Transforming Delhi's Power Grid

A Comprehensive Guide to Enhancing Flexibility

Report / July 2024

BSES Rajdhani Power Limited (BRPL) is a joint venture between Reliance Infrastructure Limited (RInfra) and the Government of NCT of Delhi, with a shareholding of 51%:49%. BRPL covers an area of 691 sq km and serves over 30 lakh customers in 22 divisions across South and West Delhi. Since privatisation of Delhi electricity distribution in 2002, BRPL has reduced Aggregate Technical & Commercial (AT&C) losses by more than 45% to under 7% currently.

The company is dedicated to sustainable growth through promoting green power by facilitating solar rooftop and increasing renewable energy in power portfolio. By FY 2026-27, BRPL aims to have 55% of its power portfolio green. BRPL has been awarded the highest A+ rating in the 'Consumer Service Ratings of Discoms' by REC Ltd in the latest rating and has topped for consecutive 3 years in a row, demonstrating its customer centric approach.

BSES Yamuna Power Limited (BYPL) is a joint venture between Reliance Infrastructure Limited (RInfra) and the Government of NCT of Delhi, with a shareholding of 51%:49%. BYPL covers an area of 160 sq km and serves over 19 lakh customers in 14 divisions across East and Central Delhi. Since privatisation of Delhi electricity distribution in 2002, BYPL has reduced Aggregate Technical & Commercial (AT&C) losses by more than 56% to under 7% currently.

The company is dedicated to sustainable growth through promoting green power by facilitating solar rooftop and increasing renewable energy in power portfolio. By FY 2026-27, BYPL aims to have 55% of its power portfolio green. BYPL has been awarded the highest A+ rating in the 'Consumer Service Ratings of Discoms' by REC Ltd in the latest rating and has topped for consecutive 3 years in a row, demonstrating its customer centric approach.

RMI is an independent nonprofit, founded in 1982 as Rocky Mountain Institute, that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut climate pollution by at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; Abuja, Nigeria; and Beijing. RMI has been supporting India's mobility and energy transformation since 2016.

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Abbreviations

AC	Air conditioner
ADR	Automated demand response
AMI	Advanced metering infrastructure
API	Application programming interface
AS	Ancillary services
BDR	Behavioural demand response
BESS	Battery energy storage system
BRPL	BSES Rajdhani Power Limited
BTM	Behind the metre
BYPL	BSES Yamuna Power Limited
C&I	Commercial and industrial
CAISO	California Independent System Operator
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CLP	China Light and Power Company
CONE	Cost of new entry
CV	Commercial vehicles
DAM	Day-ahead market
DERC	Delhi Electricity Regulatory Commission
DER	Distributed energy resources
DERMS	Distributed energy resource management system
Discom	Distribution company
DR	Demand response
DRAM	Demand response auction mechanism
DSM	Demand side management
DT	Distribution transformer
e-bus	Electric bus
EV	Electric vehicle
FY	Fiscal year
GW	Gigawatt
HP-DAM	High-price day-ahead market
IESO	Independent Electricity System Operator
M&V	Measurement and verification
MSW	Municipal solid waste
MOP	Ministry of Power
MW	Megawatt

NDMC	New Delhi Municipal Council
NWA	Non-wire alternative
O&M	Operations and maintenance
PG&E	Pacific Gas and Electric
RA	Resource adequacy
RE	Renewable energy
SCADA	Supervisory control and data acquisition
SCED	Security-constrained economic dispatch
SLDC	State Load Dispatch Centre
SMUD	Sacramento Municipal Utility District
T&D	Transmission and distribution
TOD	Time-of-day
TPDDL	Tata Power Delhi Distribution Limited
VPP	Virtual power plant

Executive Summary

India's electricity system is rapidly transforming due to its growing electricity demand and increased adoption of clean electricity resources. The elevated demand for space cooling coupled with the country's economic growth and electrification of new sectors such as transportation are driving the surge in demand. These trends are starting to affect the affordability and reliability of the grid, driving the need to integrate new demand and supply flexibility solutions.

A prime example of the ongoing transformation is Delhi, where the capital city has drawn up ambitious plans to electrify its transportation sector and aims to meet its growing electricity needs through clean energy sources. Delhi's peak electricity demand is projected to grow 50% this decade, and the share of renewable energy (RE) capacity is projected to account for 50% of the city's power supply during the same period. Integrating novel supply and demand solutions while maintaining a reliable and affordable supply will determine the success of this transition.[1] Examining similar transitions around the world reveals that adopting grid flexibility measures such as demand response (DR), managed charging of electric vehicles (EVs), battery energy storage systems (BESS), and virtual power plants (VPPs) can play a crucial role in a modernised grid that can meet evolving supply and demand requirements.[i]

Grid flexibility technologies can help manage and mitigate increasing demand peaks in Delhi. By 2030, RMI estimates that Delhi could reduce 250–1,350 megawatts (MW) of peak demand through air conditioning (AC) DR programmes, up to 400 MW of demand shifting potential through managed charging of the electric bus (e-bus) fleet, and 500–2,500 MW of shiftable demand through BESS (see **Exhibit 1**). Combined as VPPs, these measures could unlock maximum demand reductions of nearly 4,000 MW, about one-third of Delhi's projected peak demand in 2030. Moreover, these flexibility measures can significantly benefit Delhi's distribution companies (Discoms) and consumers.[ii] We estimate that the annual net benefits to Delhi Discoms could reach up to 150 crore rupees (US$18 million) for AC DR programmes, up to 110 crore rupees (US$13 million) for e-bus managed charging, 850 crore rupees (US$100 million) for BESS, and a combined benefit of up to 1,050 crore rupees (US$124 million) for an integrated VPP.[iii]

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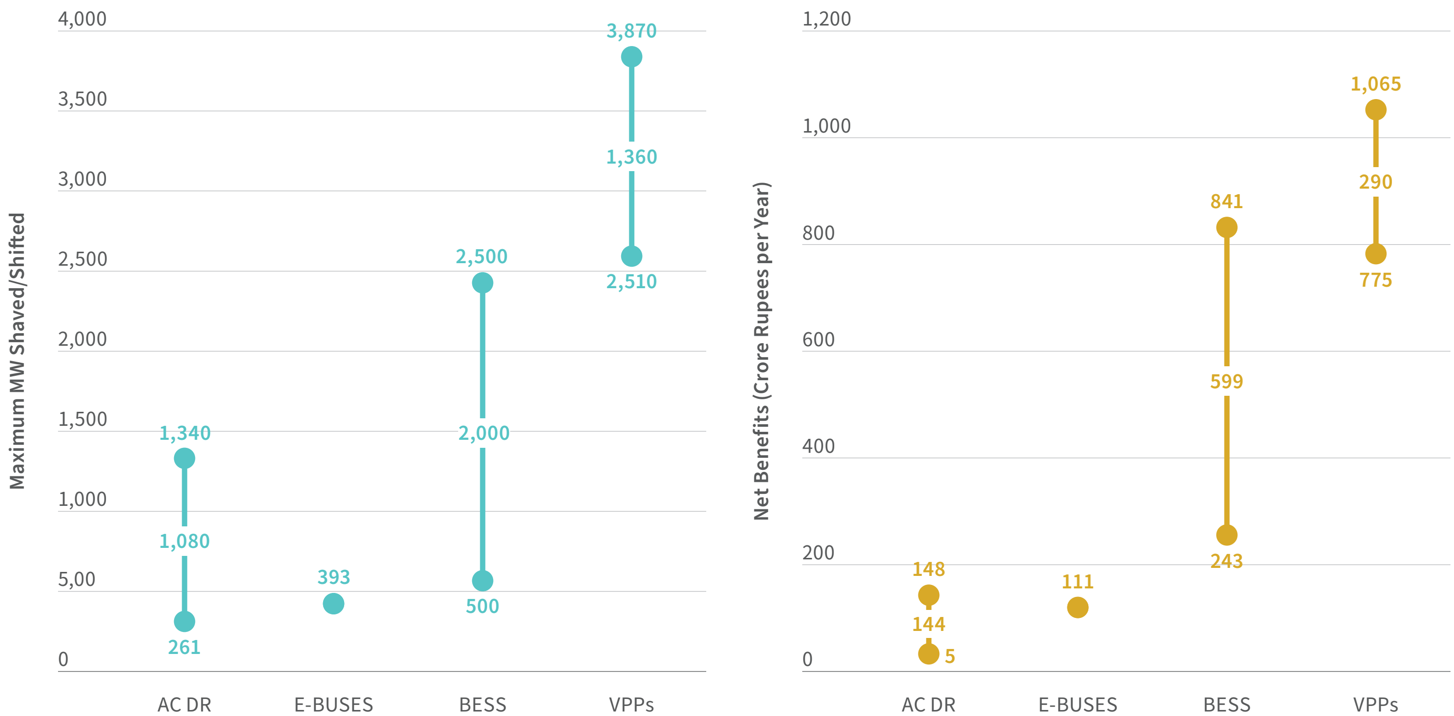
i. A VPP is a collection of small-scale energy resources that, aggregated together and coordinated with grid operations, can provide the same kind of reliability and economic value to the grid as traditional power plants. At its core, a VPP is composed of numerous households and businesses that offer the latent potential of their thermostats, EVs, appliances, batteries, and solar arrays to support the grid. See **https://rmi.org/a-key-climate-solution-is-lifting-off**.

ii. Discoms (or distribution companies) are the electricity supply providers to Indian end-users and have licenses to operate the distribution networks in their service territories

iii. 1,050 crore rupees (US$120 million) per year net benefits translate to savings around 1,500 rupees (US$18) per electric consumer per year (assuming total of 6.85 million consumers). These savings are on the order of a month's power bills for a domestic consumer.

Exhibit 1 **Grid flexibility potential and projected range of annual net benefits by technology, for Delhi in 2030**



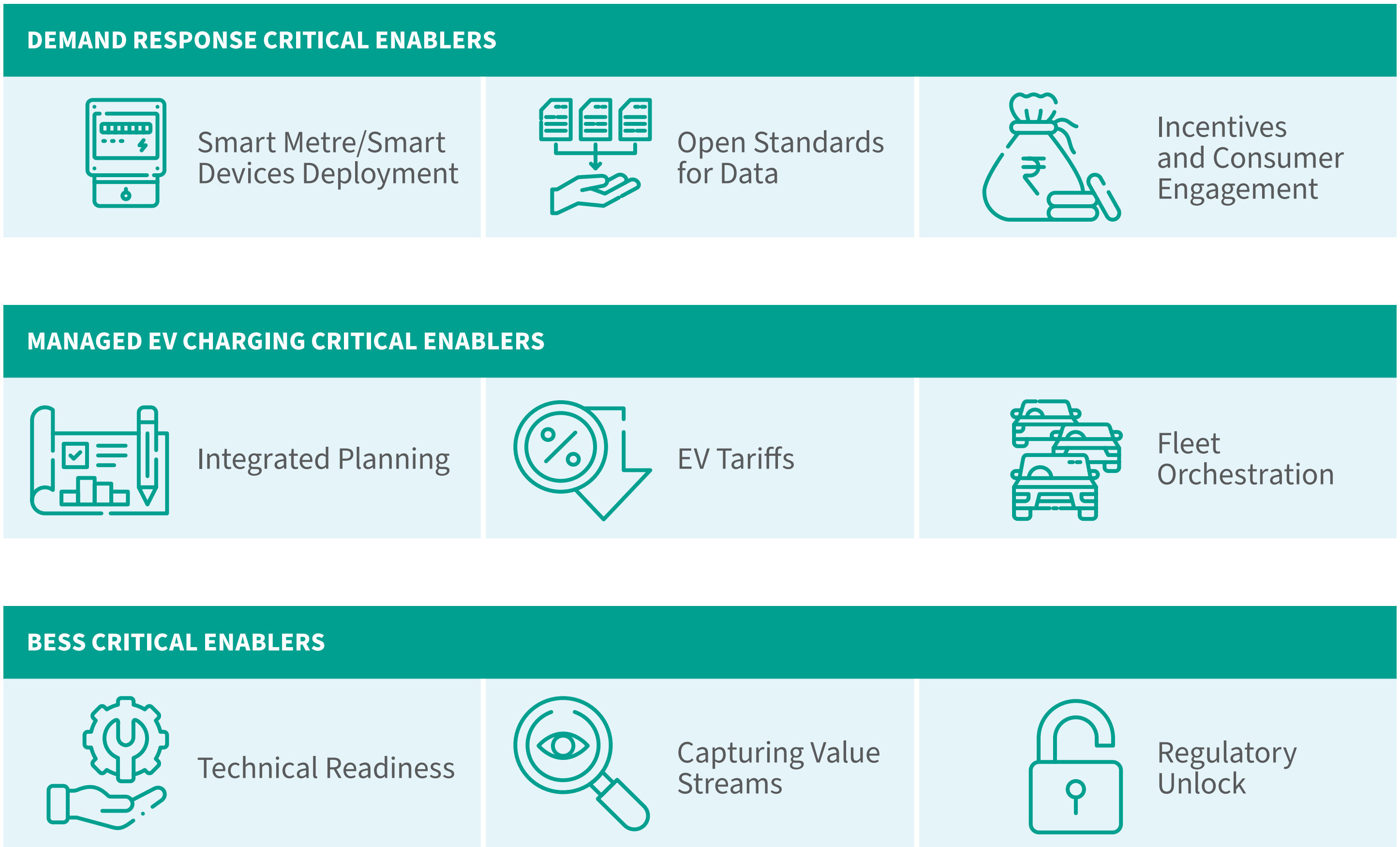
RMI Graphic. **Source:** RMI analysis

RMI's analysis indicates that adoption of space-cooling appliances (ACs and space coolers), e-buses, and commercial four-wheeler EVs could account for about 6,000 MW of Delhi's annual peak demand, about 50% by 2030. As most of this demand occurs throughout the day and is seasonal (mostly space cooling), Delhi will experience periods of sharp peak demand. Meeting these peaks can significantly elevate power procurement costs and require major distribution infrastructure upgrades along with operations and maintenance (O&M) expenses, which can, in turn, lead to higher electricity tariffs and system reliability challenges.

An array of factors, including supporting policies, regulations, and incentives, will dictate the adoption and scalability of grid flexibility measures in Delhi. This report highlights the factors essential for enabling grid flexibility in the capital city based on the best global practices that aid successful adoption of these measures. The report also guides the effective implementation and scaling of these programmes.

To reach the maximum potential for grid flexibility, Delhi Discoms and regulators can consider the critical enablers outlined in **Exhibit 2** for each measure to set a strong foundation for implementation of these programmes and technologies.

Exhibit 2 Critical enablers of grid flexibility



RMI Graphic. **Source:** RMI

Because each of these enablers is at a different stage, they necessitate distinct actions. To develop full-scale programmes following the implementation of these enablers, the report provides a development guide for stakeholders, including Discoms and regulators, to enhance Delhi's grid flexibility. The guide, composed of practical steps to be taken once the enablers are implemented, has three parts:

1. Establish an evaluation framework.
2. Validate with regulatory pilots and sandbox experimentation.
3. Scale to larger grid flexibility programmes.

By using this development guide, Delhi can meet its rising peak electricity demand with clean energy resources while maintaining a reliable and affordable electricity supply for all consumers.

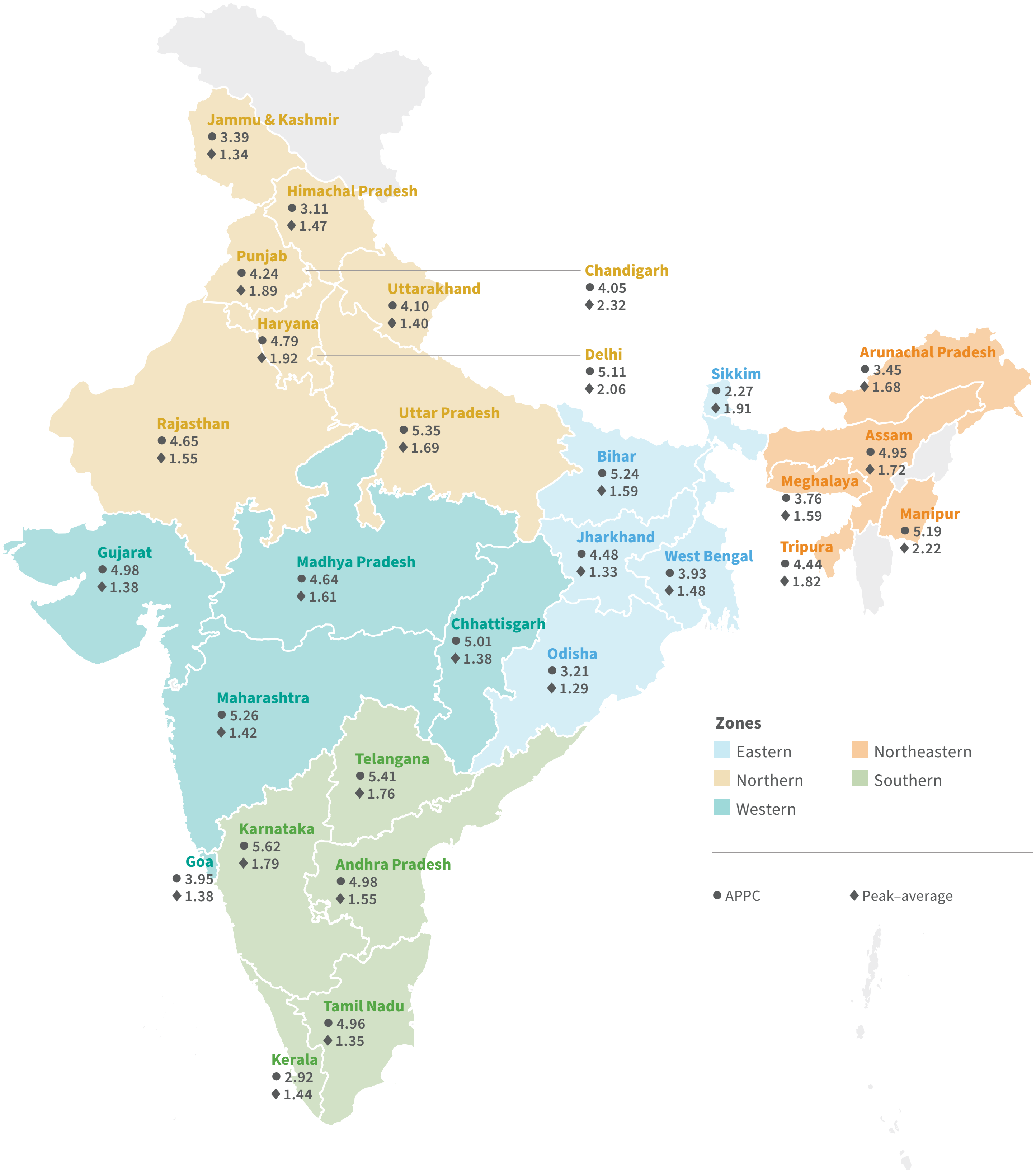
Introduction

India’s remarkable progress in the electricity sector has led to the electrification of 100% of its households over the past decade.[2] Since 2014, India’s electricity demand has grown over 50% and peak demand has increased almost 80%, leading to the country’s power generation capacity ramping up 70% over the period to meet the growing demand.[3] India’s power sector is subject to an environment of increasing electricity demand and peak demand growth coupled with a rising share of renewable energy (RE).[4] If unmanaged, increasing peak demand can affect power system affordability and grid reliability. As India’s capital, Delhi reflects these challenges in a more pronounced manner.

Delhi’s urban expansion is one of the fastest around the globe. With a current population of about 2 crores (20 million), it is projected to be the world’s largest metropolitan city (by population) by 2030. With a gross state domestic product growth rate of over 9% in 2022–23, mainly fuelled by the service sector (over 80%), Delhi is also one of the fastest-growing regions in the country.[5]

Delhi’s rapid and profound urbanisation has resulted in a steep rise in peak electricity demand. The city has one of the highest peak-to-average demand ratios across Indian states (see **Exhibit 3**). Rapid urbanisation coupled with growing renewable energy (RE), electric vehicle (EV), and electric bus (e-bus) penetration is changing its electricity demand and supply. As consumers increasingly adopt air conditioners (ACs) and EVs, Delhi’s peak loads are projected to rise by about 50% from existing levels during this decade.[6] Delhi has one of the highest power purchase costs in the country, and the confluence of future demand and supply trends can further spike its power procurement costs and strain its distribution network.

Exhibit 3 Comparison of peakiness of electricity demand and average power purchase cost (APPC) across all Indian states for fiscal year (FY) 2022



RMI Graphic. **Source**: Government of India Ministry of Power Central Electricity Authority; Power Finance Corporation; RMI analysis

Despite these challenges, new load drivers such as ACs and EVs and new resources such as battery energy storage systems (BESS) create opportunities to develop a flexible grid that can manage uncharacteristic growth in peak demand and help increase share of RE on the grid. These demand flexibility resources can shift or store power in response to grid requirements. Grid flexibility measures could be aligned with the future electricity system requirements, as they are cost-effective and can provide a range of grid services within the existing infrastructure.[7]

> **Load drivers such as ACs and EVs and new resources such as battery energy storage systems create opportunities to develop a flexible grid that can manage the rapidly growing peak demand.**

This report assesses Delhi's evolving power system and the impact of the AC demand response (DR) programme, managed EV charging, and distribution and customer-sited BESS on the management of grid flexibility, integrating RE capacity and power procurement cost in the capital city.[iv] It also studies the potential of virtual power plants (VPPs) in Delhi. This report evaluates the potential of these measures and highlights the relevant policy and regulatory levers needed to enable them to provide grid flexibility based on global best practices. Although the study focuses on Delhi, the results and recommendations have national implications given that increasing peak demand and flexibility challenges are present across India's power system.

iv. Delhi is served by four main Discoms: BSES Rajdhani Power Limited (BRPL), BSES Yamuna Power Limited (BYPL), New Delhi Municipal Council (NDMC), and Tata Power Delhi Distribution Limited (TPDDL). RMI has collaborated with BSES, the parent company of BRPL and BYPL, for the analysis and insights of this report. The results presented here encompass the entire city, not just the areas served by BSES Discoms.

Need for Grid Flexibility in Delhi

Delhi's electricity demand has grown by 20% since 2014–15 while peak load has increased over 30%.[8] It implies that the city's load factor (average load to peak-load ratio)[v] is declining. Delhi's annual load factor is one of the lowest in the country, about 60% below the national average. Lower load factor can lead to higher requirement for distribution infrastructure augmentation to meet peak demand and can also result in higher technical losses.[9] Hence, managing future growth in peak demand will be critical.

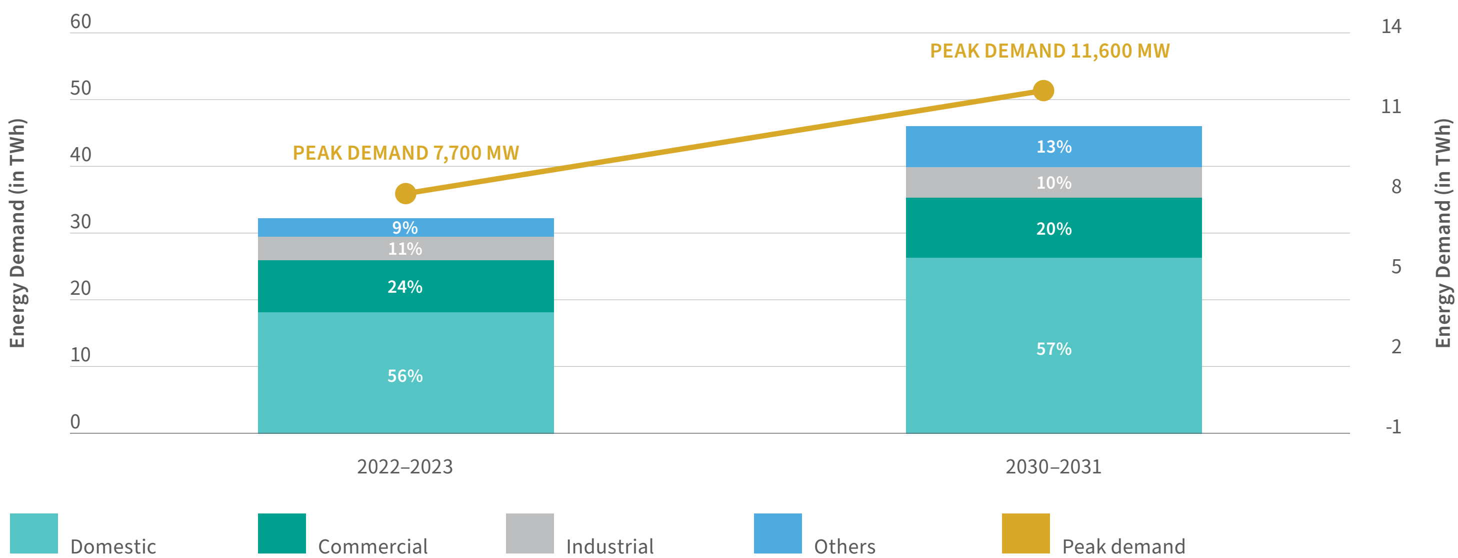
On the supply side, Delhi currently meets over 83% of its electricity demand through out-of-state power procurement contracts and electricity imports, with most of the electricity supply dependent on thermal coal generation.[10] The remaining demand is met mostly through in-state natural gas generation and rooftop solar.

