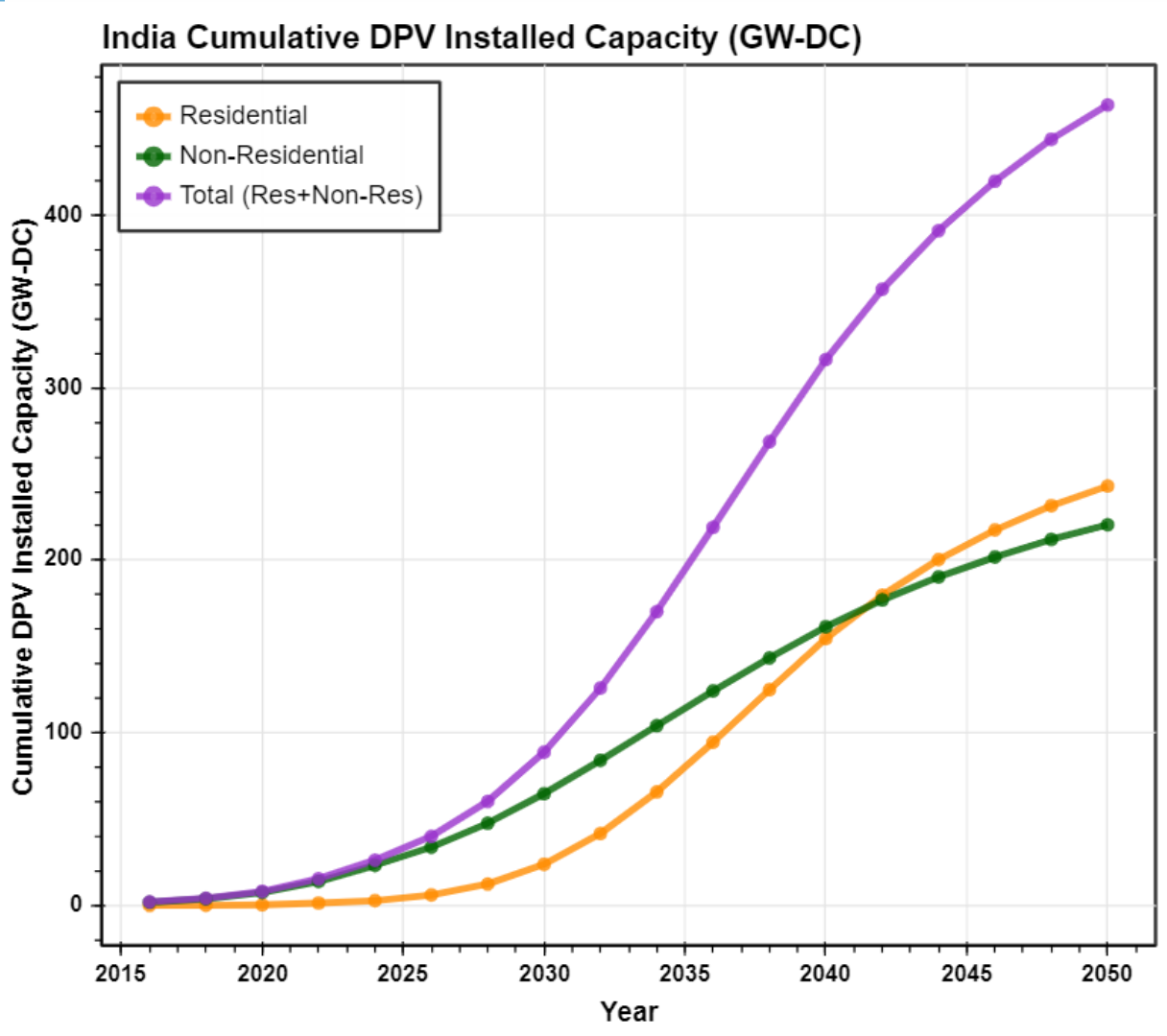




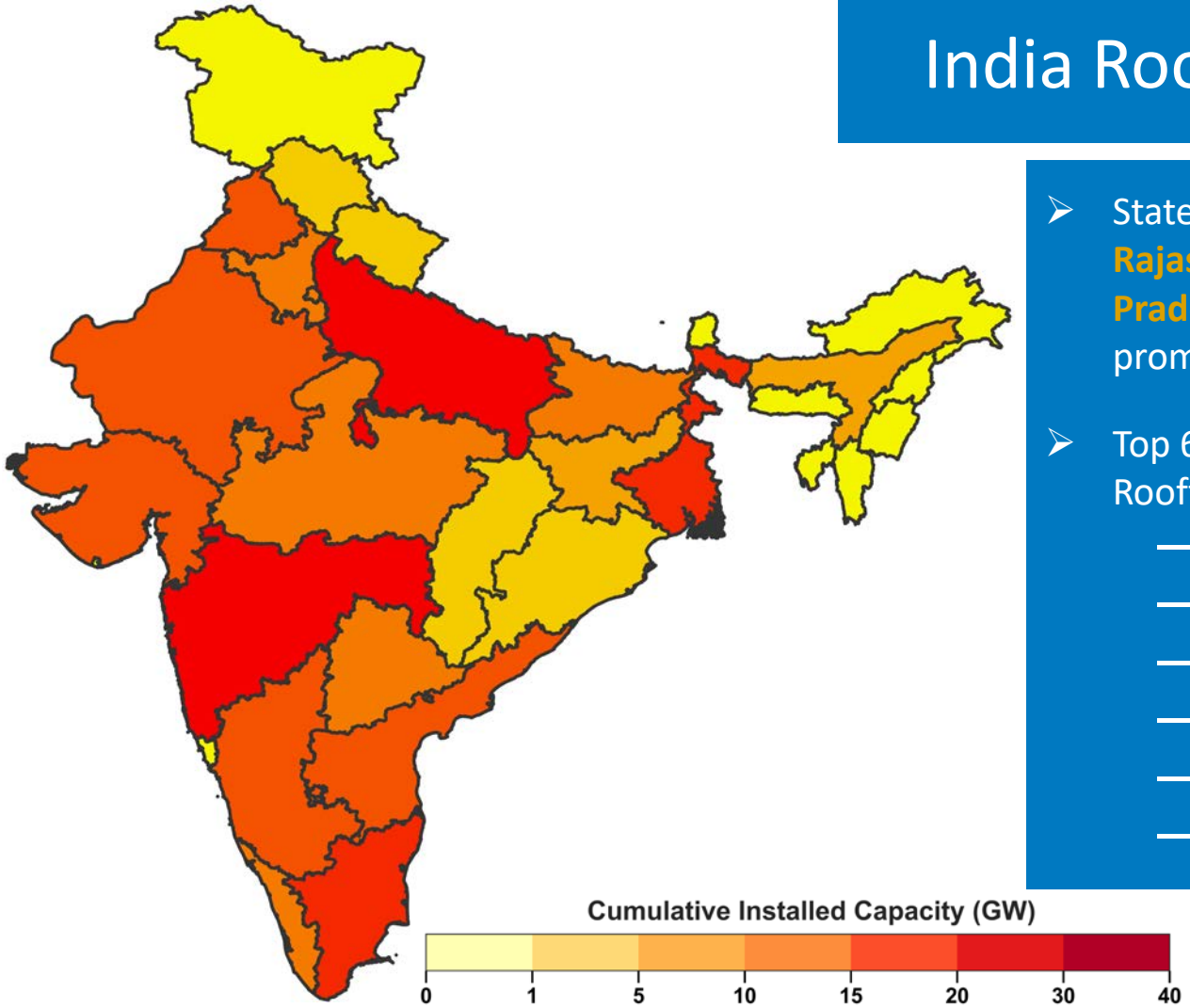
Rooftop PV Adoption Results

India Rooftop PV Adoption

- Under the **Midcase scenario** approximately **316 GW** of distributed solar could be adopted by **2040**
- **Non-residential sector** continues to grow steadily and is projected to be **161 GW** by **2040**
- Growth in the **residential sector** has been slow **(155 GW by 2040)** due to the challenges consumers face without access to financing and regulatory/policy barriers



India Rooftop PV Capacity



- States such as **Maharashtra, Rajasthan, Karnataka, Gujarat, Uttar Pradesh, and Tamil Nadu** have promising potential for Rooftop PV
- Top 6 States in 2040 By Installed Rooftop PV Capacity (GW)
  - **Maharashtra:** 40 GW
  - **Uttar Pradesh:** 36 GW
  - **Tamil Nadu:** 23.6 GW
  - **West Bengal:** 23.4 GW
  - **Rajasthan:** 18.8 GW
  - **Karnataka:** 18.2 GW

