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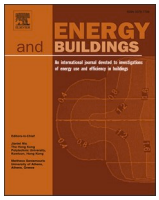

Upscaling residential solar rooftop in Uttar Pradesh: review of policy, practices and stakeholders perspective, identification of challenges and solutions

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ABSTRACT

This research paper examines the barriers and solutions related to the adoption of residential rooftop solar (R-RTS) in Uttar Pradesh. Despite government policy interventions, R-RTS uptake remains limited compared to the state's energy consumption-based potential. The study systematically analyses key adoption issues, stakeholder perspectives, policy landscape and identifies critical issues such as policy gaps, implementation challenges, and stakeholder collaboration deficits through policy review, stakeholder analysis, and adoption drivers. Methodologically, the study employs a mixed qualitative approach, including document analysis, stakeholder consultations, and field insights. The study proposes following actionable solutions:

i) Policy interventions for subsidies beyond 3 kW.
ii) Relaxation on system capacity limits.
iii) Enhanced compensation for excess electricity injected into the grid.
iv) Strategies to improve vendor participation.
v) Addressing DISCOM inefficiencies regarding net meter availability and verification delays.
vi) Speedier subsidy transfers.
vii) Targeted awareness campaigns.

The research highlights the importance of post-installation service ecosystems, advocating for skilled manpower development and product standardization to improve local service access. The intended policy outcome is to create a more enabling environment for residential R-RTS adoption, supporting climate goals and decentralized renewable energy expansion. This paper provides a structured roadmap for policymakers, vendors, consumers, and implementors to scale rooftop solar adoption in Uttar Pradesh.

Abbreviations: R-RTS, Residential Rooftop Solar; RTS, Rooftop Solar; PV, Photo Voltaic; LCOE, Levelized Cost of Electricity; AT&C, Aggregate Technical and Commercial; T&D, Transmission and Distribution; DISCOMS, Distribution Companies; KW, Kilo Watt; MW, Mega Watt; NDC, Nationally Determined Contributions; SDG, Sustainable Development Goals; IRENA, International Renewable Energy Agency; ISA, International Solar Alliance; CEA, Central Electricity Authority; RPO, Renewable Purchase Obligation; CAPEX, Capital Expenditure; MSME, Micro, Small and Medium Enterprises; ALLM, Approved List of Models and Manufacturers; PMSGY, PM Surya Ghar Yojana; kWp, Kilo Watt peak; DCR, Domestic Content Requirement; MNRE, Ministry of New and Renewable Energy; MoP, Ministry of Power; NBFCs, Non-banking Financial Companies; NSM, National Solar Mission; CAGR, Compound Annual Growth Rate; CEEW, Council on Energy Environment and Water; PMSG MBY, PM Surya Ghar Muft Bijli Yojana; SARAL, State Rooftop Solar Attractiveness Index; SSDP, Suryamitra Skill Development Programme; IMPRI, Impact and Policy Research Institute; NPRS, National Portal for Rooftop Solar; HHs, Households; UPNEDA, Uttar Pradesh New and Renewable Development Agency.

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1. Introduction

To avoid the negative effects of climate change, the world is undergoing a major energy transition to achieve net-zero targets, with renewable energy playing a crucial role. Renewables are projected to account for 50 % of the global power mix by 2030 and 85 % by 2050 [1]. Solar energy has become a central pillar of this shift, evident in its rapid capacity growth, employment expansion and rising investments. Over the past two decades, global solar capacity has surged from 1.22 GW (GW) in 2000 to 1418.97 GW in 2023, reflecting an astonishing 40 % annual growth rate. In 2023 alone, 345.83 GW of solar power was added, making up three-quarters of new renewable capacity worldwide. Solar generation has followed a similar trend, increasing from 1.03 TWh in 2000 to 1628.27 TWh in 2023. Declining manufacturing costs and growing supply are expected to make solar energy more affordable, while solar jobs have risen to 7.1 million, with global capacity projected to reach 7203 GW by 2030 [2]. India's energy system is at a critical transition point, as the fossil fuel-dominant energy mix is gradually shifting toward renewables. This shift is evident in both installed capacity and energy generation figures. India's total electricity generation capacity has reached 472.47 GW, with renewables making up a significant share. As of April 2025, India's renewable energy-based power generation capacity reached 223.63 GW, accounting for 47.3 % of the country's total installed capacity. Among renewables, solar power leads with 107.95 GW, contributing 22.85 % to the total capacity [3] (see Figs. 1–3).

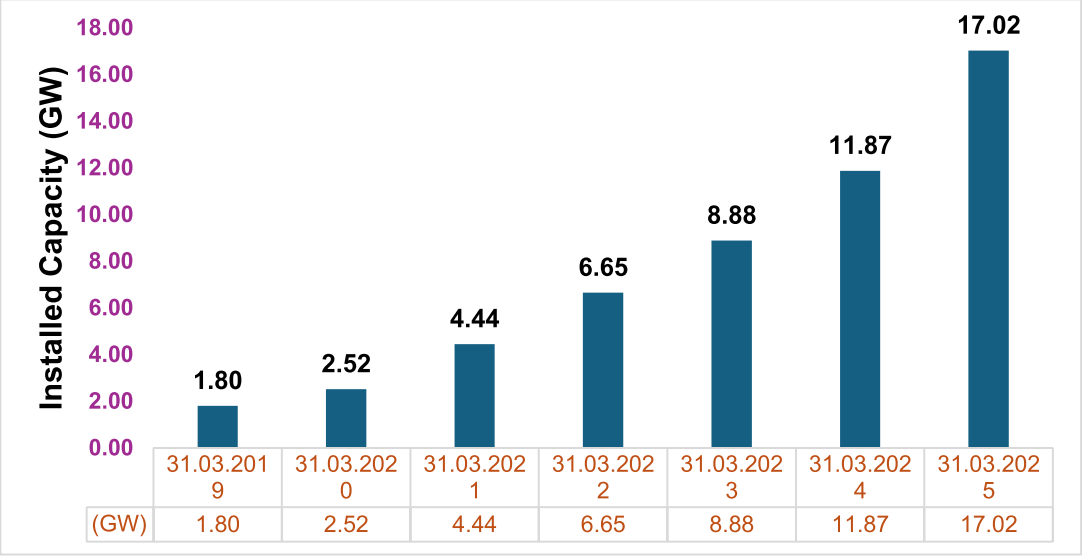
This transition is driven by domestic energy demands, urbanization trends and environmental concerns, as well as global commitments to sustainable development. According to the International Energy Agency (IEA), India's energy demand is expected to double by 2040, while its power demand is projected to quadruple.

By 2050, an estimated 814 million people will live in cities, increasing the strain on the energy sector. Additionally, air pollution remains a pressing issue, impacting public health and hindering sustainable development. Beyond domestic factors, India has pledged to increase renewables to 40 % of its energy mix by 2030, as part of its Nationally Determined Contributions (NDCs). The country also aims to reduce emissions intensity by 33 %–35 % by 2030, aligning with global decarbonization efforts. Commitment to the Sustainable Development Goals (SDGs), particularly Goal 7, highlights India's focus on universal electricity access, clean energy adoption and efficiency improvements to support the ongoing energy transition.

The rooftop solar (RTS) photovoltaic (PV) sector has emerged as a key focus area in India's renewable expansion. RTS is an attractive solution for consumers, vendors, financial institutions and utilities, given its low-cost, efficient and scalable attributes. India aims to deploy 40 GW of RTS by 2027, recognizing its transformational role in sustainable development. Various technological, delivery and financing models have been tested, leading to steady RTS market growth, with installed capacity reaching 17.69 GW as of April 2025 [5–7].

RTS PV systems offer unique advantages over conventional solar installations due to their modularity and adaptability. They can be deployed in stand-alone, grid-connected, or hybrid formats, tailored to consumer needs. One of RTS's biggest strengths is its minimal space requirement, a critical factor in land-scarce India. Land acquisition for large-scale solar projects is often slow and expensive, making RTS a viable alternative. RTS also provides significant cost savings, with lower interconnection expenses. Additionally, India's high aggregate technical and commercial (AT&C) losses make RTS an efficient solution to prevent energy wastage in transmission. AT&C losses currently stand at 15.37 % (FY 2023) [8].

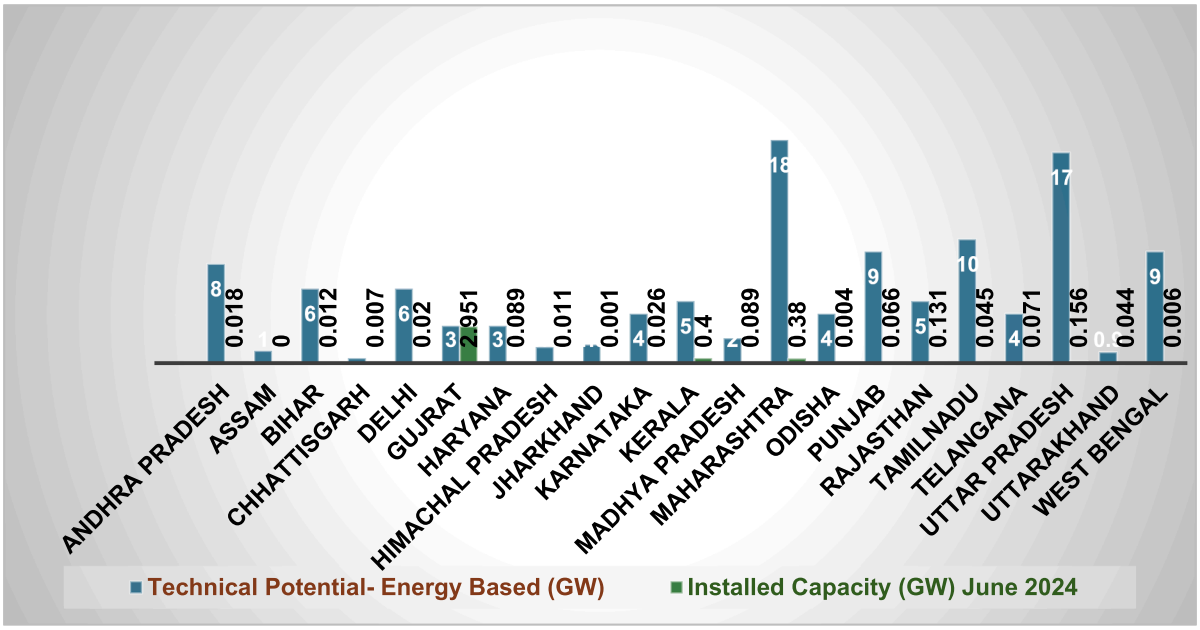
RTS offers strategic benefits for distribution utilities, including meeting Renewable Purchase Obligations (RPOs), reducing grid congestion, managing peak loads, minimizing transmission losses and deferring capital expenditure on infrastructure upgrades. Distribution Companies (DISCOMs) can earn 22 paisa per kWh from RTS-generated electricity due to avoided costs in generation capacity, procurement and transmission. Smart inverter management can further enhance



Source: MNRE, Author's Analysis

This bar graph illustrates the steady increase in installed capacity (GW) of Grid Connected Rooftop Solar from March 31, 2019, to March 31, 2025. The data highlights significant growth, reaching 17.02 GW in 2025.

Fig. 1. Growth in Grid Connected Rooftop Solar Capacity in India (2019–2025). .
Source: MNRE, Author's Analysis. This bar graph illustrates the steady increase in installed capacity (GW) of Grid Connected Rooftop Solar from March 31, 2019, to March 31, 2025. The data highlights significant growth, reaching 17.02 GW in 2025



Source: CEEW 2023; Bridge To India, 2024, Author's analysis

This bar chart provides a comparative view of energy consumption based technical potential (GW) and actual installed R-RTS (GW) across various Indian states as of June 2024. The significant gap between potential and installed capacity highlights key areas for policy intervention and infrastructure investment.

Fig. 2. Comparative Analysis of Energy Consumption based Potential of R-RTS vs. Installed Capacity Across Indian States (2024). Author's analysis. This bar chart provides a comparative view of energy consumption based technical potential (GW) and actual installed R-RTS (GW) across various Indian states as of June 2024. The significant gap between potential and installed capacity highlights key areas for policy intervention and infrastructure investment.
Source: CEEW 2023; 4

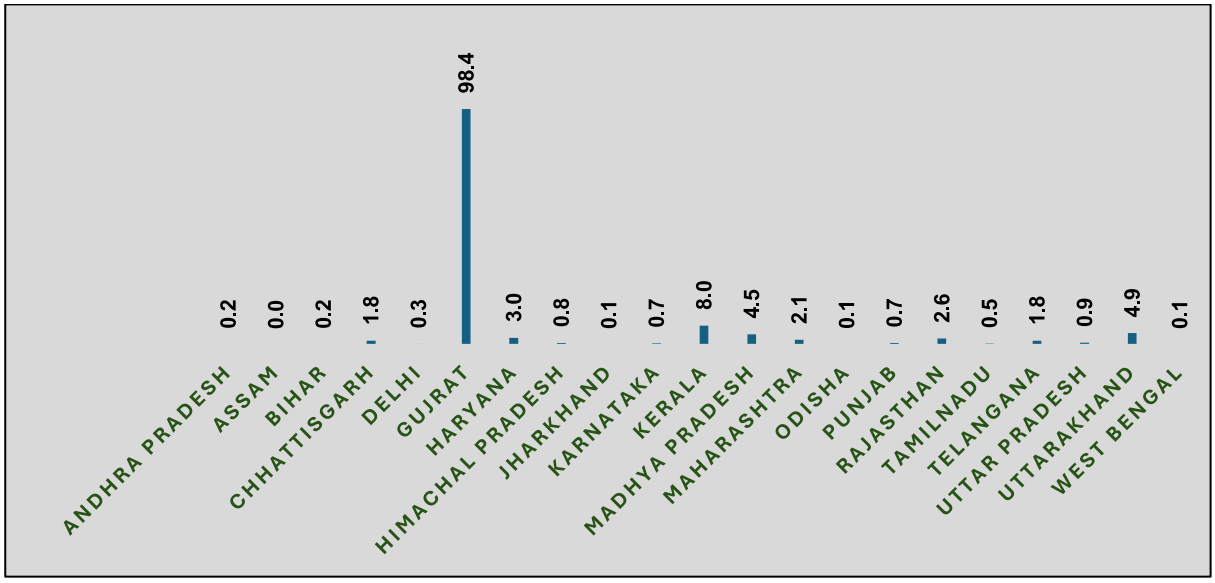
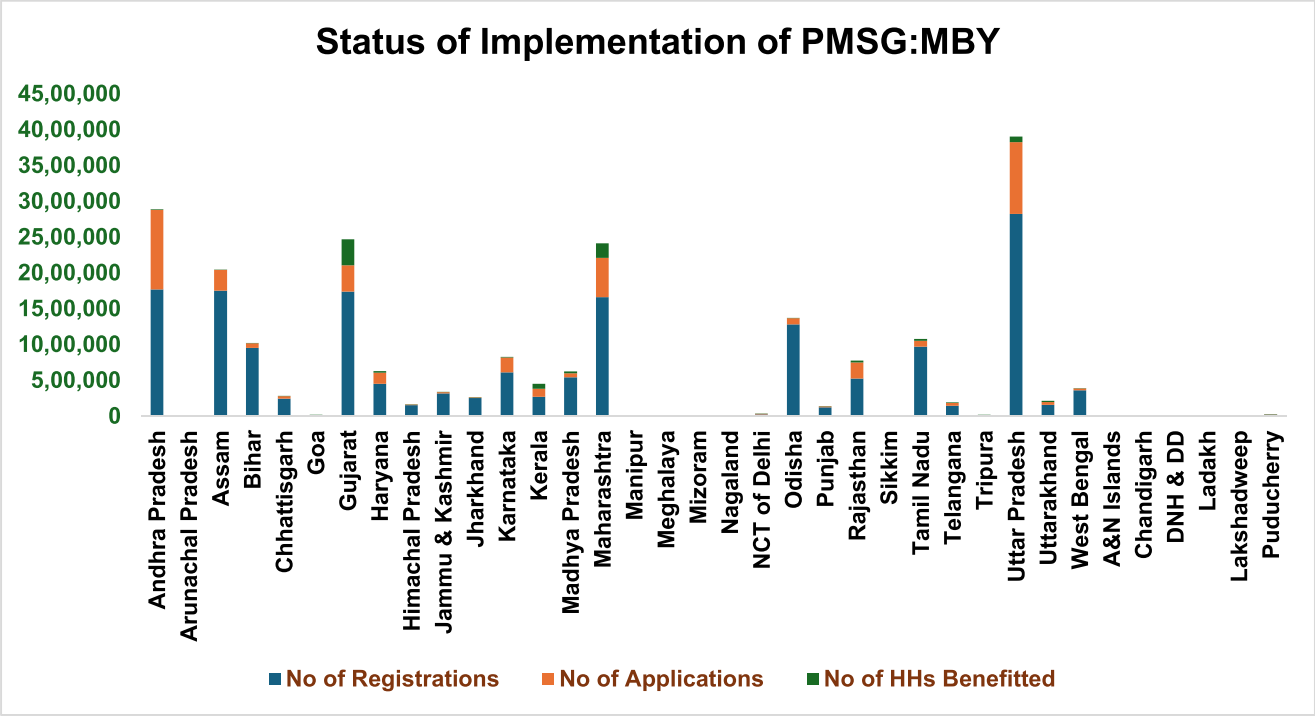


Fig. 3. State-wise % Utilization of Energy Consumption Based Potential for R- RTS. Author's analysis. This bar chart illustrates the distribution of % utilization of energy consumption based potential across various Indian states as of 2025. The significant variation among states highlights regional disparities in solar adoption and potential areas for policy intervention.
Source: CEEW 2023; 4

RTS's integration with the grid, improving supply quality and reliability, which remains a challenge in rural India (see Fig. 4).

