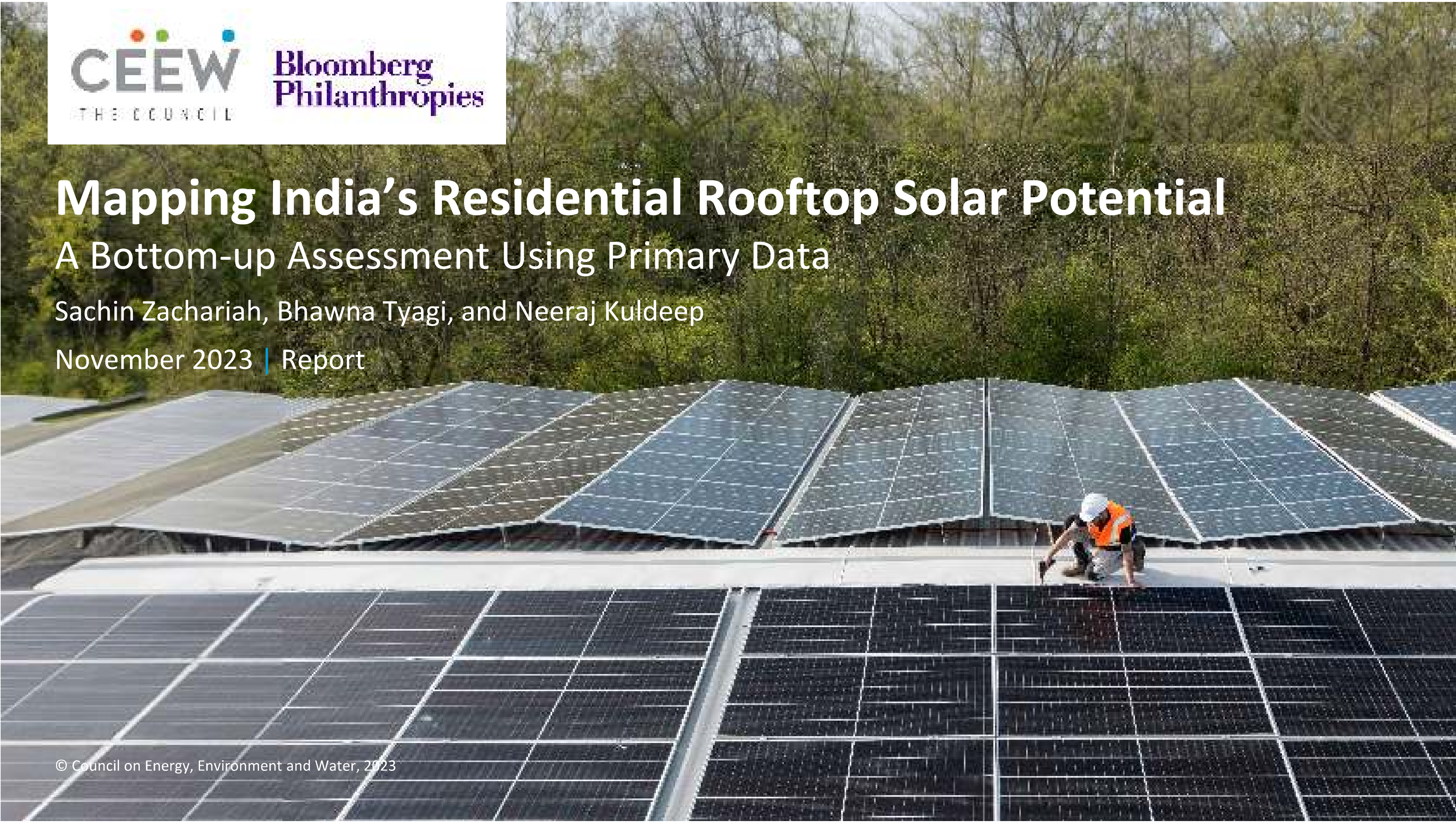


Mapping India's Residential Rooftop Solar Potential

A Bottom-up Assessment Using Primary Data

Sachin Zachariah, Bhawna Tyagi, and Neeraj Kuldeep

November 2023 | Report


Image: iStock

Contents

Image: CEEW

Key highlights

Rooftop solar potential in India

Image: CEEW

637 GW of residential rooftop solar (RTS) potential in India

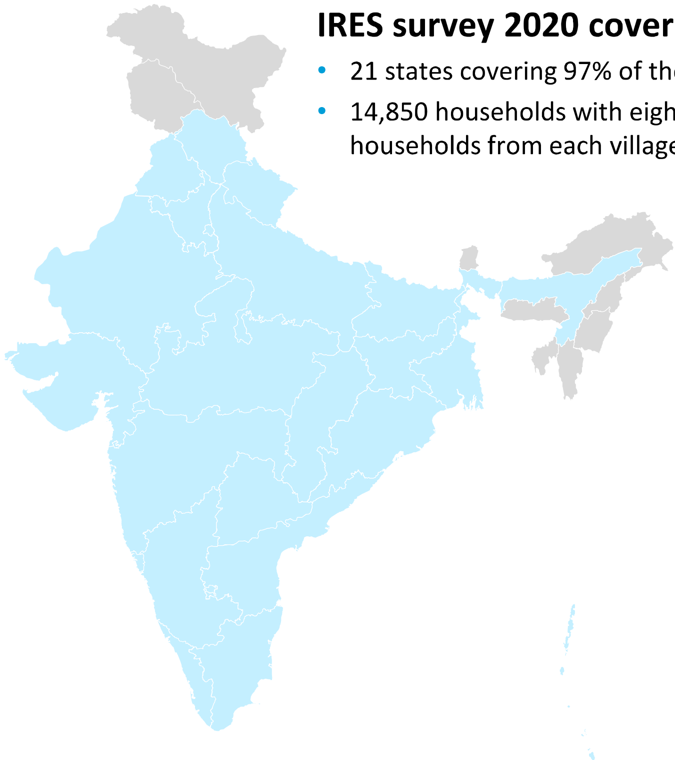
Technical potential → **Economic potential** → **Market potential**

637 GW
All suitable rooftops are entirely covered with solar.

118 GW
Restricting rooftop solar (RTS) size to meet households' electricity demand.

~102 GW
Estimation based on economic viability (Net present value > 0).

~11 GW
Based on consumer willingness to pay and payback in a five year period.



IRES survey 2020 coverage

- 21 states covering 97% of the population
- 14,850 households with eight households from each village/ward

- Unlocking the technical potential in the residential segment requires introducing innovative business models to utilise excess roof space.
- This can play a significant role in India's energy transition and contribute towards its renewable energy (RE) target of 500 GW of installed capacity by 2030.

Source: Authors' analysis.
Note: Potential assessment based on the India Residential Energy Survey (IRES) dataset. The estimated RTS potentials are without any capital subsidy.

Decoding rooftop solar potential at the national and state levels

National-level insights

Technical potential reduces to one-fifth when system size is restricted to meet households' electricity consumption **due to lower electricity consumption per sq ft.**

In total, 85% of the technical potential is concentrated in RTS systems size between 0-3 kW as **electricity consumption across states in India is concentrated in the lower slabs.**

In total, **~30%** of the technical potential lies in the 0-1 kW category. However, **this category is not recognised in policy and subsidy schemes.**

The decline in technical potential is higher in rural areas due to low electricity demand per sq ft (6.8 kWh per sq ft) compared to urban areas (7.7 kWh per sq ft).

The Ministry of New and Renewable Energy (MNRE) subsidy[1] is effective for an RTS system size of 1-3 kW, and can increase the economic potential by ~5 GW by making systems economically feasible for more consumers with no change in system sizes above 3 kW.

Source: Authors' analysis.

Note: 1. Capital subsidy of INR 14,558 per kW for 1-3 kW RTS category under MNRE Phase II RTS scheme.

Decoding rooftop solar potential at the national and state levels

State-level insights

More than 60% of the technical potential is concentrated in **seven states** in India.

A significant decline in technical potential is witnessed in states such as Assam, Bihar, Odisha, Madhya Pradesh, Rajasthan, Jharkhand, and Uttarakhand **due to the large share of households with low energy consumption per sq ft.**

Net-metering regulations further reduce the economic potential from 102 GW to ~81 GW, due to minimum kW restriction limits for RTS in 15 states. For West Bengal, the potential reduces to zero due to a minimum limit of 5 kW.

Flat MNRE capital subsidies increase the economic potential in states by making systems economically viable.

Consumer awareness about solar is < 60% in most of the states. Awareness in urban areas is only 6% higher than rural areas.

Consumers in most states find RTS systems to be costly, making them averse to buying them.

Source: Authors' analysis.
Note: 1. Capital subsidy of INR 14,558 per kW for 1-3 kW RTS category under MNRE Phase II RTS scheme.

Unlocking the rooftop solar potential in the residential sector

Recommendations

Policy and regulatory interventions

- **Introducing targeted capital subsidies**, particularly for RTS systems of size 0-3 kW.
- **Recognising RTS systems of <1 kW,** both in policies and regulations, as significant potential lies in this category.

Consumer-centric interventions

- **Rolling out a national awareness campaign** to generate a more significant demand for RTS.
- **Creating one stop platform at the state level** to provide consumers basic, reliable, and compelling information about RTS.

