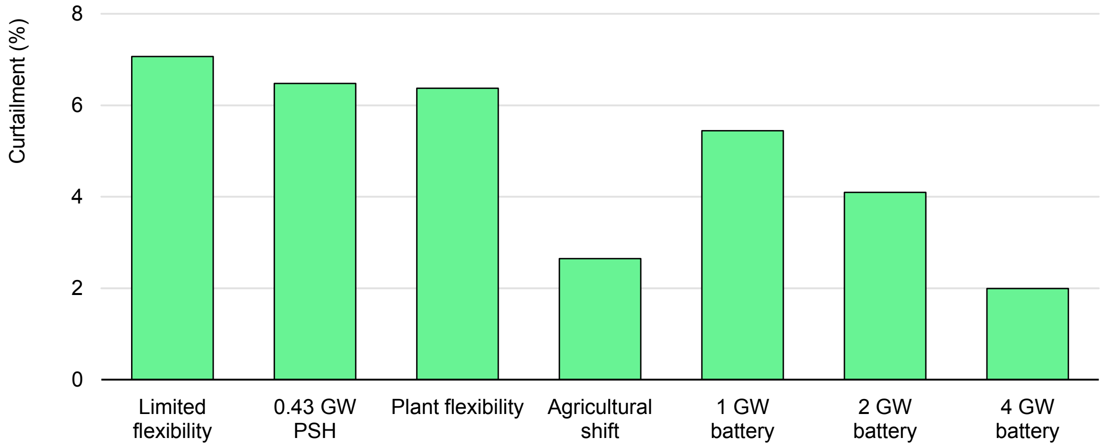
Annual curtailment in different Gujarat power system flexibility scenarios, 2030

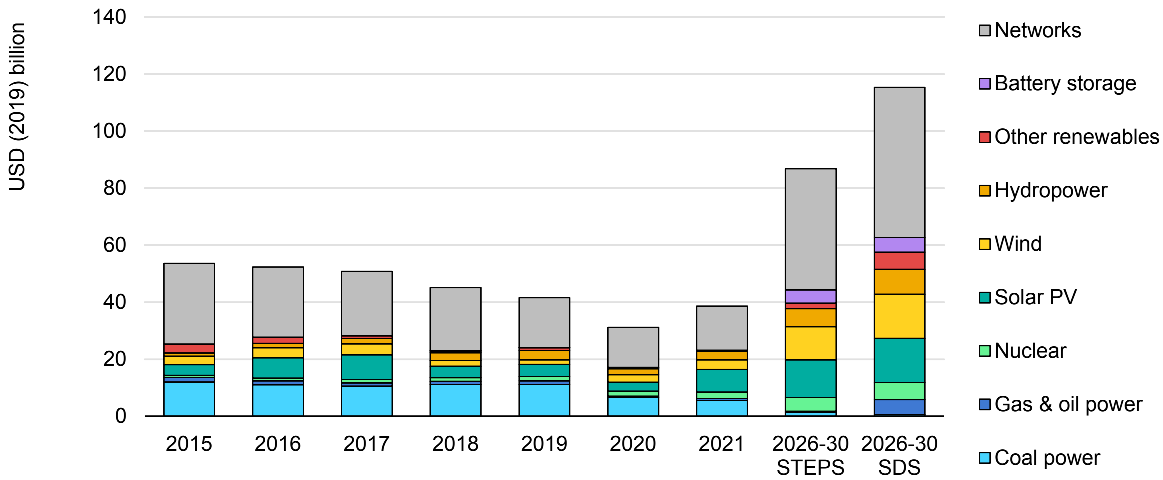


Source: Gujarat Power System Transformation Workshop Report 2020.

Curtailment and investment

Influenced by Covid-19, power sector investment in India fell by USD 10 billion year-on-year to USD 39 billion in 2020, including a decline in solar and wind investment. Improving investor confidence will be an important factor in the coming years as India will need to increase power system investment twofold by 2026 in the STEPS or threefold in the SDS, relative to 2020 levels.