RTS also strengthens local economic ecosystems by providing reliable electricity access for micro, small, and medium enterprises (MSMEs). Over 4 million micro-enterprises in rural areas experience intermittent power issues, which RTS can address, driving economic growth through job creation and income generation. In agriculture, RTS supports mechanization, irrigation systems, cold chain storage, and fertilizer applications, benefiting farmers and rural industries [9].

Given this context, this study identifies key policy and implementation barriers to residential rooftop solar adoption in Uttar Pradesh and presents practical solutions based on stakeholder insights and policy



Source : Sansad 2025

This bar chart presents the progress of the PMSG: MBY scheme across various states and union territories in India. It categorizes the total number of registrations, applications submitted, and households benefiting from the scheme. The significant variation highlights regional adoption trends and potential gaps in policy implementation.

Fig. 4. Status of Implementation of PMSG: MBY Across Indian States and Union Territories (2025). Source: Sansad 2025. This bar chart presents the progress of the PMSG: MBY scheme across various states and union territories in India. It categorizes the total number of registrations, applications submitted, and households benefiting from the scheme. The significant variation highlights regional adoption trends and potential gaps in policy implementation.

evaluation. The goal is to inform and guide policymakers and implementers to optimize deployment strategies and accelerate rooftop solar adoption in the residential sector (see Fig. 5).

2. Methodology

This research aims to explore the status, potential and gaps of R-RTS adoption in Uttar Pradesh and to propose a comprehensive and feasible roadmap for promoting the R-RTS by highlighting the appropriate policy and implementation interventions through national policy review and the key drivers along with due consideration of the stakeholder's perspective through vendor and consumer surveys. The research employs a mixed-methods approach, integrating both qualitative and quantitative techniques for a robust understanding of the issue. The literature review includes policy documents, regulatory guidelines, government reports and academic studies related to solar energy and rooftop solar systems in India, with a special focus on Uttar Pradesh. Secondary data on solar adoption trends, installation capacities and subsidy disbursements were collected from official databases such as MNRE, Uttar Pradesh New & Renewable Energy Development Agency (UPNEDA) and CEA. Primary data were collected through structured interviews and questionnaires administered stakeholders survey conducted across the state of Uttar Pradesh by with the help of UPNEDA.

The vendor questionnaire included items on policy awareness, technical and procedural challenges, subsidy processing issues and market behaviour. The consumer survey focused on awareness levels, financial viability, post-installation experiences and barriers to adoption. Semi-structured interviews were also conducted with officials from DISCOMs and local implementing agencies to understand systemic challenges and preparing the questionnaire.

For data analysis, qualitative responses were coded thematically, allowing for identification of recurring patterns and stakeholder-specific challenges. Quantitative data from surveys were analysed using descriptive statistics in MS Excel to determine trends in adoption and perception metrics. Additionally, a comparative state analysis was conducted using SARAL scores to evaluate rooftop solar adoption trends across states. Pearson correlation analysis ($r = 0.69$ for technical potential utilization, $r = 0.66$ for household adoption) validated policy effectiveness, while a Composite Performance Index (CPI) ranked implementation outcomes, highlighting policy-to-performance alignment (see Fig. 6).

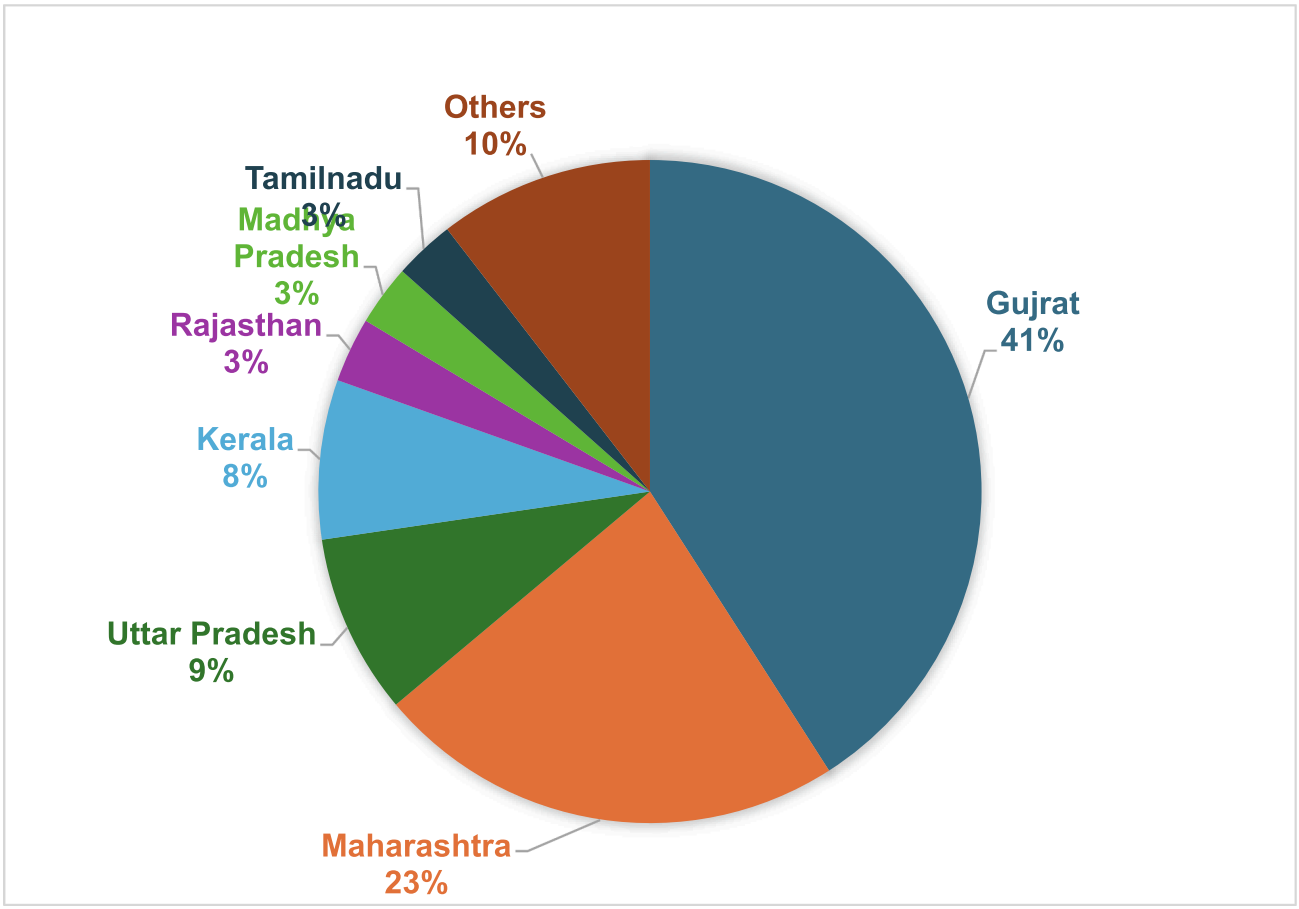
To strengthen the comparative perspective, the study also referred to rooftop solar deployment in high-performing states such as Gujarat and Maharashtra. These comparisons were drawn qualitatively by reviewing government scheme designs and subsidy models and quantitatively by benchmarking parameters such as consumer uptake ratios, subsidy utilization rates and average installation times.

The methodological approach ensures triangulation of data from multiple sources policy documents, field surveys and stakeholder consultations to develop context-specific and actionable policy recommendations for Uttar Pradesh.

3. Results and analysis

3.1. Status of solar roof top adoption in India

As of 31 March 2025, India's total installed capacity of grid-connected rooftop solar plants stood at 17.02 GW. Notably, over 73 %



Source : Sansad 2025

This pie chart illustrates the proportional distribution of -R-RTS installations across key Indian states in 2025 PMSG:MBY. Gujarat leads with 41%, followed by Maharashtra at 23%, and Uttar Pradesh at 9%. The remaining states, including Kerala, Tamil Nadu, Madhya Pradesh, and Rajasthan, collectively contribute to the total installations.

Fig. 5. State-Wise Distribution of R-RTS Installations (2025) under PMSG: MBY Under PMSG: MBY, a registered vendor plays an important role in the entire lifecycle of rooftop solar installations, from system design and component supply to installation, commissioning, and comprehensive maintenance contract for 5 years. The scheme ensures a streamlined process through the National Portal for efficient implementation. The government is dedicated to enhancing the vendor experience by addressing concerns, providing clear guidelines, and simplifying processes. The number of registered vendors per one lakh households serves as a reasonably good indicator of the status of ecosystem for implementation for the scheme. Source: Sansad 2025. *This pie chart illustrates the proportional distribution of R-RTS installations across key Indian states in 2025 PMSG:MBY. Gujarat leads with 41 %, followed by Maharashtra at 23 %, and Uttar Pradesh at 9 %. The remaining states, including Kerala, Tamil Nadu, Madhya Pradesh, and Rajasthan, collectively contribute to the total installations.*

(approximately 12.58 GW) was installed between April 2021 and March 2025. Until the fiscal year (FY) 2019, rooftop solar capacity remained modest at 1.8 GW. However, annual additions since then have ranged from 0.72 GW to 5.15 GW, culminating in 17.02 GW by FY 2025. The FY 2024–25 period witnessed a record-high addition of 5.15 GW, driven by falling solar module prices, a temporary postponement of Approved List of Models and Manufacturers (ALMM) enforcement until March 2024, and increased domestic module manufacturing capacity (see Fig. 7).

India's rooftop solar market comprises three segments: residential, commercial and industrial (C&I), and government. Adoption in the residential sector has remained comparatively low. By March 2024, the residential rooftop solar segment had reached 3.2 GW, with Gujarat accounting for approximately 75 % of this capacity [10].

3.2. R-RTS potential installations in India

India has almost 300 million households and enjoys abundant sunshine practically year-round, with an annual average of 300 bright days. This demonstrates the vast potential for rooftop solar installations in residential sector in India. However, India's cumulative R-RTS market is still far from reaching its full potential. While residential Solar Photovoltaic (PV) use remains limited in India, countries such as Australia have achieved household adoption rates exceeding 30 % [8]. The National Solar Mission (NSM), formerly known as the Jawaharlal Nehru National Solar Mission, was launched in January 2010 as part of India's dedicated efforts to adopt solar power. The NSM is a broad project to develop solar power in India. Under this aim, the central government gave subsidies to install R-RTS. Along with this plan, some governments offered their own R-RTS subsidies, in addition to the national subsidies [11].

In February 2019, the central government set a clear target of installing 4 GW of R-RTS capacity by 2022. However, even the provision of government subsidies was insufficient to spur the expansion of this segment. Thus, rooftop solar penetration in the residential segment has

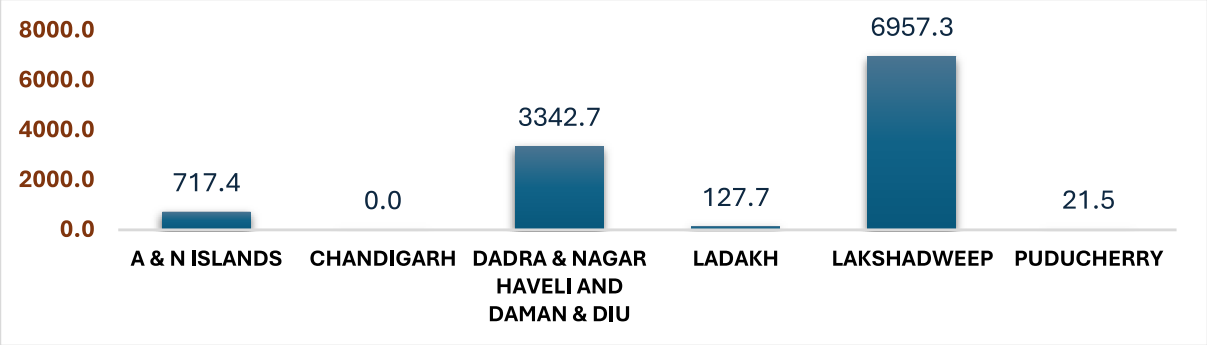


Fig. 6. UT-wise Number of Registered Vendors per One lakh HHs in NPRS. .
Source: NPRS & NSS Report No 589. * Vendor information in NPRS is available DICOM wise. A vendor registered in different DISCOMS are counted as different *This bar chart illustrates the number of registered vendors in NPRS per one lakh households across various Union Territories in India, including A & N Islands, Chandigarh, Dadra & Nagar Haveli and Daman & Diu, Ladakh, Lakshadweep, and Puducherry. The wide variance in vendor availability from 0.0 in Chandigarh to 6957. in Lakshadweep highlights regional disparities in the ecosystem readiness for R-RTS adoption*

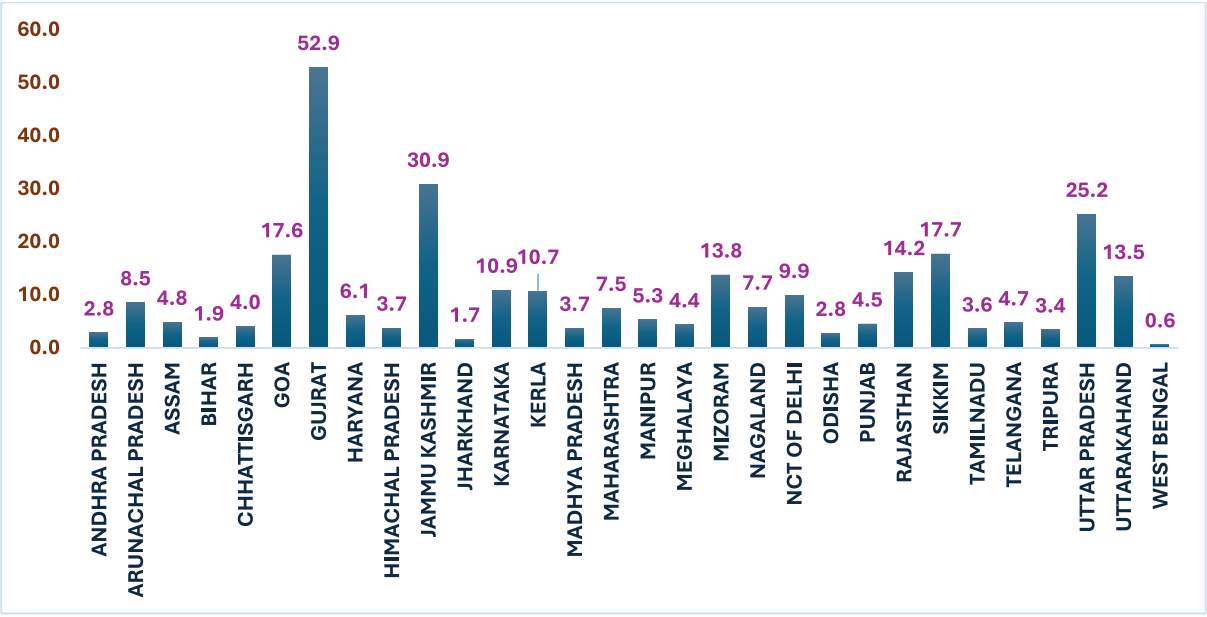


Fig. 7. State-wise Number of Registered Vendors per One Lakh Households (HHs) in NPRS. .
Source: NPRS & NSS Report No 589, Author's analysis. * Vendor information in NPRS is available DICOM wise. A vendor registered in different DISCOMS are counted as different. *This bar graph illustrates the number of registered vendors in NPRS per one lakh households across Indian states. Gujarat leads significantly (52.), followed by Jammu & Kashmir (30.9) and Uttar Pradesh (25.2). The performance reflects varying levels of vendor availability PMSG: MBY*

been poor across states with exception of Gujarat. One of the greatest barriers to acceptance was a lack of consumer knowledge, particularly prior to the COVID-19 pandemic. Following COVID-19, there has been a significant increase in demand, fuelled by heightened awareness of cost savings, the environment, and so on.

