Spotlight on water stress in the Indian power sector

Half of India faces the highest water stress levels in the world. The water consumption impacts of the electricity sector in India in areas that are already under significant water stress should be carefully considered in light of power system flexibility recommendations. The power sector affects water resources in the following ways:

- Agricultural demand shifting and demand response change the timing of water use for irrigation within a day or week.
- Pumped-storage hydro generation changes the reservoir evaporation rates.
- Conventional generation uses water cooling for turbines.

Agricultural demand response

Areas with high potential for agricultural demand shifting overlap with areas of high water stress in India. The water and food production implications of shifting agricultural demand to the middle of the day need further consideration because (1) it has an impact on water efficiency, and (2) it may have an impact on crop yields.

According to local experts, water management (conservation and efficiency) has the highest priority in agricultural decisions, followed by crop yields and only then followed by energy conservation and energy efficiency.

Water efficiency: The irrigation methods used in India already have high evaporation rates and thus low efficiency. By 2030 CEEW estimates that the agricultural sector will be responsible for about 87% of all water withdrawal in India if current irrigation practices such as flood-irrigation continue to be used. Flood-irrigation is a technique used to grow rice internationally. It not only contributes to high water use (5 000 litres of water to grow 1 kg of rice), but it also creates methane (20% of all global methane comes from paddy fields), a powerful greenhouse gas. In India, 20-47% of irrigation water losses could be saved by 2030 to 2050 using different irrigation methods.

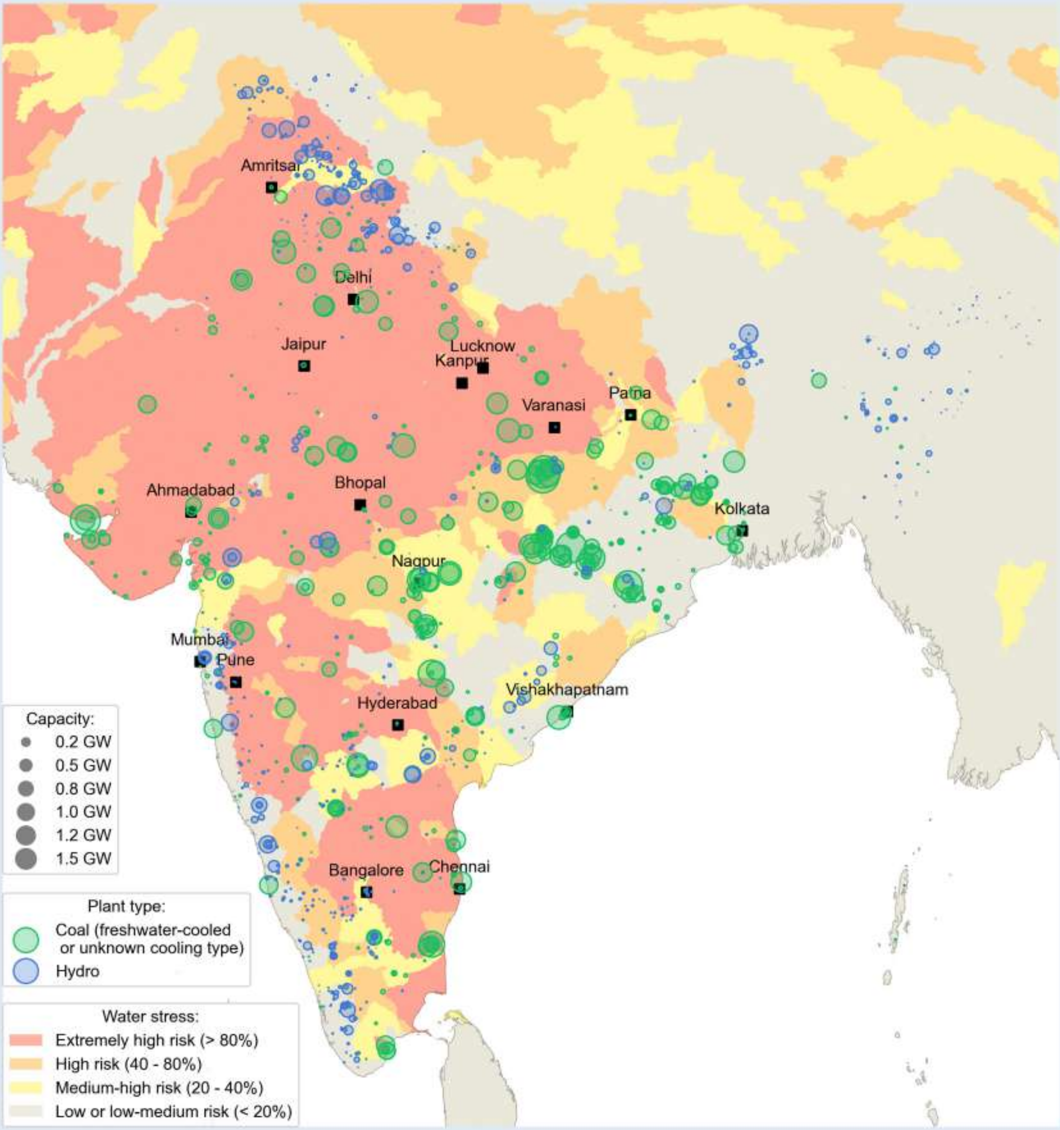
However, the currently low water efficiency could further decline with demand shifting, because water evaporation is significantly higher in the middle of the day than in the morning, late afternoon or evening. The role of agricultural demand shifting as a flexibility option is contingent on a proper evaluation of its impact on the water stress of each region. Further targeted analysis will be required to estimate the more precise impact of demand shifting on water evaporation and water efficiency.