Delhi's Electricity Demand Assessment

Delhi's electricity demand experiences seasonal swings

Delhi's annual peak demand is about 7,700 MW, recorded during the summer of 2022.[11] This demand is driven by domestic electricity consumption, which accounts for almost 60% of the city's total demand and is projected to be the largest driver of demand until 2030 (see **Exhibit 4**).[12]

Exhibit 4 Delhi's electricity demand breakdown in 2022 and 2030

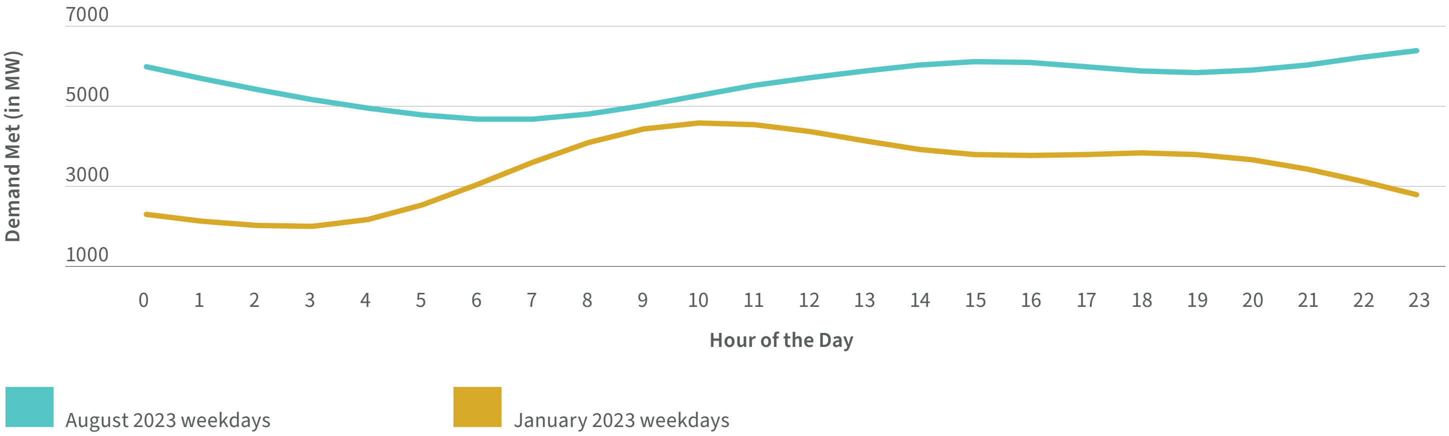


RMI Graphic. **Source**: Government of India Ministry of Power Central Electricity Authority, Report on Twentieth Electric Power Survey of India (Volume-I)

v. Load factor is the ratio of annual average demand and peak demand. (Peakiness of demand is the inverse of load factor as highlighted in Exhibit 3.)

Delhi's existing electricity demand during summer remains above 5,000 MW for most of the day. The two prominent peak demand periods are afternoon (1–4 p.m.) and late evening (8 p.m.–midnight). However, during winter, Delhi's electricity demand stays below 5,000 MW throughout the day (see **Exhibit 5**). The significant seasonal variance in Delhi's electricity demand can be attributed to outdoor temperature and humidity.

Exhibit 5 Delhi's hourly load profile during winter and summer



Note: Delhi observed the highest summer peak in August 2023.
RMI Graphic. **Source**: IIT Kanpur Department of Management Sciences, Energy Analytics Lab; RMI analysis

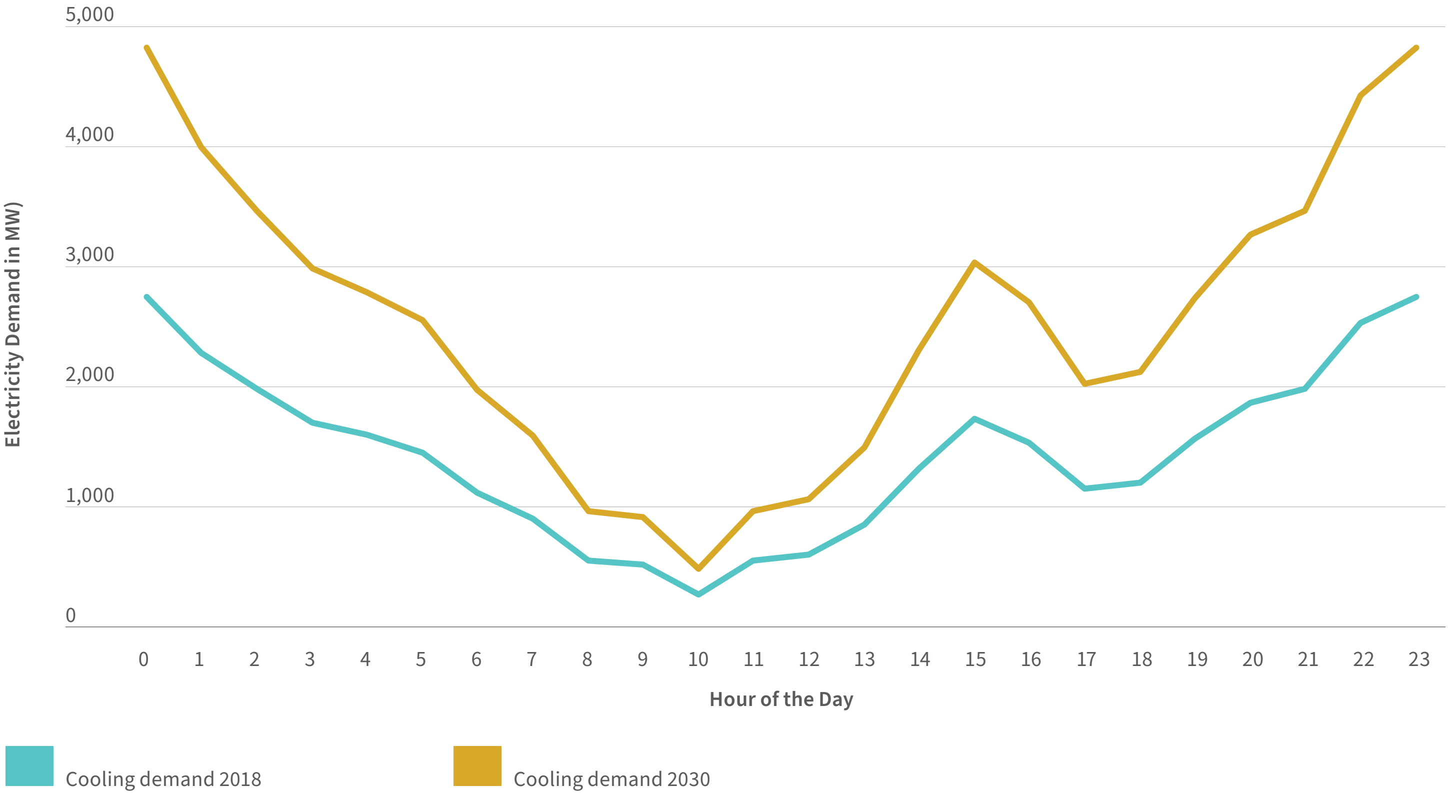
What Drives Delhi's Peak Demand?

Domestic Space-Cooling Appliances

Delhi's summer electricity demand peaks largely due to consumer use of space-cooling appliances (coolers and ACs), which is growing rapidly. This growth is attributed to the rapid rise in relative humidity and sustained levels of high ambient nighttime temperatures in Delhi. Rising humidity can add up to 8°C to the ambient temperature. And every 1° rise in outdoor heat index beyond 22.5°C is estimated to add nearly 200 MW of peak demand.[13] The typical consumption of a domestic AC causes two visible peaks: afternoon and night (see **Exhibit 6**), similar to Delhi's summer demand profile (see **Exhibit 5**). This suggests that space-cooling appliances are a critical factor in determining the city's existing and future peaks.[14]

RMI's bottom-up analysis of appliance ownership in Delhi revealed that about 40% of the 5.2 million registered domestic consumers in the city had installed either an AC or an air cooler at their premises as of FY 2019–20. This assessment is supported by the National Family Health Survey in 2022 which found 40% ownership of ACs and space coolers among urban households across India.[15] Based on this adoption rate, cooling requirements contribute about 3,200 MW (about 40%) to Delhi's peak demand of 7,700 MW.

Exhibit 6 Delhi's hourly domestic cooling demand in 2018 and projected domestic cooling demand in 2030 during summer (hour of the day)



RMI Graphic. **Source**: 2020 BSES Load Research Report; RMI analysis

A recent International Energy Agency study projects that India's peak electricity demand will rise by 60% between 2022 and 2030, with cooling accounting for nearly half of the increase. Growth in cooling demand will be driven by rising AC ownership, which is expected to outpace the growth of every other major appliance (including televisions, refrigerators, and washing machines).[16] Hence by 2030, it is estimated that domestic AC demand could account for about 4,800 MW of Delhi's peak electricity demand, making up about 40% of the city's summer peak demand. (See **Appendix A** for details).

EVs and E-Buses

Delhi has made significant strides over the past few years to become India's EV capital. The 2022 launch of the city's EV policy, with attractive incentives for consumers, led to the rapid adoption of EVs.[17] Delhi accounts for about 5% of the country's EVs and roughly 15% of all its charging stations.[18] Delhi's EV policy is aimed at electrification of all commercial vehicles (CVs) in the city by 2030.[vi] RMI estimates that this can lead to about 78,000 commercial four-wheeler EVs plying Delhi roads by 2030, requiring about 26,000 chargers to support these vehicles.

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vi. For the purposes of this report, commercial EVs include four-wheeler commercial EVs only.

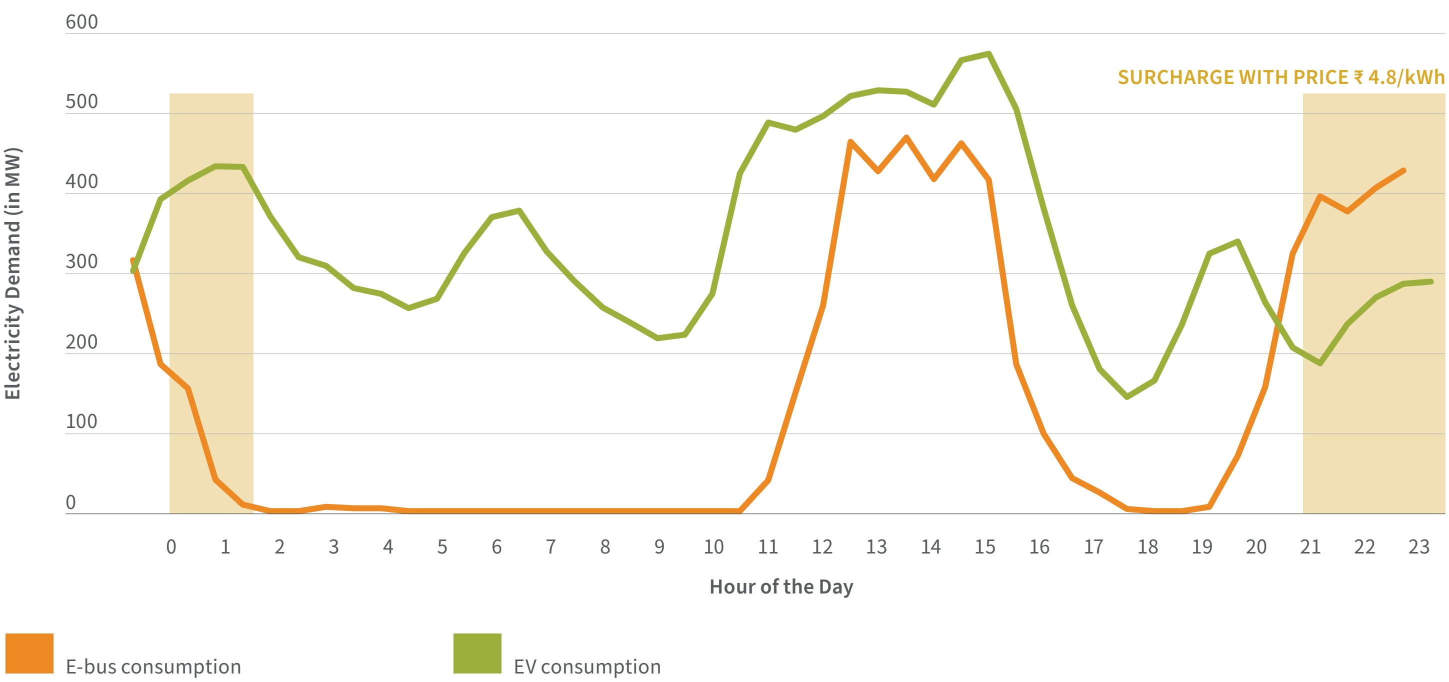
Delhi also aims to electrify its entire bus fleet by 2028 and to deploy 12,000 e-buses by 2030.[19] In line with this goal, Delhi has so far deployed 1,300 electric buses, making it the city with the most e-buses in India.[20] With sustained rapid growth in transport sector electrification, EVs and e-buses will propel Delhi's future electricity demand and contribute to its peak demand.

The electricity consumption pattern of a typical e-bus charging depot in Delhi highlights twin peak demand periods during a typical day (see **Exhibit 7**). These peaks can be attributed to most buses being charged in the afternoon (noon–3 p.m.) and late evening (9–11 p.m.).[vii]

With Delhi's e-bus fleet estimated to grow by over nine times this decade, these charging depots could contribute around 450 MW to Delhi's peak demand by 2030. The twin peaks of the depot's electricity consumption coincide with the peak periods Delhi experiences during summer. Hence, the unmanaged charging of e-buses can amplify Delhi's peak demands and further strain its distribution infrastructure.

A similar assessment of a four-wheeler commercial EV charging hub in Delhi reveals that peak periods occur in the afternoon (1–3 p.m.) and late night (midnight–2 a.m.). With plans to make Delhi's entire CV fleet electric by 2030, these charging hubs are projected to add more than 570 MW of additional peak demand. (See **Appendix B** and **Appendix C** for details.)

Exhibit 7 2030 hourly demand profile of depots and commercial EVs in Delhi in 2030 (projected)



RMI Graphic. **Source**: RMI analysis of Rohini Bus Depot's load profile (e-bus consumption), BSES Data (4W EV consumption)

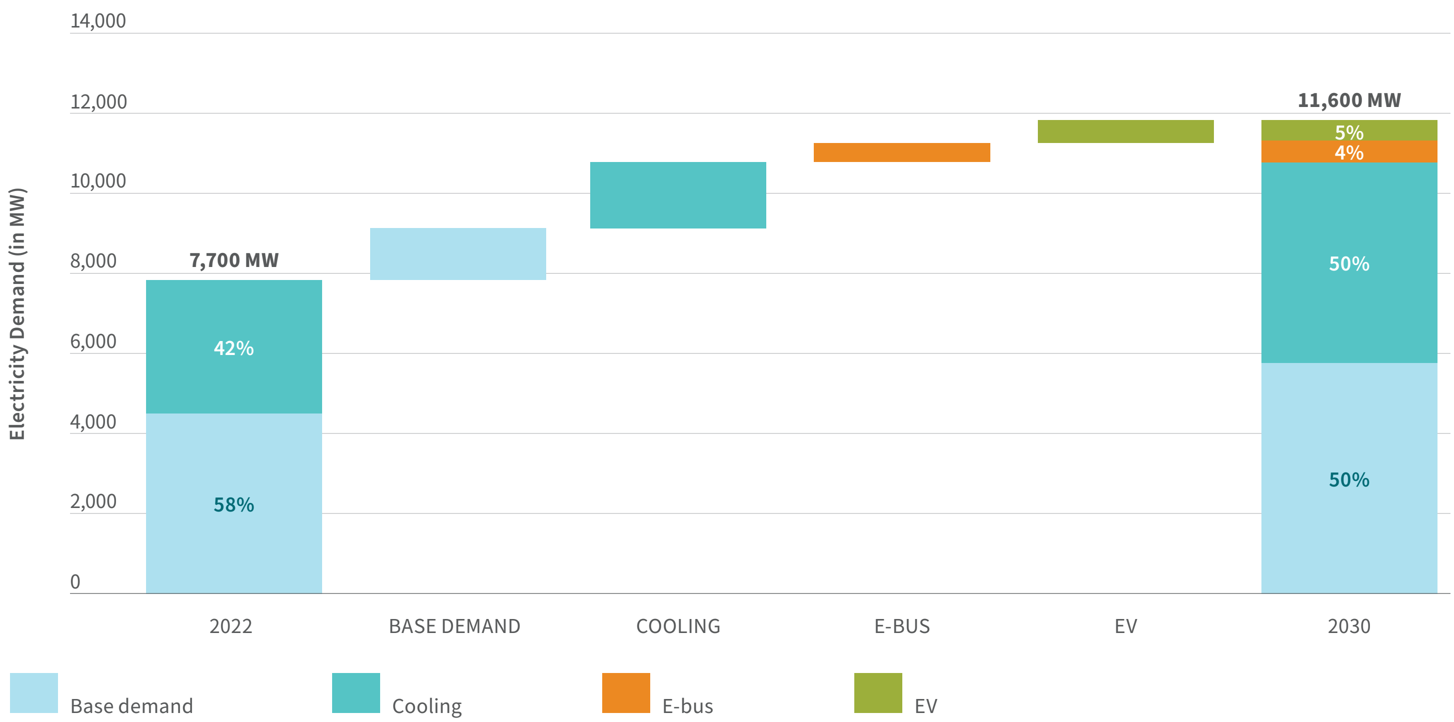
vii. Rohini Bus Depot's load profile data provided in FY23.

The anticipated growth in demand for EVs and e-buses in Delhi will have an impact on Delhi's power system. By 2030, an expected increase in demand of around 1 gigawatt (GW), largely from commercial four-wheeler EVs and e-buses, could constitute up to 10% of Delhi's peak loads.

Delhi's peak demand to rise rapidly by 2030

Delhi's peak demand is projected to reach 11,600 MW by 2030, largely driven by the adoption of ACs, EVs, and e-buses.[21] Taking this into account, RMI estimates that space-cooling appliances, commercial four-wheeler EVs, and e-buses could account for up to 50% of Delhi's future peak demand during summer in 2030 (see **Exhibit 8**).

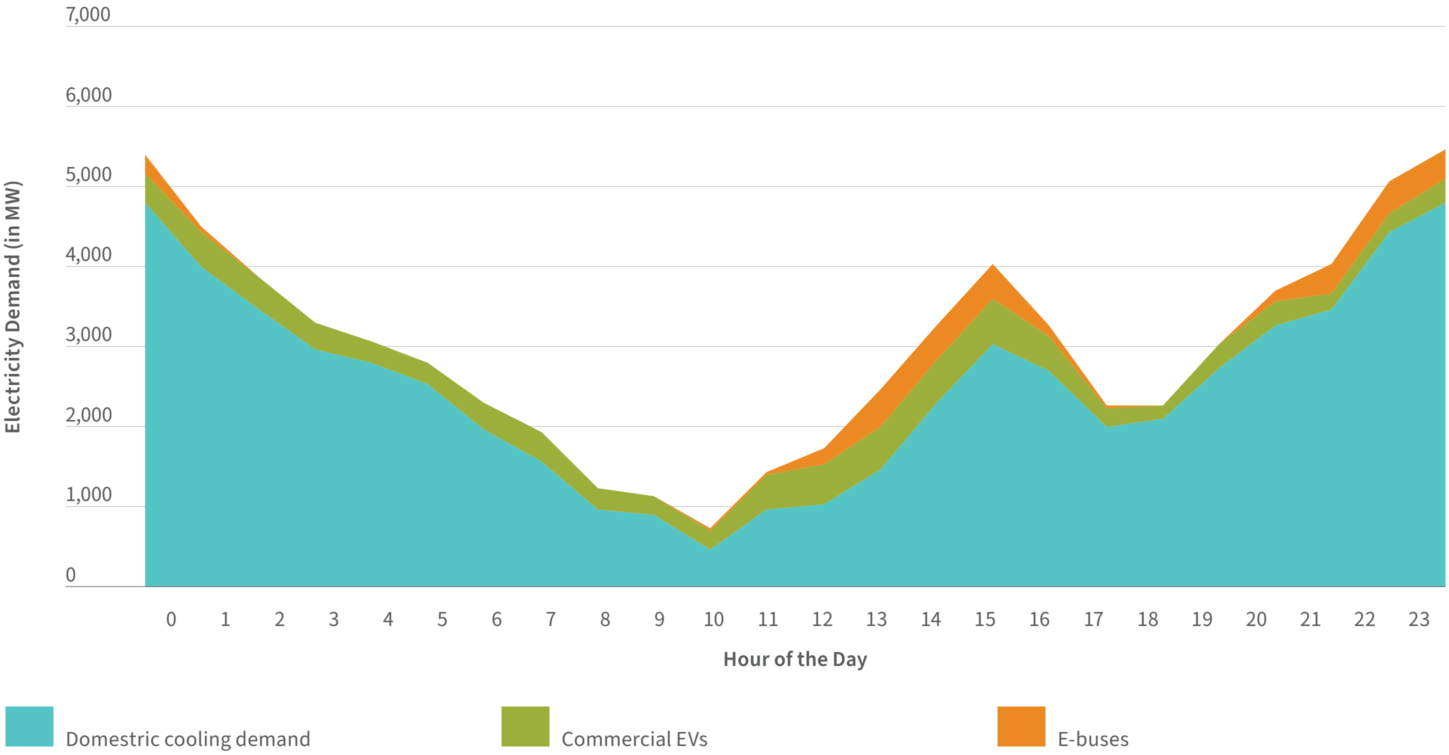
Exhibit 8 Peak demand drivers of Delhi's power requirements in 2030 (MW)



RMI Graphic. **Source**: Load Research Report BSES; RMI analysis

The greater challenge for Delhi's power sector will be the overlapping nature of peak loads from the use of ACs, air coolers, commercial four-wheeler EVs, and e-buses (see **Exhibit 9**). Managing these seasonal peaks can be difficult as Discoms must plan infrastructure and power procurement to meet the increasing peaks caused by these demand drivers.