Despite the slow pace of solar adoption in India's residential sector, the country has remained the world's most affordable residential solar power market for nearly a decade. In 2020, the average cost of a R-RTS system in India was US$ 658 per kilowatt (kW) a 73 % decline from 2013 levels. By comparison, R-RTS costs in leading residential markets, including Japan, the United Kingdom, Switzerland, and the United States, were 3.3 to 6.4 times higher than in India. As of FY 2022, India's rooftop solar market had a total installed capacity of 11,770 megawatt (MW). The residential segment accounts for only 17 % (2010 MW), with the commercial and industrial (C&I) segment accounting for 66 % (7715 MW). From FY 2019 to FY2022, the residential segment experienced a 90 % compound annual growth rate (CAGR). The rooftop solar boom in Gujarat, particularly during the last three fiscal years, has contributed significantly to this upward trend in cumulative installations. As of FY 2022, Gujarat has 61 % (1227 MW) of India's total residential segment capacity [12].

In February 2024, the Government of India (GoI) announced a revision of the subsidy scheme for residential users who choose rooftop solar systems under the Pradhan Mantri Surya Ghar Yojana (PMSGY). The project intends to create an enabling ecosystem for the R-RTS industry and install 30 GW of solar systems in 1 crore (10 million) households in India by March 2027. To do this, PMSGY boosted central financial aid (CFA) for systems with capacities less than 3 kW peak (kWp), established strict procedural timetables, and integrated with the National Portal for Rooftop Solar (NPRS) to give residential users with a digitised user experience (see Table 1).

As of 10th May 2025, the scheme has garnered around 47.3 lakh (4.73 million) applications, leading to a total of 10.09 lakh (about 1.10 million) installations. This translates to about 3 GW of new R-RTS capacity, or more than half of India's total, in just less than a year [13].

The Government of India (GoI) has placed significant emphasis on

Table 1
SARAL Score-Based Ranking of Indian States on Rooftop Solar Policy and Implementation (2018–19).

Ranking	States	SARAL Score	Robustness of policy framework	Effectiveness of policy work/ implementation	Investment climate	Consumer Experience	Business ecosystem
1	Karnataka	78.76	99.54	76.77	80.79	67.02	70.5
2	Telangana	72.21	61.48	68.08	81.79	80.59	66.63
3	Gujarat	67.87	31.25	81.11	83.28	75.25	61.06
4	Andhra Pradesh	66.1	79.17	66.84	72.08	54.5	58.95
5	Rajasthan	62.25	66.67	64.29	80.76	51.53	46.03
6	Madhya Pradesh	58.27	12.5	63.1	77.98	78	52.1
7	Delhi	54.61	31.25	68.61	60.52	56.86	48.76
8	Punjab	53.42	45.83	48.08	78.51	55.75	35.25
9	Maharashtra	52.01	31.25	50.57	74.93	52.07	58.09
10	Tamil Nadu	50.87	40.97	46.82	65.98	51.72	53.43
11	Chandigarh	48.33	4.17	53.4	56.37	71.68	48.09
12	Haryana	43.35	14.58	50.55	72.28	30.34	66.01
13	Kerala	42.92	27.08	46.81	42.87	50.49	44.35
14	Odisha	39.44	25	46.23	40.99	45.94	31.15
15	Jharkhand	37.68	40.28	38.72	38.24	27.26	55.27
16	Chhattisgarh	36.52	10.42	39.35	44.24	43.07	50.17
17	Goa	31.83	45.83	31.22	20.18	23.85	45.38
18	Uttarakhand	31.58	30.56	33.5	52.92	14	38.54
19	Assam	29	62.5	13.04	11.8	25.9	40.61
20	Uttar Pradesh	26.54	40.28	26.83	23.18	12.79	39.51
21	Sikkim	22.8	25	13.75	11.8	34.04	30.72
22	Arunachal Pradesh	21.58	33.33	11.15	11.8	24.82	32.94
23	Himachal Pradesh	20.75	29.17	15.6	0	25.6	38.69
24	Nagaland	20.46	25	13.73	11.8	27.75	24.29
25	Bihar	20.32	34.72	11.24	31.19	5.1	36.41
26	Mizoram	20.28	20.83	16.24	11.8	31.99	13.64
27	West Bengal	19.39	20.83	13.1	14.72	17.35	44.88
28	Manipur	19.31	25	6.16	11.8	33.39	18.23
29	Tripura	17.66	27.08	3.64	11.8	24.33	27.52
30	Meghalaya	17.59	25	3.75	11.8	28.21	20.93
31	Jammu & Kashmir	14.38	20.83	13.73	4.1	10.82	29.07

Source: SARAL, MNRE 2019.
This table ranks Indian states based on their SARAL Score, which evaluates the robustness of policy frameworks, effectiveness of implementation, investment climate, consumer experience, and business ecosystem for rooftop solar adoption. Karnataka leads with the highest score of 78.76, reflecting strong policy support, investor confidence, and favourable consumer experience, while Jammu & Kashmir ranks lowest at 14.38, indicating challenges in implementation and investment climate.

financing alternatives and terms for R-RTS, leading to a sharp rise in the number of financiers from just a handful a few years ago to around 25 by 2025 [14]. These include major private and public sector banks, non-banking financial corporations (NBFCs), and fintech firms. Many financiers are forging industry-wide partnerships with project-executing entities and equipment suppliers, offering customers a one-stop solution for rooftop solar installation.

For financiers, these partnerships ensure supply chain reliability, improved cost dynamics, and greater market reach by leveraging the strengths of multiple stakeholders. As the rooftop solar market matures technologically, market commoditization has expanded significantly, prompting some firms to introduce tailored home kits for fast and efficient project installation (see Fig. 8).

The growth of India's decentralized energy market, where rooftop solar plays a pivotal role, is crucial to achieving energy independence and security. Under Pradhan Mantri Surya Ghar Yojana (PMSGY), the government has set an annual installation target of 8–10 GW, contributing significantly to India's broader renewable energy goal of 500 GW by 2030.

Despite these advancements, several challenges remain. A key issue is the limited availability of domestic content requirement (DCR) modules for the residential sector, exacerbated by India's shortfall in PV cell and module manufacturing capacity. Additionally, concerns persist regarding the scheme's adoption by small and medium-sized electrical consumers, as cost economics and loan availability continue to favour wealthier, creditworthy residential consumers (see Fig. 9).

In regions like Assam, a significant gap between project applications and vendor availability threatens short-term installation growth. Addressing these barriers will be critical to ensuring the success of PMSGY and sustaining India's rooftop solar expansion.

India's R-RTS potential is estimated at 637 GW, according to Council on Energy, Environment and Water (CEEW's) India Residential Energy Survey (IRES) 2020. Considering factors like rooftop availability and household energy usage, the energy consumption-based potential or the capacity of solar PV systems feasible for installation is 118 GW.

As of June 2024, India's installed R-RTS capacity stands at 4.605 GW [4]. Nationwide, the utilization of energy consumption based technical capacity averages 3.8 %, with Gujarat nearing full utilization at 98.4 %. Other states exceeding the national average include Kerala (8 %), Uttarakhand (4.9 %), and Madhya Pradesh (4.5 %).

3.3. *State initiatives for adoption of R-RTS*

a) **State-level Rooftop Solar Subsidies (Applicable Over and Above the MNRE Subsidy):** The Ministry of New and Renewable Energy's (MNRE's) rooftop solar plan has made it easier for several governments to adopt household subsidy packages. Some even provide their own subsidy packages (i.e., subsidies supported by state budgets), which are in addition to the central subsidy program.
b) **Net Metering**: In addition to government initiatives like financial aid and the creation of the single-window portal, a solid regulatory environment is vital to the R-RTS market's success. Compared to the C&I category, state electrical regulators and DISCOMs have a more positive outlook on the R-RTS segment. Net metering provisions are available to residential consumers in almost every state. Under net metering, the reimbursement for excess energy injection at the end of

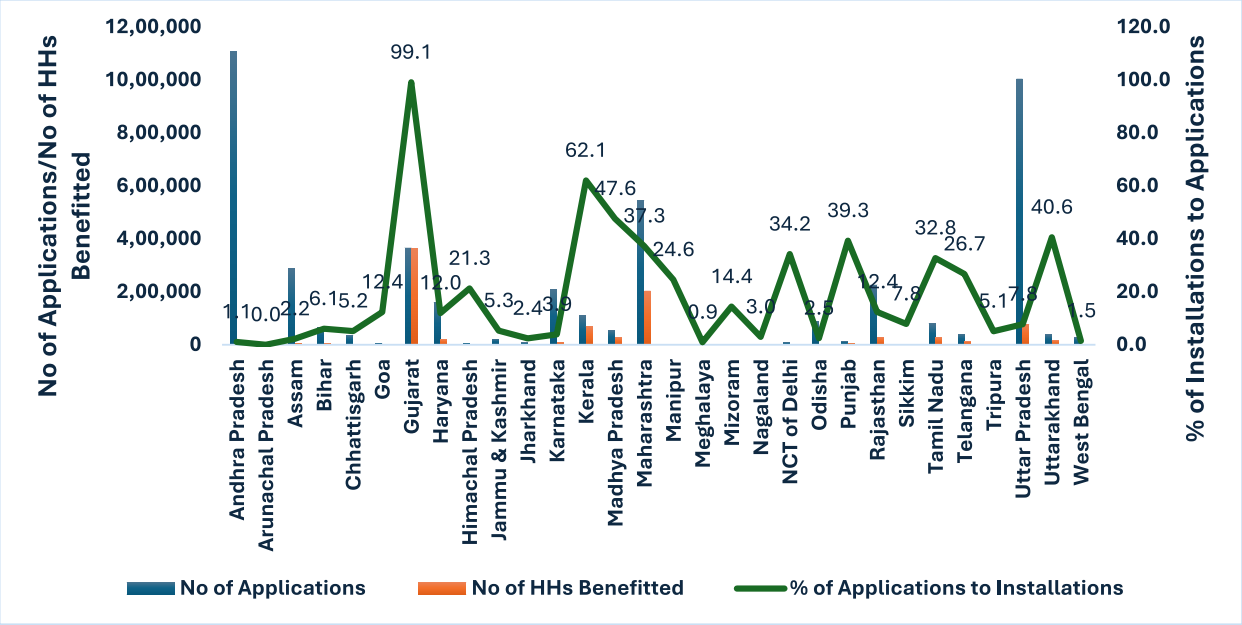


Fig. 8. State-wise Rooftop Solar Applications, Beneficiary HHs and Conversion Efficiency (as of June 2024). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Source: MNRE 2024; NPRS 2025; Author's Analysis. *This multi-axis graph compares the number of solar-RTS applications received (blue bars), the number of households benefitted (orange bars), and the percentage of successful installations (% of applications resulting in installations – green line) under the -PMSG:MBY across Indian states. Gujarat stands out with a high conversion rate (99.1%), followed by Madhya Pradesh (62.1%) and Maharashtra (47.6%), indicating better execution of rooftop solar programs. States like Bihar, Jharkhand, and Tripura exhibit very low conversion rates, reflecting implementation bottlenecks*

the settlement period makes rooftop solar an appealing offer for the end user. This is especially true for residential consumers, as their demand patterns are very varied and unpredictable. Because of the mismatch between peak solar hours and peak load demand hours in the residential segment, residential consumers may inject a significant amount of surplus energy into the grid. In most jurisdictions, the surplus energy injection tariff ranges between Rs2/kWh (US$ 0.024/kWh) and Rs 4.5/kWh (US$ 0.055/kWh). This is much cheaper than the current household OPEX tariff rates of Rs 5.5 (US$ 0.067/kWh) to Rs 6 (US$ 0.073/kWh). Notably, several major states, including Tamil Nadu, Punjab, West Bengal, and Haryana, do not offer compensation for excess energy input [12].

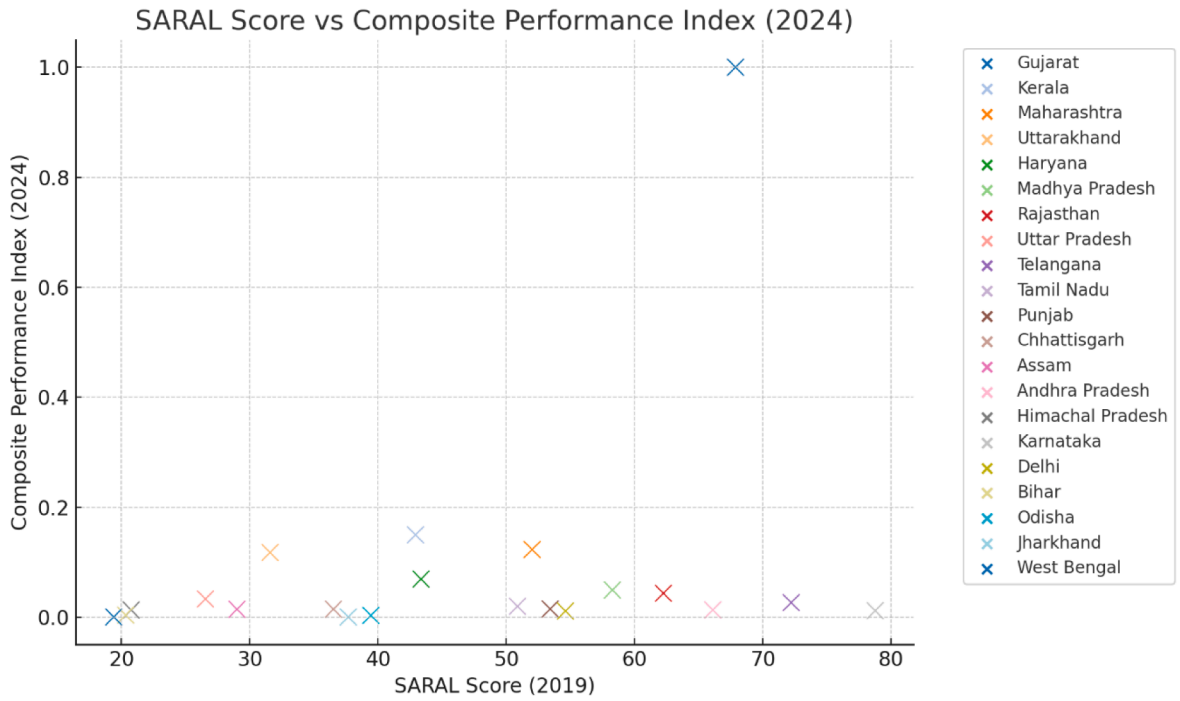
c) **Payback on Rooftop Solar Systems Versus Residential Grid Tariffs**: Payback on the investment for R-RTS systems varies across states with respect to the respective grid tariff rates. The payback period also depends on other factors, such as solar irradiance and generation. In the states of Maharashtra, Karnataka, West Bengal, Madhya Pradesh, Tamil Nadu, Haryana, Uttar Pradesh, Chhattisgarh, Gujarat, and Delhi, the grid rates (excluding fixed costs) for residential customers range from Rs 4.5/kWh (US$ 0.055/kWh) in Delhi to Rs 8.7/kWh (US$ 0.11/kWh) in Maharashtra.

For a 1 kW non-subsidised, R-RTS plant, the payback period varies from 3.2 years (Maharashtra) to 7.1 years (Delhi). In addition, the payback periods decrease substantially if the central and state-level subsidies are considered. For example, for a 1 kW R-RTS plant linked with the new CFA, the payback period would vary from 2.3 years (Maharashtra) to 5.1 years (Delhi) [12] (see Fig. 10).

4. Challenges in rooftop solar adoption in India

Despite the recognised inherent benefits of RTS systems and the GoI push to disseminate these interventions, progress remains insufficient. While the goal is to produce 40 GW of RTS PV by 2022, progress has been slow, with only 12 % (4.4 GW) achieved by 2019. Out of the total RTS deployed in the country, the residential sector has performed the worst, accounting for 16 %, compared to other competitive sectors such as industrial and commercial [9]. Persistent policy discrepancies, procedural complexities, and inefficient and fragmented implementation of net metering policies at the subnational level were major roadblocks to R-RTS adoption. Apart from legislative and technological obstacles, socio-cultural and informational constraints such as users' lack of knowledge of the benefits of RTS pose a significant hurdle, which is exacerbated by the high initial capital cost. Studies on low penetration of R-RTS highlight the necessity for bottom-up initiatives based on intense consumer interaction and a flexible policy and regulatory system. There should be a clear understanding of how existing intervention types perform in different policy, regulatory, and governance situations. Despite its potential, barriers like as low consumer awareness, finance gaps, and regulatory difficulties continue to prevent widespread deployment of RTS systems. Addressing these hurdles is important to meeting India's high solar ambitions [15]. High retail electricity rates, low solar power costs, appealing and effective government subsidies, and other factors are significant drivers for increased R-RTS penetration in advanced countries [12]. Despite existing national and state-level rooftop solar promotion programs, such as the National Rooftop Scheme and state government subsidies, participation rates have been low. One of the most significant obstacles is the complex and time-consuming installation process, which is exacerbated by bureaucratic delays and a lack of understanding among potential recipients. Furthermore, the lack of simplified financing options, as well as restricted production capacity for solar cells and modules, present further hurdles. Inefficient load extension methods and the necessity for feasibility studies impede progress, contributing to a delayed growth trajectory for R-RTS installations [16].

a) **Policy and Regulatory Challenges**: A major challenge that added to the hesitation of installers and consumers in setting up rooftop solar systems was the uncertainty and inconsistency of rooftop solar- related policies and regulations.