Power sector investment in India, 2015-2030



Source: IEA, Clean Energy Investment Trends 2020.

The increasing solar and wind curtailment and lack of related policies are critical concerns for investors. According to the *Clean Energy Investment Trends 2020* report by the IEA and the Council on Energy, Environment and Water (CEEW), an investor's internal rate of return on solar PV projects declines by 160 basis points for every 2.5% production loss per year. The expectation of future curtailment can therefore significantly increase solar power purchase costs.

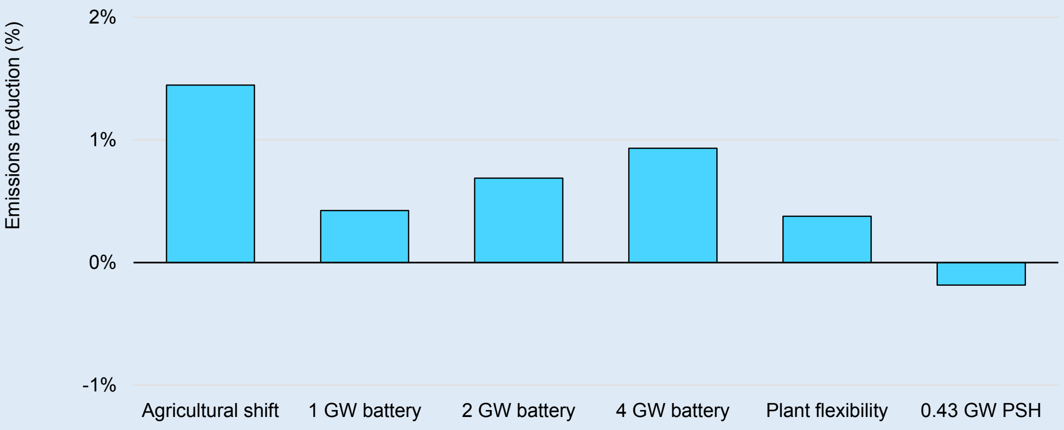
Spotlight on the impact of flexibility options on CO_2 emissions

Flexibility options are key to integrating renewables, and are an integral part of the clean energy transition. At the same time, they also affect CO_2 emissions by influencing the final generation mix. Avoided curtailment is a straightforward case, whereby flexibility options allow a higher amount of renewable generation to be utilised and thereby reduce emissions. This is illustrated at the all-India level, where emissions in the India Regional Model in 2030 with all flexibility options are 4% lower than in a downside case where needed flexibility from power plants, demand response, energy storage and grids does not materialise. This is primarily due to the improved integration of renewables and avoided curtailment as a result.

Some flexibility options result in higher emissions even if they reduce curtailment in Gujarat

In Gujarat, for most 2030 flexibility scenarios, emissions fall relative to the inflexible case. However, some flexibility options may have the unexpected effect of higher emissions than the less flexible case. This is illustrated for Gujarat in 2030, where the pumped-storage hydro case has slightly higher emissions than the inflexible case. This is because in some specific cases, flexibility measures may result in an increase in coal generation that outweighs the curtailment reduction in its emissions impact, particularly in the absence of explicit emissions pricing.

Power system emission reductions in Gujarat for different flexibility options relative to the limited flexibility case, 2030



Source: IEA analysis based on assumed emission intensities by plant depending on technology (around 0.9-1.05 g CO_2/kWh for coal and around 0.42 g CO_2/kWh for combined-cycle gas).

The principal mechanism for reducing emissions is increasing clean generation, such as from solar and wind. Flexibility options help to achieve this. At the same time, where a key objective is emissions reduction, it is important to be aware that flexibility options in themselves can both decrease and increase emissions by enabling lower-cost generation to contribute more to the mix. Moreover, incentives such as carbon pricing to encourage preferential dispatch of lower-emission technologies may be needed in some systems to avoid unintended consequences.