Exhibit 9 **Projected hourly demand of domestic cooling, commercial EVs, and e-buses in Delhi in 2030**



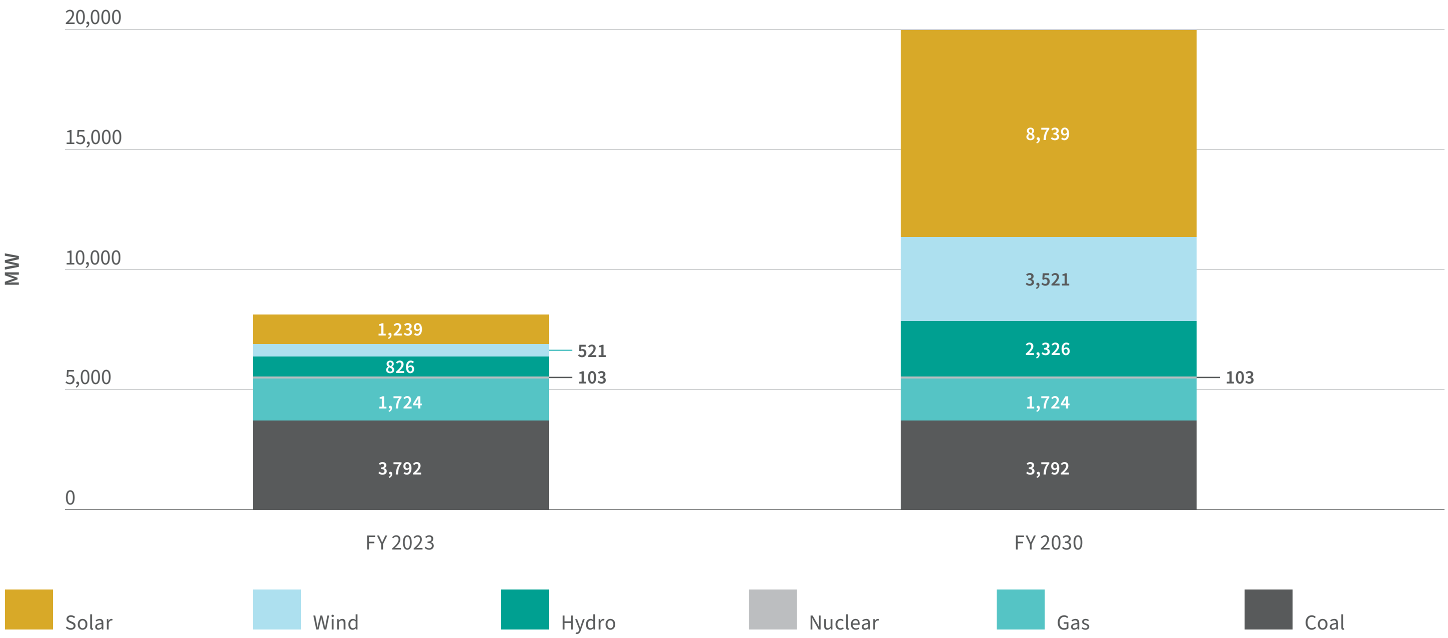
RMI Graphic. **Source**: State Load Dispatch Centre Delhi; RMI analysis

Delhi's Electricity Supply Assessment

Most of Delhi's current electricity supply is met though out-of-state thermal generators. Delhi's existing power allocation stands at approximately 8,200 MW, with thermal generators (coal and natural gas) accounting for about 70% (5,500 MW) of the supply (see **Exhibit 10**). Delhi's in-state generation capacity is limited to natural gas and rooftop solar, which account, respectively, for about 2,235 MW and 250 MW.[22]

Delhi's supply portfolio is expected to change significantly as it plans to meet its rising demand with clean energy. In the next three to four years, Delhi aims to fulfil about 50% of its electricity demand with clean energy resources.[23] Realising Delhi's 2030 electricity demand will require the existing power generation portfolio to ramp up significantly. We model a scenario in which Delhi contracts an additional 7,500 MW of solar, 3,000 MW of wind, and 1,500 MW of hydro to meet its 2030 demand (see **Appendix D**). This will more than double Delhi's power generation portfolio to over 20,000 MW.

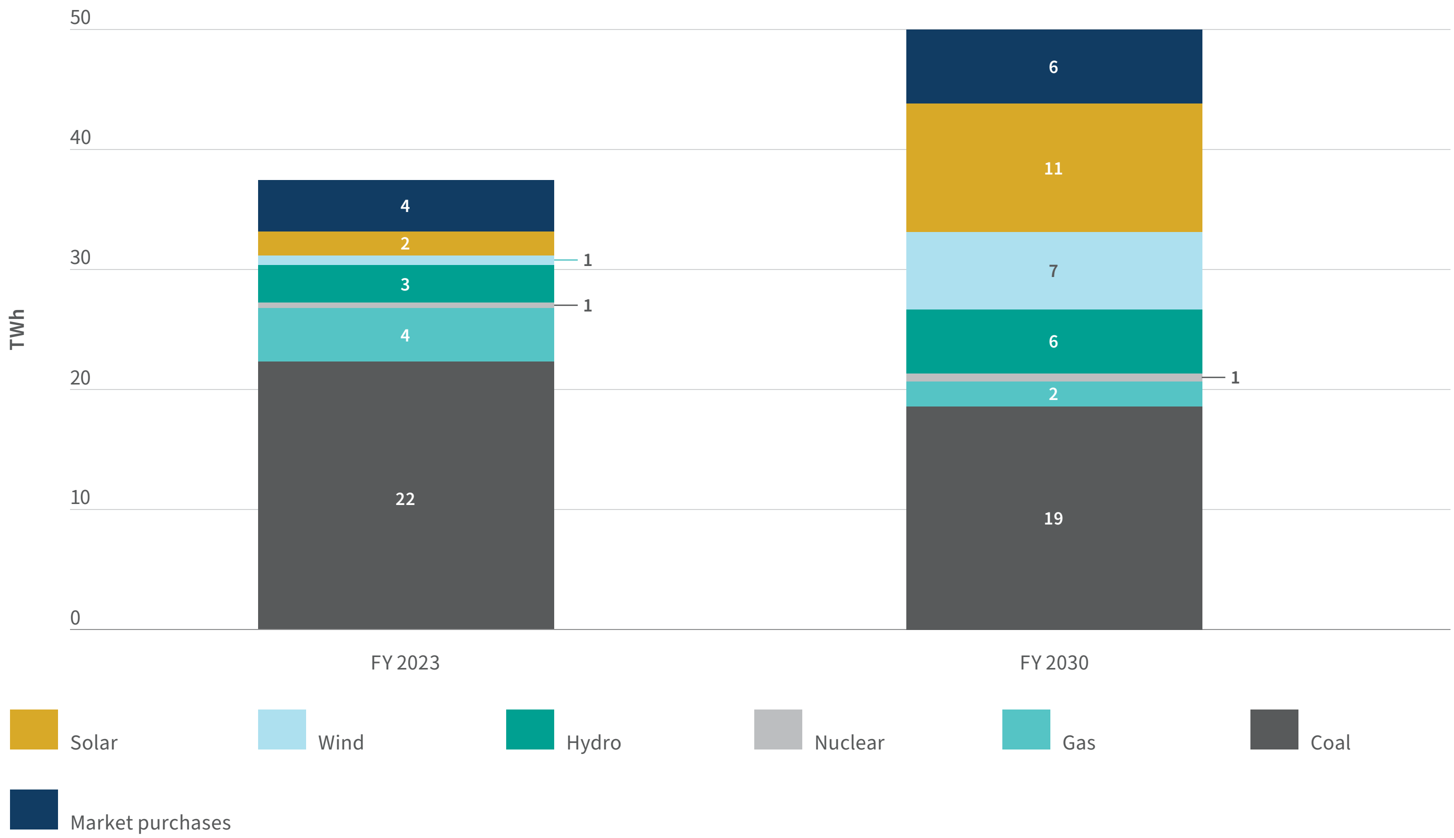
Exhibit 10 Delhi contracted supply (MW), FY23 and FY30



RMI Graphic. **Source**: State Load Dispatch Centre Delhi, **https://delhisldc.org/Resources/allocation%20in%20MW.pdf.**; RMI analysis

Demand growth and an influx of renewables capacity will affect the generation mix from FY23 to FY30. The share of solar-powered electricity serving the city will increase markedly from 5% in 2023 to 21% in 2030. Wind generation will increase from 2% to 11%, while hydropower will increase from 8% to 11%. The share of coal-powered generation will decline significantly, from about 60% to 37%, to accommodate the increased RE generation. The share of gas generation will also decline, from 11% to 4% of total generation. Market purchases are projected to increase, reflecting the need for flexible resources to meet Delhi's rising and peak demand (see **Exhibit 11**).

Exhibit 11 Delhi projected annual generation by source (TWh), FY23 and FY30

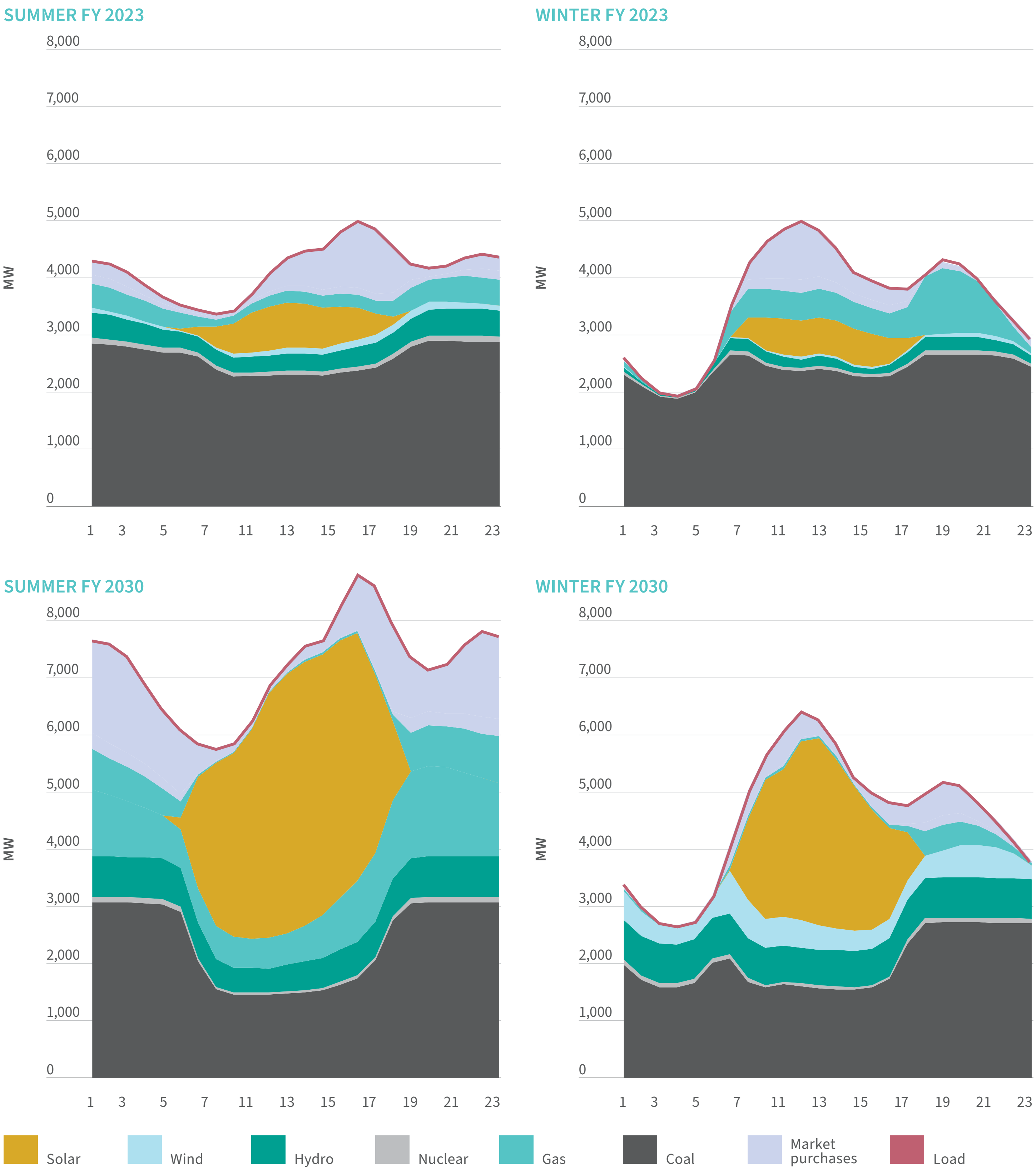


RMI Graphic. **Source**: RMI analysis

Hourly dispatch patterns reveal operational changes required from the power system between FY23 and FY30. **Exhibit 12** shows summer and winter hourly average dispatches, for FY23 and FY30, as optimised through RMI's production cost model (see **Appendix D**). In FY23, thermal generation (coal, nuclear and natural gas) provided baseload power across winter and summer. Increased coal, hydro, and gas-powered generation meets Delhi's late evening and night peak demand across both seasons. Solar generation aligns well with Delhi's afternoon peaks but is unable to meet the evening peak demand. Short-term market purchases fill the supply-demand gap throughout the day as needed.

By FY30, wind and hydro generation will provide additional electricity throughout the day. Solar generation will grow substantially and align with Delhi's afternoon peak demand. Meeting the night peak demand requires gas generation and market purchases. Coal-powered generation also scales to requirement, ramping down when economical to integrate solar-powered generation. Enabling DR, managed EV charging, and battery storage could help meet peak demand, thus allowing Delhi to save on high-cost gas generation and market purchases.

Exhibit 12 Hourly merit order dispatch for winter and summer, FY23 and FY30



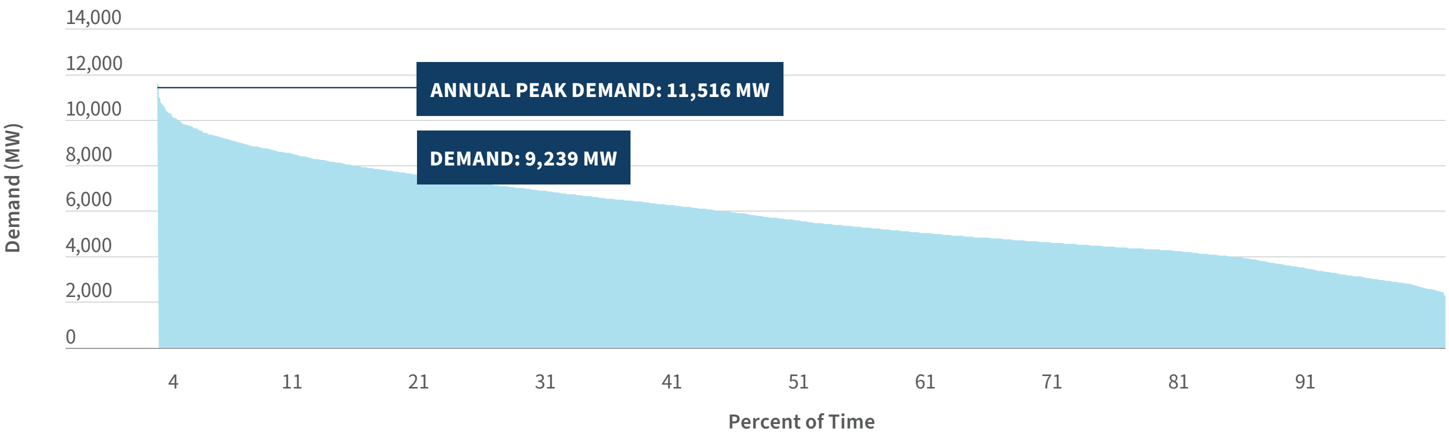
RMI Graphic. **Source**: RMI analysis

Challenges and Costs of Managing Delhi's Current Peak Demand

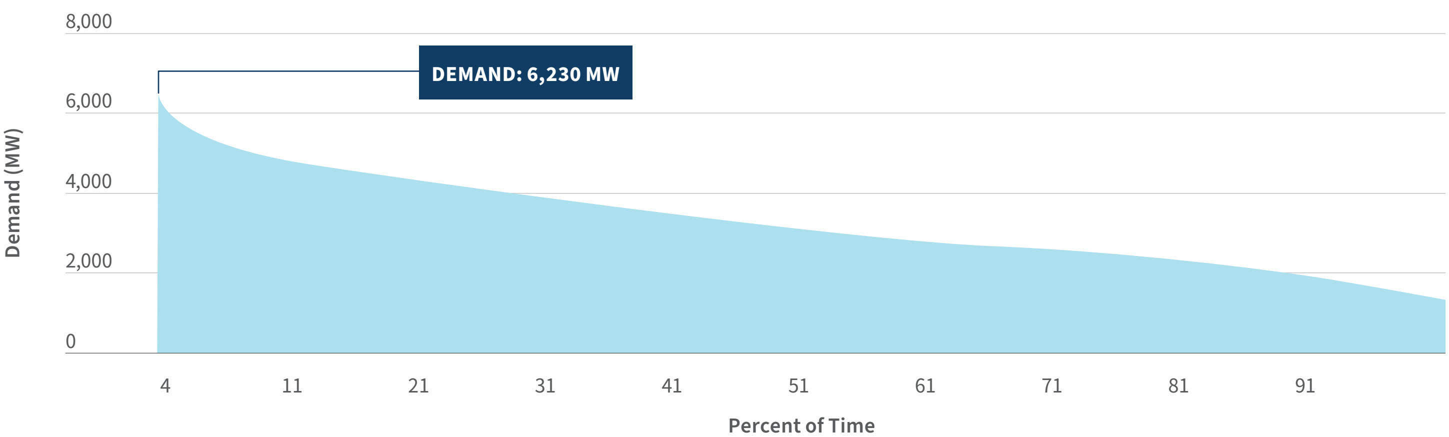
Although Delhi's peak loads are rising rapidly, the duration and frequency of peaks are concentrated over a short span of the year. Delhi's load duration curve from 2023 highlights that the city's peak demand exceeds 6,200 MW for less than 4% (about 350 hours) of the year (see **Exhibit 13**). These peak duration hours are seasonal and concentrated during summer, as highlighted in earlier sections. Delhi's load duration curve is projected to continue to peak higher in 2030, with demand exceeding 9,200 MW for less than 4% of the year.[24]

Exhibit 13 Delhi's load duration assessment in 2023 and 2030

DELHI LOAD DURATION CURVE 2030



DELHI LOAD DURATION CURVE 2023



RMI Graphic. **Source**: IIT Kanpur Department of Management Sciences, Energy Analytics Lab; RMI analysis

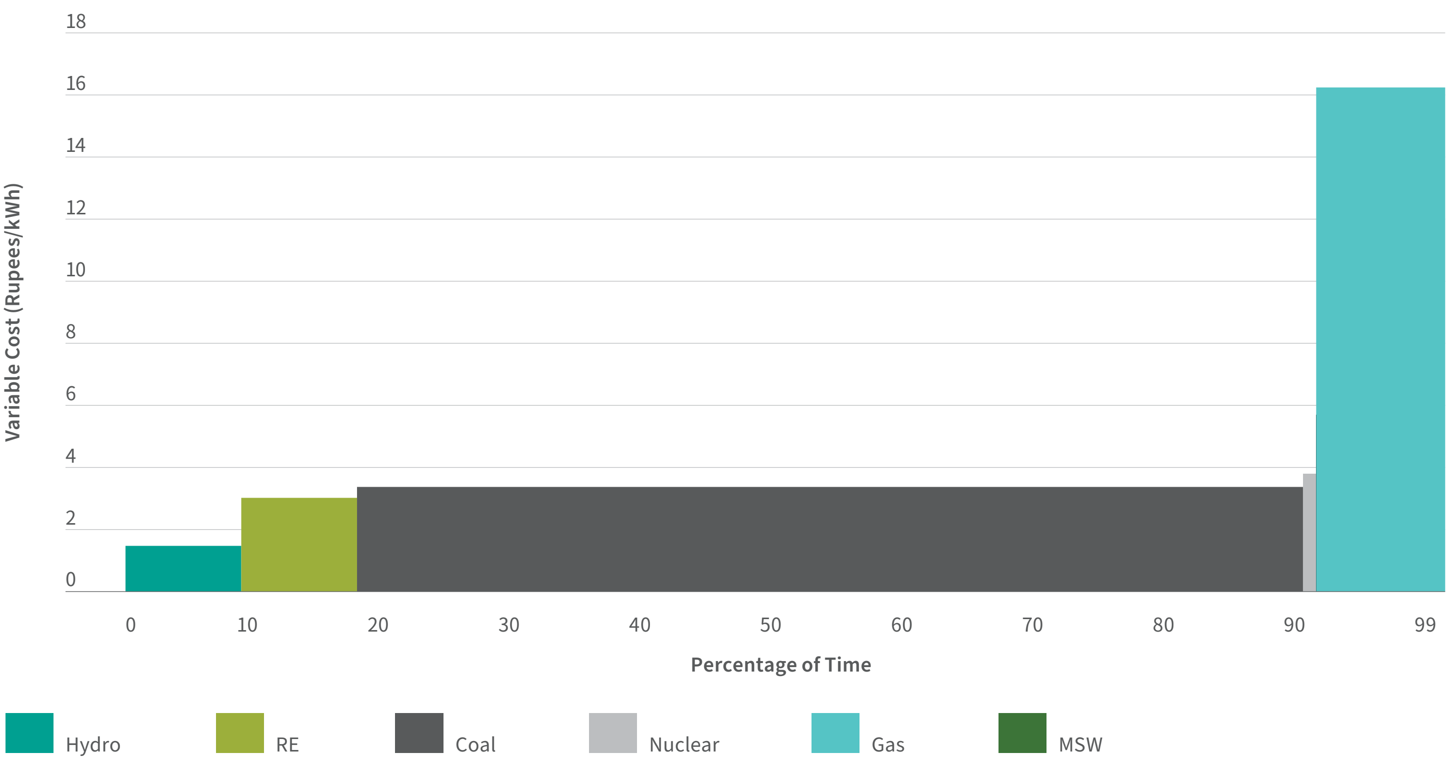
Intermittent periods of peak demand can pose a challenge for grid operators and Discoms, as they can result in an electricity supply crunch and strain the distribution infrastructure, in turn causing grid imbalances.

Impact of Peak Demand on Power Procurement Costs

As Discoms in India follow a merit order dispatch, the least cost-effective generators are brought on line only during peak demand periods. Hence, Discoms incur high power procurement costs during peak periods as the costliest generators (such as gas-powered ones) also need to be dispatched to meet the peak demand.

BSES procures most of its electricity below 4 rupees/kWh (US$0.05/kWh), sourced via coal, hydro, nuclear, and RE generators. Gas-based power generators are cost-prohibitive, as their variable costs are significantly higher than other generators in the stack (see **Exhibit 14**). An assessment of BSES' power procurement costs from its existing long-term power purchase agreements indicates that although gas generators met only about 10% of the annual electricity demand, they accounted for about 20% of the Discoms' annual power procurement costs in 2023 (see **Appendix IX**).

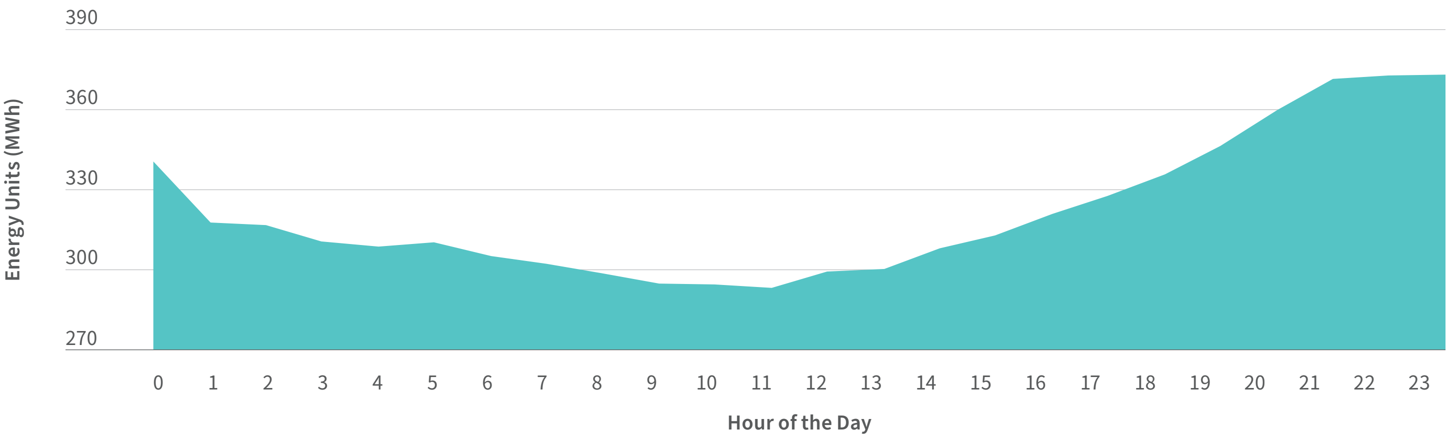
Exhibit 14 Merit order stack of BSES' generators



RMI Graphic. **Source**: BSES

A deeper look at BSES' contracted gas generators depicts how these typically operate during the summer (see **Exhibit 15**). In August 2023, BSES' gas generators ramped up generation in the evening when Delhi reaches peak demand, as highlighted in the previous sections.[25] As Delhi's seasonal peaks continue to rise, increased use of gas generators can significantly inflate power procurement costs for Delhi's Discoms.