Source: MNRE (2024), SARAL Report (2019), Author's Analysis

This scatter plot compares the SARAL Score (2019), which evaluates the policy and regulatory environment for rooftop solar adoption, with the Composite Performance Index (2024), which measures actual implementation progress under PM Surya Ghar: Muft Bijli Yojana (PMSG: MBY). Each point represents a state, with Gujarat emerging as the top performer both in policy readiness (SARAL Score ~65) and implementation (Index Score = 1.0). Most other states cluster at lower performance levels despite varying SARAL scores, indicating a gap between policy intent and on-ground outcomes.

Fig. 9. SARAL Score vs Composite Performance Index (2024). .

Source: MNRE (2024), SARAL Report (2019), Author's Analysis. *This scatter plot compares the SARAL Score (2019), which evaluates the policy and regulatory environment for rooftop solar adoption, with the Composite Performance Index (2024), which measures actual implementation progress under PM Surya Ghar: Muft Bijli Yojana (PMSG: MBY). Each point represents a state, with Gujarat emerging as the top performer both in policy readiness (SARAL Score ~65) and implementation (Index Score = 1.0). Most other states cluster at lower performance levels despite varying SARAL scores, indicating a gap between policy intent and on-ground outcomes*

i. Net Metering Policies: In some states, the delay in approving net metering connections by DISCOMs is a significant hurdle. This occasionally causes residential customers to reconsider their decision to purchase a rooftop solar system [12]. The termination of net metering schemes, for example, has had an influence on the prospective adoption of R-RTS PV systems in specific regions, emphasising the necessity of supportive policies in boosting uptake. In contrast, programs such as NEM 2.0 in Malaysia have played an important role in encouraging consumers to install solar PV on their rooftops by allowing surplus generated energy to be exported to the grid on favourable terms (Mathew et al., 2024).

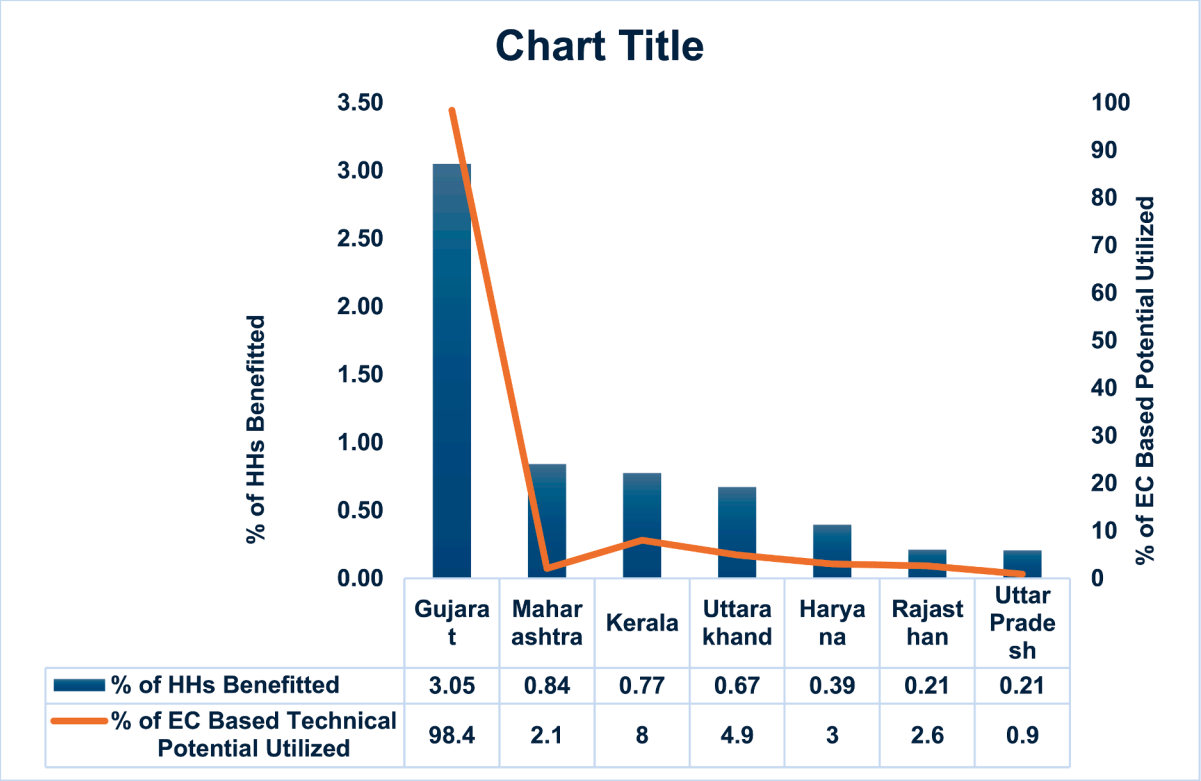
ii. Feed-in Tariffs: Feed-in tariffs (FiT) and feed-in premiums (FiP) programmes have helped to accelerate the growth of RTS by boosting the economic feasibility of systems in the early stages of the sector. Countries such as the United States, Italy, China, and Japan have effectively adopted these schemes in a phased manner, gradually lowering the FiT rate while maintaining strong market demand in the distributed PV segment. In contrast, Vietnam's FiT scheme failed because to a lack of a long-term regulatory framework, inadequate energy infrastructure, and restricted grid capacity, resulting in the plan's eventual demise despite its initial momentum [17].

iii. **High Upfront Cost**: The barriers to rooftop solar PV system adoption are diverse and include a variety of obstacles that prevent widespread implementation of this renewable energy technology. One notable hurdle found in the research is the high upfront expenses associated with acquiring solar systems outright, which disproportionately affect

iv. low- and moderate-income households. This price hurdle is worsened by the fact that installation expenses account for around 60 % of system expenditures, making them a considerable deterrent to potential adopters.

b) **Subsidies**: So far, household installations under the central government's rooftop solar initiative have been mediocre. The installers got a subsidy through the centre's Grid-Connected Rooftop Solar and Small Solar Power Plants Programme (Phase 2). However, DISCOMs frequently delay subsidy payments to installers, interrupting their working cash flow. However, the new simplified subsidy plan (launched by the government in July 2022) has the potential to greatly accelerate the expansion of installed capacity in the residential sector. Furthermore, the Direct Benefit Transfer (DBT) system will help to smooth the subsidy disbursement process by removing the DISCOM from the subsidy equation [12].

i. Benchmark Cost: Every year, many states fix the benchmark system costs, which are far lower than the real cost of a rooftop solar system. The poor viability of installation due to sub-optimal state-assigned pricing became a key impediment for many high-



Source: NPRS; CEEW 2023; Bridge To India 2024, Author's own analysis

This dual-axis chart illustrates the percentage of households benefitted (blue bars) and the percentage of EC-based technical rooftop solar potential utilized (orange line) across selected Indian states. Gujarat leads significantly, with 3.05% of households benefitted and 98.4% utilization of its estimated rooftop solar potential. Other states like Maharashtra, Kerala, and Uttarakhand show moderate household coverage but very low utilization of potential, indicating underperformance in exploiting available rooftop solar capacity.

Fig. 10. Comparative Performance of Indian States under PMSG: MBY9. Author's own analysis. This dual-axis chart illustrates the percentage of households benefitted (blue bars) and the percentage of EC-based technical rooftop solar potential utilized (orange line) across selected Indian states. Gujarat leads significantly, with 3.05% of households benefitted and 98.4% utilization of its estimated rooftop solar potential. Other states like Maharashtra, Kerala, and Uttarakhand show moderate household coverage but very low utilization of potential, indicating underperformance in exploiting available rooftop solar capacity.
Source: NPRS; CEEW 2023; 4

quality developers or installers. This has been observed in all states except Gujarat and Kerala [12].

ii. Mandating Domestic Content Requirement (DCR) Modules: The mandate to use domestically manufactured, or DCR, modules in subsidy-based R-RTS projects has been a deterrent. First, DCR modules are more expensive than imported modules. Second, DCR modules typically have low wattage performance, and energy generation per unit of these modules is underwhelming [12]. As per the current market rates the DCR Modules (Mono-crystalline Passivated Emitter and Rear Cell-Mono PERC) are priced at Rs. 22–23/Wp approx. while non-DCR modules are priced at Rs. 16–17/ Watt peak (Wp) creating the gap of around Rs. 6/Wp which is around 30 % of the price. DCR Modules are priced around 30 % higher than the non-DCR modules which depletes the effective benefit for the projects under the subsidy scheme. The cost of DCR modules is as high as Rs. 29/Wp and minimum up to Rs. 25.5/Wp as on March 2025 [18,19].

iii. High System Cost: Prices for solar equipment skyrocketed during the global commodity supply bottleneck that began in early 2020, primarily due to market disruption brought on by COVID-19. Further driving up the price of solar systems was an increase in the goods and services tax (GST) and customs duties on such equipment. Because imported cells and modules are subject to basic customs tax (BCD), the cost of R-RTS systems increased by 10–15 % per kW. Currently, an R-RTS system costs between Rs 45,000 (US$ 550.69) and Rs 65,000 (US$ 795.45). The cost of the system varies mostly depending on the type of solar module. A rooftop system in subsidy-linked systems using DCR modules costs between Rs 45,000/kW (US$ 550.69/kW) and Rs 50,000/kW (US$ 611.88/kW). The cost of subsidy-free systems using high-quality non-DCR modules ranges from Rs 50,000/kW (US$ 611.88/kW) to Rs 65,000/kW (US$ 795.45/kW) [12].

c) **Financing Challenges**: High product-side risks force third-party financiers to avoid lending in the R-RTS category. RTS solutions are considered 'high-risk' since the installer is responsible for the quality of RTS goods as well as the delivery of linked services. Furthermore, the lack of loan standardisation for R-RTS solutions is a significant impediment to residential market expansion. Banks and other financial institutions (FIs) are often unwilling to fund R-RTS projects because to their small size. There are very few occurrences of third-party financing for this industry, therefore financiers have limited access to relevant data. Financiers are also often hesitant to lend to this market due to the low resale value of rooftop solar systems [12].

The availability of numerous financing options at favourable terms is

a vital facilitator for unlocking the growth of any asset-heavy market sector. However, Indian funders are often hesitant to engage in R-RTS, citing small project sizes and a lack of comprehensive knowledge of the associated dangers.

With the Government of India's attention on R-RTS and the start of the ambitious PMSGY plan in February 2024, market stakeholders like as regulators, investors, financiers, developers, and consumers have significantly expanded their interest on this market segment. According to the NPRS, the number of financiers increased from a handful in 2021 to 25 by August 2024.

All major public and private sector banks, including State Bank of India (SBI), Punjab National Bank, Canara Bank, Bank of Baroda, HDFC Bank, and IDBI Bank, offer R-RTS loans. Most banks classify these loan products as either standalone (for solar installations) or composite (solar integrated with consumers' home loans for new construction). Most schemes provide an attractive loan rate of only 7 % to encourage small-scale consumers to acquire sub-3kWp systems. Almost all commercial bank lending schemes require consumers to invest between 10 and 20 % of the project cost. Furthermore, hypothecation of assets is the normal payment security strategy, in which the solar project being built serves as collateral against the loan amount.

The R-RTS finance industry has witnessed the entry of fintech firms and NBFCs, offering digitalized, fast, and streamlined loan application processes. Residential clients often prefer these financiers due to their collateral-free loans, designed to ensure that monthly savings from solar energy offset Equated Monthly Instalment (EMI).

However, these loans come with shorter durations and slightly higher interest rates compared to commercial bank loans. Financing plans typically cap loan terms at seven years, with NBFCs and fintech firms generally limiting loan terms to five years, aligning with the five-year project Annual Maintenance Contract (AMC) offered by Engineering, Procurement, and Construction (EPC) firms.

Industry stakeholders emphasize that to ensure healthy project cash flow and broader customer adoption, a minimum loan duration of ten years is essential [10].

d) **DISCOMs Related Issues**: Regarding the rules governing residential solar, all DISCOMs are required to approve net metering for customers in a very short time. DISCOMs should be limited to two tasks when it comes to R-RTS systems: checking solar plants and closing the net meters [12]. To cut down on installation time and speed up project completion, DISCOMS should simplify the process of supplying solar and net meters [16].
e) Lack of Awareness:

Homeowners' lack of awareness regarding the benefits and feasibility of rooftop solar photovoltaic (RTPV) systems is a major barrier to adoption, compounded by budgetary constraints. This ignorance further fuels hesitancy among potential adopters, discouraging investment in solar technology. Additionally, households considering RTPV installation face administrative complexity and ambiguous solar PV regulations, which create further obstacles.

Consumer perception and behaviour play a crucial role in adoption. Studies highlight key concerns, including high upfront costs, long-term returns on investment, and limited access to reliable information, as significant deterrents. One of the most pressing adoption challenges is information asymmetry, where consumers lack access to accurate details about RTPV benefits. A survey across five Indian cities found that nearly 50 % of respondents were unaware of residential rooftop solar (R-RTS) technology making low awareness a critical hurdle to adoption (see Table 2).

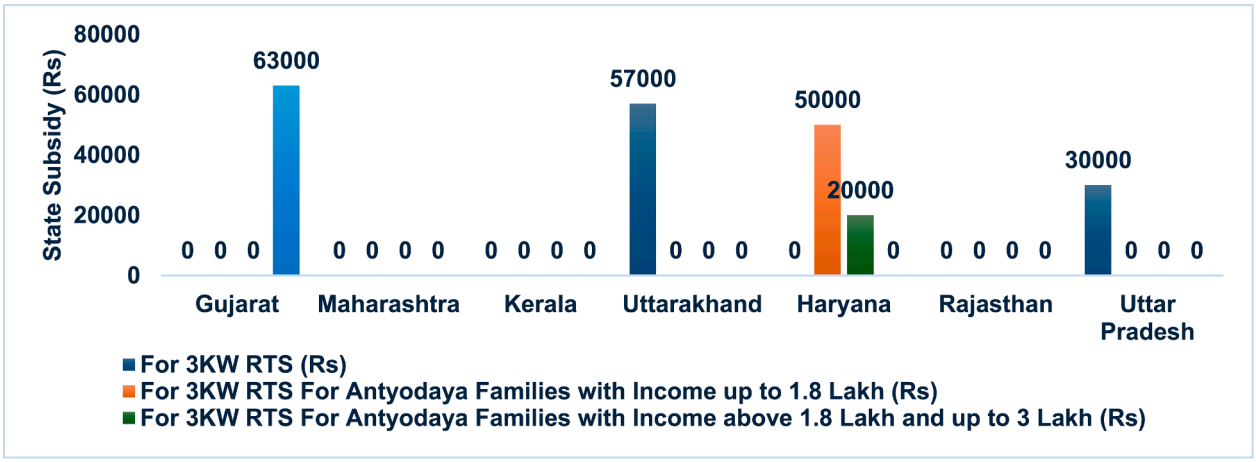
Beyond general information gaps, there is also poor understanding of specific components, procedures, and approval systems involved in RTPV projects. With limited reliable and impartial sources, customers often depend on vendors for guidance. To enhance R-RTS adoption and increase access to government incentives, spreading awareness of its advantages is essential [9] (see Figs. 11–13).

Additionally, institutional challenges such as the absence of robust government financing mechanisms and limited participation from energy firms further complicate adoption. These factors contribute to the difficulties faced by individuals seeking to install rooftop solar panels.

Table 2
Progressive performance of the Selected States Against SARAL Ranking 2019.

States	SARAL score	Mutual SARAL Ranking of the Selected States	% of Energy Consumption Based technical Potential Utilized	EC Based Technical Potential Utilization Ranking	% of HHs Benefitted	% of HHs Benefitted Ranking
Andhra Pradesh	66.1	4	0.23	16	0.09	12
Assam	29	17	0.00	21	0.11	11
Bihar	20.32	20	0.20	17	0.02	19
Chhattisgarh	36.52	15	1.75	9	0.03	17
Delhi	54.61	7	0.33	15	0.07	14
Gujarat	67.87	3	98.37	1	3.05	1
Haryana	43.35	11	2.97	5	0.39	5
Himachal Pradesh	20.75	19	0.85	11	0.06	15
Jharkhand	37.68	14	0.07	19	0.00	20
Karnataka	78.76	1	0.65	13	0.06	16
Kerala	42.92	12	8.00	2	0.77	3
Madhya Pradesh	58.27	6	4.45	4	0.17	8
Maharashtra	52.01	9	2.11	7	0.84	2
Odisha	39.44	13	0.10	18	0.02	18
Punjab	53.42	8	0.73	12	0.08	13
Rajasthan	62.25	5	2.62	6	0.21	6
Tamil Nadu	50.87	10	0.45	14	0.13	9
Telangana	72.21	2	1.78	8	0.12	10
Uttar Pradesh	26.54	18	0.92	10	0.21	7
Uttarakhand	31.58	16	4.89	3	0.67	4
West Bengal	19.39	21	0.07	20	0.00	21

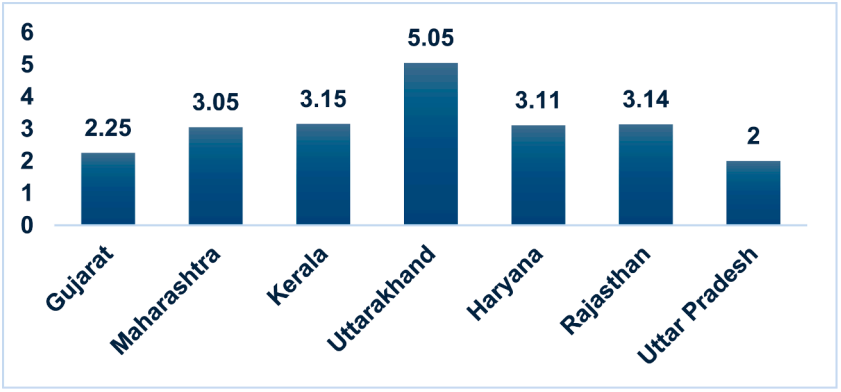
Source: SARAL, MNRE 2019: SANSAD 2025; BRIDGE TO INDIA 2025 & Author's analysis.
This table provides a comparative analysis of state's performance and ranking based upon outcome parameters namely utilization of energy consumption based potential and percentage of households benefitted against the state's SARAL ranking reflecting upon the effectiveness of implementation of enabling policies in states.