Market-driven interventions

- **Unlocking untapped potential by moving beyond traditional models** to overcome constraints such as limited roof space, ownership of roofs, and capital constraints.
- **Introducing low-cost financing options** with a fast approval process and a separate line of credit for residential consumers.

 Source: Authors' analysis.

01 Study background

Image: CEEW

Solarising India's households for an accelerated energy transition

Establishing the need for RTS

As of 2022, Indian households consume about a fourth of the total electricity sold annually (1317 billion units). Consumption in the residential sector is likely to double by 2030 as per the projections of the 20th Electric Power Survey of India. This will be fuelled by growing per capita electricity consumption, rapid urbanisation, and a return to normalcy after the COVID-19 pandemic.

Shifting existing and future household electricity needs to clean energy remains critical to achieving India's nationally determined contributions (NDCs) targets and deep decarbonisation of the economy in the long run.

Limited residential RTS deployment

RTS provides an excellent opportunity for Indian households to contribute significantly to the ongoing energy transition by substituting their electricity consumption with solar. As of August 2023, India has installed about 11 GW of RTS capacity against 55.3 GW of utility-scale projects. Further, the share of residential rooftops is only 21 per cent of the total RTS capacity, given that RTS adoption is largely skewed towards commercial and industrial consumers.

Key rooftop solar policy initiatives

Over the years, the MNRE and states have introduced a slew of policy, regulatory and market initiatives to promote RTS among residential consumers. Some of these key initiatives include the National Rooftop Solar Portal, which has a simplified RTS adoption procedure, direct benefit transfer for capital subsidy under the *Central Financial Assistance scheme* and provision of net-metering, among others.

Source: CEA, 2023; NREL; MNRE; Bridge to India

Solarising India's households for an accelerated energy transition

Assessment of rooftop solar potential is crucial for targeted intervention

The residential rooftop sector requires targeted policies and market interventions to accelerate growth in RTS adoption. This necessitates an in-depth understanding of RTS potential across the entire consumer strata. There is a dearth of studies that estimate the potential of RTS for residential consumers in India. Existing studies on RTS potential are based on secondary literature and provide limited understanding with no information on state-wise potential.

Approach to estimate the rooftop solar potential

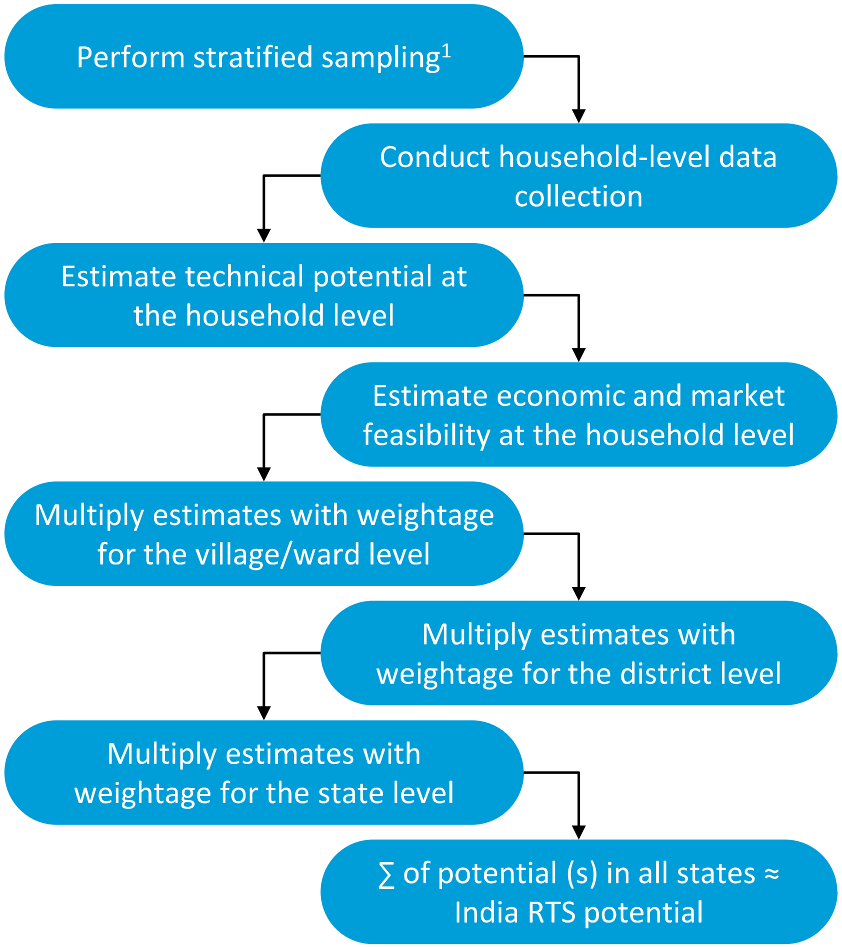
The true economic and market potential can be captured only by considering households' economic strength and energy footprint. We conduct a detailed assessment of the technical, economic, and market potential of households in India by adopting the bottom-up approach. The assessment further provides insights on the RTS potential of different states, the urban-rural split, and potential for different system sizes.

Source: CEA, 2023; NREL; MNRE; Bridge to India

02 Approach

Image: CEEW

Bottom-up approach



Types of potential

Resource potential

The amount of sunshine over the roof area that can be used to generate electrical energy using a solar PV system.

Technical potential

The capacity of a solar PV system that can be installed on a rooftop, accounting for factors such as rooftop availability and energy consumption of the house.

Economic potential

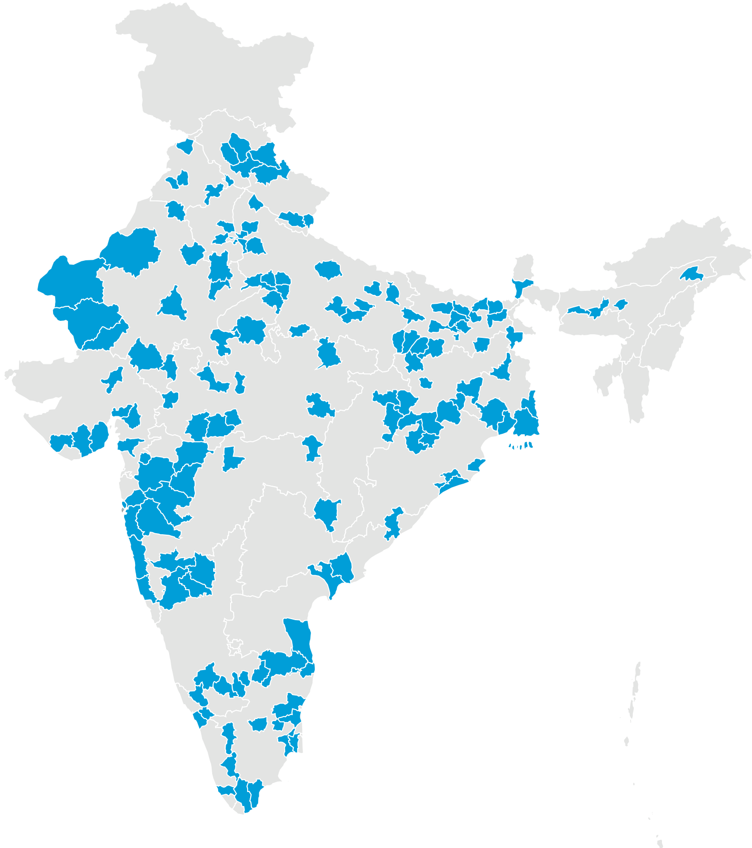
The portion of technical potential that is economically feasible i.e. the net present value of savings that is greater than the expenses of setting up a system.

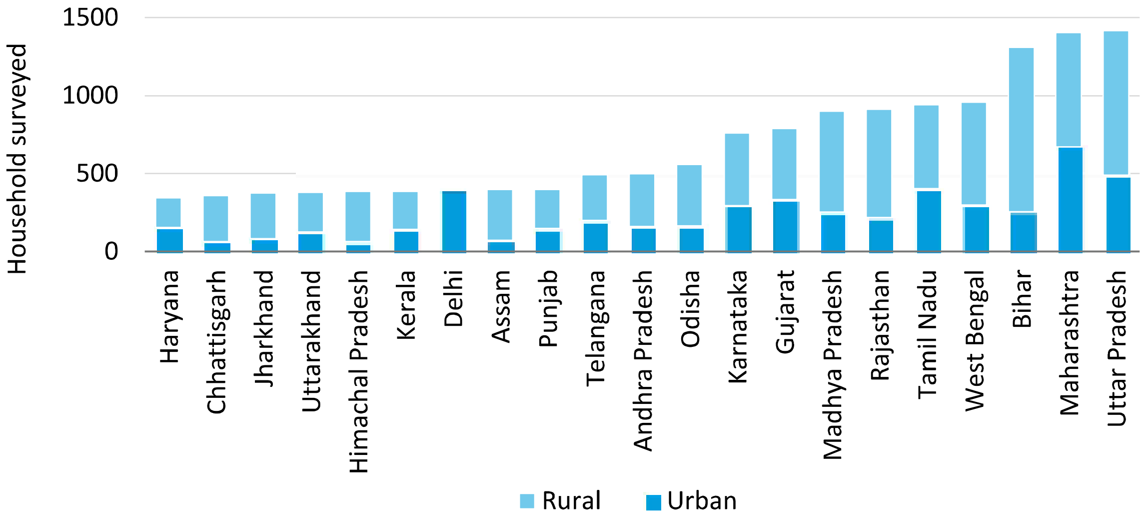
Market potential

The portion of economic potential where either the payback period of the solar PV system is less than five years or consumer willingness to buy is positive.