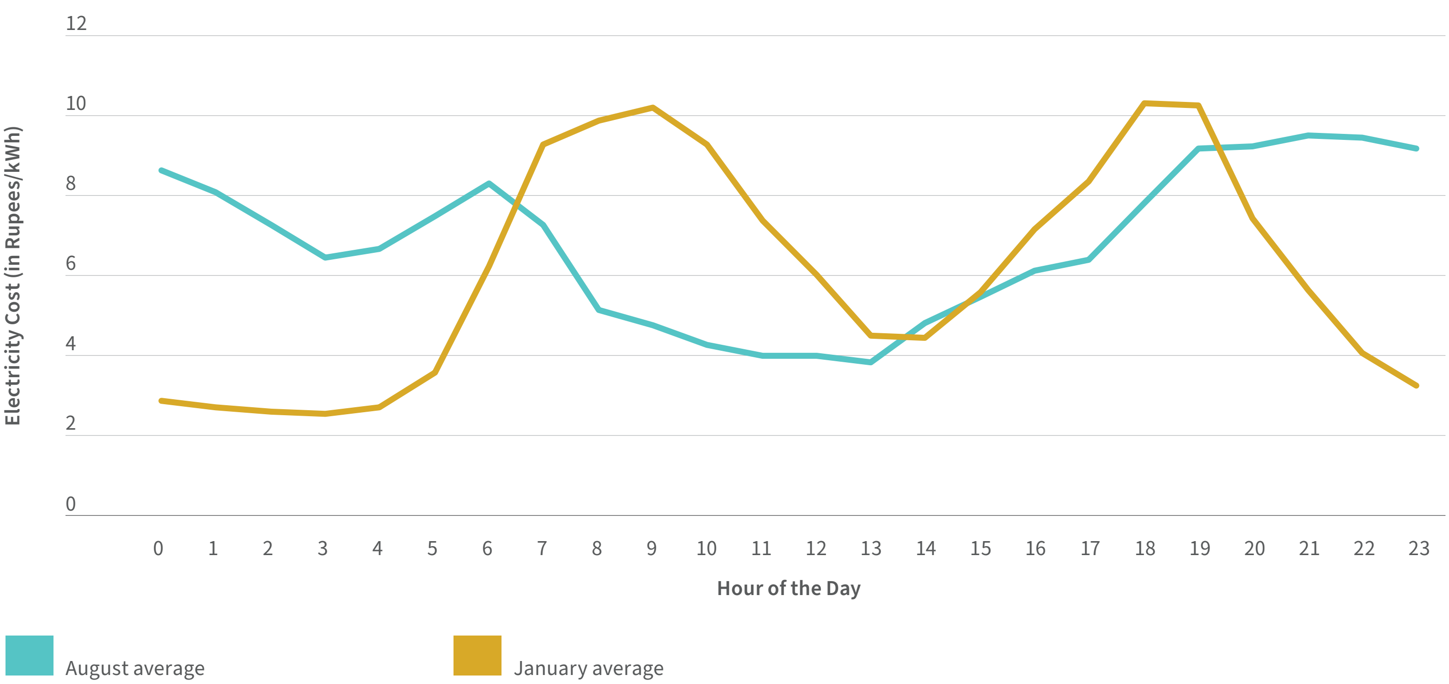
Exhibit 15 Average hourly generation of Delhi's gas generators (August 2023)



RMI Graphic. **Source**: State Load Dispatch Centre, Delhi

Discoms also procure electricity from short-term wholesale markets to meet seasonal peak demands. This is significantly more expensive than the average power procurement costs. A comparison of the average hourly electricity prices (see **Exhibit 16**) on the day-ahead market (DAM) shows a significant difference in cost between summer and winter. During summer, pricing on the DAM is at a ceiling rate of 10 rupees per kWh (US$0.1/kWh) in late evenings, which is significantly higher than the Discoms' average power procurement costs.[26]

Exhibit 16 Average hourly pricing on the DAM

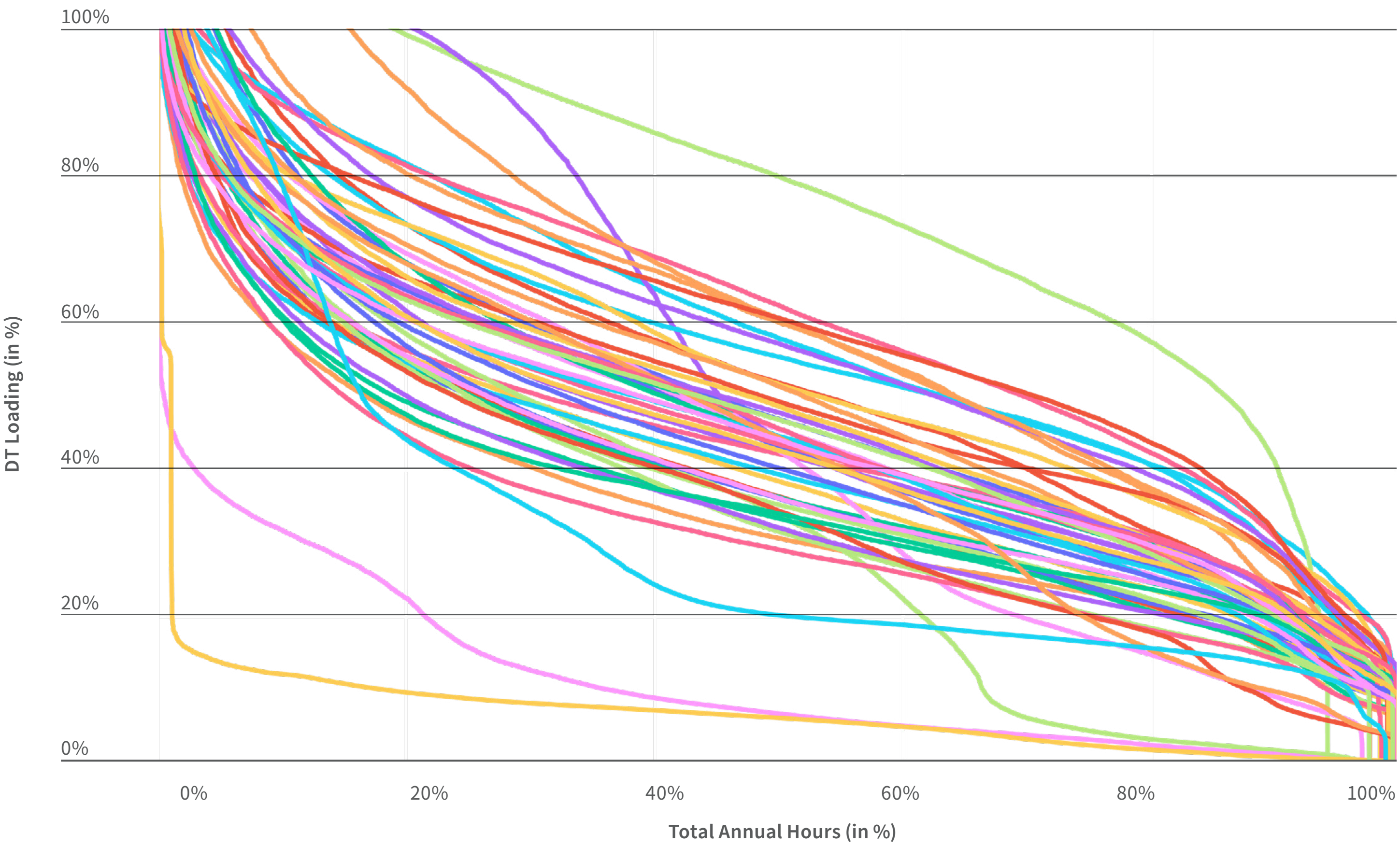


RMI Graphic. **Source**: Indian Energy Exchange

Impact of Peak Demand on Distribution Infrastructure

The seasonal peak in Delhi affects the distribution infrastructure (such as low-voltage transformers), as it may be loaded beyond norms during peak demand. An assessment of 50 overloaded BSES distribution transformers across Delhi reveals that most transformers operate beyond their peak capacity during peak periods (see **Exhibit 17**). The load duration curve assessment highlights that most sample transformers operate at more than 90% of their capacity for less than 5% (450 hours) of the year.

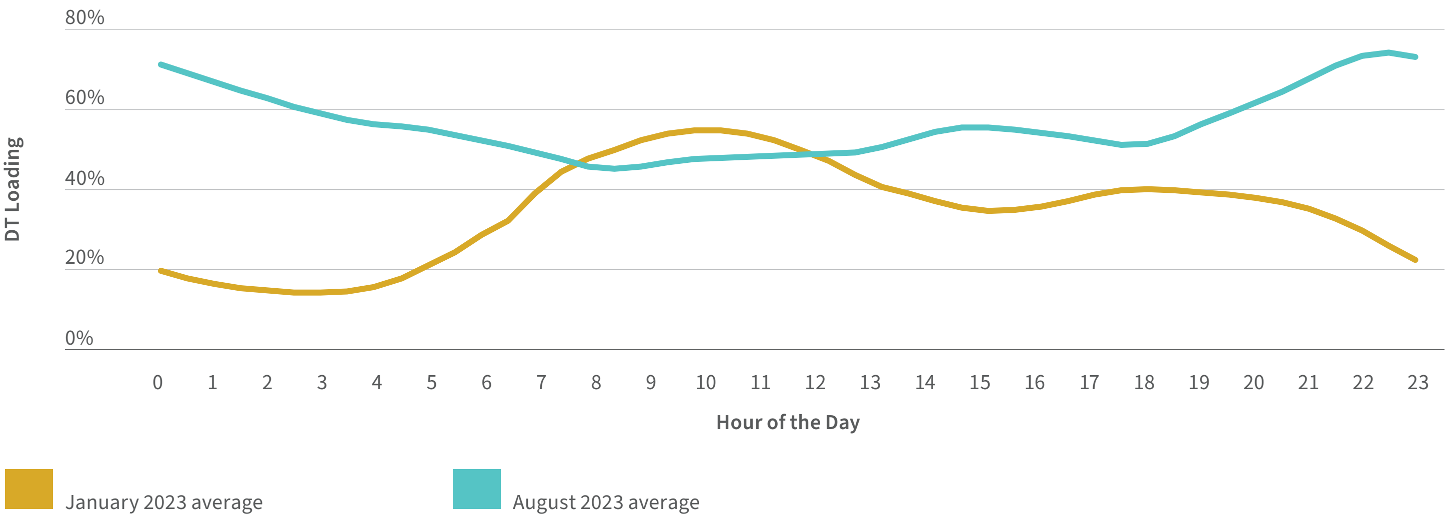
Exhibit 17 Load duration curve of BSES' distribution transformers (2023)



RMI Graphic. **Source**: BSES Distribution Transformers Loading

An analysis of seasonal loading of transformers highlights that these units record peak load during late evenings in summer. This follows a trend like that in Delhi throughout the year, primarily driven by greater use of space cooling (see **Exhibit 18**).

Exhibit 18 BSES' distribution transformers average demand pattern in August and January 2023



RMI Graphic. **Source**: BSES

Operating at peak capacities can be detrimental to the performance and life span of transformers, so adding new transformers or upgrading existing transformers to higher capacities can relieve pressure on existing infrastructure and ensure they can meet future peak load requirements. These upgrades increase the Discoms' capital expenditure and are often a challenge to execute in dense urban areas due to the lack of available space for larger equipment. As of 2023, close to 7% of BSES' distribution transformers qualify to be relieved based on the summer peak demand of 2022.[27]

As the peaking of transformers is seasonal and specific to a few times a year, the mitigation of these peaks through demand-side interventions can minimise the need for transformer upgrades and related expenditures.

Box 1 California's experience with unmanaged peak demand and rising RE penetration

Unmanaged rising electricity demand coupled with intermittent renewables pose a challenge to electricity grids worldwide. Globally, innovative solutions can ensure grid reliability and stability. California has been a leader in the clean energy transition path, with 60% renewable energy anticipated on the grid by 2030 and 100% clean energy by 2045. The state offers valuable insight into the challenges caused by integrating renewables along with peak demand growth.

One of California's biggest challenges is a high reliance on renewable energy with a large increase in demand during peak hours, particularly during heat waves when cooling demand spikes. This leads to the formation of a "duck curve" in net demand (see **Exhibit 19**) as solar generation during the day meets most of the electricity demand but grid operators need to manage a sharp uptick in net load when the sun goes down and domestic electricity usage rises simultaneously. The steep ramp-up in demand can be upwards of 13 GW during the evening hours of 4–7 p.m., which strains grid infrastructure and increases reliance on expensive gas-powered peaker plants.

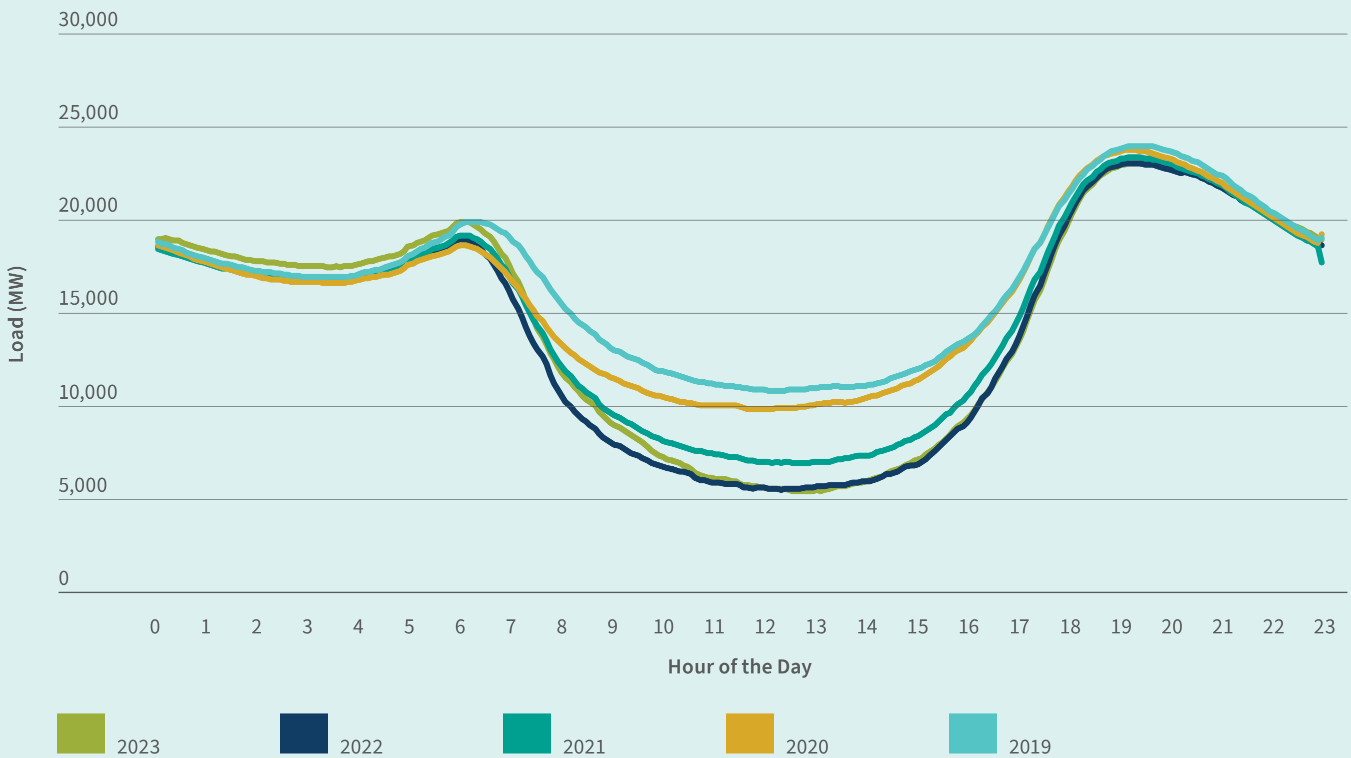
In August 2020, these challenges came to a head as the state experienced several rolling blackouts over two days due to unprecedented high temperatures approximately 5–11°C above normal. This led to higher air-conditioning demand coupled with outages of natural-gas-fired generation (as high ambient temperatures affect a thermal generator's ability to produce power) and less power available to be imported.

Despite the California Independent System Operation (CAISO) forecasting balancing challenges days ahead — and preparing through cautioning generators to avoid activity that could jeopardise reliability and issuing a Flex Alert** urging energy conservation — rising demand still threatened reliability, especially as solar generation decreased in the evening. This led to a Stage 3 emergency, and CAISO conducted rolling blackouts across the state, affecting about 400,000 customers for 8–150 minutes over the two events. These emergency events highlight the need for flexible technology as a solution for threatened reliability. CAISO's report specifically highlights the need for accelerated deployment of demand-side resources to improve system reliability.

California has since taken measures to bolster grid reliability. In 2023, it added more than 4,000 MW of new capacity, half of which was battery storage. Programmes such as the Self Generation Incentive Program further this work by increasing behind-the-metre storage by offering rebates. Demand response programmes are gaining popularity as incentives and inclusivity increase customer engagement. For example, under the Emergency Load Reduction Program, offered by California utilities, consumers receive notifications that they can receive a $2/kWh credit for reducing their energy consumption when the grid is strained. California utilities also incentivise managed EV charging by offering rates designed for consumers who charge vehicles at home. Additionally, research is under way to tackle future challenges, like the large electricity demand increase associated with EV charging, to understand the impacts on the grid, environment, and ratepayers.

*Net demand is total demand minus solar and wind generation.
**Flex Alerts are notifications issued by CAISO to consumers to voluntarily lower their electricity load when there is an anticipated shortage.

Exhibit 19 California net demand, March–May 2019–23



Source: CAISO, https://www.caiso.com/todays-outlook

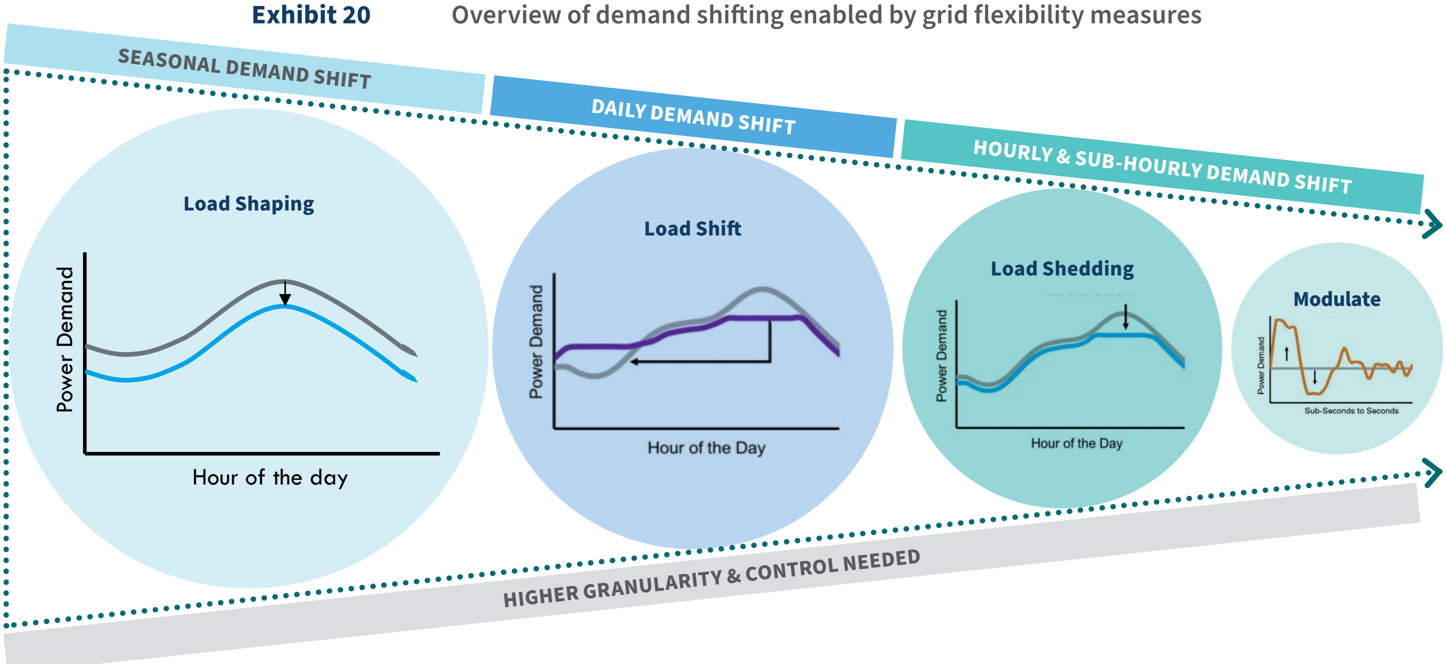
The California example highlights the challenges of increasing RE generation in tandem with the growth in demand. Delhi, much like California, can experience a similar trajectory this decade.[28]

With rising peak demand, Delhi's Discoms face the uphill challenge of expanding their distribution infrastructure in an environment characterised by high urban population density and space limitation while maintaining affordable electricity rates for consumers. Hence, grid flexibility is imperative in order to address these challenges while supporting RE growth to decrease the likelihood of balancing challenges, strained infrastructure, and emergency events.

Value of Grid Flexibility in Delhi

Grid flexibility refers to the tools and resources available to the grid operators and Discoms to maintain the balance between generation and demand on a seasonal, daily, hourly, and sub-hourly basis (see **Exhibit 20**). It involves the ability to modify consumption patterns, often in response to the changes in supply and demand. Grid flexibility measures can reduce Delhi's rising peak demand and make use of its increasing RE generation, thereby lowering power procurement and other system costs for Discoms.

Exhibit 20 Overview of demand shifting enabled by grid flexibility measures



RMI Graphic. **Source**: RMI analysis

- **Load Shaping:** Can help reshape demand profile of consumers with price signals or behavioural programs based on a prior notice given months, weeks, or days of peak events
- **Load Shifting:** Can help shift electricity demand from periods of high demand to periods of low demand or to the time of day when there is surplus renewable energy generation available.
- **Load Shaving:** Can help reduce electricity demand during periods of high demand to support the stability of the grid during emergency events.
- **Load Modulating:** Can help dynamically adjust electricity demand to mitigate any disturbance on very short time frames of seconds to an hour.

This report covers four grid flexibility measures that can benefit Delhi:

a. Air conditioning (AC) demand response (DR)
b. Managed EV charging
c. Battery energy storage systems (BESS)
d. The combined participation of the tools above as VPPs

Each of the grid flexibility measures outlined offers distinct load adjustment capabilities and advantages to the grid, as detailed in **Exhibit 21**. In this chapter, we explore the technical potential and the value these measures could deliver to the Delhi power system by FY30.