Source: Concerned State Policies & Schemes: Author's Analysis

*This bar chart presents state-wise subsidy for **3KW rooftop solar (RTS) systems**, including differentiated subsidy schemes for Antyodaya families with annual incomes up to ₹1.8 lakh and between ₹1.8 lakh and ₹3 lakh. Gujarat and Uttarakhand provide the highest general subsidies, while Haryana has targeted subsidies specifically for low-income families. Maharashtra, Kerala, and Rajasthan currently offer no direct state subsidies for rooftop solar installations.*

Fig. 11. Comparative State Subsidy for R-RTS. The states of Maharashtra, Kerala and Rajasthan did not provide any subsidy above the CFA. .
Source: Concerned State Policies & Schemes: Author's Analysis. This bar chart presents state-wise subsidy for 3KW rooftop solar (RTS) systems, including differentiated subsidy schemes for Antyodaya families with annual incomes up to ₹1.8 lakh and between ₹1.8 lakh and ₹3 lakh. Gujarat and Uttarakhand provide the highest general subsidies, while Haryana has targeted subsidies specifically for low-income families. Maharashtra, Kerala, and Rajasthan currently offer no direct state subsidies for rooftop solar installations



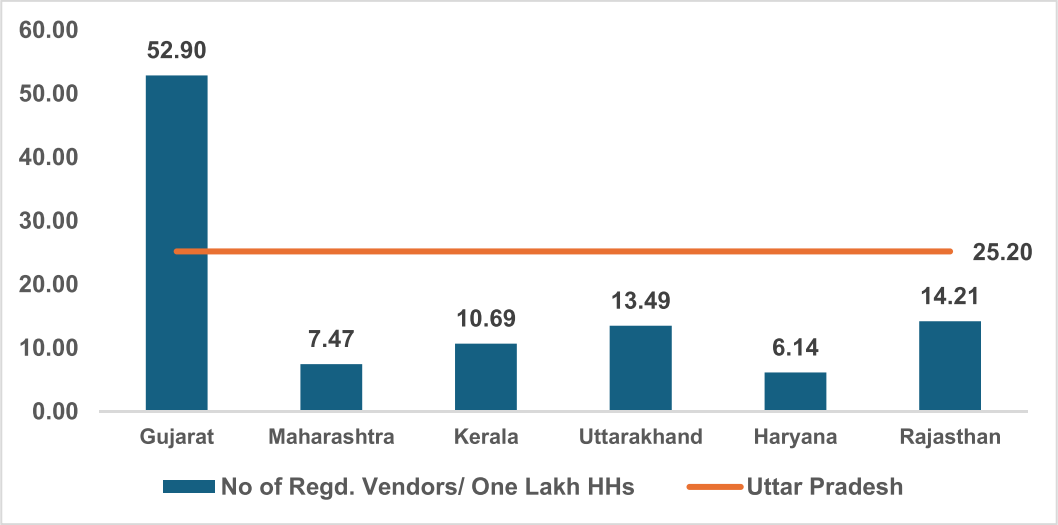
Source: Respective SERCs and Author's analysis

This bar chart compares compensation for excess electricity injected in to grid by R-RTS in the states with Uttarakhand leading (INR 5.05) with and Uttar Pradesh being the lowest (INR 2.0) reflecting variations in transfer of benefits for savings and production to the R-RTS prosumers

Fig. 12. State wise Compensation for Excess Electricity Injected (INR) for the selected States.) reflecting variations in transfer of benefits for savings and production to the R-RTS prosumers.
Source: Respective SERCs and Author's analysis. This bar chart compares compensation for excess electricity injected in to grid by R-RTS in the states with Uttarakhand leading (INR 5.05) with and Uttar Pradesh being the lowest (INR 2.0

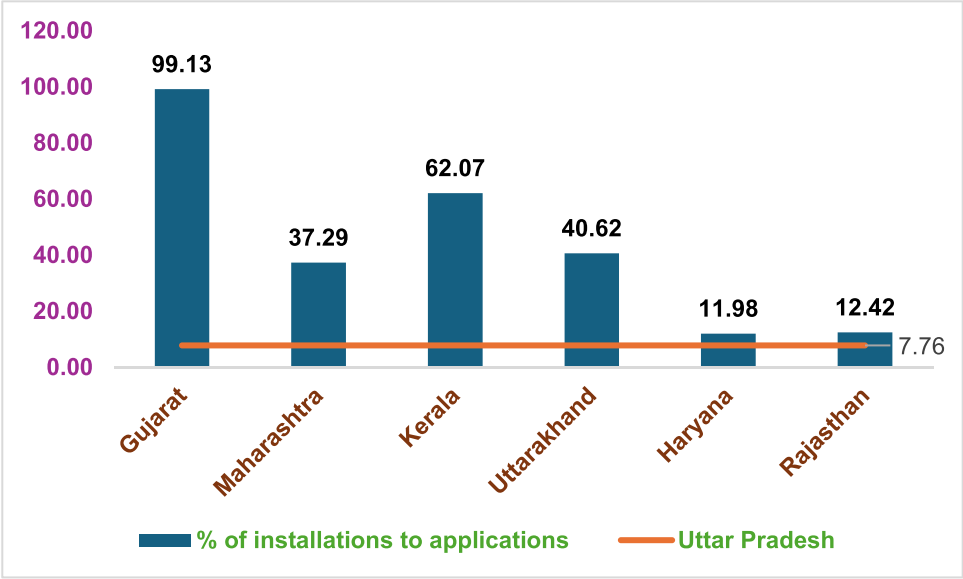
f) **Market and Supply Issues**: The supply side of the R-RTS market is still in its infancy. There aren't many well-known brands that provide dependable home solutions. Quality rooftop solar solutions require improvements to the market's whole value chain, which includes business facets like financing, insurance, equipment supply, installation, Operation and Maintenance (O&M), etc. In this regard, the simplified subsidy plan helps to strengthen the home market's sales and service infrastructure. Furthermore, the purchasing process for customers may be made easier by suppliers who integrate or bundle various business components [12]. A common obstacle to scaling up these treatments is a lack of technical expertise, especially in rural areas. Both the much-needed supply chain and the necessary market ecosystem have not yet been developed. Despite the fact that GoI funds have been set out specifically for capacity creation, implementing agencies that is, distribution utilities have not taken the necessary steps to increase that capability [9].

g) **Consumer Perspective**: One important difficulty is homeowners' unwillingness to install rooftop solar because many states give free electricity. This diminishes the program's potential effectiveness, which is based on substantial public participation. Furthermore,



This bar chart compares the number of registered rooftop solar vendors per one lakh households across selected Indian states. Gujarat leads with 52.90 vendors, followed by Rajasthan (14.21) and Uttarakhand (13.49), while Haryana has the lowest at 6.14. Uttar Pradesh is included as a reference state, showing 25.20 vendors per lakh households. The variation underscores disparities in market penetration and vendor availability across regions.

Fig. 13. State-Wise Distribution of Registered Rooftop Solar Vendors per One Lakh HHs. *This bar chart compares the number of registered rooftop solar vendors per one lakh households across selected Indian states. Gujarat leads with 52.90 vendors, followed by Rajasthan (14.21) and Uttarakhand (13.49), while Haryana has the lowest at 6.14. Uttar Pradesh is included as a reference state, showing 25.20 vendors per lakh households. The variation underscores disparities in market penetration and vendor availability across regions.*



This bar chart illustrates the percentage of rooftop solar installations relative to applications across selected Indian states. Gujarat leads with an impressive 99.13% installation success rate, followed by Kerala at 62.07% and Maharashtra at 37.29%. In contrast, Haryana and Rajasthan show significantly lower conversion rates, at 11.98% and 12.42%, respectively. Uttar Pradesh is included as a reference state, showing a 7.76% installation rate. These variations reflect disparities in policy implementation, administrative efficiency, and infrastructure readiness.

Fig. 14. State-Wise Comparison of Rooftop Solar Installations vs. Applications. *This bar chart illustrates the percentage of rooftop solar installations relative to applications across selected Indian states. Gujarat leads with an impressive 99.13% installation success rate, followed by Kerala at 62.07% and Maharashtra at 37.29%. In contrast, Haryana and Rajasthan show significantly lower conversion rates, at 11.98% and 12.42%, respectively. Uttar Pradesh is included as a reference state, showing a 7.76% installation rate. These variations reflect disparities in policy implementation, administrative efficiency, and infrastructure readiness.*

DISCOMs encounter financial strain under the net metering regime, as reimbursing surplus solar energy impacts their already tight budgets, which are already burdened by fixed expenses and power purchase agreements. Past schemes have likewise fallen short of their objectives, showing systemic flaws that impede effective implementation. Recently, Telangana had technical difficulties with the scheme's web interface, which may prolong delays, frustrate potential beneficiaries, and dampen excitement [20].

5. State's performance in R-RTS Adoption

Uttar Pradesh has India's second-largest energy consumption-based potential for R-RTS adoption, after only Maharashtra. Gujarat and Kerala have the greatest utilisation rates of their energy consumption-based potential. As of February 6, 2025, Gujarat, Maharashtra, and Uttar Pradesh are the states with the most families benefiting from the PM Suryaghar Muft Bijli Yojana (PMSG: MBY) (Sansad, 2025)[21].

As on 06.02.2025, with respect to number of households benefitted under PMSG:MBY, the states of Gujrat, Maharashtra and Uttar Pradesh only account for 73 % of achievement. The uptake of the scheme in Gujrat and Maharashtra is noteworthy. However, the number of applications received in the National Portal for Rooftop Solar, Andhra Pradesh (11,07234) tops the list followed by Uttar Pradesh (10,04,105), Maharashtra (5,46,307), Gujrat (3,66,097) and Assam (2,89,307) etc. which account for about 78 % applications received in India (Sansad, 2025)[21] (see Fig. 14).

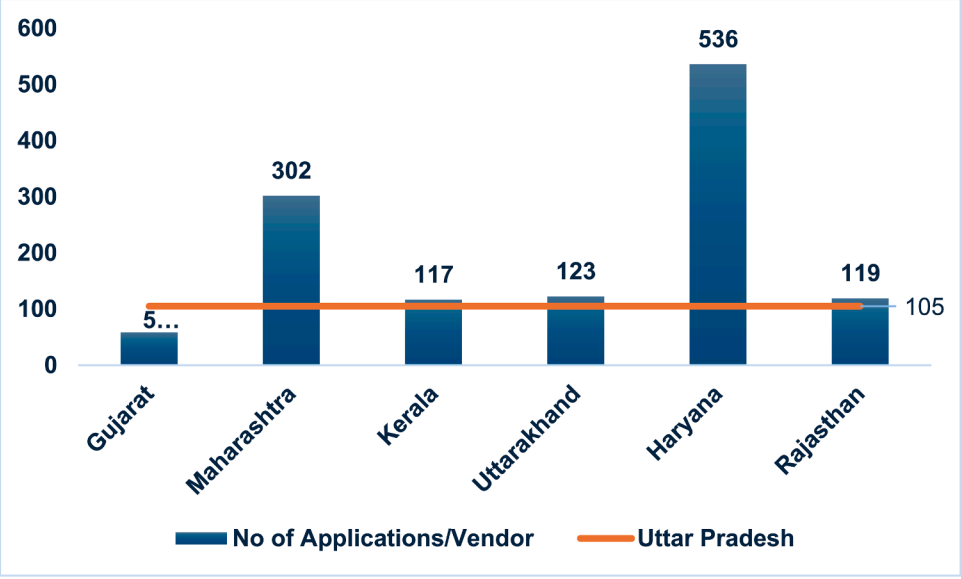
Among the states, Gujrat has maximum number of registered vendors per one lakh households whose positive impact, along with other drivers, is reflected in the almost complete (99.1 %) installations with respect to the total applications received. However, among the larger states of Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu and Uttarakhand are having better conversion rate of applications to installations than Uttar Pradesh even though the number of vendors per one lakh households is lower in them. This clearly shows that there are other crucial drivers than just the availability of vendors for speedy adoption of residential solar rooftop in the states (see Fig 15).

6. Drivers of solar rooftop adoption in states

On the basis of research review, there are many drivers for adoption of rooftop solar in the residential sector ranging from the subsidy or financial assistance given by the centre and the states, payback period which is based upon the retail residential electricity tariffs, feed in tariff for excess power injected in the grid, consumer awareness, financing, net metering policy regulations to governance issues with respect to DISCOMS etc (see Fig. 16).

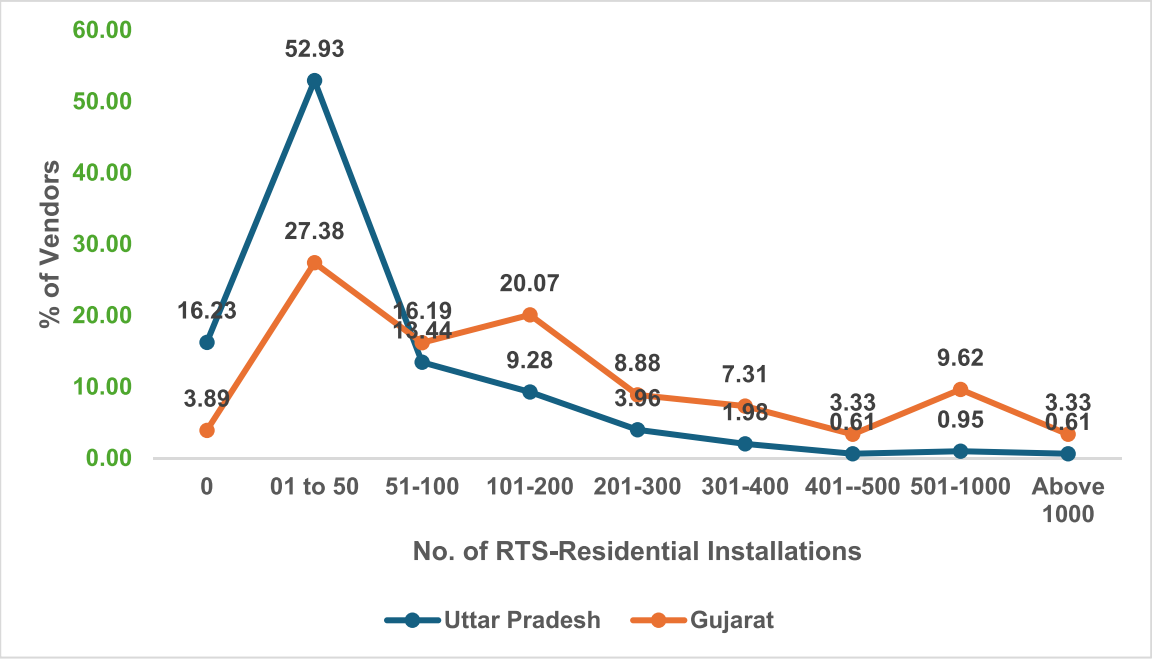
The Ministry of New and Renewable Energy (MNRE) launched the State Rooftop Solar Attractiveness Index– SARAL for financial year 2018–19 in 2019. SARAL is the first of its kind index to provide a comprehensive overview of state-level measures adopted to facilitate rooftop solar deployment. It was aimed to create a more conducive environment for solar rooftop installations, encourage investment and lead to the accelerated growth of the sector, by creating healthy competition among the States. Karnataka was placed at the first rank in the index followed by Telangana, Gujarat and Andhra Pradesh. SARAL captures five key aspects namely Robustness of policy framework, Implementation environment, Investment climate, Consumer experience and Business ecosystem. The SARAL states score in five broad drivers are given below (see Fig. 17):

Now it would be worthwhile to compare the states ranking under SARAL in 2019 with outcome performance ranking of the states in PMSG: MBY based upon updated data in NPRS as on 06.02.2025 on ranking with respect to percentage of households benefitted and percentage of utilization of energy consumption based technical potential for RTS based upon total installations as on June 2024 in the states. This comparison would assess the progressive performance of the selected states in a period of about next five to six years (2018–19 to 2024–25) and reflect on the state's endeavours to improve its performance with interventions in broad categories of drivers identified in the SARAL framework. It is evident from the comparison that the state of Gujrat,



This bar chart compares the number of applications per rooftop solar vendor across selected Indian states. Haryana records the highest number with 536 applications per vendor, while Gujarat has the lowest at 58. Uttar Pradesh is included as a reference state, with 105 applications per vendor. These variations reflect differences in market saturation, vendor availability, and policy effectiveness across states.