1. Sampling approach is provided in detail in the annexures.

Data on Indian households captured through the India Residential Energy Survey (IRES)





IRES survey 2020 coverage:

- 21 states covering 97% of the population. Data consists of 66% rural and 34% urban households.
- 152 districts selected through cluster sampling
- 1210 villages and 614 urban wards through cluster sampling
- 14,850 households with eight households from each village/ward

Source: Agrawal, Shalu, Sunil Mani, Abhishek Jain, Karthik Ganesan and Johannes Urpelainen. 2020. India Residential Energy Survey (IRES) 2020: Design and data quality. New Delhi: Council on Energy, Environment and Water.

Decision tree to estimate residential rooftop solar potential

Resource potential

Parameters used for calculation

- State weather profile
- States rooftop area available

Technical potential
Rooftop area based

Parameters used for calculation

- Rooftop area
- Rooftop availability factor[1]
- Rooftop sustainability factor[2]

Technical potential
Consumer energy consumption based

Parameters used for calculation

- Consumers’ energy consumption
- Rooftop area

Minimum of technical potential {Rooftop area, energy consumption}

Economic potential = {Technical potential, if system is economically viable 0, if system is economically unviable}

Economic potential

Systems economically viable if NPV> 0

Parameters used for calculation are

- RTS system cost[3]
- Energy consumption
- Retail electricity tariff

Market potential = {Yes, if consumer is interested and NPV_5>0 or consumer is not interested but NPV_5 > 0; No, otherwise}

Market potential

Parameters used for calculation

- Payback period less than five years
- Consumers willingness to install RTS

Notes: 1. Rooftop availability factor determines the availability of roof space for installation after accounting for shading, obstructions, and other constraints.
2. Rooftop suitability factor determines the suitability of the roof to put up the system for 25 years.
3. The RTS system cost is considered without subsidy.

03 National estimations for RTS potential in the residential segment

Image: CEEW

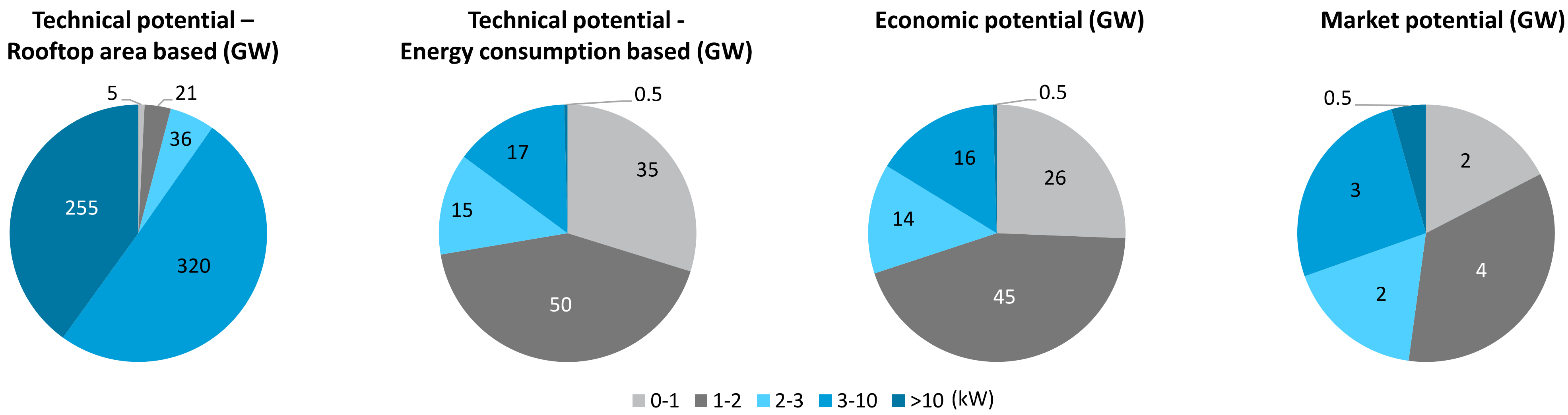
India's households can deploy more than 600 GW of rooftop solar

Potential	Capacity	Basis	Explanation
Technical potential	637 GW	All suitable rooftops are covered with solar.[1]	**Technical potential reduces to one-fifth after limiting the system size by electricity consumption**. This is primarily driven by **lower electricity consumption per sq ft in most of the states in India**.
Economic potential	118 GW	RTS size equal to a household's electricity demand.	Most residential consumers fall in low consumption slabs – **(0-100) and (100 – 300) kWh per month**. Typically, these consumers receive electricity at a subsidised rate to make electricity affordable for them.
	~102 GW	Estimation based on economic viability (NPV > 0).	**As a result, low residential electricity tariff rates reduce the economic viability** of rooftop systems even though they are technically feasible. This **reduces the technical potential by 16 GW** to arrive at economic potential.
Market potential	~11 GW	Based on consumer willingness to pay and payback period.	The **potential reduces further to 11 GW** when the payback period is restricted to five years and with consumers' limited willingness to pay. This is primarily driven by lower electricity tariff rates and high system costs, making the system unable to recover the investment cost in five years, further worsened by limited consumer awareness about the benefits of RTS.

Source: Author's analysis

Note: 1. For rooftop with shading, only 50% of the space is considered available for RTS. 2 The estimated RTS potentials are without any capital subsidy.

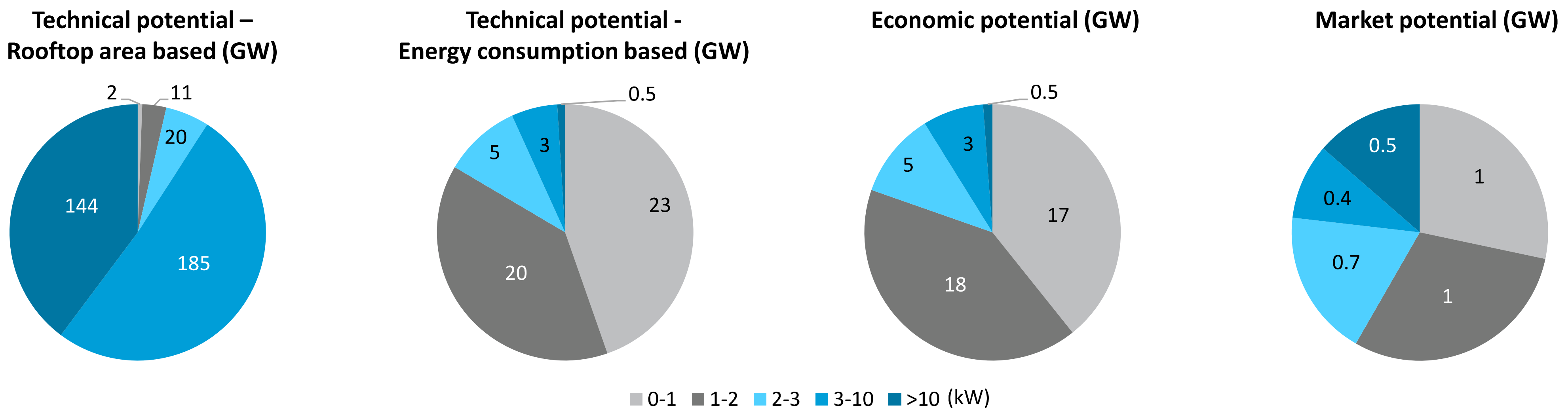
Rooftop solar potential shifts to <3 kW system sizes restricted by electricity consumption



- **Technical potential based on rooftop area is concentrated in system sizes above 3 kW**, indicating the potential for putting up larger systems primarily based on high average rooftop space across states.
- Limiting the system size by electricity consumption reduces and shifts the potential to the <3 kW system size categories as electricity consumption across states in India is concentrated in the lower two slabs – **(0-100) kWh and (100 – 300) kWh per month.**
- Current RTS net metering regulation in most states **restrict the installation of an RTS system to below 1 kW** by specifying the minimum capacity criteria.

Source: Authors' analysis using IRES data.
Note: The estimated RTS potentials are without any capital subsidy.