Exhibit 21 **Grid flexibility measures considered for the Delhi grid and its impact on load adjustments**

Grid Flexibility Measures	Description	Load Adjustments
AC DR	DR involves modifying the normal consumption patterns of demand-side appliances for residential as well as commercial and industrial (C&I) consumers, such as ACs or other appliances. It could be in response to the changes in electricity prices over time to induce lower electricity use, especially during periods of peak electricity demand (e.g., using time-of-day [ToD] tariffs). DR has been commonly deployed via DR event signals that provide incentives to consumers to shave demand during the event period. With rising demand for cooling, AC-based DR programmes offer an effective resource to enable grid flexibility and alleviate strain on Delhi's grid during periods of high electricity demand, such as heat waves.[29]	Load Shaving
Managed EV Charging	Managed EV charging programmes optimise the charging of EVs over time by minimising charging during peak hours and maximising charging during off-peak hours. Well-designed EV ToD tariffs incentivise consumers to charge EVs during off-peak hours. A similar framework could be applied to managed fleet EV charging as well as commercial and personal EV charging. As Delhi grows its e-bus fleet, managing e-bus charging also will be crucial to supporting the grid flexibility requirements.	Load Shifting

Exhibit 21 **Grid flexibility measures considered for the Delhi grid and its impact on load adjustments (continued)**

Grid Flexibility Measures	Description	Load Adjustments
BESS	A BESS system can store electricity when low-cost electricity like RE is widely available, and discharge it during periods of peak electricity demand. BESS can be deployed across the electricity system value chain (e.g., hybrid renewables, distribution-sited BESS, and consumer-sited BESS). This report highlights the value of distribution-sited BESS. A similar value framework could be considered for customer-sited BESS. Hybrid and transmission-connected BESS are not considered in the scope of the report.	Load Shifting
VPPs	A VPP is an aggregation of grid flexibility measures that can balance electrical loads and provide utility-scale and utility-grade grid services. In this report, **AC DR, managed EV charging, and BESS have been combined into an umbrella VPP case**. As the technological readiness for new flexibility measures increases in Delhi, the actual scope of VPPs could be much larger than the combined portfolio considered for the report.	Load Shaving and Shifting

RMI Graphic. **Source**: RMI analysis

Framework for Valuing Grid Flexibility Measures

The core principle behind valuing grid flexibility measures involves assessing the costs associated with deploying flexibility programmes against the savings they generate. A programme is cost-effective if its benefits exceed costs (the benefit-cost ratio is greater than 1:1). Cost-effectiveness is a key criterion for programme development, as per the Model Demand Side Management Regulations published by the Forum of Regulators in May 2010 and since adopted by the Delhi Electricity Regulatory Commission (DERC) in 2014.[30] This study applies standard methodologies to assess the cost-effectiveness of grid flexibility measures.[viii]

This study quantifies the following three types of benefits:

a. **Avoided energy:** These benefits arise from reduced power purchase costs by Discoms, or by shifting power purchases from periods when expensive gas-powered generators or market purchases are required to periods when low-cost resources are abundant.

viii. That is, as per the Total Resource Cost Test described in *Cost Effectiveness of Utility Driven DSM Programmes: Issues and Challenges*, Utility CEO Forum on Demand Side Management, 2014. Further research could explore additional measures of cost-effectiveness, such as Participant Cost Test, Ratepayer Impact Measure, and Programme Administrator Cost Test. There is a need to develop standardised regulatory guidelines for cost-effectiveness analysis at the central and state levels and clarifying applicability of different tests in approving grid flexibility programme measures.

b. **Avoided generation capacity:** These benefits stem from mitigating the need for additional capacity necessary to meet future resource adequacy (RA) obligations through grid flexibility measures.

c. **Distribution capacity deferral:** These benefits arise from potential deferred investments in new distribution infrastructure that Discoms would incur to meet peak demand without any grid flexibility measures.

Grid flexibility measures could unlock these key value streams for Delhi's Discoms and provide additional qualitative benefits such as competitive electricity tariffs for consumers, reduced line losses, improved reliability and grid resiliency, emissions reduction, and community empowerment. Costs include investments in equipment, programme administration, and annual operations and maintenance.

The complete list of benefits and costs assessed in this study is provided in **Exhibit 22**. In this framework, we have not included the potential benefits of ancillary services (AS). According to the AS regulations proposed by the Central Electricity Regulatory Commission (CERC), BESS and other demand-side resources are theoretically eligible to contribute to AS.[31] However, market-based AS requirements are still being established in India. The lack of clear regulatory guidelines and price signals for AS participation of demand-side resources has led to uncertainty around their potential value. We have also not quantified the potential for transmission upgrade deferrals, the potential reliability benefits from increased distribution system flexibility, or the health and environmental benefits associated with avoided emissions. The DERC and Delhi Discoms can include these benefits in subsequent analysis of grid flexibility programmes cost-effectiveness.

Exhibit 22 Benefits and costs quantified for evaluating cost-effectiveness of grid flexibility measures

		AC DR	MANAGED E-BUS CHARGING	BESS	VPP
Assessed Benefits	**Energy Value**	Load Shaving	Load Shifting	Load Shifting	Load Shifting and Shaving
	Resource Adequacy Value	Avoided marginal capacity value to meet future RA obligations			
	Distribution Deferral Value	Included	No savings included*	Included	Included
Costs		Equipment and software investments, Discom programme administration and marketing costs	Software investments, Discom programme administration and marketing costs	Costs of building and maintaining BESS equipment	Combined across options

*Managed e-bus charging shifts electricity demand from peak (9 p.m.–1 a.m.) to off-peak periods (3–9 a.m.). However, Discoms still need to develop the local distribution system to meet the additional demand of the e-bus depot during daytime peak, as there is limited charging optimisation potential during the daytime hours given the current bus-route system in Delhi.
RMI Graphic. **Source**: RMI analysis

Value of Grid Flexibility in Delhi

By FY30, RMI estimates that Delhi could reduce 250–1,350 MW of peak demand through AC DR programmes,[ix] up to 400 MW of demand-shifting potential through managed charging of the e-bus fleet, and 500–2,500 MW of shiftable demand through BESS (see **Exhibit 23**). Combined as VPPs, these measures could unlock maximum demand reductions of nearly 4,000 MW, about one-third of Delhi's projected peak demand in 2030. Moreover, these flexibility measures can significantly benefit Delhi's Discoms. We estimate that the annual net benefits to Delhi utilities could reach up to 150 crore rupees (US$18 million) for AC DR programmes, up to 110 crore rupees (US$13 million) for e-bus managed charging, 850 crore rupees (US$100 million) for BESS, and a combined benefit of up to 1,050 crore rupees (US$124 million) for integrated VPPs.[x]

Benefit-cost ratios range from 1.3:1 to 2.9:1 for AC DR, 4.3:1 for e-bus managed charging, 1.5:1 to 1.8:1 for BESS, and 1.6:1 to 1.8:1 for VPPs. Delhi Discoms have great potential to leverage these grid flexibility measures and cost-effectively plan for increasing demand. The details of the potential savings, net benefits, and benefit-cost analysis are discussed below.

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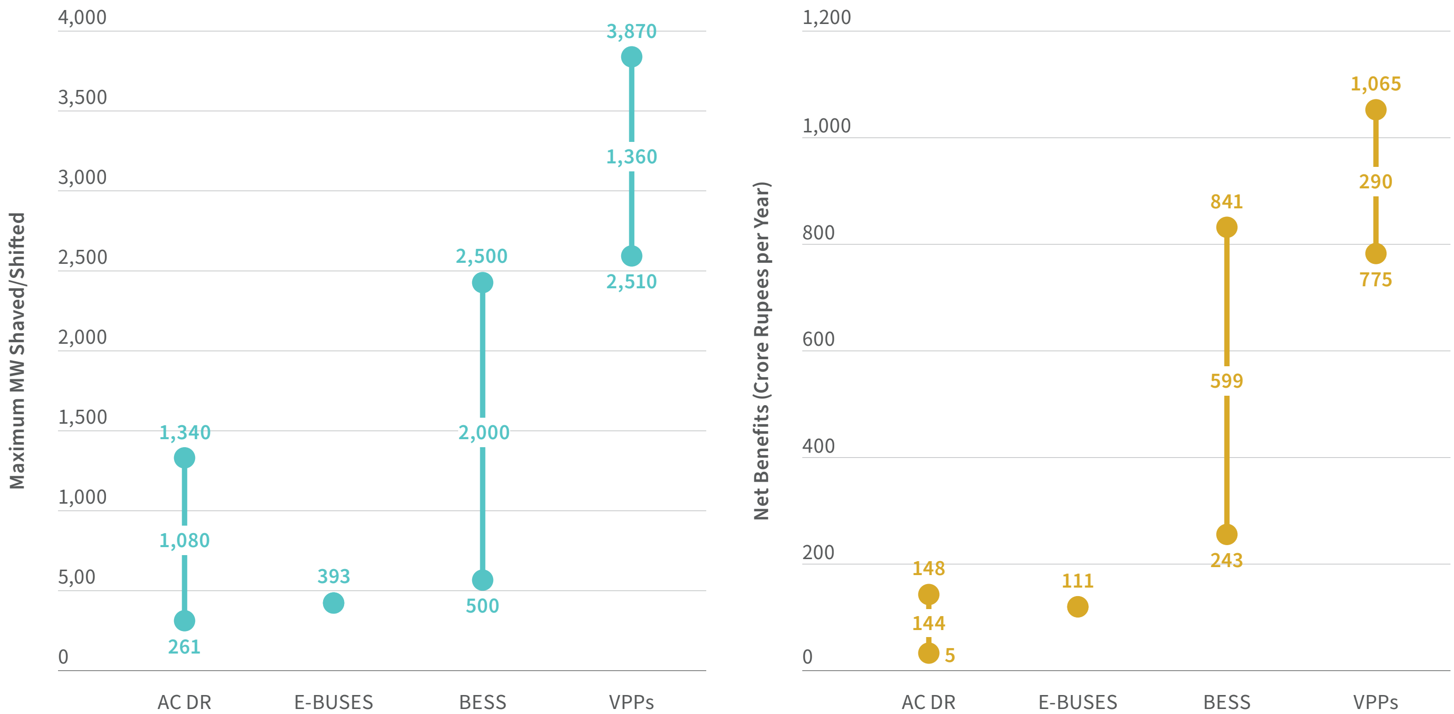
ix. Based on the following consumer participation lates – Low: 7% domestic behavioural demand response (BDR) participation, 0% domestic automated demand response (ADR) participation, 0% C&I ADR participation; Mid: 17% domestic BDR participation, 0% domestic ADR participation, 10% C&I ADR participation; High: 24% domestic BDR participation, 5% domestic ADR participation, 25% C&I ADR participation.

x. 1,050 crore rupees (US$124 million) per year net benefits translate to savings around 1,500 rupees (US$18) per electric consumer per year (assuming total of 6.85 million consumers). These savings are on the order of a month's power bills for a domestic consumer.

Exhibit 23 FY30 grid flexibility potential and annual net benefits by technology, Delhi



RMI Graphic. **Source:** RMI analysis

Assessment of AC-based DR Potential in Delhi

In this report, we consider two avenues for AC-based DR in Delhi:

- **Behavioural demand response (BDR)** encourages consumers to reduce electricity consumption during peak periods based on signals or alerts triggered by Discoms. BDR aims to raise awareness and influence consumer behaviour to enhance grid flexibility. This can include both price-based DR (i.e., ToD rates) and incentive-based DR. For this report, we have considered incentive-based BDR potential.

- **Automated demand response (ADR)** uses advanced technologies, such as smart metres, sensors, and control systems, to automatically adjust electricity consumption in real time. ADR minimises human intervention and enables swift responses to grid signals.

Thus far, BDR is more feasible in India, as the technological readiness needed for BDR participation is lower. BDR has been implemented in some of the leading DR pilot projects in India, including actively running programmes in Mumbai.[32] However, ADR has a higher potential for DR savings than BDR. Therefore, with increased technological readiness, ADR could be an appealing choice for Discoms and consumers.

Tata Power Mumbai is extending its DR programmes to include BDR and ADR elements — offering incentives to reduce demand via text messages and email as well as controlling loads directly through in-home smart plugs.[33] This programme aims to engage over 55,000 domestic consumers and 6,000 large C&I consumers to reduce peak capacity by 75 MW, clearly exhibiting the impact of implementing ADR and BDR together. Going forward, Discoms across India are likely to expand BDR and ADR programmes to maximise the reach and depth of their demand-side programmes.

Box 2 **Behavioural vs. automated DR**

There are advantages and disadvantages associated with BDR and ADR, making it beneficial to implement both programmes. Since BDR does not require an advanced level of technical integration, it is accessible to consumers, making it an impactful starting point for consumers without smart appliances. However, as Discoms have no control over how much demand will be shaved through BDR, investments in consumer engagement and education are imperative for a successful programme.

For ADR, once consumers are enrolled, Discoms can directly communicate to and trigger appliances, thereby minimising the need for consistent consumer engagement. But ADR programmes require investing in lucrative incentive programmes for consumers and infrastructure like smart appliances to achieve the technical readiness they need. With ADR, Discoms have relatively high visibility into demand, which can be manipulated on the consumer's end unlike BDR.

Although they differ in the ease of implementation and level of investment, both the programmes are necessary to effectively reduce Delhi's growing peak demand. Additionally, both require a robust measurement and verification process to establish bona fide system-level impacts.

For this study, RMI developed three outlooks based on a wide variety of possible assumptions with the aim of providing a comprehensive picture of DR potential in Delhi by 2030.

- **Low-participation case:** This scenario captures the savings potential via a domestic AC-based BDR programme, reflecting the current technological limitations associated with deploying an ADR programme. This case assumes 7% domestic customer participation, with 10 events called during summer nights for two hours each.

- **Mid-participation case:** This scenario captures the savings potential for both a domestic BDR and a C&I ADR programme, reflecting the pilots and programmes already implemented in India. This case assumes 17% domestic participation, with 15 events called during summer nights for two hours each; and 10% C&I participation, with 15 events called during summer afternoons for three hours each.

- **High-participation case:** This scenario captures the savings potential of domestic BDR and ADR programmes coupled with a C&I ADR programme, reflecting the potential of a fully realised DR programme by FY30. This case assumes 24% domestic BDR participation, with 20 events called during summer nights; 5% domestic ADR participation, with 20 events called during summer nights; and 25% C&I participation, with 20 events called during summer afternoons.

Rationale for these assumptions is based on several DR pilots and programmes conducted in India and the United States. Participation rates for domestic BDR are based on programme result ranges provided by Pacific Gas & Electric (PG&E), a California utility, and the Association of Energy Services Professionals.[34] C&I ADR are somewhat reflective of these rates as well, with a wider range to gain a comprehensive picture. Domestic ADR participation rates are extracted for PG&E's SmartAC programme, a long-run AC DR programme in California.[35] Event numbers, seasons, and energy shaving potential per event are based on a Tata Power Delhi BDR pilot and the DOE data of multiple utility programmes in the United States.[36] Residential DR customers are assumed to provide a 0.5 kW load shave per event, while the C&I DR programme is expected to provide a 5 kW load shave per event[xi] (see **Appendix E** for more information). Furthermore, domestic ADR is included only in the high-participation case, which is an optimistic, yet feasible, scenario for shaving load (see **Exhibit 24**).

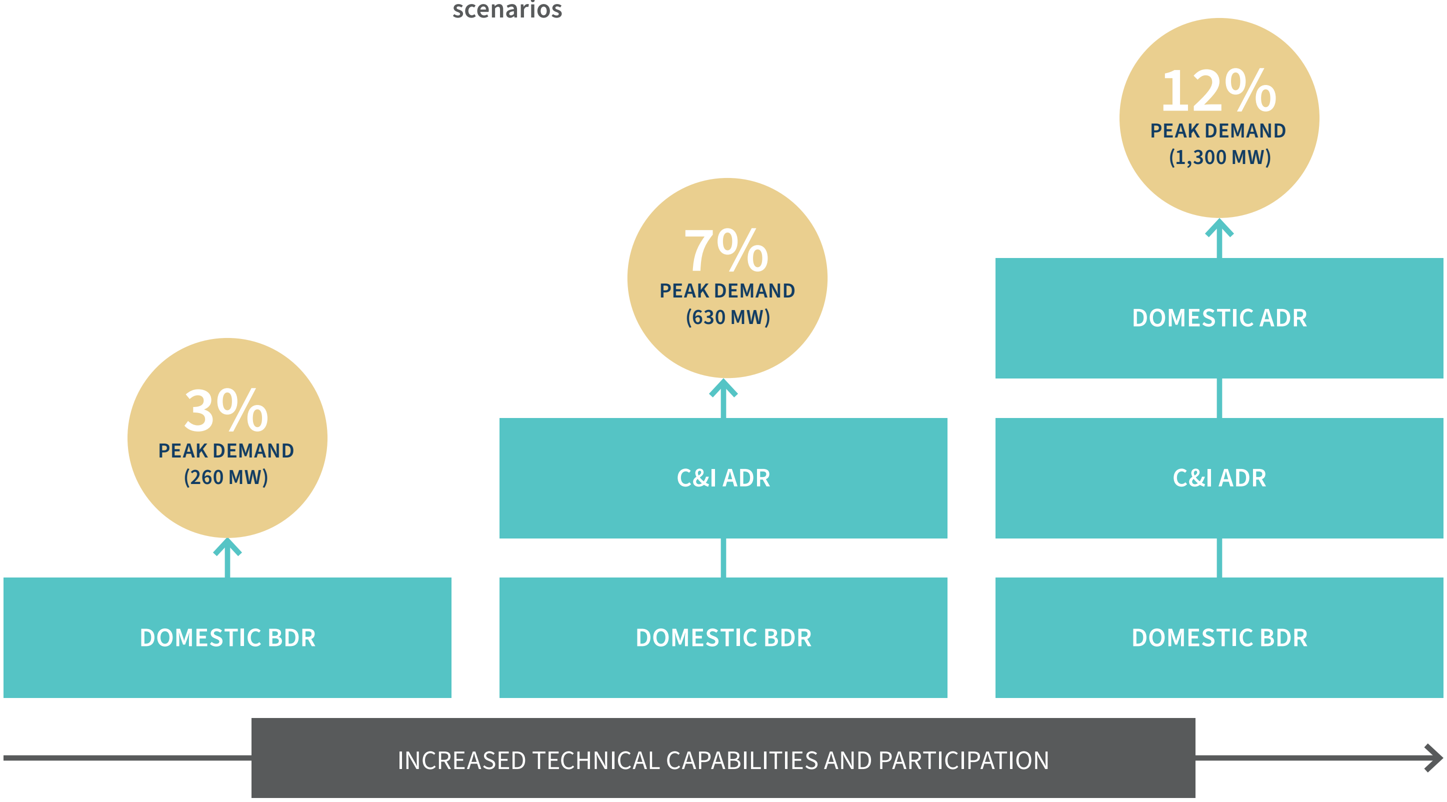
> **"Although BDR and ADR differ in the ease of implementation and level of investment, both programmes are necessary to effectively reduce Delhi's growing peak demand."**

These programmes do not require complete shutoff of air conditioners, but rather incentivise consumers to either pre-cool their spaces or temporarily set their thermostat to a higher temperature during peak demand periods. Additionally, the option of alternating between on and off settings during the event period could be explored with ADR. These adjustments can reduce electricity consumption without compromising comfort levels.

xi. For reference, a typical 1.5-ton window AC consumes about 1.2 to 1.5 kW of electricity per hour.

Successful residential and C&I DR programmes have been implemented in various regions. For example, the China Light and Power DR programme in Hong Kong (discussed in *Impactful Programme Incentives in China*, **Box 7**) demonstrates that consumers are willing to make modest adjustments to their cooling practices in exchange for compensation. However, there might be certain challenges in operationalising these practices in Delhi. Delhi Discoms could roll out a large-scale DR pilot program to test and validate different AC DR participation and incentive strategies.

Exhibit 24 **Maximum peak demand reduction potential for AC DR in Delhi by FY30 under three scenarios**



Note: Enabling BDR and ADR programmes over time with advances in technological readiness for domestic and commercial consumers.

RMI Graphic. **Source**: RMI analysis

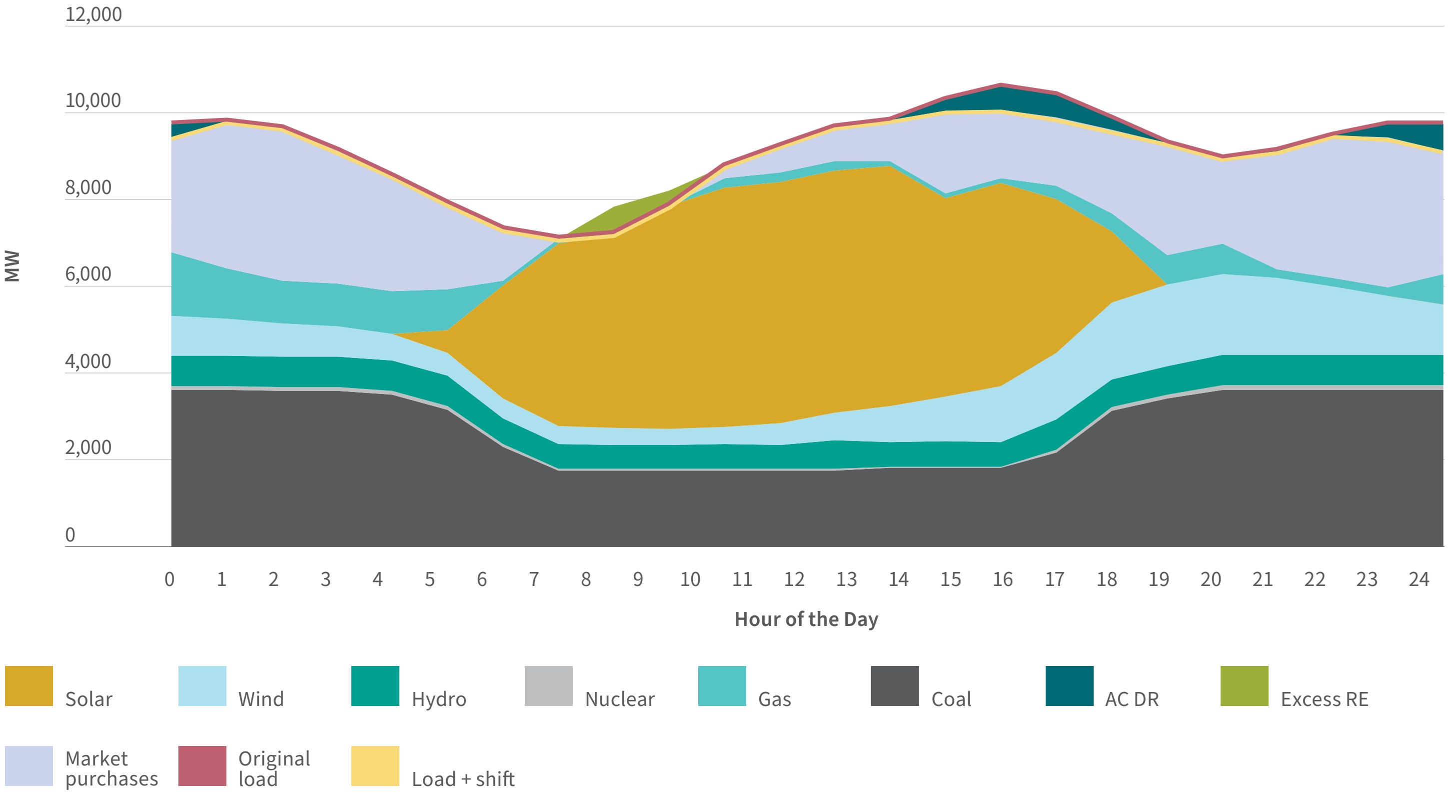
Benefit-Cost Analysis for AC DR by FY30

The benefit-cost ratio of AC DR ranges from 1.3:1 to 2.9:1.

Energy Value

AC DR provides benefits by reducing load during afternoon and midnight peak hours, avoiding expensive market purchases, and lowering peak demand. **Exhibit 25** illustrates the dispatch of the various power generation resources and the impact of AC DR under the mid-participation case assumptions for a typical summer day in 2030. On this day alone, AC DR is estimated to lead to 3,000 MWh in energy savings and 18 million rupees (US$216,000) in avoided power procurement costs via market purchases. The detailed methodology to estimate these savings is discussed in **Appendix F**.

Exhibit 25 Delhi hourly generation dispatch and impact of AC DR case on a summer peak day in 2030 under mid-participation case



RMI Graphic. **Source**: RMI analysis

Distribution Deferral Value

AC-based DR programmes offer economic benefits beyond electricity cost savings during peak hours for Discoms. With distribution infrastructure needing to keep pace with rising peak demands, DR programmes provide the opportunity to defer the upgrade of overloaded infrastructure during peak demand periods. The distribution deferral value is regional and Discom-specific. For this study, we estimate deferral value for Delhi at 500 rupees/kW per year (US$6/kW per year), based on a review of existing studies and the cost data book for Delhi Discoms (see **Appendix D** for details).