Fig. 15. State-Wise Comparison of Applications Per Rooftop Solar Vendor. *This bar chart compares the number of applications per rooftop solar vendor across selected Indian states. Haryana records the highest number with 536 applications per vendor, while Gujarat has the lowest at 58. Uttar Pradesh is included as a reference state, with 105 applications per vendor. These variations reflect differences in market saturation, vendor availability, and policy effectiveness across states.*



Source: NPRS & Author's analysis

This line graph compares the percentage distribution of rooftop solar vendors in Uttar Pradesh and Gujarat based on installation numbers. Uttar Pradesh sees the highest vendor concentration (52.93%) in the 1–50 installation range, while Gujarat shows a broader distribution, with notable representation across higher installation categories. The contrast between states highlights key differences in market penetration, vendor activity, and policy effectiveness.

Fig. 16. % of Registered Vendor Vs No. of installations in NPRS for Gujarat & UP. .
Source: NPRS & Author's analysis. *This line graph compares the percentage distribution of rooftop solar vendors in Uttar Pradesh and Gujarat based on installation numbers. Uttar Pradesh sees the highest vendor concentration (52.93%) in the 1–50 installation range, while Gujarat shows a broader distribution, with notable representation across higher installation categories. The contrast between states highlights key differences in market penetration, vendor activity, and policy effectiveness*

Rajasthan, Madhya Pradesh and Maharashtra have shown a consistent high performance and the states of Uttarakhand, Kerala and Haryana have remarkably improved their performances and the state of Uttar Pradesh has also shown significant improvement (see Fig. 18 and Fig. 19).

7. Comparative state analysis

The comparison of SARAL scores (2019) with recent performance metrics under the PMSG: MBY reveals both the consistency and the dynamism of state-level policy environments in facilitating rooftop solar (RTS) adoption. To evaluate whether early policy readiness as captured in SARAL translated into measurable performance outcomes over the medium term (2018–2024), we performed two analytical exercises:

(i) Pearson correlation analysis and
(ii) Composite scoring index for outcome performance.

The Pearson correlation between SARAL scores revealed that:

a. % of energy consumption-based technical potential utilized = r = 0.69, indicating a moderate to strong positive correlation.
b. % of households benefitted = r = 0.66, also indicating a moderate positive correlation.

This suggests that states with robust SARAL scores generally saw higher technical potential utilization and greater household adoption, supporting the validity of the SARAL framework in predicting downstream performance.

To provide a more granular view, a composite performance index (CPI) was developed for each state based on normalized scores (0–1 scale) of:

- % of EC-based technical potential utilized (weight = 0.6),
- % of households benefitted (weight = 0.4), reflecting the relative importance of capacity deployment versus consumer reach.

Additionally, to enhance interpretability and learn from success stories, a new comparative summary table (Table 3A) was included to document key policy and implementation actions that contributed to improved CPI scores in select states.

Such examples help to elucidate what specific governance or market strategies enabled better performance outcomes beyond what SARAL scores initially predicted.

Composite Performance Index (CPI) rankings of selected states, reflecting their effectiveness in translating rooftop solar policies into measurable outcomes (Table 3B). It highlights top performing states like Gujarat, Kerala, and Maharashtra that demonstrate both high technical potential utilization and significant household adoption.

The index clearly reflects Gujarat's exceptional progress in translating policy into practice, topping both technical utilization (98.37 %) and household penetration (3.05 %). Other states like Kerala, Uttarakhand, Haryana, and Maharashtra also show remarkable performance improvements despite modest SARAL rankings in 2019 highlighting effective policy adaptations and strong implementation post 2019 (see Tables 4 and 5).

Notably, Uttar Pradesh and Himachal Pradesh, despite low SARAL scores, have moderately improved technical potential utilization and

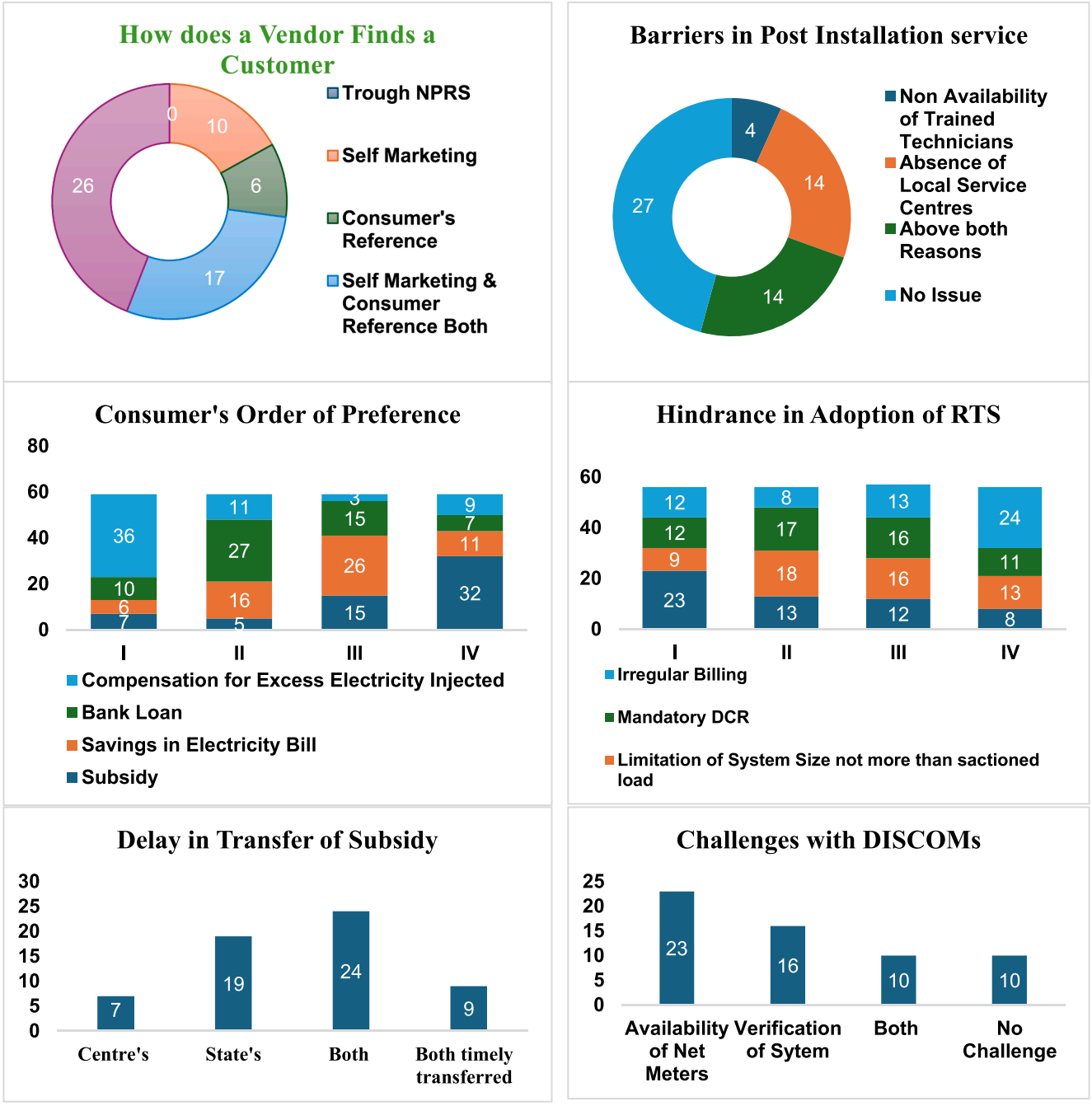


Fig. 17. Results of Vendor Survey.

household coverage, indicating positive transition paths and improved governance structures, possibly due to targeted interventions under PMSG: MBY.

This analysis validates the SARAL framework's relevance as a baseline predictor while also emphasizing the need for continuous policy innovation, focused DISCOM coordination, and demand-side awareness campaigns to sustain performance. States that failed to improve (e.g., Bihar, Jharkhand, and West Bengal) exhibit persistent structural or governance bottlenecks, requiring targeted fiscal support, institutional strengthening, and streamlined regulatory processes.

This scatter plot helps visualize the relationship between the 2019 SARAL scores and the actual state performance (CPI) by 2024. States like Gujarat, Kerala, and Maharashtra show both high SARAL scores and high CPI values, indicating strong policy-to-performance alignment and implementation coherence.

8. Identification of key drivers and selection of states

In order to understand the challenges for RTS-Residential in the state of Uttar Pradesh, the matrix of drivers of adoption is prepared and a comparison has been made of the states having better adoption with the state of Uttar Pradesh. We considered to choose the States having better performance on the basis of their performance in PMSG: MBY and the utilization of the technical potential based upon energy consumptions along with their SARAL ranking in 2019. We selected the states of Gujrat, Maharashtra, Kerala, Uttarakhand, Haryana and Rajasthan.

9. Matrix of key drivers of residential RTS adoption

On the basis of the research review in the present report we analyse the performance of the selected states of Gujrat, Maharashtra, Kerala,

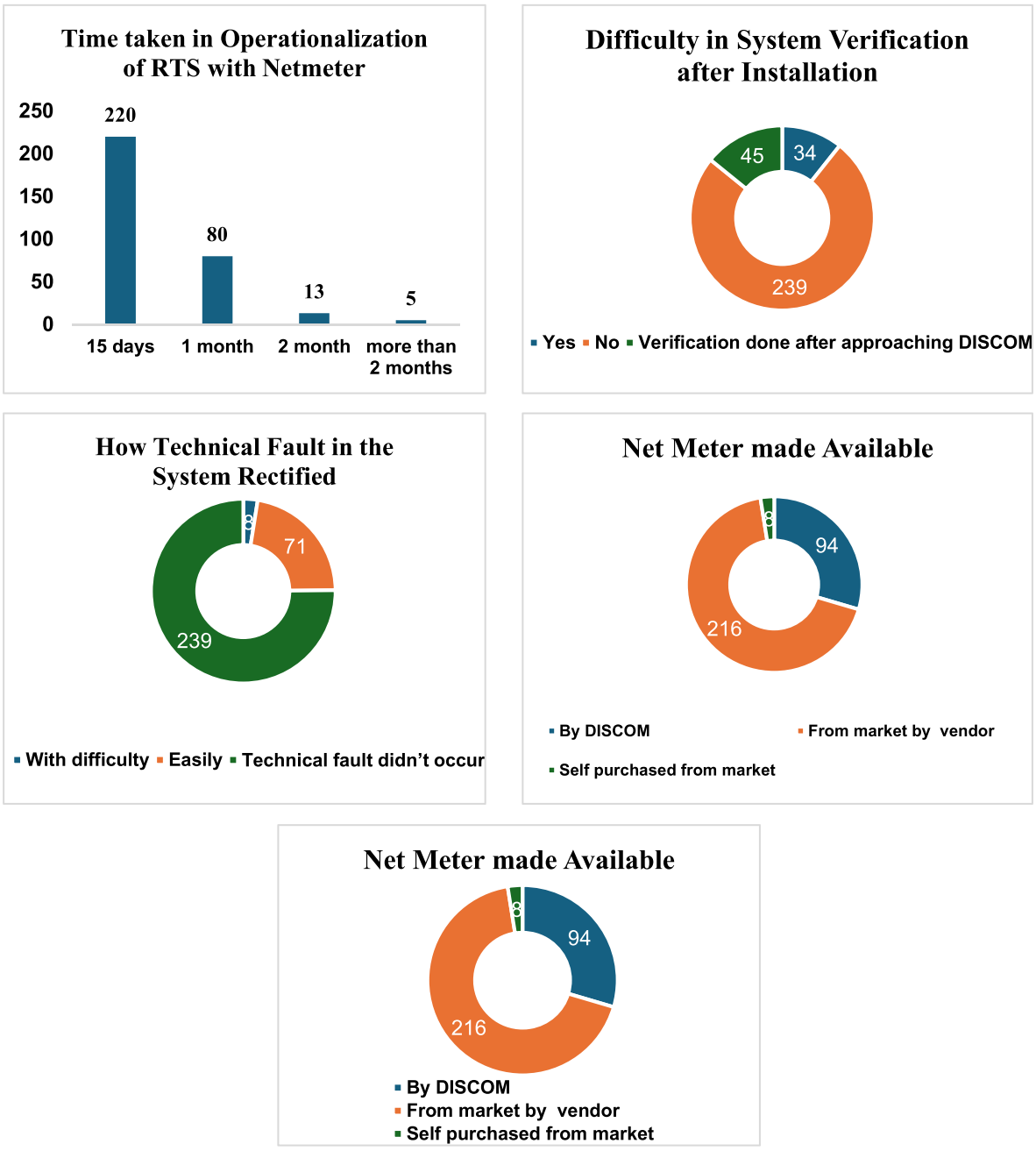


Fig. 18. Results of Consumer Survey who have Installed RTS.

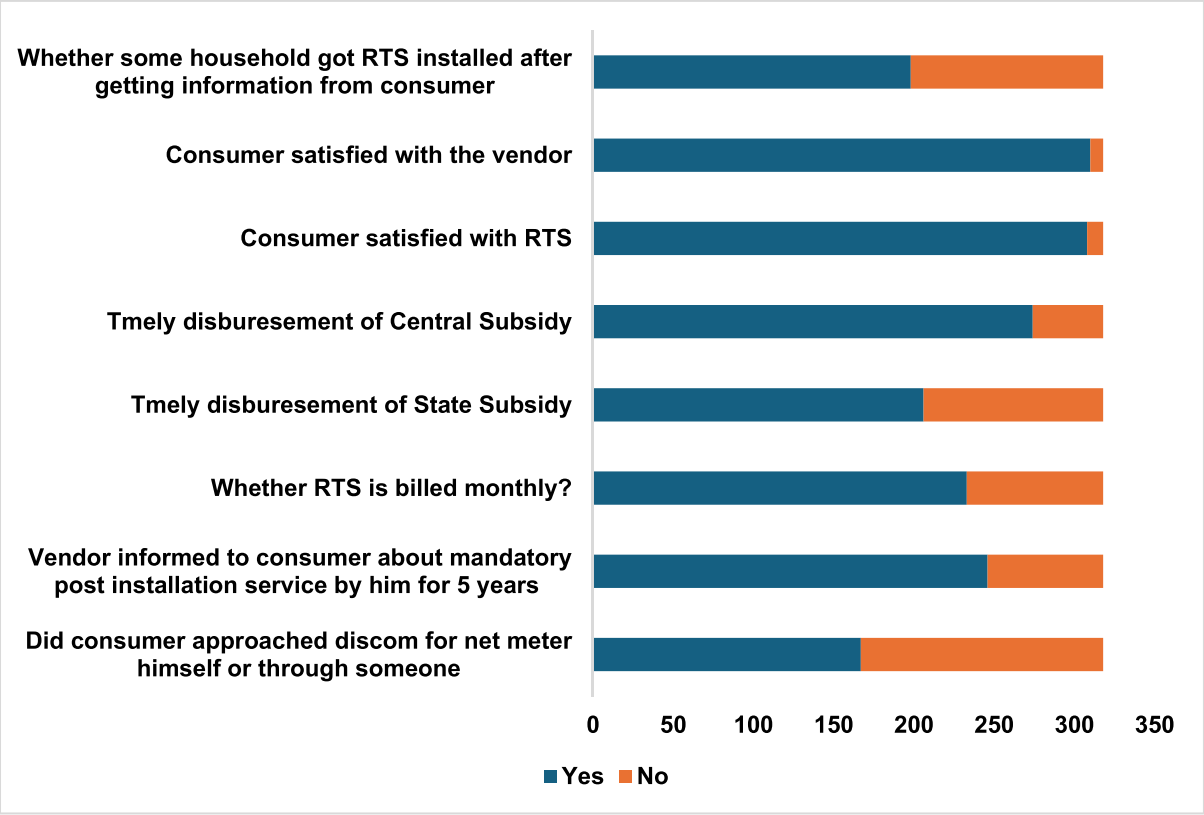
Uttarakhand, Haryana, Rajasthan and Uttar Pradesh with respect to following key drivers of Residential RTS adoption.

a) **State subsidy above the Central financial Assistance**: The State Government of Haryana provides additional financial assistance to 1 lakh Antyodaya families of the state on first come first serve basis. The additional subsidy details shall be as follows:
   i. **Category I:** The consumers with Annual Family income up to and including Rs 1.80 Lacs shall be eligible for State Financial Assistance up to Rs. 25,000/kW or 40 % of the billed amount per kW on pro-rata basis up to 2 kW (whichever is lower).
   ii. **Category II:** The consumers with Annual Family income from Rs 1.80 Lacs up to and including Rs 3.00 Lacs shall be eligible for State Financial Assistance up to Rs. 10,000/kW or 20 % of the billed amount per kW on pro-rata basis up to 2 kW (whichever is lower).