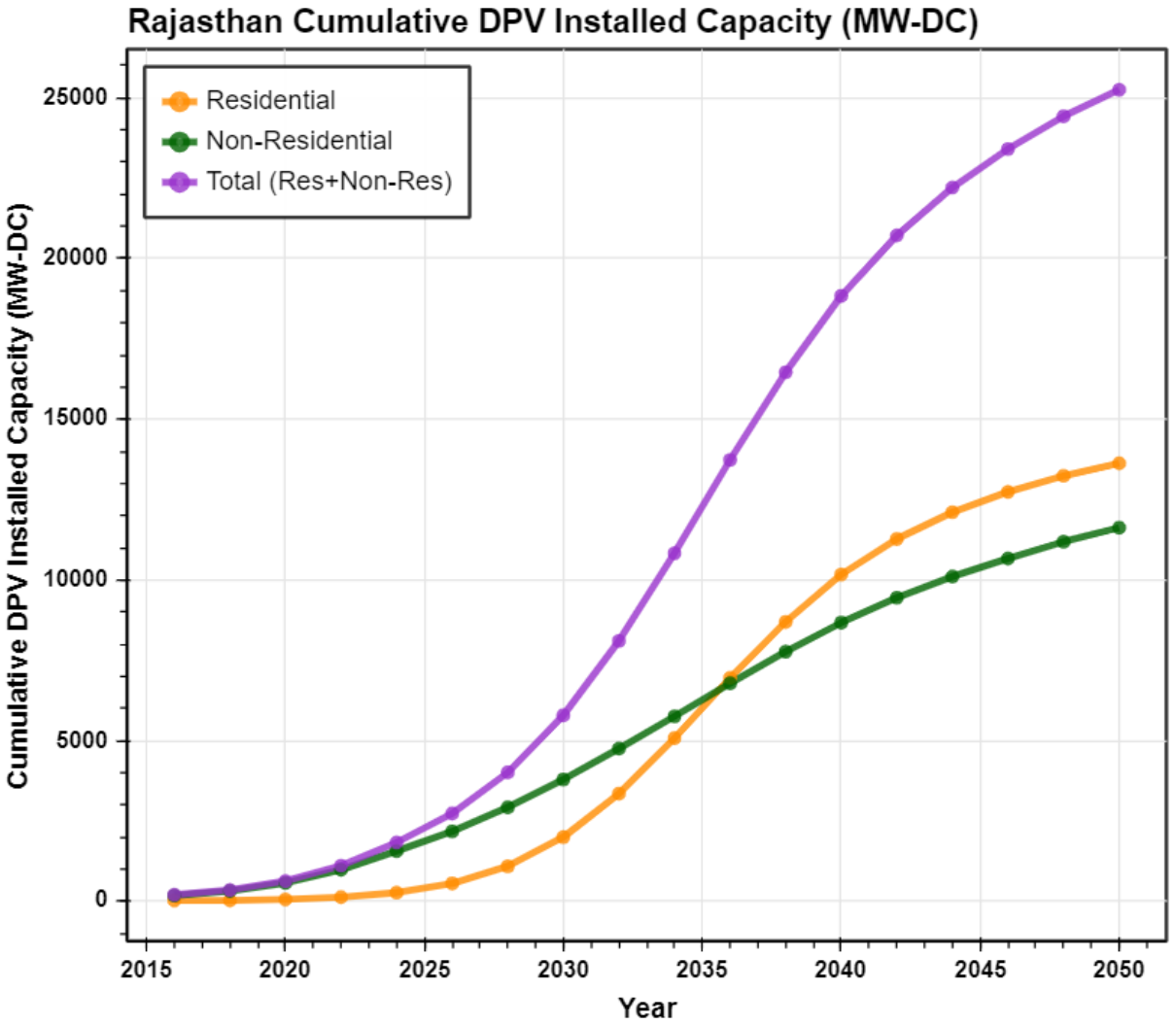
Rajasthan Rooftop PV Adoption Case Study

Geographic Resolution

33 Districts Within Rajasthan

Rooftop PV

- Under the **Midcase scenario** approximately **25 GW** of distributed solar could be adopted by 2050
- **Non-Residential sector** contributes pre-dominantly till the year **2036**
- **Slow rate** of adoption is observed in the **residential sector** but **increases long-term** as PV prices continue to decline.



Conclusion

Conclusion

Majority of the adoption of rooftop solar PV is forecasted to be adopted by non-residential sector. Commercial and Industrial (C&I) consumers continue to be well suited for rooftop PV due to the following reasons:

- Opportunity to offset a large portion of their energy consumption through rooftop PV and thus increase their electricity bill savings
- Both self-consumption and policy incentives such as Net Energy Metering (NEM) if available where excess generation is valued at retail rate is sold back to the grid help offset higher retail tariffs typically paid by C&I consumers
- Public-Private Partnerships (PPP) framework model mentored by both the central government and various state governments have been successful in creating pilot projects on government buildings and developing creative financial schemes through subsidies and tax benefits
- In the Midcase scenario, 161 GW of rooftop solar is projected to be adopted by 2040 in the non-residential sector

Conclusion

Rooftop PV adoption in the residential sector continues to be slow initially but grows rapidly as technology costs continue to decrease and financing options become more readily available.

- Clarity regarding compensation mechanisms such as NEM and an easier interconnection processes from DISCOMs will also ensure rapid growth in the future years
- In the Midcase scenario, 155 GW of rooftop solar is projected to be adopted by 2040 in the residential sector

List of Acronyms

ATB	annual technology baseline
BESCOM	Bangalore Electricity Supply Company
CAPEX	capital expenditures
CEA	Central Electricity Authority
CREST	CSTEP's Rooftop Evaluation for Solar Tool
CSTEP	Center for Study of Science, Technology and Policy
dGen	Distributed Generation (model)
DISCOM	distribution companies
DPV	distributed photovoltaics
EPS	Electric Power Survey
GCR	Ground Coverage Ratio
GW	gigawatt(s)
LiDAR	Light Detection and Ranging
MW	megawatt(s)
O&M	operations and maintenance
PAM	Partial Adjustment Model
RE	renewable energy
ReEDS	Regional Energy Deployment System
TWh	terawatt-hour

Thank you

www.nrel.gov