Crop yields: Watering crops in the middle of the day can result in a reduction of crop yields. For example, some plants absorb water less effectively during these hours, and rapid midday water loss means plants cannot get enough water to maintain crop yields and quality.

Pumped-storage hydro

IEA analysis shows that many of the planned pumped-storage hydro plants fall into extremely high water stress areas, for example those in the Northern States, and in Gujarat, Maharasthra and Karnataka. In Gujarat and Karnataka, the impact of pumped-storage hydro retrofits on water management is currently under review by local governments, while publicly available analysis is lacking on the impacts of water evaporation rates and water efficiency.

India's water stress areas, coal and hydro power plants



Sources: Expanded based on analysis presented in India Energy Outlook 2021, based on data from the World Resources Institute Aqueduct Water Risk Atlas and the Platts World Electric Power Plants Database.

Coal power plants

Water availability has already had an impact on India's coal-fired power plants and electricity system: between 2013 and 2016, 14 of India's 20 largest thermal utility companies experienced one or more shutdowns due to water shortages. Additionally, droughts and water shortages caused India to lose 14 TWh of thermal power generation in 2016. IEA analysis published in India Energy Outlook 2021, which mapped existing and under-construction capacity against water stress, found that almost half of India's existing coal-fired plants are in areas experiencing high water stress, and up to 90% rely on freshwater for cooling.

The connections between electricity and water issues can also affect the power sector through extreme weather events. Heatwaves, flooding and drought can change the availability of water resources necessary for the effective use of power system flexibility resources: agricultural demand response, pumped-storage hydro and conventional power plants. Improvements in water management practices may also, therefore, result in a more flexible, secure and resilient power sector.

Cooling demand could become more flexible

Cooling is expected to be the largest source of residential demand growth in the next two decades, with air conditioner stock expected to climb from 30 million today to 670 million in the STEPS in 2040. The large rise in cooling demand is expected to increase the sectoral share of building demand from 41% of India's electricity consumption in 2019 to 48% in 2040. With rising urban temperatures and per capita incomes, the growth in ownership of air conditioners is expected to be led over the coming decades by middle- and low-income households in urban India.

This highlights the importance of energy-efficient cooling in line with the India Cooling Action Plan, launched in 2019, which calls for a 25-40% reduction by 2037/38. Furthermore, cooling demand response has the potential to mitigate the impact of higher cooling demand on generation and grid requirements, and at the same time can become a source of power system flexibility.