Resource Adequacy Value

To the extent that DR programmes can reliably reduce peak demand, they can provide the additional benefit of avoided generation capacity, as quantified by the RA value. The RA guidelines shared by the Ministry of Power (MOP) direct Discoms to procure capacity resources to meet the RA requirement.[37] DR programmes can contribute to the RA requirement. However, the RA regulations are in the initial stages of implementation in India, and as of now, there are no regulatory approved RA capacity credit evaluation methodologies for the demand flexibility resources. Therefore, while demand flexibility resources can contribute to the RA requirement, they are currently unable to monetise RA value. In this report, we have estimated RA value for DR programmes based on evaluation methodologies used in US capacity markets.[xii]

If Delhi regulators adopt an RA regulations framework by FY30, Discoms will be responsible for meeting planning reserve margin requirements and procuring for capacity obligations, either through building new generating resources or securing bilateral contracts. DR programmes can provide resource adequacy value — through either obviating the need to build new capacity resources or reducing the need of Discoms under an RA construct to enter long-term capacity contracts. Considering that the FY30 supply-side projections post high reliance on market purchases, we estimated generation capacity value through avoided bilateral capacity contracts at 2,793 rupees/kW-year (US$33.5/kW-year) and capacity accreditation of 19%–37% for DR programmes (see **Appendix F** for details).

Costs

The costs of an AC DR programme consist of the expenses of administration to establish and run the programme and smart thermostats necessary for automated demand response. Based on a review of previous DR studies (see **Appendix F** for detailed calculations), we estimate costs of 600–900 rupees/kW-year (US$7.2-10.8/kW-year). A rollout of a large-scale DR pilot programme could provide more accurate and location-specific cost estimates to Discoms.

Net Benefits

Exhibit 26 shows the stacked benefits compared with costs for the three proposed DR participation cases. Benefit-cost ratios range from 1.3:1 to 2.9:1 across scenarios. Under the high-participation case, total annual net benefits to Delhi's Discoms could reach 150 crore rupees (US$18 million). In this case, RA value reaches 145 crore rupees (US$17 million), reflecting the ability of 1,340 MW of AC DR to replace about 480 MW of power generation capacity needed during peak demand periods. We show the RA value with dotted lines, to emphasise that it is not yet monetisable.

Although RA may be the greatest source of value, the savings from avoided energy purchases and distribution deferral are substantial, exceeding total costs in the mid- and high-participation cases. The mid- and high-participation cases are most cost-effective due to the addition of C&I DR (see **Appendix F**), which enables savings during the afternoon peaks, when energy is most expensive and the system faces the greatest capacity constraints.

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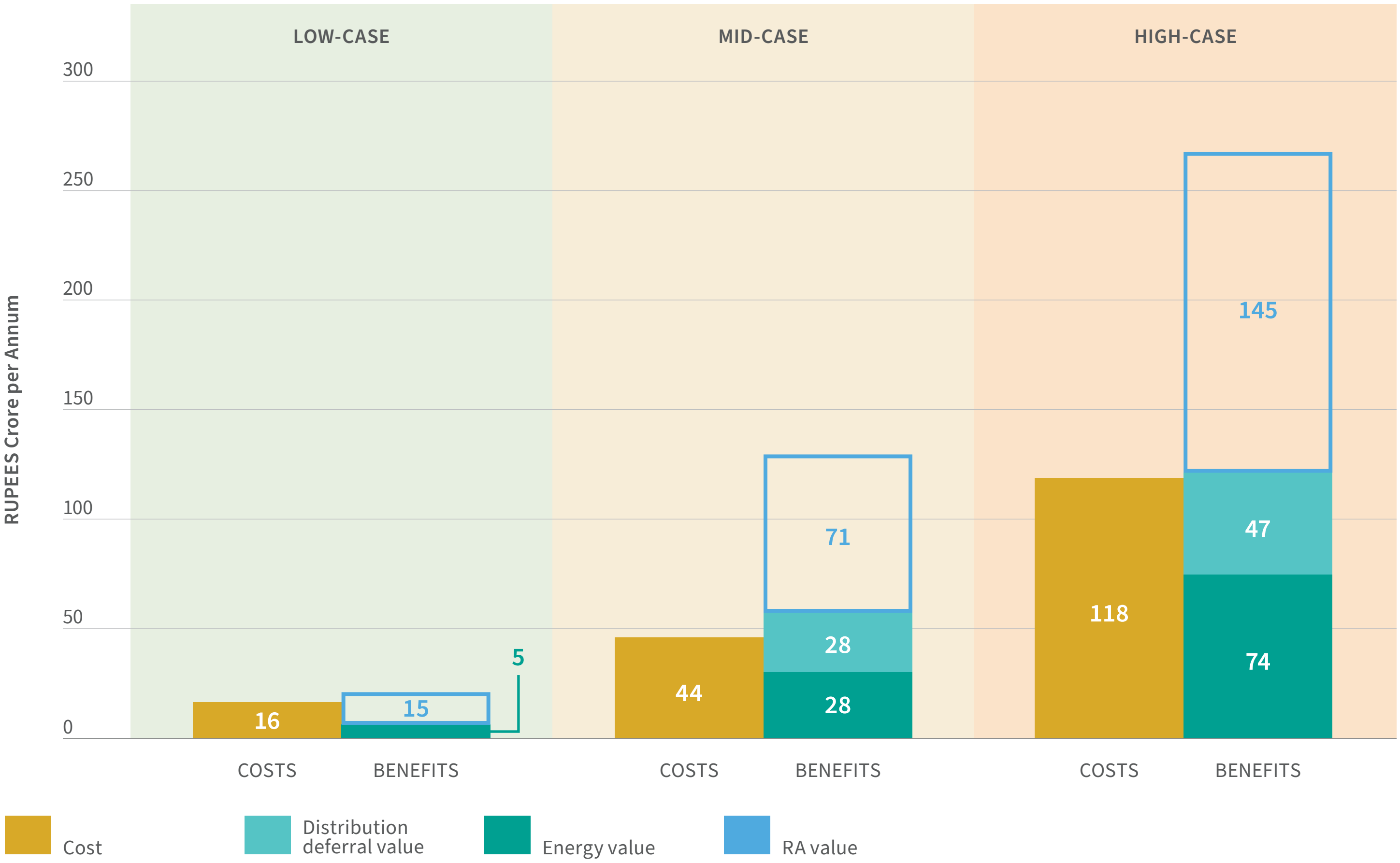
xii. To estimate the price of capacity, we use a net cost of new entry (CONE) methodology used in the US electricity market PJM's centralised capacity market. The CONE represents the total levelised annual cost for the new resource built to meet system reliability. A net-CONE estimate subtracts any forecast net revenue from energy and reserve markets from the CONE. See **https://www.pjm.com/-/media/library/reports-notices/special-reports/2022/20220422-brattle-final-cone-report.ashx**.

Exhibit 26 Annualised costs and benefits of AC DR programmes to Delhi utilities in FY30



RMI Graphic. **Source**: RMI analysis

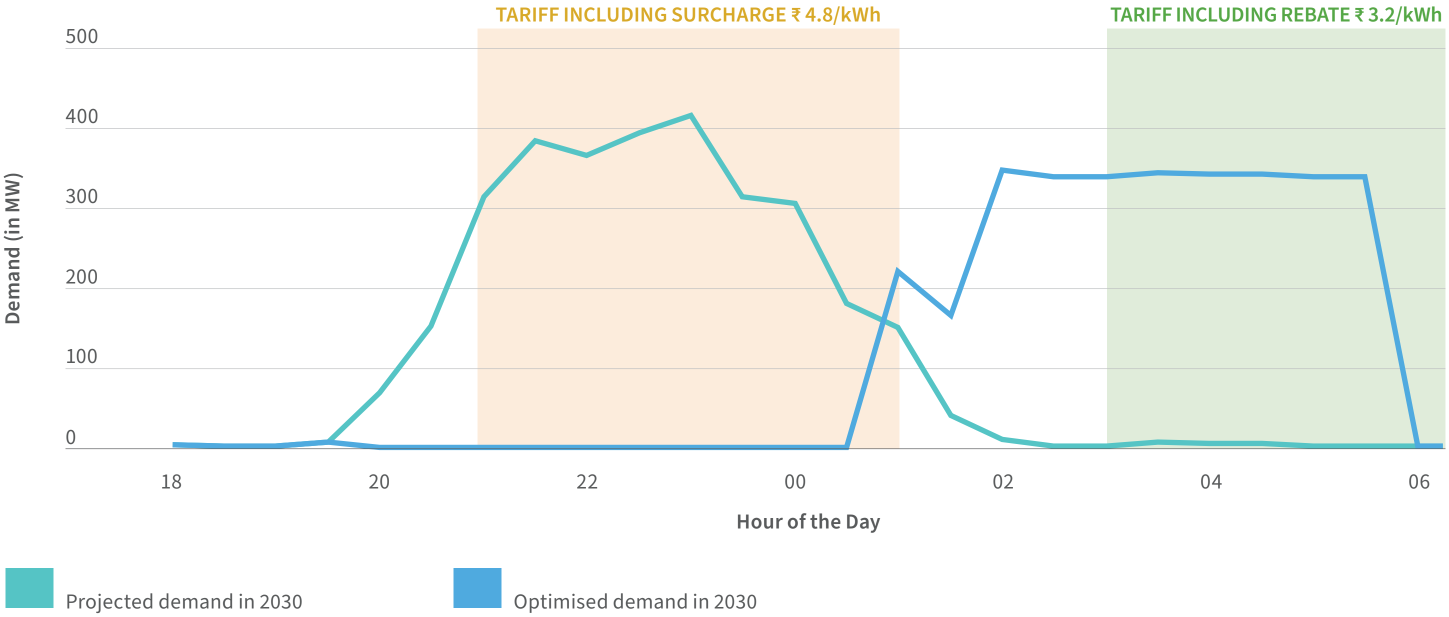
Assessment of Managed E-Bus Charging Potential in Delhi

Delhi's existing fleet comprises 1,650 e-buses, contributing about 50 MW of Delhi's peak demand. By 2030, as highlighted in earlier sections, the charging of these buses during late evenings and night will increase Delhi's peak demand, causing Discoms to incur significant power procurement costs.

Bus depot operators add a 20% surcharge on the electricity tariff of 4 rupees/kWh (US$0.05/kWh) during the summer months (from May to September) during the periods of 1–5 p.m. and 9 p.m.–1 a.m. During the same months, they offer a tariff rebate of 20% for charging from 3 a.m. to 9 a.m. As e-buses currently are charged during the peak hours (when the surcharge is applicable), depot operators can save 1.6 rupees/kWh (US$0.02/kWh) by charging during off-peak hours (when the rebate is applicable). With the city's e-bus fleet projected to rise to 12,000 buses, Delhi could use this shift to mitigate its peak demand by close to 400 MW by 2030 (see **Exhibit 27**).

Due to existing bus routes in Delhi, there is limited flexibility for optimising charging during the day. Therefore, managed charging of e-buses during these hours has not been considered despite a tariff rebate offered between 1 and 5 p.m. during the summer.

Exhibit 27 Potential of managed charging of e-buses in Delhi in 2030



RMI Graphic. **Source**: RMI analysis

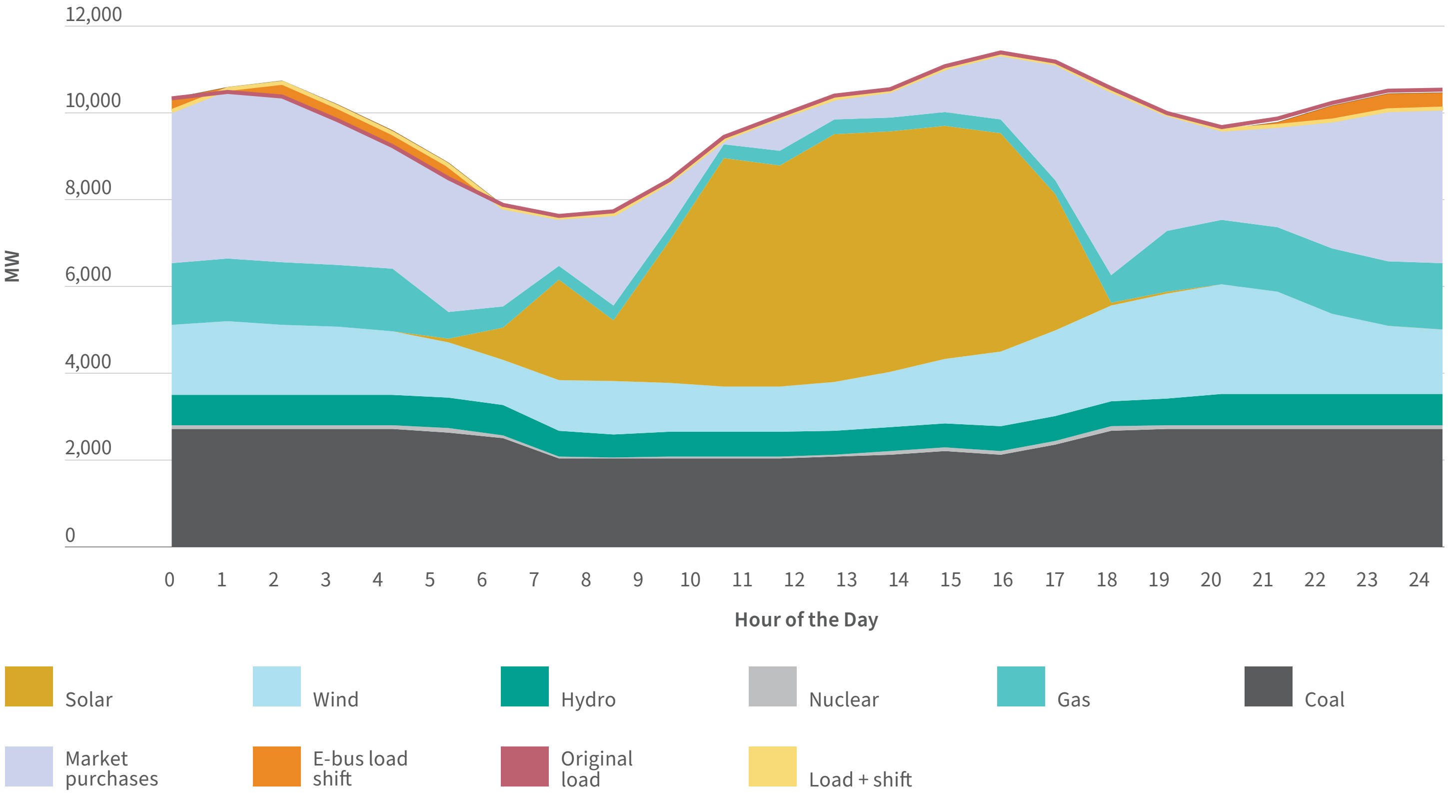
Benefit-Cost Analysis for Managed E-Bus Charging by FY30

The benefit-cost ratio of managed e-bus charging is 4.3:1.

Energy Value

Exhibit 28 shows the impact of e-bus demand on the Discoms' generation purchases for a simulated summer peak day in 2030. ToD rates incentivise managed charging to move the e-bus demand away from the night peak hours towards the early morning off-peak hours when Delhi's demand begins to ramp down. This smooths demand and saves energy costs by shifting from higher- to lower-priced market purchases.

Exhibit 28 Delhi's hourly generation dispatch and the impact of managed e-bus charging programme on a summer peak day in 2030



RMI Graphic. **Source**: RMI analysis

Distribution Deferral Value

Although e-bus managed charging could provide distribution system benefits by shifting charging demand from peak to off-peak periods, its potential to defer distribution system upgrades is limited. Therefore, this study does not include distribution deferral benefits from managed e-bus charging.

Resource Adequacy Value

However, e-bus managed charging could provide RA value to Delhi's Discoms, by lowering demand during system-wide peak hours and reducing the need for Discoms to procure generation capacity. RA benefits of the e-bus programme were estimated by analysing load reductions during the top net-demand periods of the year. Due to the existing charging patterns of the e-buses during the day, a small RA capacity value for this programme is possible. However, if future programmes can move charging away from peak demand hours, the potential for RA capacity value could increase.

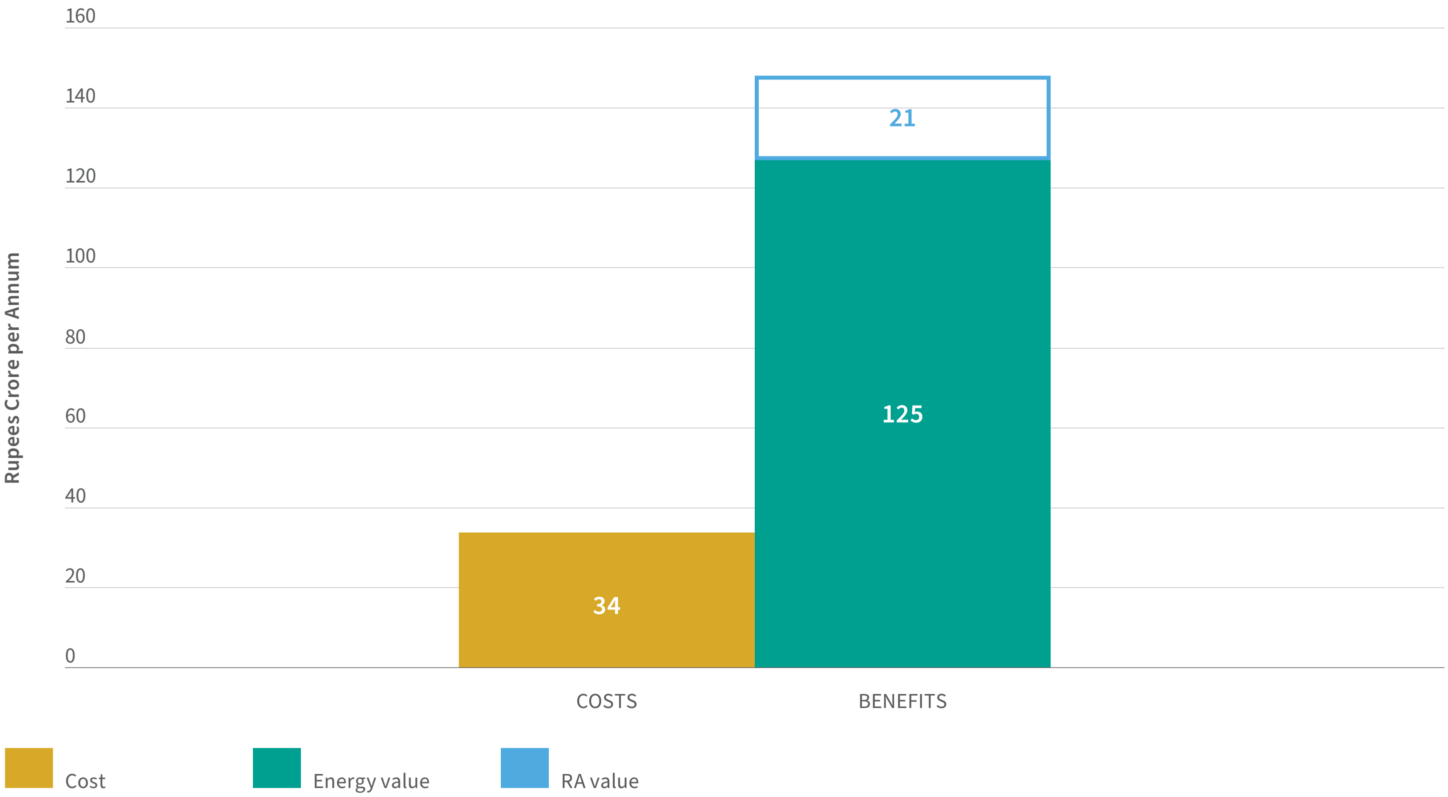
Costs

Establishing a managed charging programme effectively consists of two cost components: the initial cost for setting up the infrastructure for the planning, and scheduling of buses and the annual operational cost for running the programme. The initial cost for a typical e-bus depot was estimated based on consultations with existing solution providers.

Net Benefits

Exhibit 29 shows the benefits compared with costs for establishing and operating an e-bus managed charging programme. The benefit-cost ratio is estimated at 4.3:1. Delhi's Discoms can save 125 crore rupees (US$15 million) annually on power procurement costs by establishing managed charging of e-buses by 2030, yielding net benefits of over 100 crore rupees (US$12 million) per year.

Exhibit 29 Annualised costs and benefits of e-bus managed charging to Delhi utilities in FY30

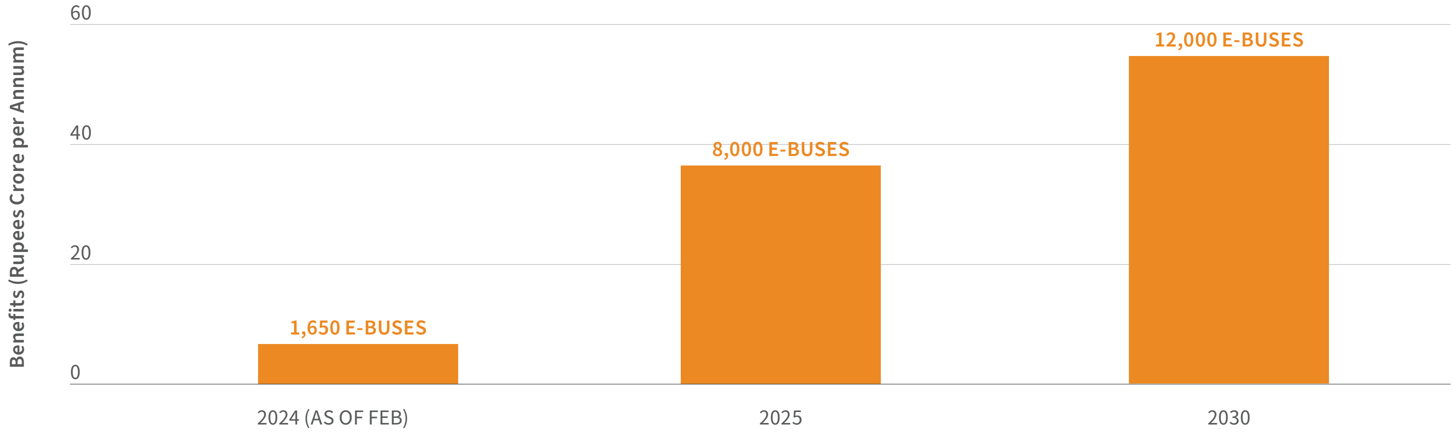


RMI Graphic. **Source**: RMI analysis

Electricity Cost Savings from Managed E-Bus Charging (for E-Bus Depots)

With 12,000 e-buses projected to join Delhi's bus fleet by 2030, bus depots stand to mitigate their electricity costs by about 550 million rupees (US$6.6 million) annually by optimising their charging demand from peak pricing hours to off-peak hours during summer, as highlighted in **Exhibit 27**. Bus depots can start integrating managed e-bus charging programmes and save on their electricity costs as Delhi's e-bus fleet grows throughout this decade (see **Exhibit 30**).