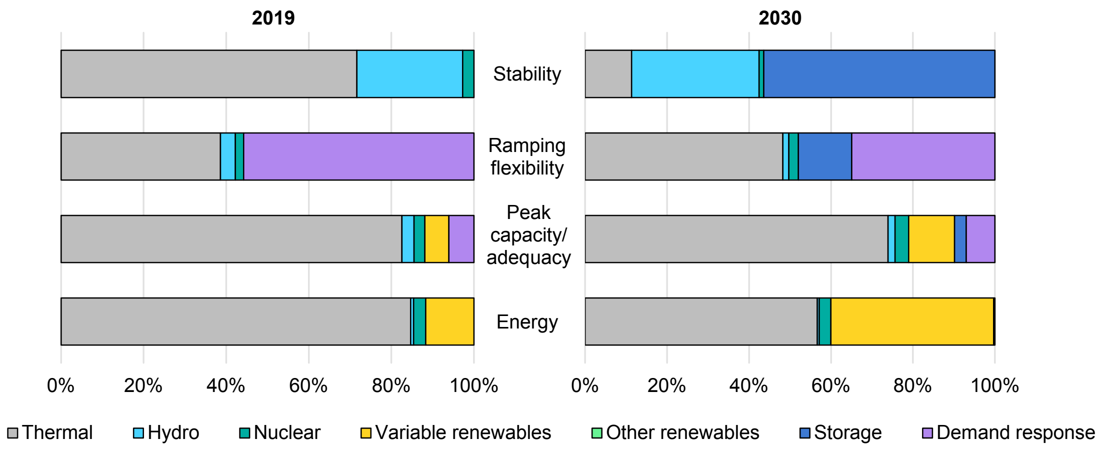
Renewables integration solutions

Power system flexibility now and in 2030

Extensive progress is being made by numerous national and state-level institutions in addressing the challenges of renewables integration in India. A detailed overview of ongoing policy, market and regulatory work is provided in the IEA India 2020 Energy Policy Review.

As India transitions to higher levels of renewable generation, improving system flexibility while ensuring electricity security and reliability would require services from a more diverse range of technologies on both the demand and supply sides. In 2019 the majority of India's energy, peak capacity and ramping flexibility was provided by coal generation, with a significant contribution also coming from hydropower plants. These resources will continue to have an important but declining role in the next decade as solar, wind, batteries and demand-side resources play an increasing role in contributing to peak capacity management and power system flexibility.

Energy and service contributions of different technologies to maintain electricity security in Gujarat, 2019 vs 2030



Notes: Storage includes batteries and pumped-storage hydropower. For calculated contributions, stability is based on provision of operating reserves, although it should be noted that reserves are only one aspect relevant to stability, and detailed technical studies are required to capture all components. Ramping is calculated from the contribution to the top 100 hourly ramps, peak capacity is based on contribution to the top 100 hours and energy is the annual energy contribution. The measures aim to give an illustration of the diverse aspects of electricity security, but do not encompass all the components or potential technology contributions that can be relevant.

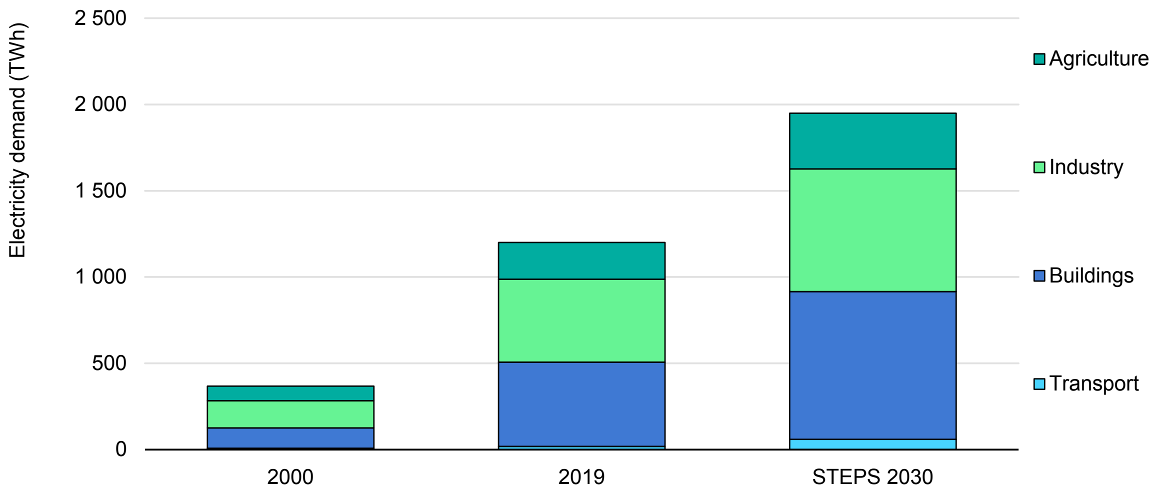
Source: Analysis based on IEA, Gujarat State Model.