The most straightforward option for demand response from cooling relies on the thermal inertia of buildings, allowing limited time shifting of cooling loads without significant impacts on the consumer experience and requiring some form of communication with and control of air-conditioning devices. To illustrate this, allowing around 40% of air-conditioning load in the STEPS in India in 2030 to be shifted within a one-hour time frame saves close to 1% of total system operating costs. Further state-level analysis is needed to estimate the costs and benefits of cooling demand response for each state.

Going further, it is also possible to achieve a much greater degree of flexibility in cooling load with explicit cold storage, for example using chilled water or ice. This can provide flexibility comparable to batteries, but at a cheaper cost where it can be applied to suitable cooling loads. Cold storage is particularly applicable to district cooling systems, which are cost-effective in specific conditions such as high-density urban areas with appropriate environmental factors such as availability of water for cooling. In India, district cooling has so far seen limited development and there is still a need to develop viable business models for the Indian context.

To benefit from cooling demand response, policy makers need to remove the main obstacles to its development. Greater policy focus is required for the deployment of advanced metering infrastructure and targeted economic incentives (such as tariffs, financing and rebates) for commercial and residential consumers.

Spotlight on cooling demand in slums: The case of Mumbai, India

Globally, close to 630 million people living in urban slums are now at risk from lack of access to cooling, including adequate refrigeration, air conditioning and fans, as heatwaves become more prevalent due to climate change. A further 2.2 billion lower-middle-income population are at the risk of an “inefficiency trap”, as they can afford to buy only cheaper and less energy efficient air conditioners, which not only push up their electricity bills, but also raise global space cooling demand.

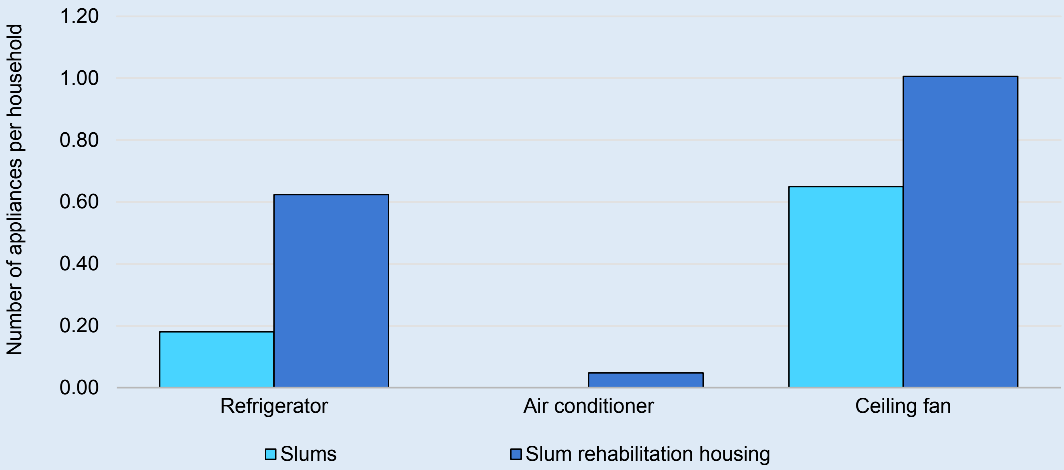
The Pradhan Mantri Awas Yojana (PMAY), a federal affordable housing programme, aims by 2030 to house 30 million people currently living in slums. In 2017 approximately 8% of Indian households in the upper- and upper-middle-income segments had an air conditioner. The Indian Cooling Action Plan aims to increase air conditioner ownership to 21% of households by 2028 and to 40% by 2038. Policy-driven cooling provision for low-income households aims to provide thermal comfort for all, reduce cooling load and increase energy savings in the long term. It stresses strategies such as energy-efficient building envelopes, cool roofs, decentralised renewables-based energy systems and localised heat action plans (Bardhan et al., 2020).

Slum rehabilitation creates an affordable housing project in Mumbai

Source: Image by R. Debnath, 2020.

The rise of cooling energy demand in low-income households is most apparent in Mumbai's slum eradication efforts. Over the last 30 years Mumbai has undergone rapid expansion. It has seen a programme to rehabilitate slum areas by moving residents to new high-rise buildings, called slum rehabilitation housing. Typical cooling device ownership in the slum, on a per-household basis, is estimated at 0.18 refrigerators, 0.65 ceiling fans and 0.00 air conditioners. When households move into the slum rehabilitation housing, their ownership of cooling appliances increases. In this case the per-household ownership of refrigerators increased to 0.62 units, ceiling fans to 1.01 units and the ownership of air conditioners to 0.05 units. This leads to a significant increase in each household's electricity demand for cooling. It also shows that the household energy bills of India's poorest city dwellers are likely to rise as India continues to rehabilitate its slums.