In case the actual project Cost/billed amount is lower than the combined eligible Central Financial Assistance and the State Financial Assistance, then the State Financial Assistance will be limited up to the difference of the actual Project Cost/billed Amount and the Central Financial Assistance.

For the purpose of the calculation of Financial Assistance (Central and State) the methodology as provided by MNRE in the guidelines amended from time to time shall be adopted [22].

The state of Uttar Pradesh provides additional state subsidy of ₹15,000 per kW, capped at ₹30,000 for residential consumers which is disbursed after the DBT of Central Financial Assistance. According to Uttarakhand state Solar Policy, 2023, the State of Uttarakhand provides subsidy over and above Central Financial Assistance (CFA) Rs 23,000 for 0–1 KW and Rs 17,000/KW for 1–3 KW rooftop solar meaning thereby a 3KW rooftop solar gets a total state subsidy of Rs 57,000 in addition to the CFA under PMSG: MBY.



This horizontal bar chart presents consumer responses regarding various aspects of rooftop solar adoption, including satisfaction with vendors and RTS performance, subsidy disbursement efficiency, monthly billing practices, and the availability of post-installation services. The data reveals that a majority of consumers were satisfied with their RTS installations and vendors, while issues persist in timely subsidy disbursement and net meter availability.

Fig. 19. Consumer Feedback on RTS Adoption, Subsidy Disbursement, and Vendor Satisfaction who have Installed RTS. *This horizontal bar chart presents consumer responses regarding various aspects of rooftop solar adoption, including satisfaction with vendors and RTS performance, subsidy disbursement efficiency, monthly billing practices, and the availability of post-installation services. The data reveals that a majority of consumers were satisfied with their RTS installations and vendors, while issues persist in timely subsidy disbursement and net meter availability.*

Table 3A
Summary of Leading State Strategies.

State	Key Strategies Implemented
Gujarat	Consistent rooftop solar subsidies, DISCOM alignment, and local installer ecosystem support
Kerala	High household-level awareness campaigns, simplified net metering
Maharashtra	Urban solar mandates, utility incentives, digital platforms for application tracking

Table 3B
Composite Performance Index (CPI) Ranking.

Rank	State	SARAL Rank (2019)	Composite Index (2024)
1	Gujarat	3	1.000
2	Maharashtra	9	0.255
3	Kerala	13	0.250
4	Uttarakhand	16	0.248
5	Haryana	11	0.229
6	Rajasthan	5	0.212
7	Madhya Pradesh	6	0.185
8	Telangana	2	0.144
9	Chhattisgarh	15	0.112
10	Tamil Nadu	10	0.098
11	Andhra Pradesh	4	0.080
12	Delhi	7	0.073
13	Punjab	8	0.066
14	Karnataka	1	0.060
15	Himachal Pradesh	19	0.050
16	Uttar Pradesh	18	0.047
17	Odisha	13	0.020
18	Assam	17	0.018
19	Bihar	20	0.012
20	Jharkhand	14	0.004
21	West Bengal	21	0.000

With a view to promote large scale Solar Rooftop System on Private Residential roofs-terraces, the Government of Gujrat had introduced a Solar Rooftop Scheme as a Surya Urja Rooftop Yojana-Gujarat (SURYA-Gujarat) which continued till the launch of PMSG:MBY. Under Surya-Gujrat, state subsidy of 40 % was available for Solar Rooftop Systems up to 3 KW and 20 % for Solar Rooftop Systems beyond 3 KW up to 10 KW, installed and commissioned by Private Residential Consumers.

b) **Net Metering Policy**: In addition to providing electricity for homes or businesses, an RTS enables excess electricity to be exported to the grid for use by other users. The RTS metering mechanisms that each state offers its customers net metering, gross metering, and net feed-in/net billing vary according on its policies and regulations. The RTS

Table 4
State-wise net metering policy, settlement mechanism, and R-RTS Size limitations.

State	Metering Mechanism	Settlement Period	Permissible RTS Size (KWp)	Limits for RTS Size		Voltage Connectivity		
				% of Sanctioned Load	% of Distribution Transformer	230 V (Single Phase) kWp	415 V (Three Phase) kWp	HT kWp
Gujarat	Net Metering /Gross Metring	April to March	1–1000	No restriction	100	up to 6	Above 6 & up to 100	Above 100
Maharashtra	Net Metering	April to March	up to 5000	100	70	up to 8	Above 8 & up to 150 (Metro): Above 8 & up to 80 (other areas)	Above 150 (Metro): Above 80 (other areas)
Kerala	Net Metering	April to March	1–1000	100	80	up to 5	Above 5 & up to 100	Above 50
Uttarakhand	Net Metering	April to March	up to 1000	100	100	up to 4	up to 75	Above 75 & up to 1500 (11 kV)/3000 (>11 kV)
Haryana	Net Metering	April to March	1–2000	100	30 % for LT & 15 % for HT	up to 5	Above 5& up to 50	Above 50
Rajasthan	Net Metering	April to March	1–1000	100	30	up to 5	Above 5 & up to 50	Above 50
Uttar Pradesh	Net Metering	April to March	1–2000	100	25	up to 5	Above 5 & up to 50	Above 50 & up to 2000 (11 kV)/ 2000–5000 (>11 kV)

Source: Respective SERCs.
This table outlines the metering mechanism, permissible rooftop solar (RTS) sizes, and voltage connectivity across selected Indian states. Gujarat allows the widest RTS range (1–1000 kWp) with no restrictions, while Maharashtra and Uttar Pradesh permit installations up to 5000 kWp. Variations in sanctioned load percentages and distribution transformer limits highlight differing regulatory approaches across states.

Table 5
Summary of Consumer Preferences, Market Challenges, and Vendor Acquisition Methods in Rooftop Solar Adoption of RTS vendor survey.

How does a vendor finds a customer	Trough NPRS	Self-Marketing	Consumer's Reference	Self-Marketing & Consumer Reference Both	All Above
	0	10	6	17	26
Consumer's Order of Preference	Subsidy	Savings in Electricity Bill	Bank Loan	Compensation for Excess Electricity Injected	
I	7	6	10	36	
II	5	16	27	11	
III	15	26	15	3	
IV	32	11	7	9	
Hindrance in Adoption of RTS	No subsidy above 3 KW	Limitation of System Size not more than sanctioned load	Mandatory DCR	Irregular Billing	No Hindrance
I	23	9	12	12	3
II	13	18	17	8	
III	12	16	16	13	
IV	8	13	11	24	
Barriers in Post Installation Service	Non Availability of Trained Technicians	Absence of Local Service Centres	Above both Reasons	No Issue	
	4	14	14	27	
How does the net meter gets available	From Discom	From Market			
	4	55			
Delay in transfer of Subsidy	Centre's	State's	Both	Both timely transferred	
	7	19	24	9	
Challenges with the DISCOM	Availability of Net Meters	Verification of System	Both	No Challenge	
	23	16	10	10	

This table presents key aspects of rooftop solar adoption, including vendor-customer acquisition methods, consumer preferences, hindrances in RTS adoption, barriers in post-installation service, net meter availability, subsidy transfer delays, and DISCOM-related challenges. Insights show that vendors most commonly acquire customers through a mix of self-marketing and consumer reference, while subsidy transfer delays remain a concern. Consumers prioritize compensation for excess electricity injected over subsidies and bank loans.

metering mechanisms choose the energy accounting strategy and control how the RTS system communicates with the grid. Customers can select from a variety of metering options offered by several states, according on their goals and requirements.

All states have implemented net metering, though some, like Tamil Nadu, restrict participation to specific consumer groups, such as residential or business customers. Additionally, net metering policies vary significantly regarding maximum RTS system size. For instance, Manipur and Mizoram cap installations at 10 kW, whereas Maharashtra permits 5000 kW, the highest capacity in the country.

Beyond net metering, twenty-eight states support gross metering, while nineteen states allow net feed-in, providing consumers with additional options to sell excess electricity at fixed prices. Recognizing that not all consumers have access to individual rooftops due to ownership or space limitations, eighteen states and UTs have introduced virtual and group net metering. These mechanisms enhance solar accessibility by enabling multiple consumers to share RTS systems, making solar energy more viable for a broader audience.

Rooftop solar capacity is usually restricted by the sanctioned load,

some jurisdictions establish lower limits, while others permit an RTS capacity at 100 % of the sanctioned load. Distribution transformers (DTs) may experience less strain thanks to RTS systems, but excess solar energy that is not used by the building or the local low-voltage network may flow back, overloading DTs and resulting in technical problems. As a result, states have placed restrictions on the maximum amount of combined RTS capacity that can be linked to a single DT. These restrictions are often stated as a percentage of the rated capacity of the DT, which can range from 20 % to 100 % [23].

In rooftop solar systems, voltage connectivity regulation refers to the guidelines and standards that govern the voltage level at which a solar panel array connects to the electricity grid. These regulations ensure that generated power remains within acceptable voltage ranges, preventing grid instability. Compliance is typically overseen by the local electricity DISCOM and must adhere to national standards such as the Central Electricity Authority (CEA) guidelines in India (see Tables 6 and 7).

Regulations generally impose limits on the maximum voltage output from the inverter and require proper synchronization with the grid frequency to maintain system stability.

A comparison of net metering policies suggest that Gujrat's success in high adoption of RTS-Residential is driven by flexibility in RTS size supported by State's subsidy of 20 % for system above 3KW and up to 10 KW as compared to State of Uttar Pradesh where RTS size is limited to sanctioned load and the additional State subsidy is not available above 2KW. As per the Uttar Pradesh Solar Energy Policy 2022 the state subsidy is applicable at Rs. 15,000/- per kW and maximum up to Rs. 30,000/- and remains the same for any higher capacity installed above 2 kW.

c) **Compensation for Excess Electricity Injected**: The Compensation for Excess Electricity Injected acts as a key driver for rooftop solar adoption by guaranteeing a fixed price at which electricity generated from a rooftop solar system can be sold back to the grid, essentially providing a reliable income stream for homeowners or businesses who invest in solar panels, thus encouraging wider adoption of rooftop solar technology by mitigating financial risk and making it more economically viable. All the selected states except for states of Haryana (95 %) and Uttarakhand (90 %) allow export of excess electricity above 100 % compared to the sanctioned load. Here we compared the feed-in tariff of the selected states and found that in the State of Uttar Pradesh, it is lowest among the selected states. The higher compensation for the excess electricity injected in to grid for RTS actually reduces the payback period for the system to the consumers. In the state of Gujrat, absence of system capacity restrictions coupled with subsidy for the bigger RTS has been complemented by better compensation for excess electricity injected than Uttar Pradesh has resulted in fast adoption of RTS.

d) **Robustness of Implementation Ecosystem**: The Ecosystem for implementation of the rooftop solar policies and initiative has been continuously evolving and may be assessed from the drivers of the adoption of PMSG: MBY in the States. There are two key parameters namely number of registered vendors per one lakh household and the

Table 6
Summary of Consumer Survey who have installed RTS.

1	How does consumer got aware of benefits, centre & state subsidies, and other things about RTS	Through Newspaper, TV, Radio Jingle etc.	Through awareness Programme of the Government	Through a vendor	Through a friend
		97	93	75	53
2	How does the consumer hired a vendor	Through NPRS	Referred by a friend	Vendor himself approached	Through awareness programme of the Government
		48	117	125	28
3	Time taken for operationalization of RTS with net meter after its installation	15 days	1 month	2 month	more than 2 months
		220	80	13	5
4	Did consumer approached discom for net meter himself or through someone	Yes	No		
		167	151		
5	Difficulty to consumer in getting the system verification by Discom after its installation	Yes	No	Yes, verification done only after approaching the DISCOM	
		34	239	45	
6	Whether vendor informed to consumer that it's mandatory for him to provide post installation service for 5 years	Yes	No		
		246	72		
7	How a technical fault in the system got rectified	With difficulty	Easily	Technical fault didn't occur	
		8	71	239	
8	Whether RTS is billed monthly?	Yes	No		
		233	85		
9	Timely disbursement of Subsidy	State	Yes	No	
			206	112	
		Centre	Yes	No	
			274	44	
10	Consumer satisfied with RTS	Yes	No		
		308	10		
11	Consumer satisfied with the vendor	Yes	No		
		310	8		
12	Whether consumer registered a grievance in NPRS	Yes	No	Not Aware	
		19	249	50	
13	Net meter made available by	By DISCOM	From market by vendor	Self-purchased from market	
		94	216	8	
14	Whether some household got RTS installed after getting information from consumer	Yes	No		
		198	120		

This table presents insights into how consumers become aware of rooftop solar benefits, vendor selection, installation timelines, net meter availability, subsidy disbursement efficiency, post-installation service awareness, and overall satisfaction. Findings indicate that most consumers are informed through mass media (97 responses) and government awareness programs (93 responses), while vendor referrals play a significant role in hiring decisions. Despite a generally positive adoption experience, challenges remain in subsidy disbursement and grievance registration on NPRS.

Table 7
Summary of Consumer Survey who haven't installed RTS.

1	Awareness regarding					
	a	RTS saves expenditure on electricity bill	Yes 293	No 11		
	b	PMSGY	Yes 280	No 24		
	c	Centre & state subsidy	Yes 279	No 25		
	d	Net Metering	Yes 208	No 96		
	e	Compensation for excess electricity injected in to grid	Yes 178	No 126		
	f	NPRS for consumer benefit	Yes 223	No 81		
	g	Availability of Bank Loan	Yes 246	No 58		
	h	Whether Registration done in NPRS	Yes 269	No 35		
2	How does consumer got aware of benefits, centre & state subsidies, and other things about RTS	Through Newspaper, TV, Radio Jingle etc. 140	Through awareness Programme of the Government 99	Through a vendor 46	Through NPRS 19	
3	Consumer gets information regarding cost of system, centre & state subsidies etc. through	A vendor 72	NPRS 90	Some other source 128	Not aware 14	
4	Consumer's willingness to get RTS installed after getting all information regarding benefits, subsidies, availability of loan, compensation for excess electricity injected etc.	Yes 269	No 35			
5	The reason for unwillingness of the consumer to get RTS installed	High upfront cost 21	Lack of all information 2	Low consumption of electricity 1	No subsidy above 3KW 11	Any other reason 269

This table presents insights into consumer awareness levels regarding rooftop solar benefits, government subsidies, net metering, and financing options. It also explores consumer willingness to install RTS systems, preferred sources of information, and reasons for hesitation. Findings indicate high awareness of financial benefits (293 responses) and subsidies (279 responses), but challenges such as high upfront costs and subsidy limitations above 3KW impact adoption rates.

percentage of conversion from applications to installations for the selected states.

The status of number of registered vendors per one lakh HHs in Uttar Pradesh is lower than that in Gujrat but marginally better rest of the selected states but the percentage of installations to applications as on 06.02.2025 is lowest in Uttar Pradesh. It would also be important to note that the number of applications per registered vendor in NPRS is lower in Uttar Pradesh than Maharashtra and Haryana but the conversion of applications to installations is very low as compared to these states.

The above analysis clearly indicates that a significant number of registered vendors in Uttar Pradesh are not active which necessitates monitoring of inactive vendors and building dialogue with them to understand the reasons for their inactiveness with an aim to make them active.

To further crystallise the issue of vendor activeness, the vendor-wise data on number of installations is not available in the public domain in NPRS. However the vendor list is available along with their rating, number and capacity of installations done by the vendors for consumers with the purpose of selecting a vendor to fill up the online application form by the vendor. In order to compare the vendor activeness between the State of Uttar Pradesh and the benchmark state of Gujrat, the author registered as a consumer and retrieved the data about the vendors on 05.03.2025 (see Fig. 20).

The analysis as depicted in Fig. 7.7 shows that over two third of the vendors have done less than 50 installations and 16.23 % vendors are completely inactive in the state of Uttar Pradesh whereas in the State of Gujarat the percentage of vendors is higher for all ranges of number of installations and a very insignificant (4 %) of the vendors without any installations. Thus, in order to scale up the adoption of RTS-residential at a faster rate, Uttar Pradesh must focus upon increasing the vendor activeness which will also improve the applications to installation conversion rate.

e) **Issues Related to Disbursement of Subsidies**: The implementation mechanism under PMSG: MBY has streamlined the disbursement of subsidy yet some challenges have been faced in disbursement of the state subsidies in Uttar Pradesh. The disbursement of the state subsidy presents a moderate challenge, primarily due to its dependency on the release of the Central Financial Assistance (CFA). Typically, the state subsidy is released within 7–10 days following the disbursement of the central subsidy. However, the process lacks consistency, as the list of beneficiaries receiving the central subsidy is not shared with the state on a regular (e.g., fortnightly) basis. Furthermore, the disbursement of CFA is neither sequential nor governed by a clearly defined timeline. This irregularity in central subsidy disbursal and the inconsistent sharing of requisite documents with the state authorities directly impact the timely processing and release of the corresponding state subsidy. The root cause of the delay, therefore, lies predominantly in the central subsidy disbursal mechanism and associated documentation practices [19]. This necessitates fixing a timeline for disbursal of central subsidy along with its fortnightly or monthly disbursal with subsidy disbursal data sharing with the state agencies through NPRS.