The example of Gujarat highlights how system services may change at a state level. In Gujarat, demand-side ramping already played an important role in 2019, and it can play an even more important role in 2030 in absolute terms due to the more advanced use of agricultural demand response. In providing hourly ramping requirements, storage can be a new player by 2030, reducing the reliance on coal. Storage, including batteries and pumped-storage hydro, is also expected to overtake coal as the most important provider of operating reserves (stability) in Gujarat by 2030.

Demand-side flexibility becomes a top priority

Between 2010 and 2019 electricity demand in India grew by more than 220% to reach over 1 200 TWh. In the STEPS, the IEA projects a further increase in demand of 62% to reach over 1 900 TWh by 2030. This growth will be shared across buildings, industry and agriculture, with transport becoming an emerging consumption sector over the next decade.

Evolution of electricity demand in India, Stated Policies Scenario, 2000-2030



Source: IEA, India Energy Outlook 2021.

Another significant change on the demand side over the coming decade will be the transformation of electricity consumers from being passive users to proactive electricity stakeholders and owners of distributed energy resources, or "prosumers". Electric transport in the form of two-wheelers, three-wheelers, cars and buses will become increasingly relevant as both potential flexible loads and electricity storage providers. In residential buildings, smart meters and smart devices will transform consumption to align with system requirements, based on economic incentives, and rooftop solar will provide electricity for local use or will be fed into the system. Industrial and commercial services will continue to increase their role as electricity producers (through captive renewable generation), consumers and storage stakeholders.

As users become increasingly proactive through digitalisation and smart devices, significant opportunity arises for their active involvement in the power system flexibility by providing demand-response services.

In the international context, demand-side response is often divided into implicit and explicit. With implicit demand response, consumers adjust their electricity consumption in response to dynamic price signals. By contrast, explicit demand response is offered through mechanisms such as balancing markets, capacity mechanisms or direct load control where a system operator can call on the dispatch of distributed energy resources. In order to unlock both implicit and explicit demand response, the right intervention mechanisms need to be in place that enable consumer demand and distributed energy resources to serve as flexibility assets.

In 2020 IEA analysis identified close to 70 GW of flexible load as being available from demand-side response initiatives globally, amounting to around 0.9% of global electricity generation capacity. This flexibility is sourced mainly through traditional arrangements such as interrupting service at critical times and retail incentives, as well as wholesale markets. The untapped potential is much higher, with less than 2% of the potential being activated today.

At present, the global leader in demand-side response is the United States, with around 28 GW from demand-side resource participation in wholesale markets and another 35 GW from retail programmes. France has over 2 GW demand response capacity, followed by the United Kingdom and Japan with around 1 GW each. Australia, Ireland and Italy also have active programmes.

In India, direct load control by utilities allows flexible load dispatch to be centrally optimised, accounting for available generation, inflexible loads and usage of transmission and distribution infrastructure. As such, involuntary demand-side management is already an important power system balancing tool today used by SLDCs. Further policy development is required to shift from the involuntary direct load control to proactive voluntary demand response in India. This shift could also improve electricity consumer satisfaction by giving farmers more control and choice.