Cooling appliance ownership in Mumbai's slum rehabilitation housing



Source: [Debnath, Bardhan and Sunikka-Blank (2019)](#).

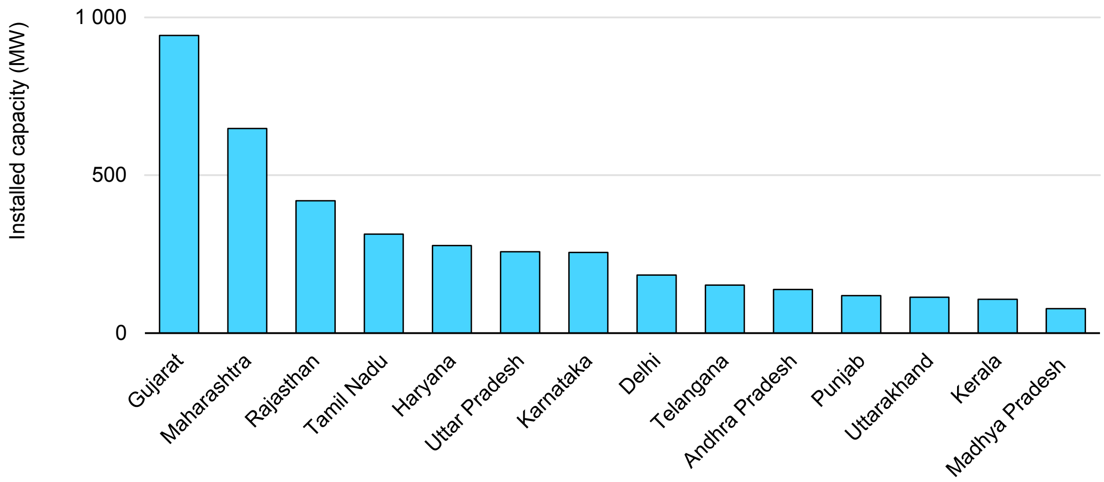
Rooftop solar systems need to be monitored and managed

Rooftop solar and solar pumps can act as proactive demand-side resources that are capable of both meeting electricity demand behind the meter and feeding additional power into local distribution networks. However, state system operators and DISCOMs are concerned about the rise of rooftop solar systems due to their impact on distribution systems and demand forecast uncertainty.

The installed capacity of rooftop solar is increasing in India's states. According to the MNRE, India had a total installed capacity of 4.3 GW of rooftop solar as of February 2021. At the same time Bridge Point data suggest that nearly 6.8 GW of rooftop solar had been installed in India by December 2020. The difference between these two sources includes the large amount of unregistered behind-the-meter installations with reverse flow relays that are not included in the DISCOM databases. More than 70% of the installed capacity comes from industrial and commercial consumers, while the residential sector represents over 16% and the public sector around 12%.

At the state level, Gujarat is the leader in rooftop solar deployment with nearly 1 GW of installed capacity, followed by Maharashtra (647 MW excluding the unregistered behind- the-meter installations), Rajasthan (419 MW) and Tamil Nadu (313 MW). Nine additional states had over 100 MW of installations, including Haryana, Uttar Pradesh, Karnataka and Delhi. The growth of rooftop solar in the leading states has been driven by net metering policies (with a number of policy changes ongoing in 2021).