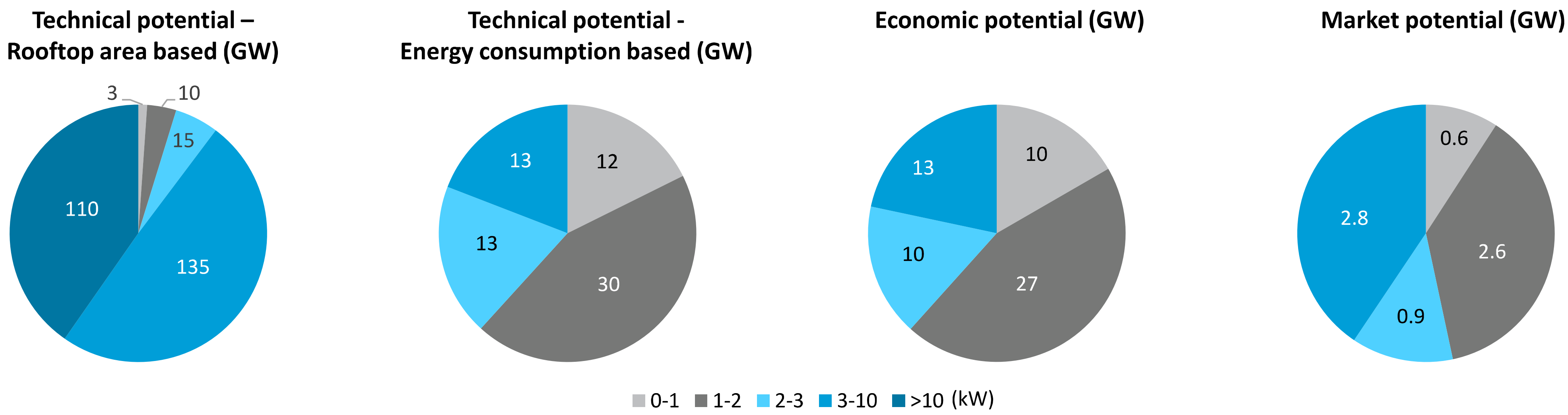
Rural households have abundant space but low electricity demand concentrates economic potential in lower kW categories



- Rooftop area-based **technical potential is higher in rural areas** (~363 GW) due to higher average roof space compared to urban areas (~274 GW).
- The **most preferred system size is less than 2 kW in rural areas** due to lower electricity demand.

Source: Authors' analysis using IRES data.
Note: The estimated rooftop solar potentials are without any capital subsidy.

1-2 kW is the most preferred RTS system size in urban areas



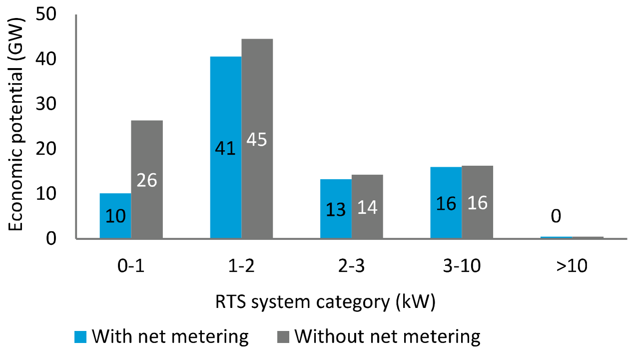
- Technical potential in **urban areas declines by 76%** when we restrict the system size requirement by electricity consumption.
- Economic potential **is higher in urban areas** due to **high electricity demand per sq ft** (7.7 kWh per sq ft) as **compared to rural areas** (6.8 kWh per sq ft).
- **Market potential is skewed in urban areas due to higher economic feasibility and consumers' willingness to buy.**

Source: Authors' analysis using IRES data.
Note: The estimated rooftop solar potentials are without any capital subsidy.

The impact of policies and regulations on rooftop solar potential

Impact of state metering regulations

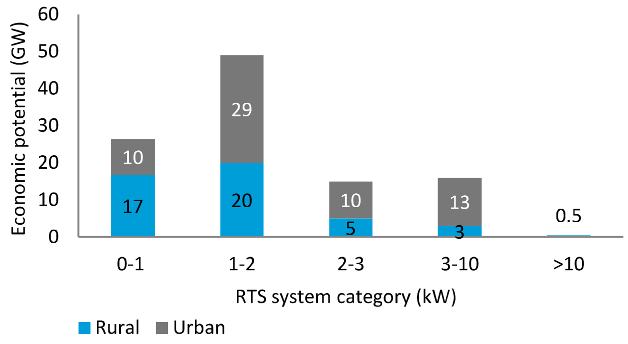
Economic 102 GW → ~81 GW



- Introducing the net metering regulation reduces the economic potential due to the minimum kW restriction limit for RTS in 15 states, ranging from 102 GW to 81 GW.
- Potential reduces to zero for West Bengal due to the minimum limit of 5 kW.
- The maximum limit doesn't have an impact on RTS potential.

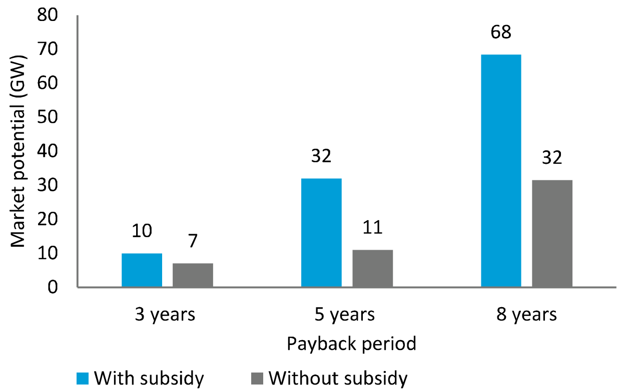
Impact of MNRE RTS subsidies

Economic 102 GW → 107 GW



- The MNRE subsidy is effective for RTS system sizes of 1-3 kW and increase the economic potential by ~5 GW by making systems economically feasible for more consumers.
- No change in potential observed in the 3-10 kW category, implying that the systems were feasible without subsidies.

Impact of variations in payback periods



- Increasing the payback period to eight years increases the market potential significantly as more households are able to recover the investment cost over a longer timeframe even with low electricity consumption.
- The market potential increases further on introducing an MNRE capital subsidy as it makes RTS feasible for more households with a five year payback period.

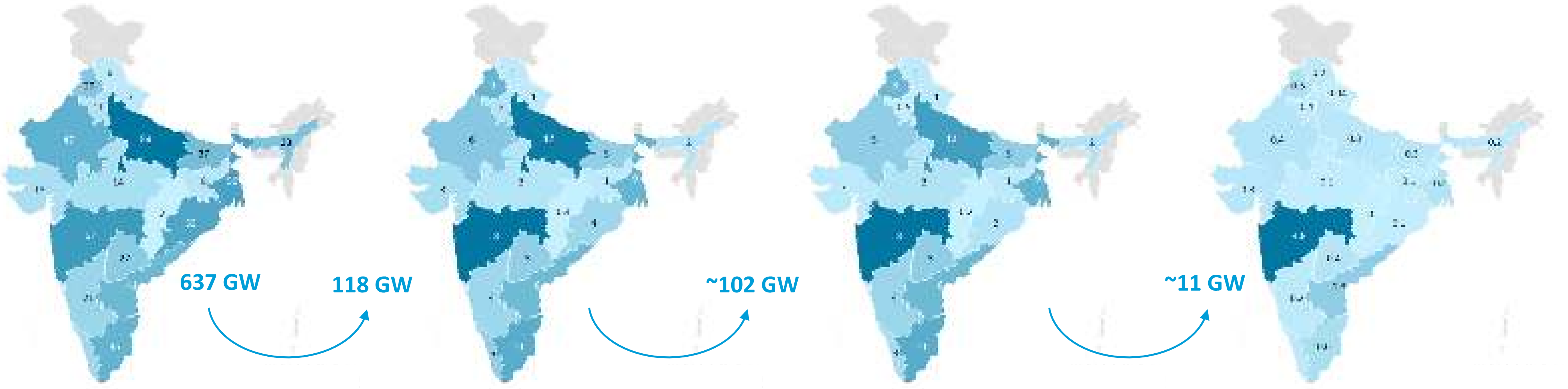
Source: Authors' analysis.

Note: 1. Net metering regulation specify the minimum and maximum system sizes that can be installed as grid-connected systems. 2. Capital subsidy of INR 14,558 per kW for the 1-3 kW RTS category under the MNRE Phase II RTS scheme.