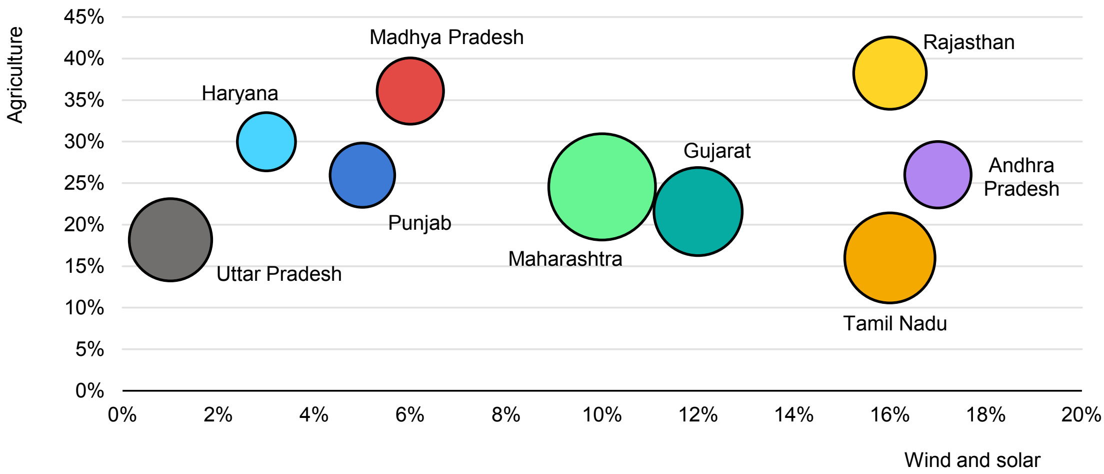
The agricultural sector is the most cost-effective source of demand response

Agricultural demand response is a significant power system flexibility opportunity for India and other emerging, developing and developed economies, because it can be the lowest cost way to align a significant amount of demand with solar peak hours.

In 2019 agricultural demand made up 18% of India's electricity consumption. Irrigation in India today is almost entirely reliant on electric and diesel pumps. Of the nearly 30 million irrigation pumps in use throughout the country, about 71% run on grid electricity, only around 1 % are solar and the remainder are powered by diesel. Policy is focused on transitioning from diesel pumps to solar and grid-connected pumps across India.

The government of India has introduced the PM-KUSUM (*Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan*) scheme to support farmers in the installation of 2 million standalone solar-powered agricultural pumps, as well as converting 1.5 million grid-connected pumps to solar power. Enabling demand response under the scheme requires real-time communication between all metering units connected to the solar pumps and a central software platform for data acquisition and management. Gujarat became the first state in 2020 to develop the Solar Energy Data Management (SEDM) platform (within the UK-funded Power Sector Reform Programme) to help it monitor solar pump assets in real time using digital technologies like the internet of things. The Ministry of New and Renewable Energy (MNRE) now plans to expand SEDM to 13 more states.

Agriculture's share of total electricity demand (2015), and solar and wind as a proportion of total generation (2018) in selected Indian states



Note: Bubble size is based on total electricity demand of each state (2015)
Source: Reproduced with permission of Khanna (2021).

In large Indian states, agricultural pumping constitutes up to 38% of total annual electricity consumption, the highest being 38% in Rajasthan, 36% in Madhya Pradesh and 33% in Karnataka, followed by 25% in Maharashtra and 22% in Gujarat (as of 2015) (Khanna, 2021). These states are also the frontrunners in wind and solar development in the country.

India has significant potential to improve agricultural load flexibility alongside increasing solar and wind penetration. An important technical enabler of this is the availability and use of dedicated agricultural feeder systems. These feeder systems allow system operators and the DISCOMs to directly control (turn on and off) agricultural users without affecting other user types. In 2020 numerous states had 100% dedicated agricultural power distribution networks: Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Punjab and Bihar. In Rajasthan and certain other states, some but not all agricultural users had dedicated power distribution networks. This means that the potential for more sophisticated agricultural demand response in India extends to many renewables-rich states.