Installed capacity of rooftop solar PV in selected Indian states, February 2021

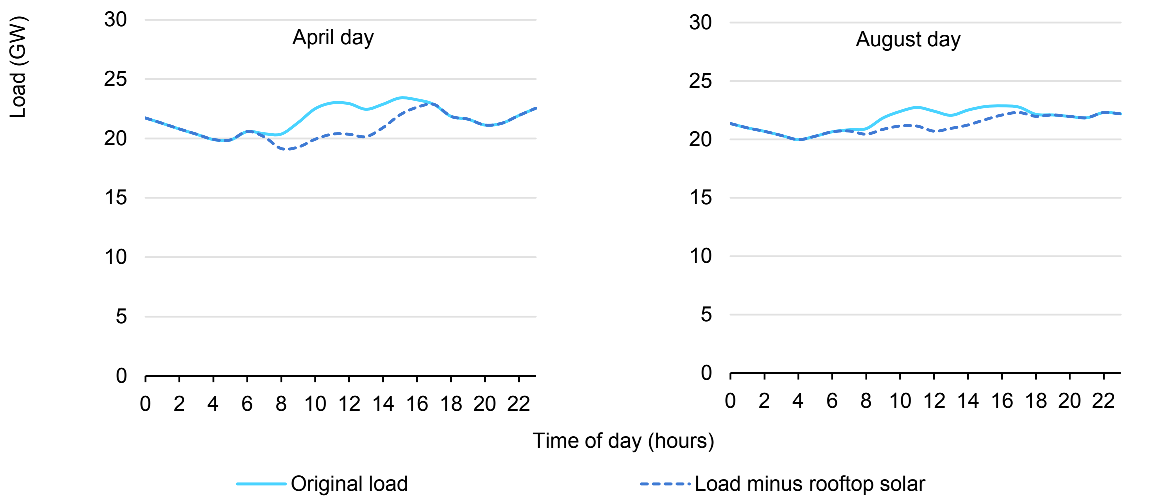


Source: MNRE renewables data.

India has a target of 40 GW of rooftop solar by 2022. Looking at the state-level targets by 2022, a further increase in rooftop solar is envisaged in many renewables-rich states, with the greatest ambitions in Maharashtra with a target of over 4 GW, followed by Tamil Nadu (also over 4 GW), Gujarat (over 3 GW), Karnataka and Rajasthan.

The IEA Gujarat State Model assumes that Gujarat will reach its rooftop target of over 6 GW by 2030. With this increase, the impact at the distribution level becomes much more significant, with implications for demand forecasting, demand variation and local grid management. According to the Gujarat SLDC, there is currently a lack of visibility of distributed solar resources for both distribution and transmission companies. A large number of behind-the-meter rooftop solar systems are not registered or included in the DISCOM databases. Moreover, rooftop solar generation is at present not being monitored in real time, although the DISCOM takes into account rooftop generation as part of the demand forecast submitted to the SLDC, similar to captive generation. In the future, this lack of visibility could lead to significant uncertainties in net demand forecasts and high rooftop solar shares could pose local distribution network issues, including reverse flows and voltage challenges.

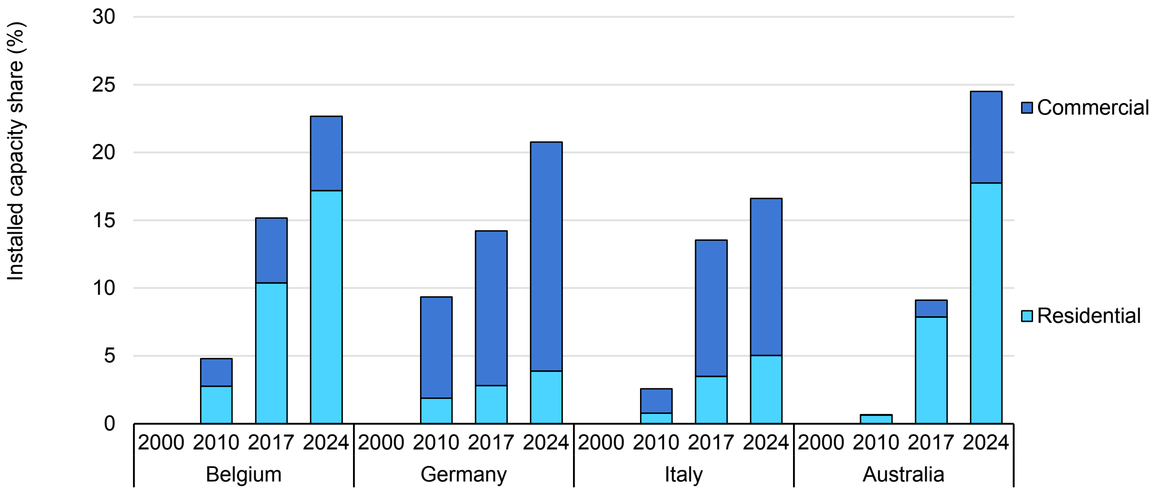
Possible impact of rooftop solar on Gujarat's daily demand at different times of year, 2030



Source: IEA analysis based on rooftop solar targets from the Gujarat government and simulated generation profiles.