04 State-level estimations for RTS potential in the residential segment

Image: CEEW

~25 crore households could support 637 GW RTS capacity across states



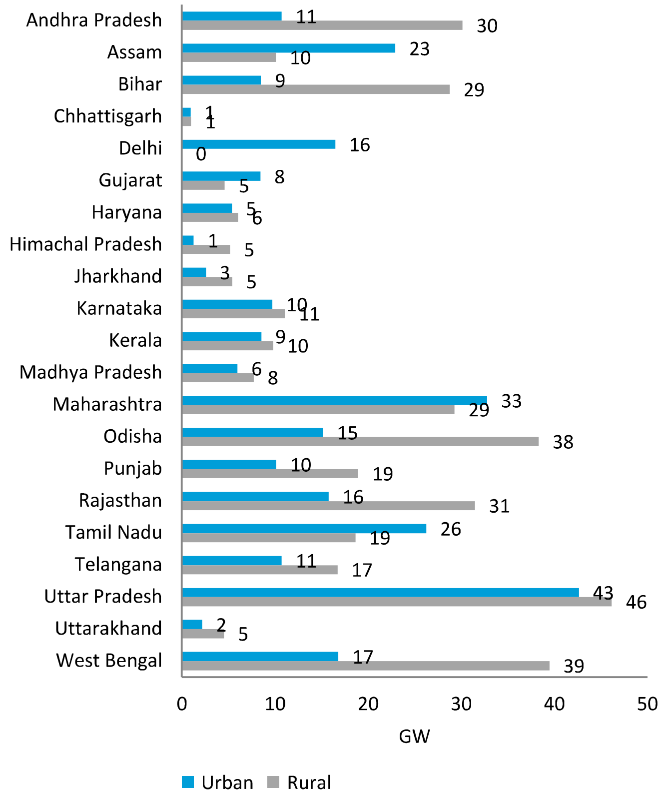
Technical potential – Rooftop area based (GW) | **Technical potential – Energy consumption based (GW)** | **Economic potential (GW)** | **Market potential (GW)**

- RTS potential is spread geographically across states in India in contrast to other renewable technologies such as utility scale solar, wind projects, etc. and could be critical to states' energy transition ambitions
- More than 60% of technical potential is concentrated in seven states in India. One-third of the total technical potential could support the entire electricity demand of the residential sector (~310 TWh), although not all of this demand is in the daytime.
- A significant decline in technical potential is witnessed in states such as Assam, Bihar, Odisha, Madhya Pradesh, Rajasthan, Jharkhand, and Uttarakhand due to the high share of households with low energy consumption per sq ft.

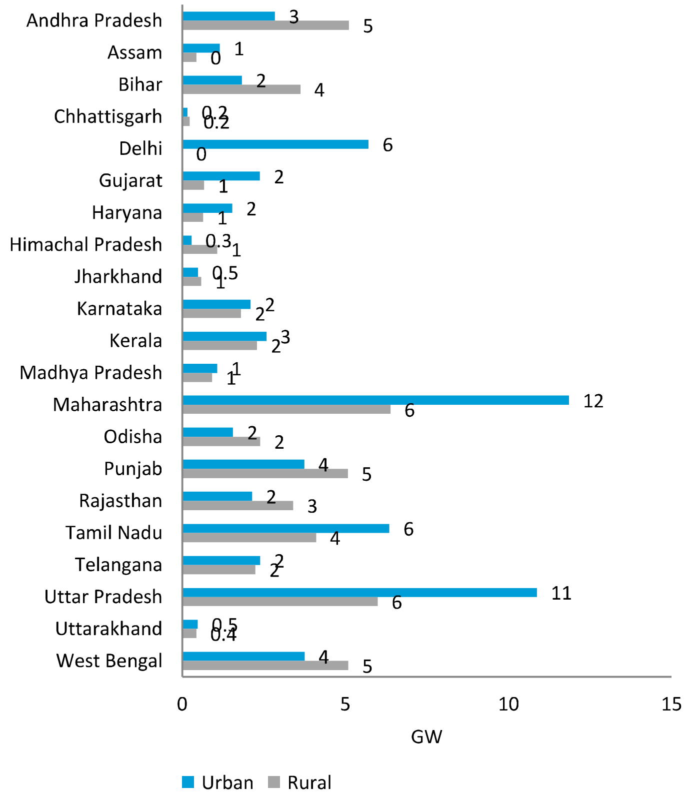
Source: Authors' analysis using IRES data.
Note: The estimated RTS potentials are without any capital subsidy.

Rural strata shows higher technical potential compared to urban areas across states

Technical potential - Rooftop area based



Technical potential – Energy based



Technical potential based on rooftop area is much higher in rural areas (363 GW) compared to urban areas (274 GW)

Technical potential based on rooftop area is much higher in rural areas compared to urban areas in most of the states except Maharashtra, Delhi[1], Tamil Nadu, Gujarat and Assam **due to more rooftop spaces in urban areas in these states.**

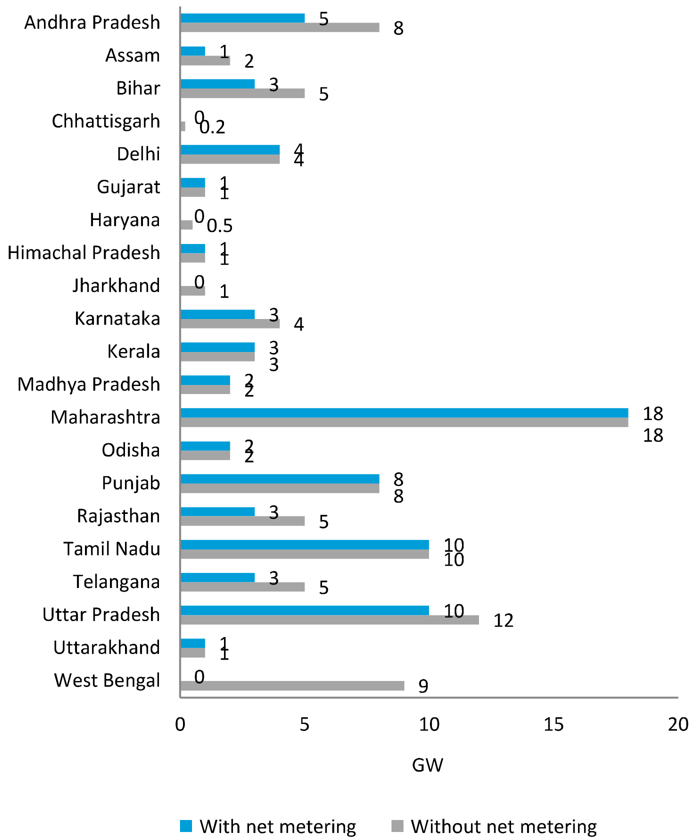
Restricting by electricity consumption, **potential declines across all states due to lower electricity consumption per sq ft, i.e., there is more roof space available than system size needed to meet electricity demand**.

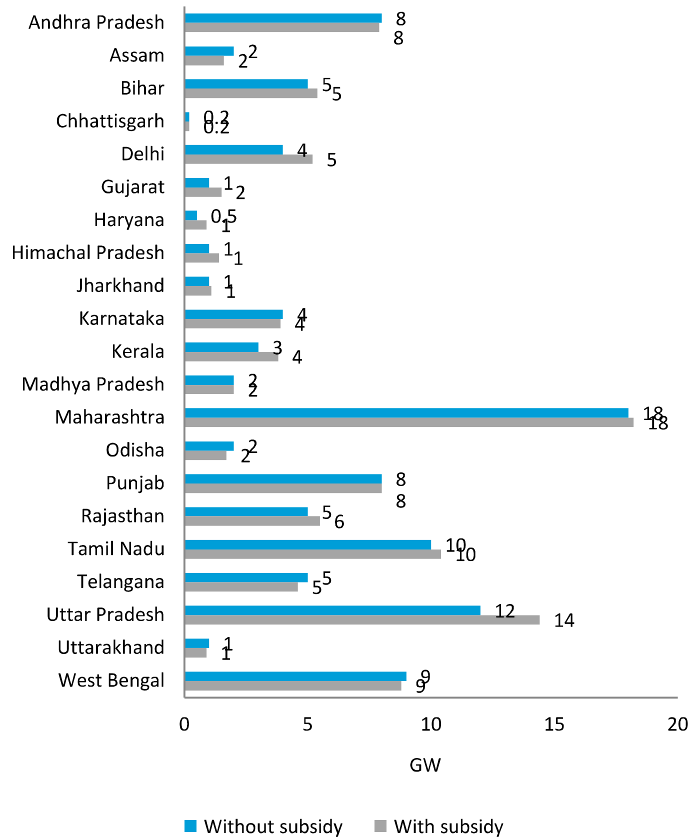
Technical potential based on energy consumption is higher in urban areas (65 GW) than rural areas (52 GW) due to higher electricity consumption in urban areas.

Source: Author's analysis using IRES data

Notes: 1. Delhi has only urban spaces in its region.

Capital subsidies have an impact on economic potential in seven states





Decline in economic potential is higher in states with lower electricity tariff rates making it economically less attractive for consumers to put up systems without upfront capital subsidies.

Lower limits in net metering regulations (i.e. 1 kW and above) **are restrictive in a few states** reducing the economic potential, especially for states with economic potential in the <1 kW category such as Uttar Pradesh, Andhra Pradesh, Telangana, Rajasthan, Karnataka, Jharkhand, and Kerala.

Economic potential declines to zero for West Bengal which has a lower limit of 5 kW and above for RTS systems under its net metering regulation.

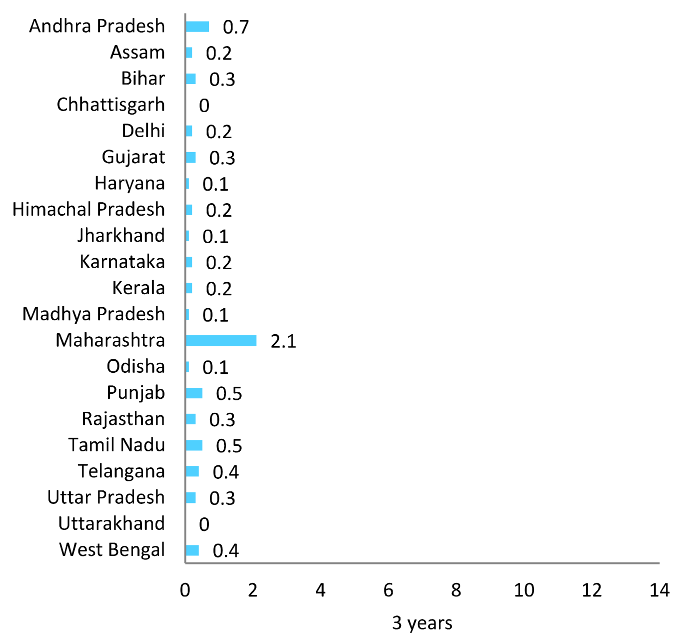
Flat MNRE capital subsidies increase the economic potential in seven states that have witnessed a decline from technical to economic potential by making systems economically viable.