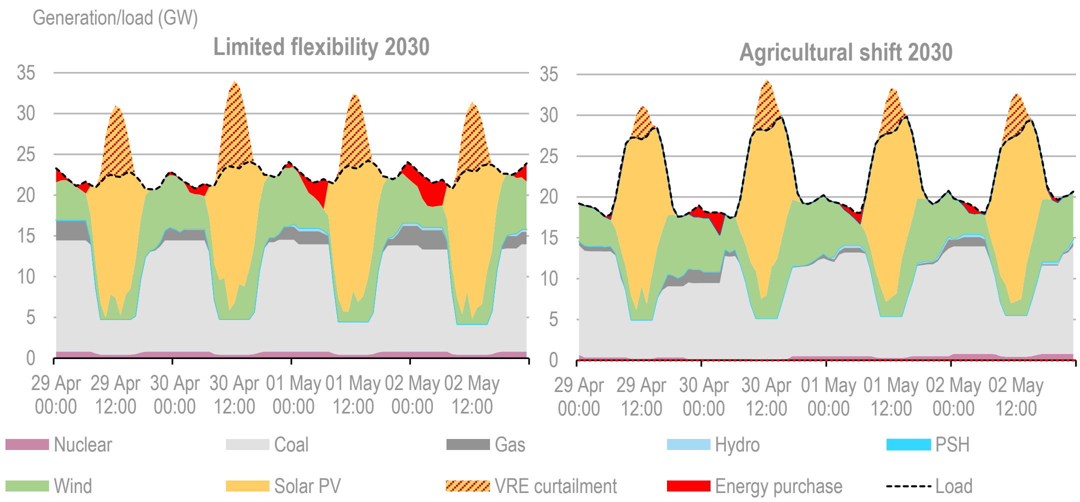
Agricultural demand response already plays an important role in balancing the power systems of Karnataka and Gujarat. The IEA Gujarat State Model (with agricultural demand response based on analysis by Khanna [2021]) shows that flexibility from agricultural demand response in Gujarat is central to cost-effective integration of increased solar generation by 2030. By that year agricultural demand shifts significantly, reducing the renewables integration challenges and curtailment levels in Gujarat to below 3% from 7% (compared to the inflexible case where demand is managed according to today's scheduling practices).

In Gujarat, agricultural load represents around 20% of total demand and has been growing by 5% to 7% annually. The supply of electricity to agriculture is heavily subsidised in Gujarat, as it is in most Indian states. To limit the subsidies and prevent their misuse, electricity for agricultural pumping is heavily controlled by the state-owned electricity utilities. This is enabled by a unique system of segregated electricity feeders (parallel power distribution network) for agricultural supply and household supply in rural areas, which allow complete control of agricultural supply without interrupting supply to non-agricultural consumers.

As such, agricultural demand is already an important source of power system flexibility in Gujarat, with agricultural pumping loads scheduled in eight-hour durations and concentrated overnight. This has the combined benefit of ensuring that agricultural pumping minimally coincides with peak demand, while also supplementing lower overnight load, allowing conventional plants such as coal-fired generation to maintain a more stable operation.

By 2030 this overnight pattern is no longer optimal due to the high PV generation in Gujarat; instead agricultural load can be scheduled predominantly during the day to align with hours of high solar output. (The existing schemes to facilitate this in Gujarat are discussed below.) In addition to reducing curtailment to under 3%, this reduces unit starts by 39% at coal- and gas-fired plants. Shifting agricultural demand to the day also results in around a one-third reduction in market purchases, for an overall variable cost reduction of nearly 11%. Note that the total system cost, including renewables tariff cost, is not included in the reported operating cost as the modelling takes an overall social welfare perspective, and from this point of view these renewables tariff costs are sunk investment costs.

Impact of agricultural demand shift on total demand and solar generation absorption



Sources: IEA, Gujarat State Model and analysis based on Khanna (2021).

In Rajasthan, the state government power development company Rajasthan Urja Vikas Nigam Limited (RUVNL) has explored optimising the rostering schedule of agriculture-heavy feeders (through a decision support tool), resulting in a decline in the overall peak demand, flattening of the load curve and the reduction of the required peak generation capacity. Trial runs of the tool have demonstrated savings of ~USD 40 million annually.