10. 10 vendors and consumer perspective about RTS policies

Stakeholders' perspective would be very important to understand the

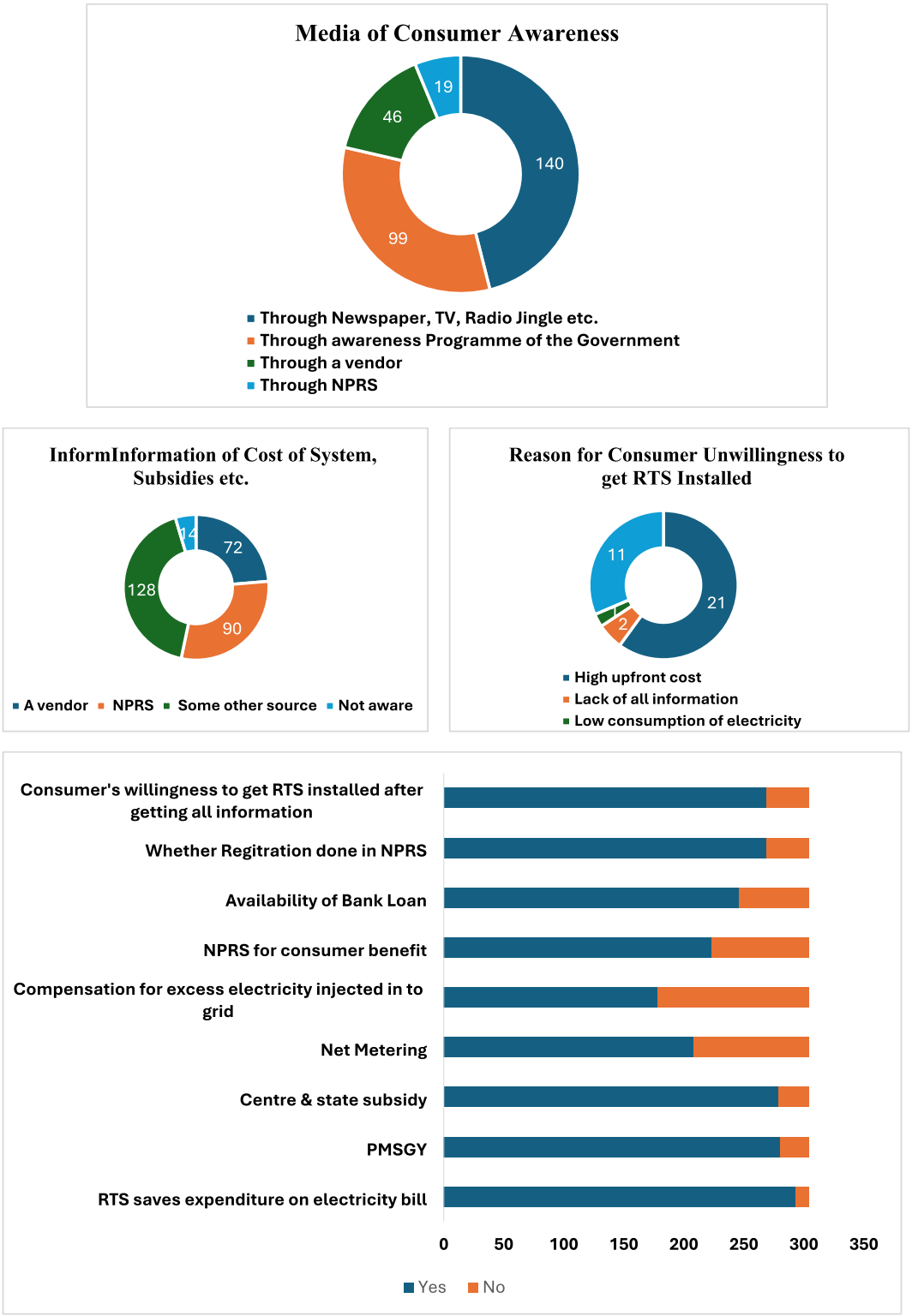


Fig. 20. Results of Consumer Survey who haven't Installed RTS.

barriers in the uptake of the policies. In order to understand this perspective of the consumers who are beneficiaries and the vendors who are media to take the benefit to the consumers would provide a key insight to the barriers of the uptake of the R-RTS policies. To take this further, a survey of the vendors, consumers who have installed RTS and the consumers who haven't installed the R-RTS has been decided to be conducted across the State of Uttar Pradesh with the help of the nodal agency for R-RTS Uttar Pradesh New and Renewable Development Agency (UPNEDA). To understand the ground level challenges in the adoption of R-RTS systems in Uttar Pradesh, a stakeholder centric empirical survey was undertaken across 59 districts of Uttar Pradesh. A total of 678 stakeholders were surveyed comprising 59 vendors, 315 consumers who have installed RTS and 304 consumers who have not yet installed RTS. Three distinct questionnaires (Annexure 1, 2 & 3) were used to capture diverse perspectives, focusing on awareness, procedural experience, service quality, and barriers to adoption. For vendors

survey, 59 vendors have been randomly selected in 59 districts of Uttar Pradesh. For consumer survey, who have installed RTS, 315 consumers have been randomly selected spread across 64 districts in Uttar Pradesh and for Consumer Survey, who haven't installed RTS, 304 consumers have been randomly selected spread across 68 districts of Uttar Pradesh. Summary of survey is given below:

10.1. Vendors perspective

Survey results reveal that vendors rely heavily on self-marketing and consumer references (26 respondents) as the primary means to acquire customers, while only 10 vendors cited NPRS as an effective platform. This underutilization of NPRS for customer outreach points to a need for enhanced digital integration and vendor incentives.

When asked about consumer motivation, vendors reported that consumers most valued compensation for excess electricity injected into the grid (36 ranked it highest) and availability of bank loans (10 first preferences). This finding suggests that financial return and access to finance are key motivators for consumers.

Barriers to adoption cited by vendors include:

a. Absence of state subsidy beyond 3 kW (ranked first by 23 vendors),
b. System size limitations linked to sanctioned load (ranked second by 18),
c. Mandatory domestic content requirement (DCR) and irregular billing were also mentioned.

In terms of service challenges:

a. 28 vendors reported either lack of trained technicians or absence of local service centres, suggesting serious capacity gaps in post-installation support.
b. 93 % of vendors (55 out of 59) indicated that net meters are sourced from the market rather than DISCOMs, pointing to systemic issues in DISCOM supply chains.

Regarding subsidies, only 9 vendors confirmed timely disbursal from both central and state governments, whereas 24 vendors noted delays from both. In DISCOM-related challenges, 23 vendors cited unavailability of net meters, while 16 mentioned verification delays highlighting inefficiencies in utility coordination.

The vendors survey reveals that:

i. The customers give highest preference to the compensation paid for injection of excess electricity in to grid and the loan from bank for getting the RTS installed.
ii. The biggest hindrance in adoption of RTS is no additional subsidy by the state above 2 KW and the limitation of the size of RTS system equal to the sanctioned load. Mandatory DCR requirement and irregular billing are also matters of concern towards the adoption of RTS in UP.
iii. The challenges in post installation services do exist owing to lack of trained manpower and absence of service centre locally for the invertors etc.
iv. Availability of net meters through DISCOMS and verification of the system by the DISCOMS are major challenges.
v. The timely transfer of subsidy from the centre and the state is not happening.

10.2. Consumers who have installed RTS:

Among 315 RTS adopters, the most common source of awareness was media (TV, newspaper, etc.) (97) followed closely by government awareness programmes (93) and vendors (75). Friend references (53) also played a significant role, underscoring the potential of peer influence. The hiring of vendors was largely driven by vendor outreach (125) and friend referrals (117), while only 48 consumers used NPRS to find vendors again reflecting its limited effectiveness.

Regarding implementation timelines, 70 % of systems (220 consumers) were operationalized with net meters within 15 days, and another 80 within a month, indicating overall efficiency in project execution. However, only 94 consumers received net meters from DISCOMs, while 216 sourced them from vendors mirroring vendor complaints.

Post-installation service delivery appears satisfactory, with 239 consumers reporting no technical faults and 71 noting easy resolution of issues. 246 consumers confirmed being informed about the five-year mandatory service clause by vendors, though 72 were not, revealing gaps in vendor compliance.

Subsidy disbursal was a mixed experience:

a. 274 consumers confirmed timely receipt from the central government, but only 206 confirmed the same from the state highlighting delays in state-level transfers, often linked to central disbursal bottlenecks.

Satisfaction levels are encouraging:

- 308 consumers were satisfied with their RTS systems,
- 310 with vendors, indicating high consumer trust. However, only 19 consumers filed complaints via NPRS, and 50 were unaware of the platform calling for improved grievance redressal outreach.

The consumer survey reveals that:

i. The activeness of vendors has been a challenge for making the consumers aware about the benefits of RTS.
ii. Apart from the marketing of RTS by the vendors, a friend's reference is emerging a powerful medium for hiring of a vendor by the consumer. The hiring of vendor through NPRS is very limited.
iii. Most of the systems got operationalised with net metering within a period of one month which shows the excellent delivery by the active vendors.
iv. The major issue with the DISCOM is the availability of net meters. However, getting the system verification from the DISCOM is also a moderate challenge.
v. The vendors informing the consumers about their mandate for providing post installation services for five years is also a moderate challenge. However, the consumers seem satisfied with respect to addressing the faults easily by the vendors.
vi. The monthly billing is also a moderate challenge.
vii. The time in disbursement of state's subsidy is a moderate challenge. As per UPNEDA, timely release of state-level subsidies is moderately hampered by delays in Central Financial Assistance (CFA), along with irregular communication and document exchange with state agencies, directly impact the timely processing and release of the corresponding state subsidy. The root of the delay, therefore, lies predominantly in the central subsidy disbursal mechanism and associated documentation practices.
viii. The consumers are largely satisfied by their RTSs and Vendors.
ix. The awareness about grievance redressal through NPRS needs to be improved.

10.3. Consumers survey who haven't installed RTS

Among 304 non-adopters, awareness of basic RTS benefits is high 293 knew about electricity savings, 280 about PMSGY, and 279 about subsidies. However, knowledge drops significantly on technical and procedural aspects:

a. Only 208 were aware of net metering,

b. 178 of compensation for excess electricity,
c. 223 of NPRS benefits,
d. 246 about loan availability.

Regarding source of information, only 46 cited vendors, compared to 140 through media and 99 through government campaigns, confirming low vendor engagement.

Notably, 269 consumers expressed willingness to install RTS if complete information was available highlighting high latent demand. Among the 35 unwilling, the main deterrent was high upfront cost (21 respondents) and lack of state subsidy beyond 3 kW (11 respondents), aligning with vendor feedback.

The Consumer Survey reveals that:

i. The status of consumer awareness is satisfactory. However, the awareness about the benefits of net metering, compensation for excess electricity injected in to the grid and about National portal for Rooftop Solar needs to be enhanced.
ii. Vendor activeness in making the consumer aware is lacking in Uttar Pradesh.
iii. Most of the consumers are willing to install the RTS. Those, however is lesser proportion, not willing find challenge in initial high cost and lack of subsidy above 3 KW in the State.

10.4. Key insights

a. **DISCOM inefficiencies**: particularly in net meter provision and system verification are a major barrier, reported by both vendors (23 out of 59) and consumers (239 faced verification challenges).
b. **Vendor inactiveness**: Despite high registration numbers, vendor outreach is minimal, only 10 vendors use NPRS effectively and only 46 non-adopters gained awareness through them.
c. **Policy gaps**: The absence of state subsidies beyond 3 kW and the sanctioned load cap are prominent barriers mentioned by all stakeholders.
d. **Subsidy delays**: The data clearly shows centre-to-state lag in disbursal cycles, which discourages adoption despite high consumer satisfaction post-installation.

This empirical evidence forms a strong basis for policy recommendations aimed at enhancing vendor accountability, streamlining DISCOM operations, and revising subsidy frameworks in Uttar Pradesh's solar adoption strategy.

11. Discussion and conclusion

In light of the policy review and stakeholder perspectives, Uttar Pradesh has the potential to lead India's energy transition given its high energy consumption-based potential (17 MW). However, to fully leverage this potential, policy interventions and a focused awareness strategy must be implemented effectively. The following recommendations are structured by priority to ensure strategic implementation.

A. Short-Term (Immediate Action)
1. **Effective Execution of PMSG: MBY**
   (i) Address technical glitches in the National Portal for Rooftop Solar (NPRS).
   (ii) Implement automatic feasibility approval for project capacities < 10kWp in line with MoP guidelines.
   (iii) Temporarily ease the **Domestic Content Requirement (DCR) policy** until domestic PV cell manufacturing and supply become robust.
   (iv) Establish fixed timelines for central subsidy disbursal.
   (v) Implement fortnightly/monthly data-sharing mechanisms for state agencies via NPRS.
2. **Resolving Net Meter Supply and Verification Challenges.**
   (i) DISCOMS must ensure timely availability of calibrated net meters.
   (ii) Streamline verification processes for RTS installations to reduce approval delays.
3. **Enhancing Vendor Activeness.**
   (i) Monitor inactive vendors, initiate dialogue, and provide support for engagement.
   (ii) Improve the vendor-to-application conversion rate by incentivizing active participation.
4. **Fostering Consumer Awareness and Behavioural Change.**
   (i) Recognize RTS adopters as "Champions of Change" to leverage peer influence.
   (ii) Launch targeted campaigns emphasizing net metering benefits and the National Portal for Rooftop Solar.

B. Medium-Term (Scalable Enhancements)
5. **Expanding State Subsidy Beyond 3 kW for Residential RTS.**
   (i) Introduce a scaled subsidy structure similar to Gujarat's SURYA scheme (40 % subsidy up to 3 kW, 20 % subsidy beyond 3 kW).
   (ii) Encourage large-scale RTS adoption for private residential consumers.
6. **Optimizing Net Metering Policy.**
   (i) Remove the restriction of RTS system size linked to sanctioned load.
   (ii) Permit RTS capacity up to 100 % of the distribution transformer capacity.
7. **Enhancing Compensation for Excess Electricity Injected into the Grid.**
   (i) Set competitive feed-in tariffs (~Rs 3.14 per unit) to reduce payback periods.
   (ii) Align compensation rates with states that demonstrate high rooftop adoption (e.g., Gujarat).

C. Long-Term (Structural Reforms)
8. Upgrade endpoint transmission infrastructure (distribution transformers, feeders).
9. Targeted RTS Expansion in Tier-2 Cities & Rural Areas
   (i) Prioritize adoption where DISCOMs face high cross-subsidization losses and AT&C reductions.
10. **Strengthening Post-Installation Service Ecosystem**.
   (i) Standardize equipment specifications to ensure local availability of service centres.
   (ii) Expand ITI/Diploma training modules for RTS-specific certifications.
   (iii) Scale Suryamitra Skill Development Programme to build a trained workforce for maintenance services.

12. Limitations and scope

This study evaluates residential rooftop solar (R-RTS) adoption in Uttar Pradesh through a mixed-methods approach, integrating policy analysis, stakeholder consultations, and comparative assessments. While the research provides a structured roadmap for enhancing R-RTS deployment, certain limitations must be acknowledged.

The geographic scope is confined to Uttar Pradesh, limiting direct applicability to states with differing regulatory frameworks, consumer profiles, and market conditions. Stakeholder insights, drawn from vendor and consumer surveys, reflect prevailing adoption trends but are subject to potential response biases, such as selective disclosure, perception-based opinions, or hesitancy in revealing operational challenges due to regulatory apprehensions. Additionally, there were constraints in accessing granular and updated datasets from DISCOMs and local authorities, which may affect the timeliness and depth of certain policy inferences. While secondary data from MNRE, UPNEDA, and CEA ensures policy alignment, real-time shifts in subsidy mechanisms, regulatory updates, and DISCOM operational practices may require further longitudinal analysis.

To enhance future research, expanding comparative assessments to high-performing states such as Gujarat and Maharashtra, incorporating broader stakeholder diversity including marginalized consumer categories and smaller vendors, and integrating long-term policy impact evaluations would provide deeper insights into the evolving dynamics of rooftop solar adoption in India.

CRediT authorship contribution statement

Ashish Tiwari: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **R.K. Mall:** Writing – review & editing. **Maheswar Rupakheti:** Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ashish Tiwari reports a relationship with Uttar Pradesh Forest Corporation, Aranya Vikas Bhavan, 21/475 Indira Nagar Lucknow under Uttar Pradesh Environment, Forest and Climate Change Department that includes: employment. NA If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enbuild.2025.116283.

Data availability

Data will be made available on request.

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