However, there was no increase in economic potential despite introducing capital subsidies in other states.

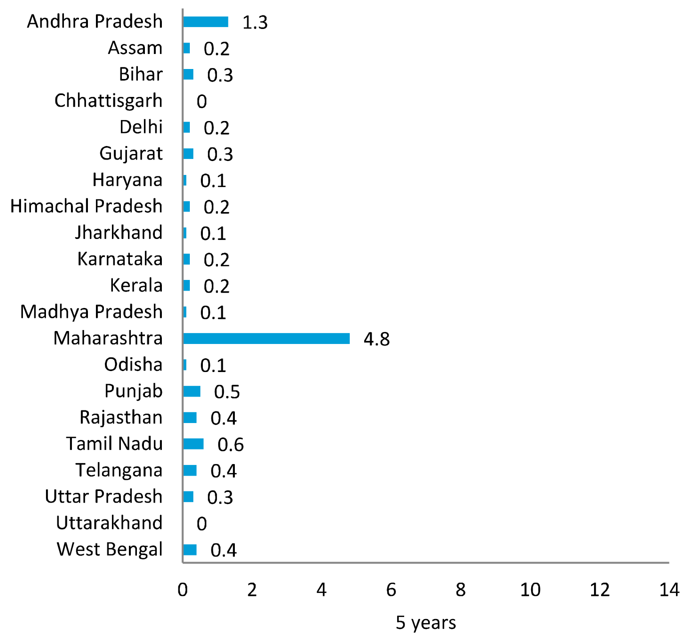
 Source: Authors' analysis using IRES data.

Market potential with different payback periods – without subsidy

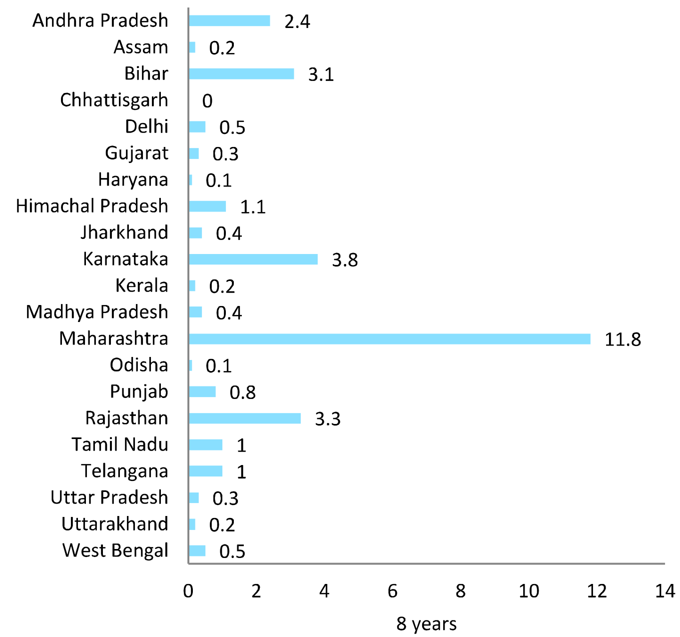
Market potential (GW) **7 GW**



Market potential (GW) **11 GW**



Market potential (GW) **32 GW**

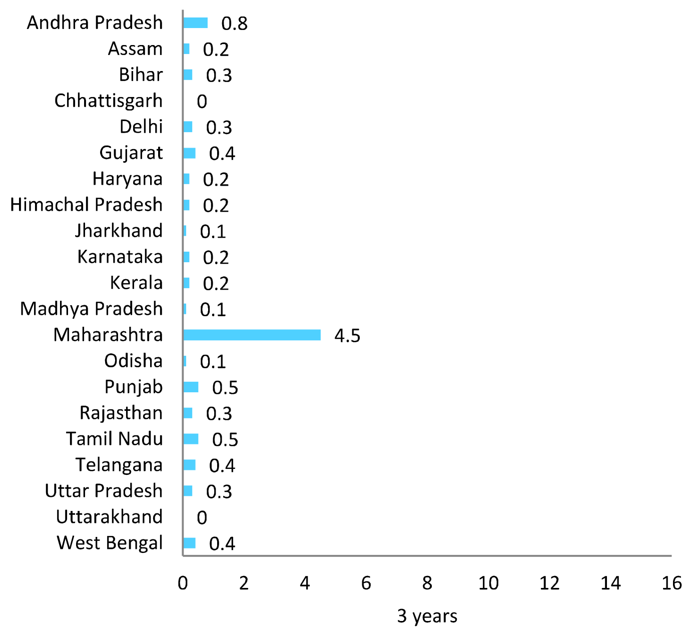


- Considering the consumer willingness to adopt and the payback period (five years), market potential reduces significantly across states to 11 GW.
- Market potential increases by increasing the payback period with significant changes seen in the case of Andhra Pradesh, Maharashtra, Bihar, Karnataka, and Rajasthan.

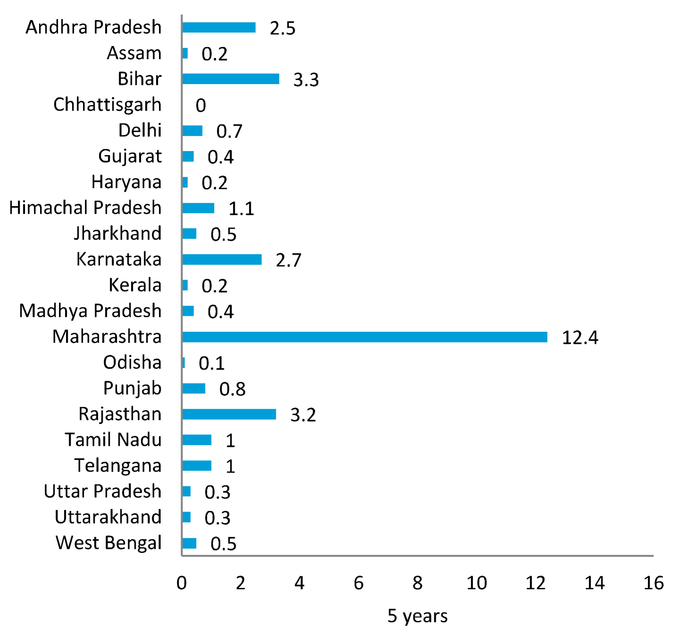
 Source: Authors' analysis using IRES data.

Market potential with different payback periods – with subsidy

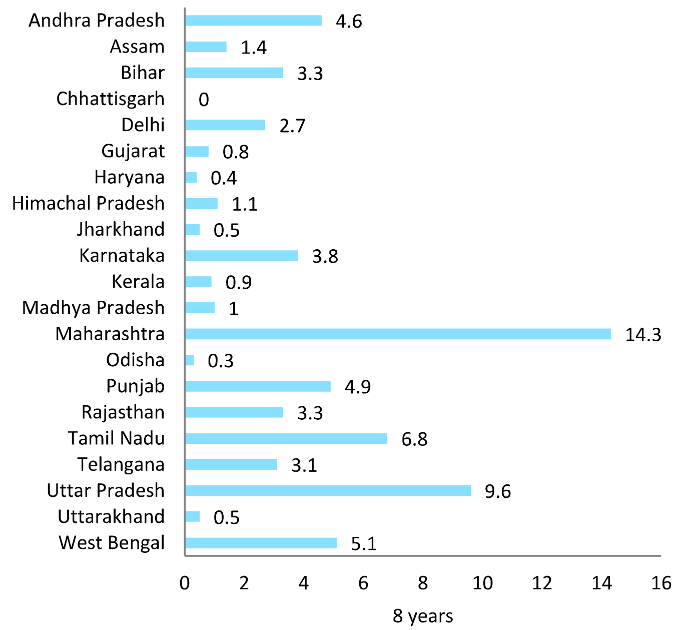
Market potential (GW) **10 GW**



Market potential (GW) **32 GW**



Market potential (GW) **68 GW**



- Market potential increases by three times after introducing a capital subsidy as more systems becomes economically viable. The increase is more than 50 per cent in the case of five-year and eight-year payback periods.
- Systems are not economically viable for most of the states with a three-year payback period due to lower electricity tariff rates.