The experience of the world's rooftop solar frontrunners provides useful insights for Indian states. The capacity of rooftop solar installations in Belgium, Germany and Australia is forecast to grow significantly, reaching over 20% of total capacity by 2024, well above the level in India at around 3%. The experience of Germany, the United Kingdom, Australia, and the US states of California and Hawaii shows that the visibility of rooftop systems on the demand side can be improved through connection requirements embedded in DISCOM and transmission connection codes.

Rooftop solar capacity (residential and commercial) of selected developed countries, 2000-2017, and projected capacity for 2024



Source: IEA, Renewables 2020.

The German rooftop solar experience, with its over 1.8 million rooftop PV systems by 2020, shows that distributed PV can support the country's low-voltage network with voltage stability and reactive power. Research carried out by the German Agency for International Cooperation (GIZ) shows that PV inverters available in the Indian market are capable of providing reactive power support. The CEA's changes to connectivity regulations (grid code) can unlock this potential in India.

In Australia, the capacity and location of the 2.75 million rooftop solar systems, with a current combined capacity of over 18.6 GW, are tracked through use of the distributed energy registry portal provided by the Australian Energy Market Operator. This register does not provide real-time information, which requires smart metering or alternative forms of monitoring. Even in the state of Victoria, where every household has a smart meter and 21% of all houses have rooftop solar, high-resolution (e.g. hourly) data is not available dynamically to the DISCOMs, but rather, smart meters submit half-hourly data every 24 hours. As rooftop solar output is fairly predictable depending on known weather patterns, this data in conjunction with the weather forecast has been found to provide sufficient insight for the DISCOMs to forecast rooftop solar output.

The main rooftop solar challenges observed in Australia include local network congestion at specific times and points in the network, high local voltage levels (over 102% of nominal voltage) and reverse flows to the distribution system during the day when demand is low. Distribution networks have been experiencing more reverse flows since PV has become cheaper and houses are installing larger systems, with the average size of newly installed systems recently reaching 9 kW. One of the solutions is a software-based approach called dynamic operating envelopes, which is being piloted by DISCOMs. This allows the export limit to the distribution system to be varied according to how much can be accommodated at specific times. National rollout and development of the detailed rules and regulations are currently ongoing. In Australia, rooftop solar currently receives a fixed (non-dynamic) feed-in tariff in most cases. But moving to five-minute settlement on wholesale markets in the future will also provide opportunities for behind-the-meter resources to be rewarded for supporting the system in real time.

In view of these international examples, Indian states could consider actions to improve the visibility of rooftop solar as a first step. State regulators could appoint an entity to develop a distributed solar registry platform available to state DISCOMs, with registration of solar pump and rooftop solar systems to be included in (new and amended) connection requirements. The registry data would ideally be publicly available in an anonymous format and data should also be made available to the SLDC by the DISCOMs. In parallel, the DISCOMs would require consumers to register new installations of distributed solar equipment on the abovementioned platform. The DISCOMs can also develop a roadmap for distributed solar forecasting and assess the technical requirements and potential policies to support more rooftop solar uptake, such as time-of-use tariffs (discussed in the following section) and real-time monitoring included in the Centre for Energy Regulation proposal.

Time-of-use tariffs to drive demand-side flexibility

Electricity pricing and tariff design in India have been significantly influenced by the government's objective to provide universal access to electricity. Affordability of electricity has been another core objective behind the current tariff design.

Hence, average household electricity prices in India in 2019 were lower than the OECD average in nominal terms. However, when adjusting for purchasing power, which better accounts for spending on electricity as a share of Indian household income, household prices are amongst the highest in the world. This is despite the fact that India – like other emerging and developing economies – has higher end-