Exhibit 30 E-bus depot estimated benefits (consumer bill savings) by using managed e-bus charging



RMI Graphic. **Source**: RMI analysis

Assessment of BESS potential in Delhi

BESS can be strategically implemented across various segments of the electricity system value chain, including hybrid renewables with battery storage, transmission-sited BESS, distribution-sited BESS, and consumer-sited BESS. This report specifically underscores the value proposition of distribution-sited BESS. A parallel value framework could apply to consumer-sited BESS if the BESS operations are co-optimised and aggregated for Discoms and on-site consumers' needs. Hybrid co-located renewables with BESS systems can provide similar energy shifting and avoided generation capacity benefits to Delhi Discoms, but not distribution deferral benefits. Opportunities to manage distribution-level constraints and defer distribution upgrades in congested metropolitan areas provide an impetus to assess the role of BESS at the distribution level in Delhi. We model three cases for capacity installed by FY30:

- **Low-adoption case:** 500 MW/2,000 MWh of four-hour BESS
- **Mid-adoption case:** 1,500 MW/6,000 MWh of four-hour BESS
- **High-adoption case:** 2,500 MW/10,000 MWh of four-hour BESS

The estimation of the FY30 BESS potential in Delhi is derived from existing studies. Notably, those studies highlight Delhi's energy storage requirements to be between 2,000 MW and 2,500 MW of capacity by 2030 and potential for up to 14,000 MWh of distribution-sited BESS, specifically for distribution deferral purposes within the same time frame in Delhi.[38] The estimates assume that all BESS units operational in FY30 will feature a four-hour duration, which is identified as the most economically viable option by 2030.[39]

Benefit-Cost Analysis of BESS in Delhi 2030

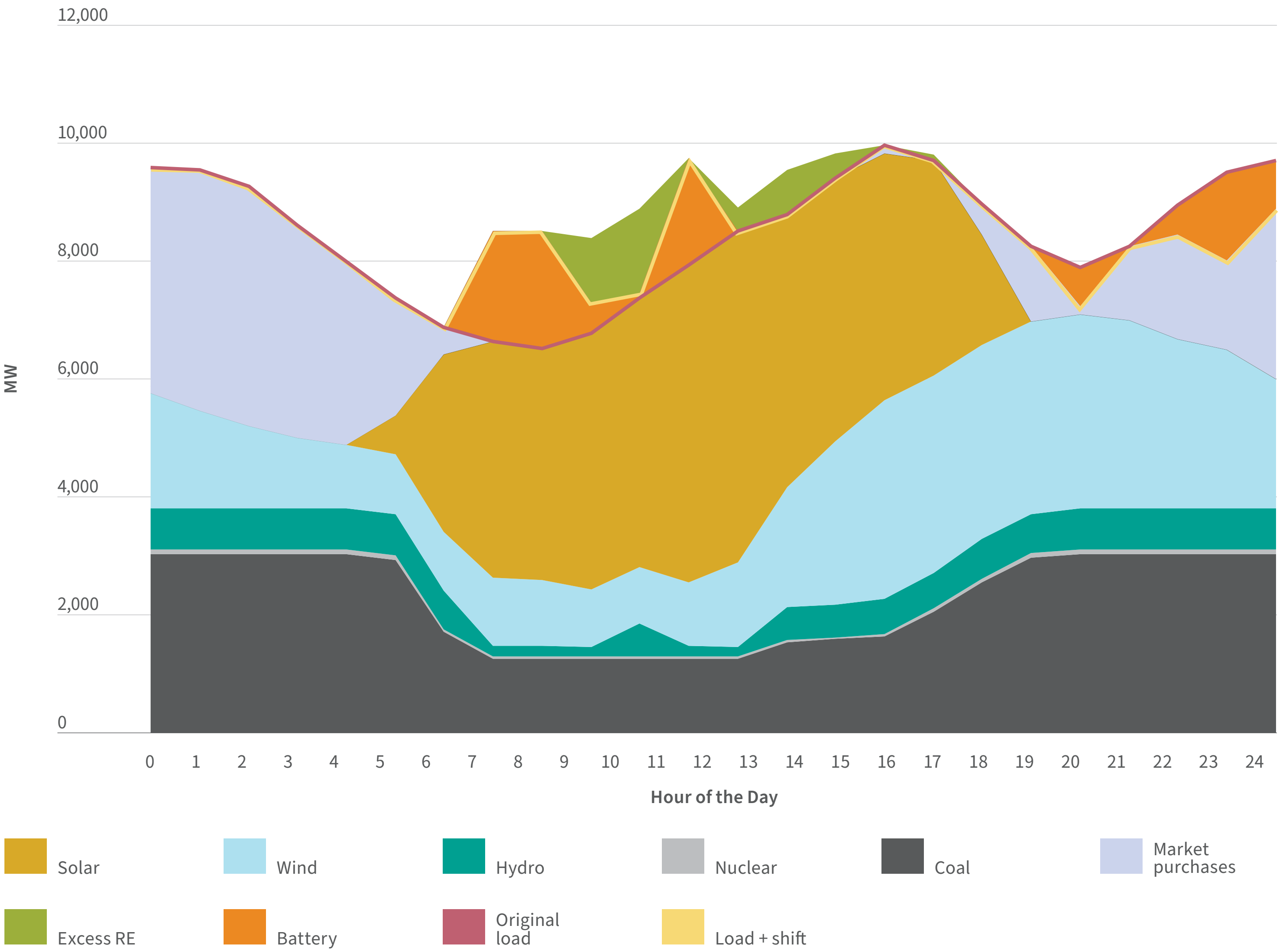
The benefit-cost ratio of BESS ranges from 1.5:1 to 1.8:1.

Energy Value

The energy benefits of BESS come from charging during off-peak periods and discharging during peak periods. In the near term, energy cost benefits accrue as the difference in cost for electricity purchases between peak and off-peak periods (energy arbitrage).

Exhibit 31 indicates battery dispatch for the mid-adoption case. The battery charges during daytime to soak up the potential curtailed solar energy, and discharges during the evening and night peak periods when electricity prices from the wholesale market are highest.

Exhibit 31 **Illustrative Delhi hourly generation dispatch and impact of BESS mid case on a summer peak day in FY30**



RMI Graphic. **Source**: RMI analysis

Distribution Deferral Value

Strategically sited BESS can be operated to minimise localised system peaks, obviating the need for distribution infrastructure deferral. We assume that BESS are located at the distribution level and operated such that local system peaks are reduced (see **Appendix F**).

Resource Adequacy Value

In the long term, BESS can also provide RA benefits by meeting system peak demand. While guidance is forthcoming, we assume BESS are given capacity credit, consistent with methodology used in US markets (see **Appendix F**).

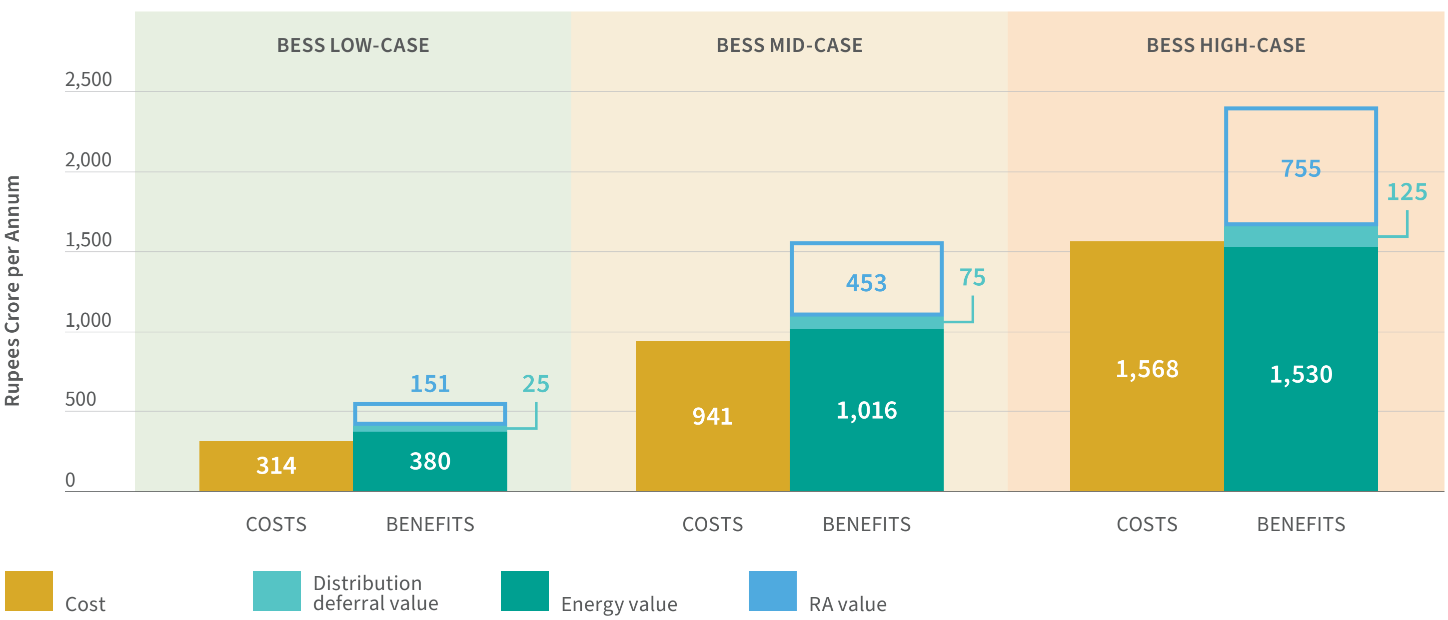
Costs

The costs of battery storage are estimated using the latest BESS market tenders in India.[40] We adjust costs to reflect four-hour duration storage, using data from the CEA's technology catalogue (see **Appendix F**).

Net Benefits

Based on these assumptions, the benefit-cost ratio of BESS is estimated to be over 1.5:1. The net benefits are positive in every scenario (see **Exhibit 32**), even without accounting for any RA value. In the high case, annual net benefits reach about 850 crore rupees (US$100 million). A detailed study — which accounts for sub-hourly energy arbitrage, localised distribution system constraints, and co-optimisation of energy with ancillary service benefits — could produce even greater net benefits.

Exhibit 32 Annualised costs and benefits of BESS to Delhi utilities in FY30



RMI Graphic. **Source**: RMI analysis

Integrating Delhi's Grid Flexibility Together as a VPP

Box 3 Scaling Grid Flexibility Measures through VPPs

A VPP is an aggregation of grid-integrated distributed energy resources (DERs) that can balance electrical loads and provide utility-scale and utility-grade grid services. The term VPP was coined as it provides the service of a conventional power plant (i.e., capacity, generation) by virtually aggregating DERs. VPPs are emerging as grid resources in many parts of the world.

National Grid's ConnectedSolutions is a pioneering VPP initiative in the United States that aggregates DERs, such as residential cooling DR, residential batteries, and C&I DR, in a multi-utility programme. This initiative is designed to reduce energy use during peak demand periods and in turn reduce total capacity obligation and energy costs. Through the programme, consumers are incentivised to turn their home or business into a network of small, flexible energy resources that are called upon to support the grid. ConnectedSolutions had 34,000 customers representing 310 MW of capacity enrolled at the end of 2020.

In Ontario, Canada, the Independent Electricity System Operator (IESO) partnered with grid-edge flexibility and VPP provider EnergyHub to offer a VPP programme to residential consumers. This programme leverages the collective power of residential cooling and heating loads to support the province's electricity grid. Through offering the free installation of smart thermostats, the programme accelerated enrolment and participation. Location benefited the programme's enrolment because Ontario is Canada's most populous province. As of mid-2023, the VPP had over 100,000 homes enrolled, capable of reducing peak demand by 90 MW.

These examples illustrate the feasibility and benefits of VPPs, showcasing how they can play a pivotal role in enhancing grid flexibility. They offer valuable insights for developing and implementing VPP initiatives in Delhi to increase the scale of DERs.

Single-asset programmes for flexibility resources such as the AC DR, managed e-bus charging, and BESS programmes described above provide benefits.[41] However, in the future Delhi can consider aggregating several different assets into a multi-technology VPP which combine different DER types, leading to increased grid services and benefits. Portfolio diversity has another resilience benefit: the ability to deliver grid services using a variety of devices reduces the risk from underperformance by a single asset class. A technology-agnostic approach ensures optimal grid benefits leading to the greatest value from grid flexible resources. Through integration using a centralised distributed energy resource management system (DERMS), VPPs can provide more visibility and control over DERs for Discoms. DERMS can efficiently handle diverse data inputs to optimise operations and create value across various technologies. Discoms can consider exploring digital platforms capable of aggregating and optimising DERs to harness these grid benefits.[42]

In this section, we consider two VPP cases: the mid-participation case combines the AC DR mid-participation case, e-bus case, and the mid-adoption BESS case. The high-participation VPP case combines the AC DR high-participation case, e-bus case, and high-adoption BESS case.

Benefit-Cost Analysis of VPPs

The benefit-cost ratio of VPPs ranges from 1.6:1 to 1.8:1

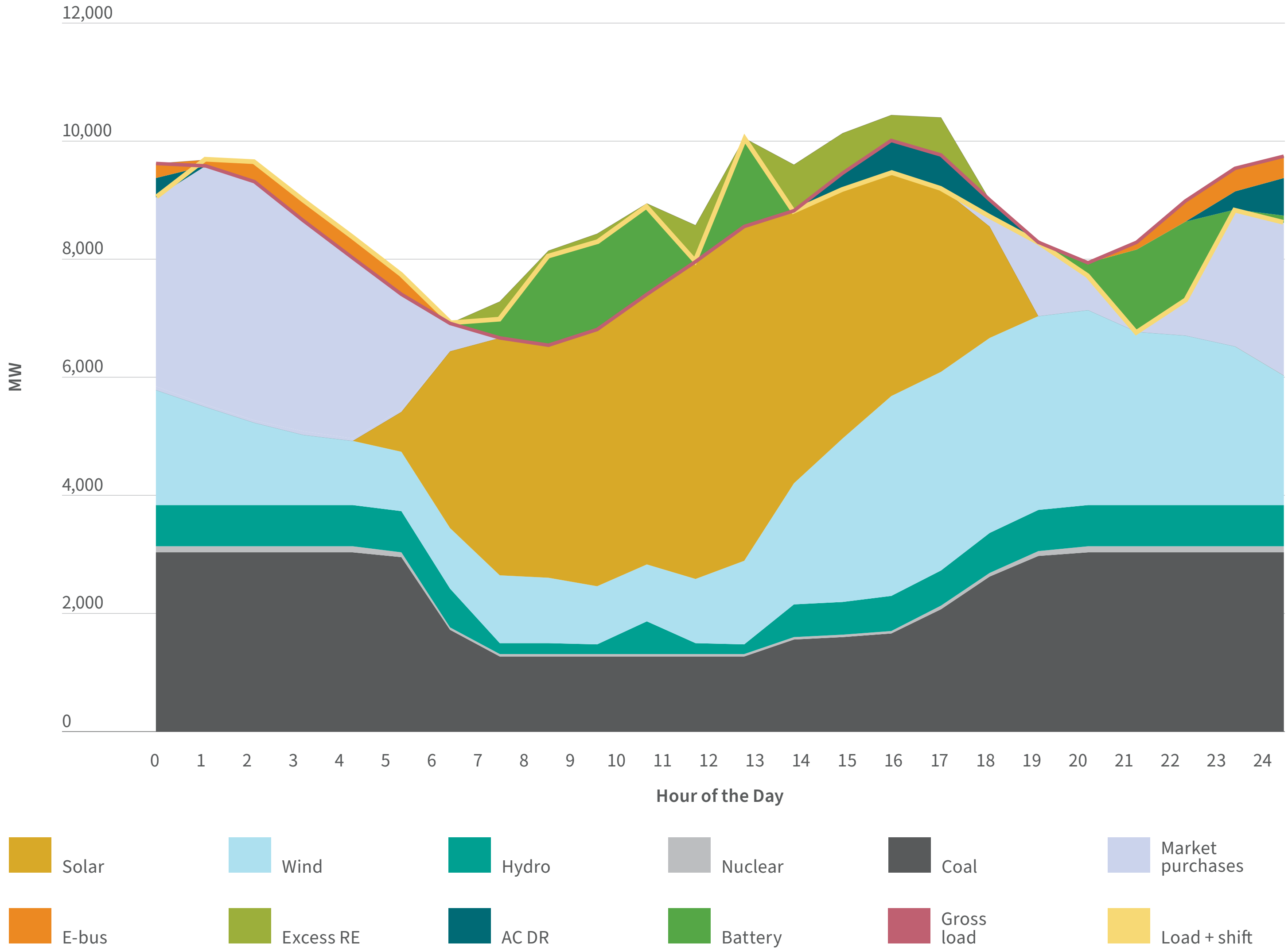
Energy Value

Individually, the various grid measures can shift or shave anywhere from 260 MW to 2,500 MW of demand in Delhi. However, as an aggregated VPP, they offer a maximum hourly demand reduction of about 2,500 MW in the mid-participation case and up to 3,800 MW in the high-participation case, representing up to 33% of Delhi's 11,500 MW projected peak demand in FY30.

“As an aggregated VPP, they offer a maximum hourly demand reduction of about 2,500 MW in the mid-participation case and up to 3,800 MW in the high-participation case, representing up to 33% of Delhi's 11,500 MW projected peak demand in FY30.”

Exhibit 33 shows a typical dispatch of all measures together, assuming the mid-participation case. As seen, these grid flexibility measures complement one another and mitigate Delhi's peak demand effectively. BESS charges during the day, soaking up the otherwise potentially curtailed local solar energy. AC DR lowers demand in the late afternoon as solar generation declines, offering Delhi utilities a chance to sell excess power to neighbouring regions. BESS discharges during the highest-priced evening peak hours, adding to the peak shavings from managed e-bus charging and an additional AC-based DR event during the same hours.

Exhibit 33 Illustrative Delhi hourly generation dispatch and impact of mid-VPP case on a summer peak day in FY30



RMI Graphic. **Source**: RMI analysis

Distribution Deferral and RA Value

The combined measures continue to provide distribution deferral and RA capacity value. We calculate these values consistently with the methodologies for individual measures, using the combined profile of demand reductions (see **Appendix F**).

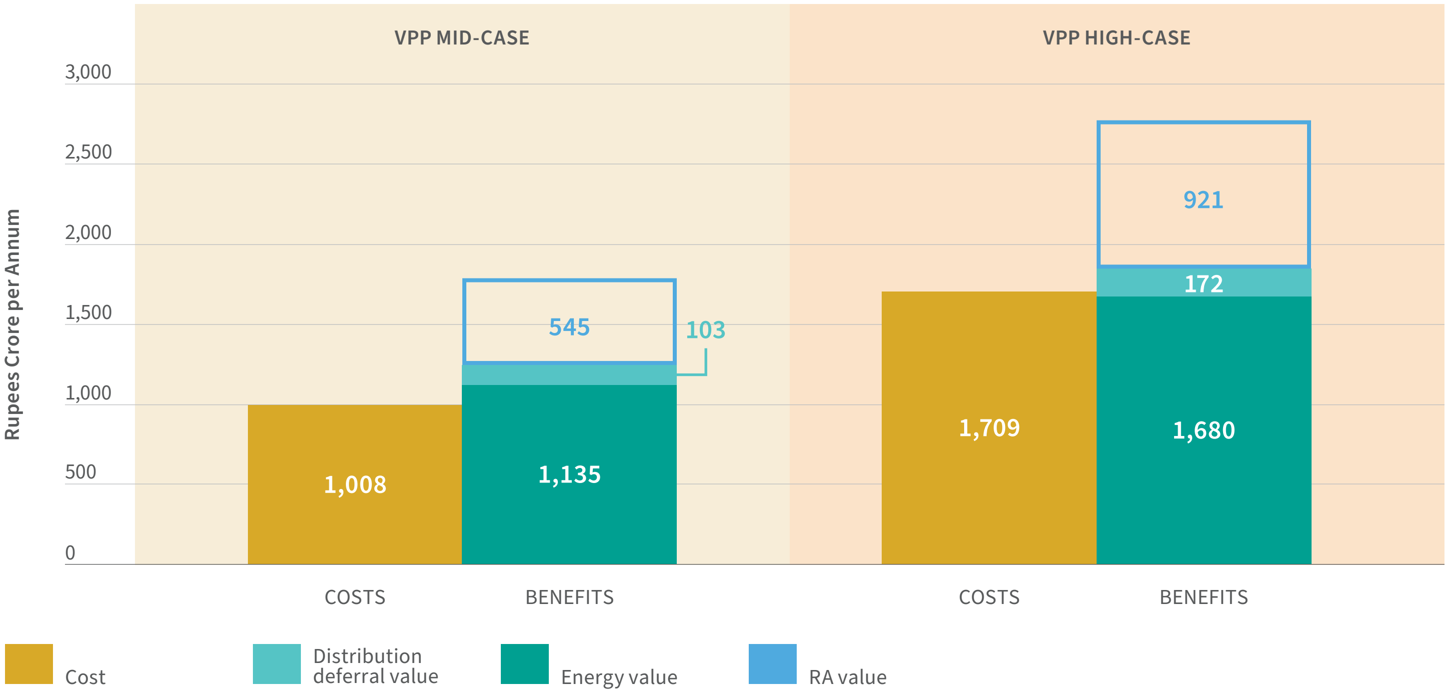
Costs

Costs are developed based on the aggregated value of individual measures highlighted in earlier sections.

Net Benefits

Benefit-cost ratios exceed 1.6:1 in both adoption cases. As shown in **Exhibit 34**, annual net benefits from the high-participation VPP case could exceed 1,050 crore rupees (US$124 million).

Exhibit 34 Annualised costs and benefits of VPPs to Delhi utilities in FY30



RMI Graphic. **Source**: RMI analysis

Enabling Grid Flexibility in Delhi

Grid flexibility is enabled by a variety of factors, including policies, regulations, and incentives. This section provides an overview of the regulatory landscape for DR, e-bus charging, and BESS in Delhi today; furthermore, it presents the critical enablers and pathways to scale these solutions in Delhi in the future.

Current Status of Grid Flexibility Measures

Time-of-day (ToD) tariffs are popular for encouraging a shift in demand from peak hours to non-peak hours, which enhances the impact for DR, e-bus charging, and BESS. Delhi currently has ToD rates mandated for consumers (other than domestic) with a load greater than 10 kW, and the ability to opt-in for all other consumers. The central government has introduced an amendment to the existing electricity rules to reduce power tariffs as much as 20% during non-peak "solar" hours and increase tariffs by up to 20% during peak hours, significantly increasing the differential. This policy also changes the existing structure by extending ToD rates to year-round and including domestic consumers starting in 2025.[43]

Current Status of DR in Delhi

Existing regulations and the success of past pilots in Delhi indicate that AC-based DR has the potential to enable grid flexibility and reduce peak demand but is yet to achieve scale.[44]

The existing demand side management (DSM) regulations rolled out in 2012 and 2014 by DERC provide guidelines for Discoms to integrate DR initiatives. They highlight the need for programmes to reduce or shift demand during peak times and lower electricity costs for consumers. Discoms are also allowed to implement these programmes through cost recovery.[45]

> **The central government has introduced an amendment to the existing electricity rules to reduce power tariffs as much as 20% during non-peak "solar" hours and increase tariffs by up to 20% during peak hours, significantly increasing the differential.**

Discoms piloted several DR programmes in Delhi aimed at reducing and shifting consumer demand, as shown in **Exhibit 35**. These pilots present the potential impact and benefits of DR in Delhi that Discoms and regulators can use for gauging the success of future programmes.

Exhibit 35 Delhi DR pilot programmes

2018

BRPL: BRPL launched a BDR Home Energy Report (HER) Programme, targeting 260,000 consumers. Consumers were notified about their energy usage through post and emails to better inform their energy-usage decisions. This programme resulted in 1%–3% energy reduction per household.

2020

BYPL: BYPL hosted an ADR pilot programme aimed at reducing peak demand costs and optimising load using automated HVAC controls for commercial and industrial consumers. During the DR events, electricity consumption was reduced by 30%.

2021

TPDDL: TPDDL launched a "critical peak rebate" pilot BDR program, targeting about 2,000 domestic consumers with smart metres. On average, 470 kW load shave was achieved across 16 events, with an average of 0.5 kW load shave per participant. Further, the study concluded that an expanded BDR programme could contribute 500 MW in load savings for Delhi.

RMI Graphic. **Source**: Alliance for an Energy Efficient Economy, https://aeee.in/wp-content/uploads/2020/07/2019-White-Paper-on-Behavioural-Energy-Efficiency-Potential-for-India.pdf; AEEE, Roadmap for Demand Flexibility in India [White Paper] (auto-grid.com).; Government of India Ministry of Power, Preparing Distribution Utilities for the Future – Unlocking Demand-Side Management Potential: A Novel Analytical Framework (nrel.gov).

Additionally, according to a 2021 demand-side survey, about 95% of domestic consumers in Delhi are interested in reducing energy consumption, and 75% of domestic consumers indicated that they could increase AC temperatures during summer evenings. This demonstrates that Delhi's domestic consumers are willing to participate in demand side management programmes.[46]

Current Status of Managed E-Bus Charging in Delhi

The integration of managed EV charging in Delhi is a promising solution to address rising peak demand, offering grid reliability and cost savings for Discoms and consumers. Although studies and pilots on managed charging are limited, existing research supports the benefits of managed EV charging.
In 2021, a study on three- and four-wheeler electric fleets assessed the benefits of managed charging for the Discoms. The study showed that by shifting the consumer demand to non-peak hours, managed charging resulted in cost reduction of 13%.[47]

As mentioned in earlier sections, e-bus charging in Delhi is subject to a ToD tariff that carries a surcharge or a rebate for charging EVs during peak and off-peak hours, respectively. This rate differential is offered only from May to September.