 Source: Author's analysis using IRES data

05 State-level estimations

Awareness of solar in the residential sector

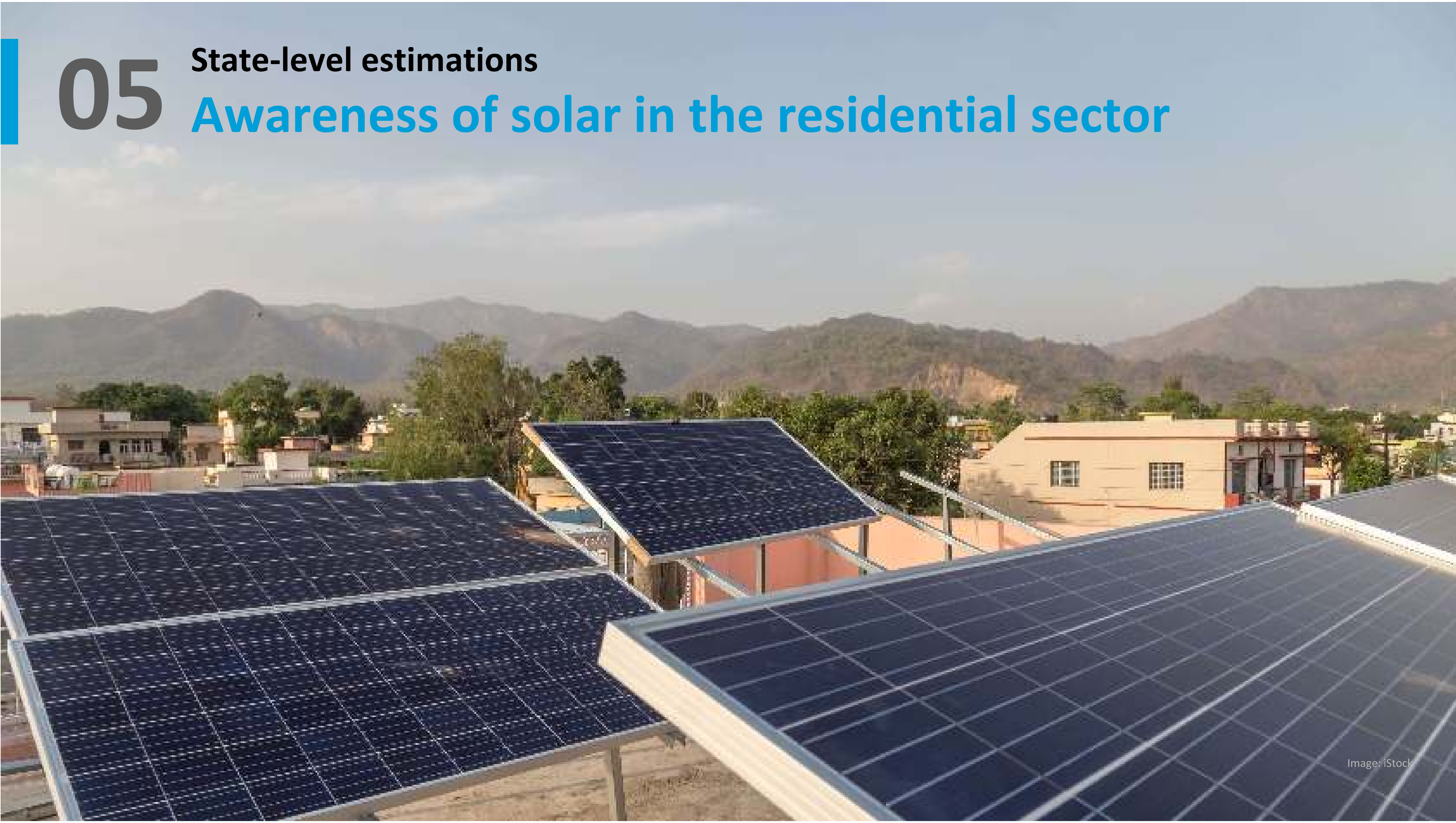
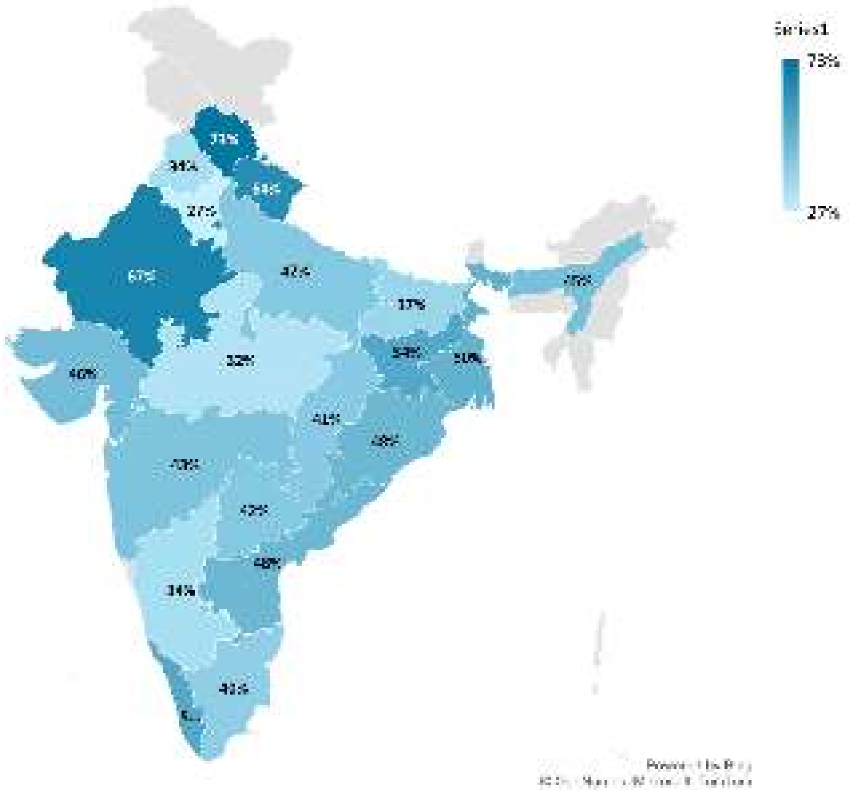


Image: iStock

Less than 50% of consumers in India are aware of solar

Consumer awareness about solar across states in India

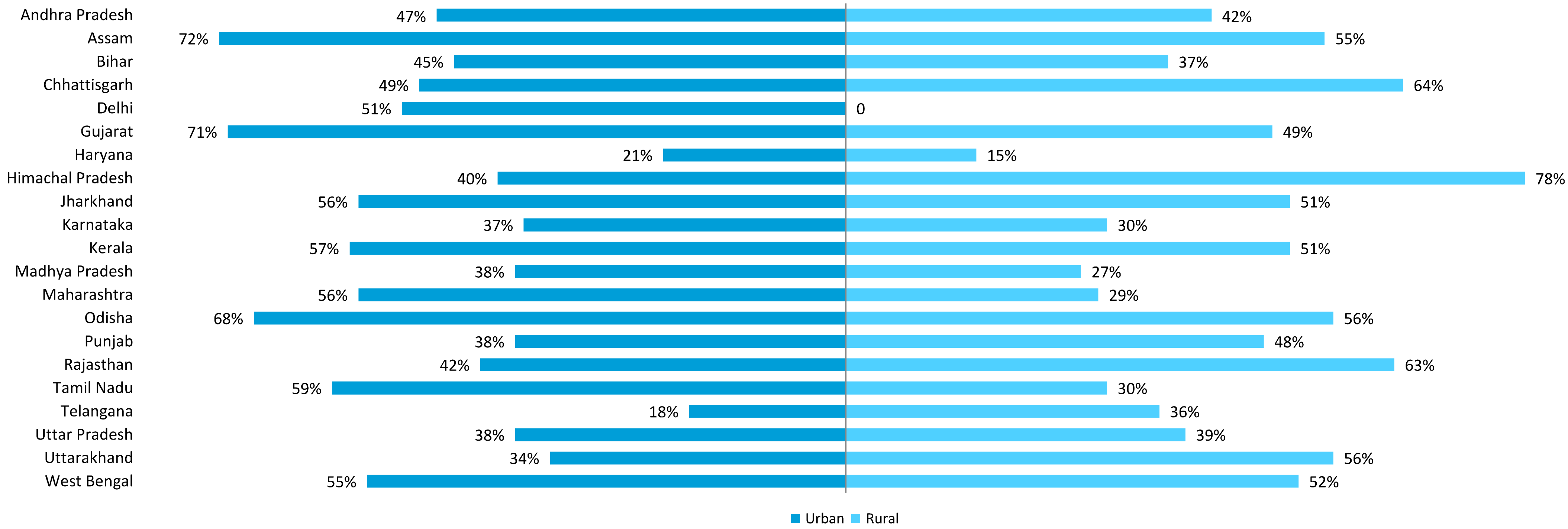


Consumers aware about of solar (%)

- **Consumer awareness of solar is still less than 50%** at the national level.
- **Awareness in most states** is clustered between **30-50%** with only **three states** reporting awareness levels above **60%.**
- The share of awareness in **urban areas is slightly higher than that in rural areas,** but it is still **lower than 50%.**
- **High capital cost and limited awareness** about the RTS systems are **leading barriers across states impacting consumers'** willingness to buy.

Source: Authors' analysis using IRES data.
Note: The survey enquired about consumer awareness of solar home systems used for household electricity needs. .

Awareness levels are higher in urban areas in most states

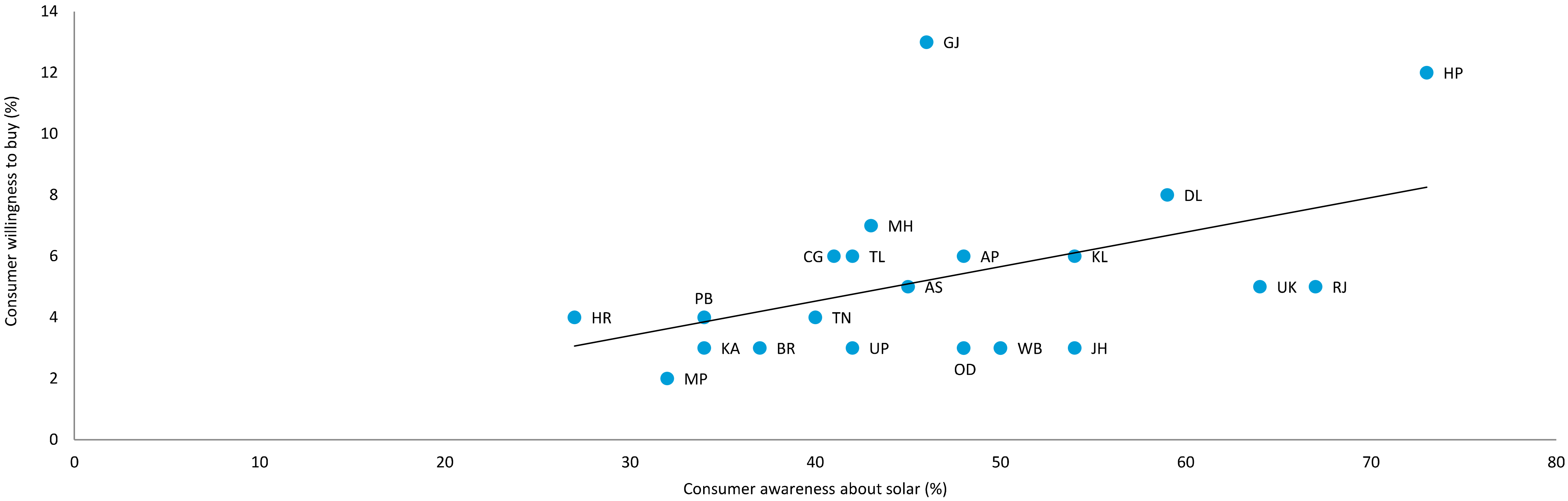


Awareness levels are higher in urban areas in most of the states as awareness campaigns are largely targeted at cities. However, awareness in rural areas is largely driven by solar pumps schemes, solar water kiosks, and solar lanterns, among others.

Source: Authors' analysis using IRES data

Note: The survey enquired about consumer awareness of solar home systems used for household electricity needs.

The relationship between awareness and willingness to buy



Mapping states' awareness with consumer willingness to buy showcases a **positive correlation. However, only 25% of consumers' willingness to buy is explained by consumer awareness levels.** There are other factors that also impact the adoption of RTS.

Source: Author's analysis using IRES data
Note: The survey enquired about consumer awareness of solar home systems used for household electricity needs.

06 Unlocking demand potential through targeted interventions

Image: CEEW

What is needed to scale up adoption? (1/3)

Policy and regulatory interventions

There is a need to **introduce targeted capital subsidies** for consumers to maximise economic potential and to ensure the economic viability of different RTS system sizes. This will help to unlock the potential in the residential segment. **RTS potential in the 0-3 kW categories shows the highest increase with the introduction of direct capital subsidies.**

There is untapped potential in the 0-1 kW category. However, current regulations in many states don't recognise <1 kW installations and central subsidies are also not applicable to this category. **There is a need to extend the capital subsidy benefit to the below 1 kW category and recognise it in the solar policies of the state.** It will boost RTS adoption in rural and semi-urban localities across India.

Presently, low electricity tariff rates make the RTS installations economically unviable for consumers. Recognising this barrier, states need to **introduce economically attractive feed-in tariffs** to facilitate solar installations and promote the sustainable growth of the sector.

What is needed to scale up the adoption? (2/3)

Consumer-centric interventions

There is a need to **roll out national awareness campaign** to garner a more significant demand for RTS. Despite significant potential, there is limited willingness to adopt and deployment is skewed towards a few states. A central push supported by state and local interventions is needed. Community-driven demand aggregation campaigns such as Solarise can be targeted.

A one stop platform for consumers at the state level to receive credible information about RTS should be created. The intent is to provide **consumers easy access to basic, reliable, and compelling information. These portals will cover information on** RTS systems, government schemes, virtual/physical system tours, tools for pre-feasibility assessment, etc. They can regularly also host interactive webinars, virtual demonstration tours, doubt-clearing sessions, and competitions.

What is needed to scale up the adoption? (3/3)

Market-driven interventions

Present regulations limit the capacity of systems, thereby, reducing the potential of RTS systems. There is a need to **introduce enabling regulations**, including the recognition of innovative models (such as community solar, solar partners) beyond traditional CAPEX and OPEX models and provisions to implement them.

Upfront capital cost also impacts the adoption of RTS system, making them economically unviable for consumers. There is a need to **introduce low-cost financing options** with a fast approval process and a separate line of credit for residential consumers to the encourage adoption of RTS.

Annexure

Image: CEEW

Estimating the technical potential of a household

Technical potential
(based on roof availability in kW)

→ (Rooftop area (sq ft) x rooftop availability factor (0.7) x rooftop suitability factor(1)) / (100 sq ft per kW)

Technical potential
(constrained by consumption in kW)

→ **Minimum of** {
(Energy consumption for the lifetime of a PV system (kWh) / lifetime energy generation per kW of system (kWh/kW)) **and** (rooftop area (sq ft) x Rooftop availability factor (0.7) x rooftop suitability factor(1)) / (100 sq ft per kW)
}

i.e. **{T.P (kW)_rb, if T.P (kW)_rb < T.P (kW)_cb**
T.P (kW)_cb, if T.P (kW)_rb> T.P (kW)_cb}

where, rb = rooftop area based
cb = restrained by household energy consumption

Estimating the economic potential of a household

Economic feasibility	{Yes if NPV> capital cost No if NPV < capital cost}
Economic potential (kW)	{Technical potential, if the system is economically viable 0, if the system is economically unviable}
Net present value (INR)	$\sum_{n=1}^{25\,yr} Net\ annual\ cashflow * discount\ factor$
Discount factor	$\frac{\mathbf{1}}{(\mathbf{1} + \boldsymbol{discount\ rate})^{\boldsymbol{n}}}$ **where,** n refers to the year
Net annual cashflow (INR)	Annual savings - annual O&M cost
Annual operations and maintenance (O&M) cost (INR)	O&M expenses *(1+ O&M escalation rate)
Annual savings (INR)	$\sum_{\boldsymbol{n=1}}^{\mathbf{12}\ \boldsymbol{months}} (\boldsymbol{Electricity\ bill\ without\ solar} - \boldsymbol{electricity\ bill\ with\ solar})$
Monthly electricity bill	(Monthly energy units consumed * electricity tariff slab rate)
Energy unit carried forward (kWh)	{Units generated - units consumed, if generation > consumption 0, if consumption > generation}

Note: O&M expenses is one percent of the system cost, whereas the tariff rate escalated by 1% every year.

Estimating the market potential of a household

Market feasibility	{Yes, if the consumer is interested and $NPV_5>0$ or consumer is not interested but $NPV_5 > 0$ No, if the consumer is interested but $NPV_5<0$ or consumer is not interested and $NPV_5 < 0$}
NPV_5	$\sum_{n=1}^{5\,yr}(Net\ annual\ cashflow * discount\ factor)$
Market potential (kW)	{Economic potential**,** if market feasibility is Yes; 0, if market feasibility is No}

Assumptions and data sources (1/2)

Assumptions

- Area required for the 1 kW system is 100 sq ft.
- We have considered only pucca houses in our analysis. Therefore, the suitability factor was considered as one.
- For shaded houses, we have considered that 50 per cent of the space can be utilised to put up the system if the area is more than 100 sq ft.
- Degradation rate for systems was assumed to be 1 per cent.
- The temperature coefficient of power is -0.0035.
- The lifetime of system was assumed to be 25 years.
- Electricity demand was assumed to be constant over the years.
- Excess generation is carried forward across months but there is no compensation for excess at the end of year.
- We assumed the systems will be self financed with no subsidy component.
- Electricity retail tariff rates escalated at the rate of 1 per cent.
- O&M was considered to be 1 per cent of the capital cost and escalated at the rate of 3 per cent.
- Discount rate was assumed to be 8 per cent.

Assumptions and data sources (2/2)

Data sources

- Weather profile was taken from the National Renewable Energy Laboratory (NREL).
- RTS system costs were taken from the MNRE Benchmark cost 2022.
- Net metering limits were taken from states' net metering regulations or renewable energy regulations.
- Electricity tariff were sourced from states' latest tariff orders.
- Households data were sourced from IRES survey data 2020.

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