Current Status of BESS in Delhi

BESS pilot projects and supportive policies have started to roll out in Delhi, increasing the potential of BESS to enhance grid flexibility. Discoms and regulators can gather lessons learned from these initiatives for scaling BESS in this decade. BESS is critical for grid balancing, with an additional 4,500 MW of solar projected to come on line in the next three years, under the Delhi Solar Energy Policy 2023. Delhi will have nearly 12,000 MW of solar generation capacity by 2030, according to RMI estimates (see *Delhi's Electricity Supply Assessment* on page 19). This will increase the value of integrating BESS in Delhi, taking advantage of high solar hours for charging, and discharging stored energy during the late evening and night peaks.

National- and state-level regulations for energy storage are in the preliminary stages of development. In 2023, the MOP issued the National Framework for Promoting Energy Storage, which provides a comprehensive overview of existing policies that support BESS, including bidding guidelines, which enable the procurement and utilisation of BESS. The MOP also allows BESS to participate in the high-price day-ahead market (HP-DAM), creating opportunities to increase revenue from arbitrage.[48] The CERC Ancillary Service Regulation allows energy storage to participate as a tertiary ancillary service, encouraging investments.[49] Additionally, the central government waived interstate transmission system charges for BESS, streamlining supply across states.[50]

> **Discoms in Delhi are leading some early distribution-sited and BTM BESS pilots. The findings from these pilots could guide Discoms and regulators to scale up these options.**

Financial incentives from the government are used to support BESS adoption. Viability gap funding will support the uptake of 4,000 MWh of BESS infrastructure nationally and fund up to 40% of the capital cost.[51] National-level policies support development of utility-scale BESS projects. However, clear policy incentives and programmes are needed to support adoption of distribution-sited and behind-the-metre (BTM) BESS. Discoms in Delhi are leading some early distribution-sited and BTM BESS pilots (see **Exhibit 36**). The findings from these pilots could guide Discoms and regulators to scale up these options. Several initiatives highlight the growing interest in BESS integration in Delhi to address reliability concerns and increase flexibility.

Exhibit 36 Delhi BESS pilots

2019

India's largest operating BESS, located in Rohini, Delhi, at a TPDDL substation, is a 10 MW/10 MWh system in operation since 2019. Advanced control systems are incorporated into the system enabling flexibility in serving multiple applications, including avoiding deviation settlement mechanism penalties, energy arbitrage, peak shaving, and reactive power control. Results of the pilot show savings from reductions in deviation settlement mechanism penalties and peak load shaving.

2020

A collaborative pilot with BRPL and international partners, started in 2020, involves installing a cumulative 410 kWh battery capacity at three different locations to cater to various consumer categories. Results from this pilot have yet to be disclosed.

2021

A distribution level 150 kW/528 kWh battery in Rani Bagh, Delhi, serves as India's first grid-connected community BESS. The system aims to defer distribution upgrades and assist the local network in case of power outages, providing invaluable services to the community.

2024

A 20 MW/40 MWh BESS pilot project has been approved for Delhi partially through concessional financing, further advancing the region's flexible infrastructure with the project's primary uses including energy arbitrage and ancillary services.

RMI Graphic. **Source:** Energy Storage News; TND India; Construction World; Mercom India

Although BESS pilots have been deployed and policies have been developed, indicating its grid flexibility potential, BESS has yet to achieve scale in Delhi.

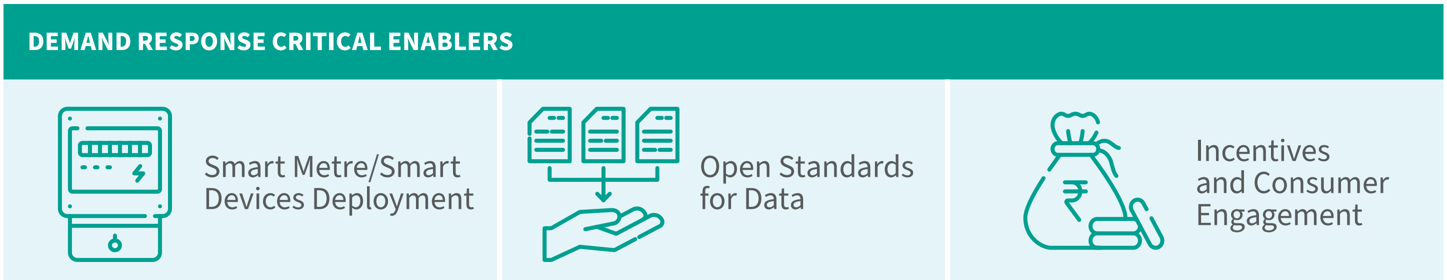
Enabling Grid Flexibility in Delhi

As Delhi aims to rapidly expand its RE capacity and records unprecedented demand growth, strengthening the grid by integrating DR, BESS, and managed e-bus charging will be crucial. Although Delhi has made considerable progress by deploying pilots and polices to promote grid flexibility, these measures have yet to achieve scale. The following section highlights the critical enablers for individual measures in scaling grid flexibility in Delhi.

DR Enablers

Implementing DR programmes requires focus on developing the following three baseline enablers: (a) smart metre deployment, (b) open standards for data, and (c) incentives and consumer engagement. These enablers need to progress in tandem with input from multiple stakeholders, including Discoms and regulators.

Exhibit 37 DR enablers



RMI Graphic. **Source**: RMI analysis

Deployment of Smart Metres/Smart Devices

Advanced metering infrastructure (AMI) (i.e., smart metres), is needed for the success of DR programmes. AMI enables two-way communication between Discoms and consumers, allowing Discoms to extract precise data. This data can be used to refine tariffs, assess DR participation, conduct programme measurement and verification (M&V), and give consumers access to their performance.[xiii,52] Without AMI, Discoms cannot quantify participation levels. However, the availability of smart devices may address the gap where there is a lack of AMI.

Smart devices, such as smart thermostats and plugs, enable DR participation for ADR programmes. Smart metres pair well with smart devices while operating end-use appliances for DR events, providing what is needed for an effective DR programme and increased consumer participation. Smart devices could also be operationalised independently of smart metre availability.

Delhi's smart metre rollout so far is limited, which inhibits the scaling of BDR programmes in the city. Regulators and Discoms need to work collaboratively to develop a comprehensive smart metre and/or smart device rollout plan, ensuring that Discoms and other industry players have the resources necessary for large-scale rollout. Additionally, consumer awareness campaigns can be used to promote the understanding and acceptance of AMI/smart devices. **Box 4** shows a successful example of leveraging AMI for residential ADR.[53]

Box 4 **Successfully leveraging AMI in the United States**

One example of a successful residential ADR programme that leveraged AMI and smart devices is Arizona Public Service's Cool Rewards programme, one of the largest "bring your own thermostat" programmes in the United States. For this programme, a participant's thermostat is automatically adjusted during events to lower peak load during summer. The two-way communication enabled by AMI allows utilities to send signals to these devices and the devices can adjust accordingly, facilitating this programme. During the summer of 2023, this programme proved successful in providing about 110 MW of enrolled capacity of 78,000 thermostats, exemplifying an impactful residential ADR programme and highlighting the need for AMI for DR implementation.

xiii. Measurement and verification (M&V) involve collecting and analysing data to understand the impact of energy conservation measures.

Box 5 Opportunity to leapfrog smart metres/AMI

Although smart metres/AMI are traditionally used to facilitate DR programmes, there is an opportunity in Delhi to potentially bypass the need for AMI by leveraging internet-connected devices. As mentioned previously, Delhi's limited smart metre rollout has inhibited the scaling of DR in the capital city. Instead of relying solely on AMI, regulators and Discoms could consider leveraging internet-connected devices like smart thermostats and plugs to enable DR participation. This approach requires developing an appropriate incentive structure and addressing potential M&V challenges but presents an opportunity to bypass the need for comprehensive AMI deployment in the short term.

Open Standard Communication Protocols

Open standard communication protocols enable interoperability and automation for devices, leading to wider impact of DR programmes. Interoperability refers to the ability of multiple devices to connect and communicate, regardless of the device or manufacturer.

Open standard communication protocols are essential for the adoption of DR programmes (e.g., OpenADR, IEEE 2030.5, or supervisory control and data acquisition [SCADA] protocols). In a traditional closed system, optimising DR encounters significant challenges. In closed systems, technologies that do not "speak the same language" are excluded, which slows DR growth.[54] Furthermore, closed systems require that Discoms manage multiple technologies. This challenge is exacerbated when Discoms need additional appliances to increase participation.[55] Open standard communication protocols address these challenges, ultimately leading to greater participation and ease of scalability for Discoms.

Communication protocols are crucial for effective implementation of DR across various levels of energy distribution, including device-to-device, device-to-Discom, and Discom-to-grid operator communications. Each of these interactions plays a distinct role in optimising DR systems, yet they require a unified approach to communicate seamlessly.

1. **Device-to-device communication:** Open standards facilitate direct interaction among multiple DR-enabled devices. This interoperability allows devices to communicate and synchronise operations without direct Discom intervention.

2. **Device-to-Discom communication:** By adopting open communication protocols, Discoms can directly connect with an array of devices. This connection is essential for enrolling existing devices, broadening participation, and ensuring that devices can receive and respond to signals for Discoms.[56] During DR events, these protocols enable two-way communication, allowing devices to both receive signals from Discoms and send back reports on the devices' state, energy usage, and other critical metrics for M&V.[57]

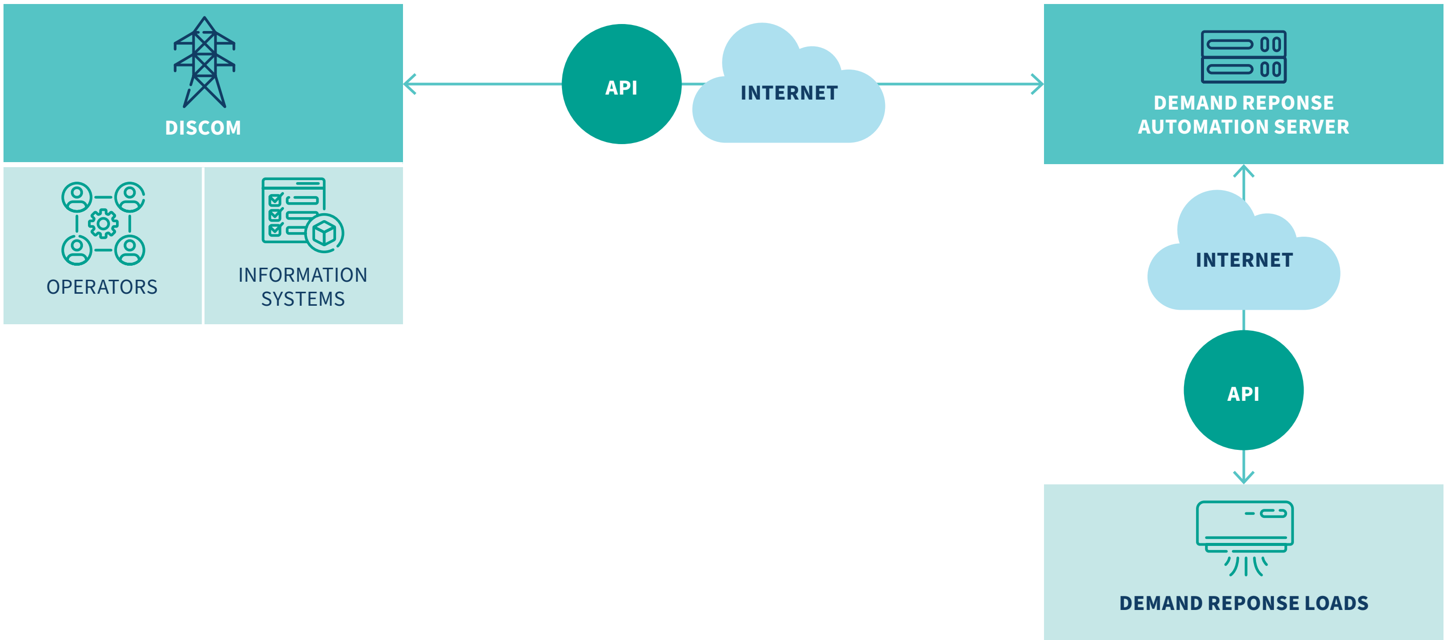
3. **Discom-to-grid operator communication:** At a higher level, open standards ensure that utilities can communicate effectively with grid operators. This communication is important for integrating DR into broader grid management by allowing grid operators to gauge the availability of DR resources in real time and incorporate them into operations during peak load periods or emergencies.

To ensure long-term success of DR programmes, regulators and Discoms need to decide on standard protocols to enable open communication standards within DR initiatives. Discoms must prioritise adoption of agnostic software platforms to manage DR resources. These platforms allow flexibility and compatibility with various technologies, enhancing scalability and adaptability.[58] Additionally, testing of communication protocols during the pilot phase of programmes is vital in order to identify and address any issues before full-scale implementation. **Box 6** showcases the function of open communication protocol for ADR.[59]

Box 6 OpenADR

Examples like OpenADR standards in the United States illustrate how standardised protocols have facilitated interoperability and communication among different entities, leading to more efficient DR deployment. Open Automated Demand Response (OpenADR) is an open and standardised way for electricity providers and system operators to communicate signals with one another and their customers using a common language. Open standard communication protocols like OpenADR specify the application programming interfaces (APIs) and the functions of the Demand Response Automation Server, which serves as the common platform among all providers and consumers (see **Exhibit 38**).

Exhibit 38 Function of OpenADR communication protocol



RMI Graphic. **Source**: OpenADR

Incentives and Consumer Engagement

Incentivising consumers is essential to ensuring their participation in DR programmes. A wide variety of incentives can be offered (see **Exhibit 39**). Stakeholder meetings and early pilots can help clarify the nature of incentives that participants favour. The programme and incentives can be designed based on this input.

Exhibit 39 Types of DR programme incentives

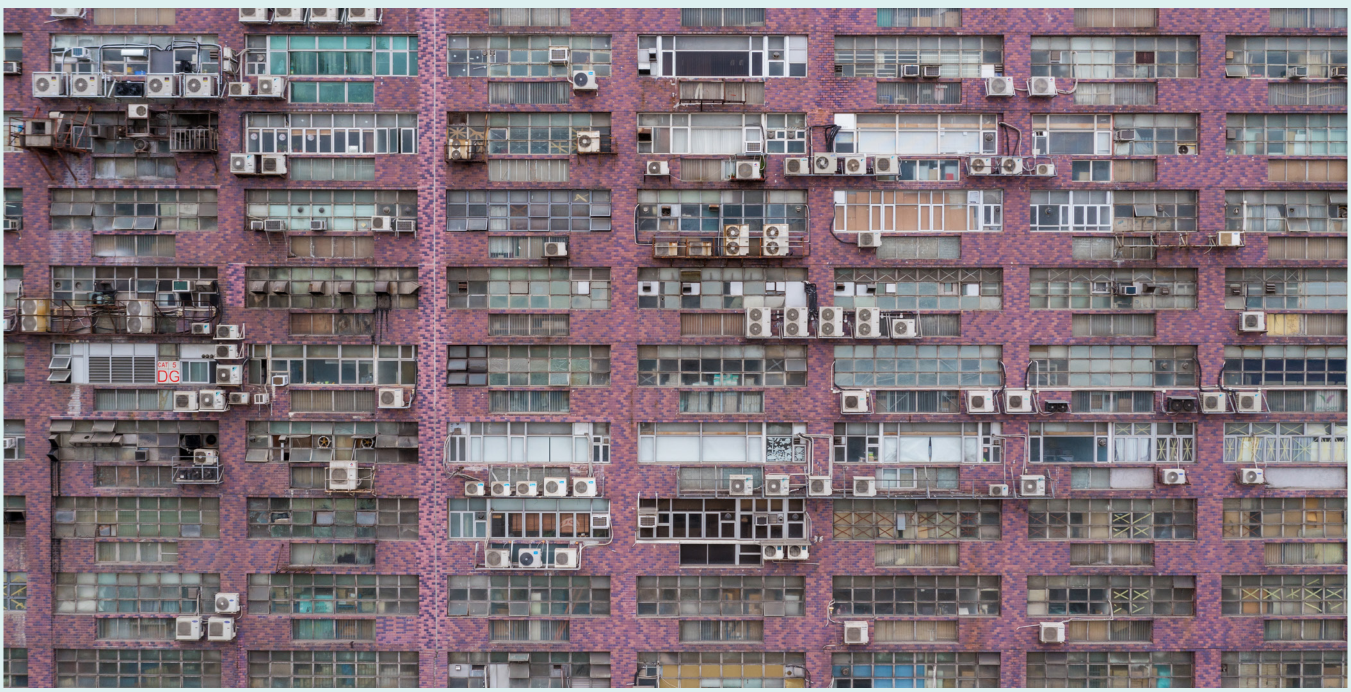
Incentive Type	Description	Examples
Bill rebates (including pay-for-performance incentives)	Provides participants with financial compensation, directly offsetting energy costs on their bill as a reward for reducing usage during event times.	Tata Power Mumbai: 2.25 rupees/kWh (US$0.03/kWh) shaved during events (C&I)
Up-front financial incentive	Provides one-time monetary payout or rebate to encourage consumer enrolment.	PG&E Smart AC Programme: $75 or discounted smart thermostat (domestic)
Other incentives	Provides participants with a non-monetary reward, such as points or vouchers, for lowering consumption.	OhmConnect: Redeem points for prizes, gift cards, smart devices, or cash

RMI Graphic. **Source**: RMI Tata Power Mumbai; PG&E; OhmConnect

Consumer engagement and education allowing consumers to see the effectiveness of a successful DR programme is essential. Lack of knowledge and familiarity is a major barrier to participation, due to the complex nature of DR programmes. Therefore, clear, understandable communication is needed to educate consumers on DR programmes.[60]

The role of end-customer-facing applications in managing enrolment and engagement of participants is important for the success of the programme. Discoms could benefit from nudging end customers and converting them into active participants. Active participants help achieve reliable load shaving throughout the programme. An enrolment and engagement portal provides an easier workflow for enrolling customers, especially in the case of ADR programmes, where permission to control the consumer's appliances is required. Additionally, sharing insights on their participation and contribution to DR events, along with custom messaging, helps retain customers in the programme. **Box 7** provides an example of impactful programme incentives in China.[61]

Box 7 **Impactful programme incentives in China**



One example of a successful residential BDR pilot is China Light and Power Company's (CLP) Energy-Saving Missions in Hong Kong. Consumers are incentivised to lower load during events by earning reward points. They can redeem these points for supermarket coupons, food coupons, smart appliances, and more. Additionally, to keep consumers engaged, the programme employs clear and effective education in strategies to earn the maximum points. This programme showed clear success when, during an extreme heat wave in July 2021, power consumption of 600,000 residential consumers was curtailed, saving 300 MWh over a four-hour period.

Workshops should be executed early and often, and should include diverse stakeholders (potential participants, regulators, Discoms, and community leaders) to determine the most effective ways to engage and educate targeted consumers. Workshops need to be interactive in order to understand how consumers react to different messaging and programme types. These workshops can also be used to evaluate interest in incentives. Understanding how interest and cost of incentives interact for Discoms is crucial in building the most beneficial programme for all parties. **Box 8** illustrates the importance of consumer engagement in a residential BDR programme.[62]

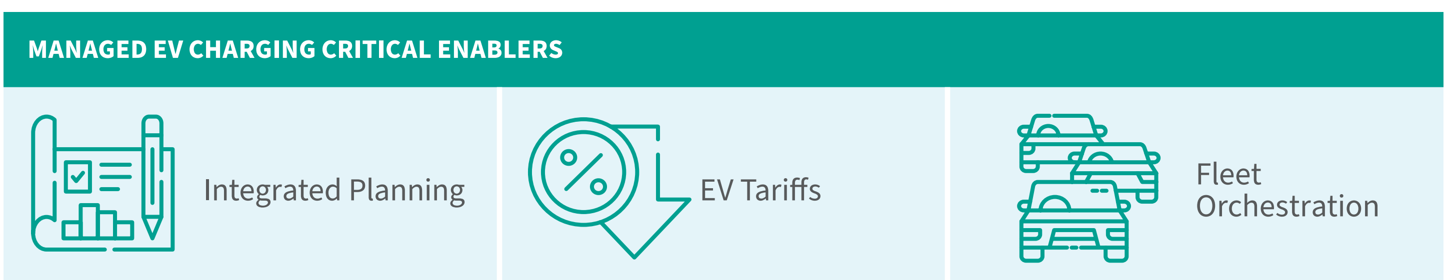
Box 8 Consumer engagement in Australia

A residential BDR pilot programme conducted by EnergyAustralia highlights the importance of consumer engagement in running an impactful programme. The DR programme alerted consumers through text before the event asking them to reduce demand, and a survey was sent to consumers after the event. The survey showed that there is a generally positive sentiment for the programme because the consumers had confidence in the actions being taken and were aware of incentives.

Managed EV Charging Enablers

Effective implementation and expansion of Managed EV Charging relies on harnessing the following enablers for maximising benefits: (a) integrated planning, (b) EV tariffs, and (c) fleet orchestration (see **Exhibit 40**). This section lays out the role of these enablers for establishing managed EV charging pilots and programmes.

Exhibit 40 Managed EV charging enablers



RMI Graphic. **Source**: RMI analysis

Integrated Planning

Efficient integration of managed charging programmes requires proactive planning during the e-bus procurement phase. In Delhi, existing norms stipulate that original equipment manufacturers and operators of e-buses are primarily responsible for following predetermined bus routes agreed upon during the tendering stage with the Delhi government's transport department.

The responsibility for establishing bus charging stations and charging the buses lies with the operators, and the electricity costs fall under the mandate of the transport department. However, the current contracts do not ask bus operators to participate in programmes that could optimise bus charging, leading to a lack of economic incentive or mandate for them to integrate managed charging at the depots. This reluctance is compounded by the technical integration challenges within the network of chargers. The following initiatives can help develop an integrated planning approach for e-bus procurement to promote managed charging:

- **Contract innovation:** Future contracts and tenders could be structured to include the electricity costs incurred during bus charging within the e-bus operator's scope. This would enable operators to identify opportunities to charge buses during off-peak hours, reducing recurring electricity costs. Additionally, this would allow operators to procure green power at low costs and contribute to the decarbonisation of the electricity used for charging buses.

- **Incentivising managed charging:** In case the contracts cannot be amended, e-bus operators could be offered a share of the economic savings from participating in managed charging programmes. This can incentivise operators to integrate chargers with the technical capabilities for participating in such programmes and synchronise maintenance practices with expected charging routines.

- **Stakeholder involvement:** Given the significant impact of e-bus depots on Delhi's distribution grid, integrated planning should involve stakeholder input from Discoms and the power departments of the state. Considering the charging profile of e-buses when optimising bus routes could be pivotal, especially if interoperability of charging e-buses at any depot is introduced in Delhi.

EV Tariffs

Delhi regulators can consider revising the EV charging tariff structure to encourage managed EV charging programmes. Currently, consumers pay a cost-effective reduced tariff of 4 rupees per kWh (US$0.05/kWh) for charging their EVs. This tariff incurs a 20% surcharge during the periods of 1–5 p.m. and 9 p.m.–1 a.m., and a 20% rebate between 3 and 9 a.m., applicable from May to September. The reduced tariff was instituted to encourage the adoption of EVs and has made Delhi the EV capital of India.

However, with growing adoption of EVs, these tariffs can be increased in phases to reflect the power procurement costs incurred by Discoms. Additionally, a reformed tariff could also extend the surcharge and rebates that incentivise consumers to charge their EVs during off-peak hours to be effective year-round. An RMI analysis provides insight into the effects of pairing ToD rates with managed EV charging. In this case, a public transit bus fleet could save close to 40% annually on charging costs and decrease peak demand by 70% through shifting the demand.[63] **Box 9** showcases an alternative strategy to motivate consumer charging behaviour.[64]

Box 9 Using rebates as a price signal – A New York State case study

While ToD rates are an effective tool for incentivising favourable charging behaviour and encouraging participation in managed EV charging programmes, Discoms can also explore alternative strategies to motivate consumer actions. A notable example of optimising EV charging through price signals is the SmartCharge programme in New York state. The tariff for charging was relatively flat, leading consumers to charge at times that were most convenient for them, which aligned with morning and evening peaks. The SmartCharge programme incentivises off-peak charging through rebate mechanisms.

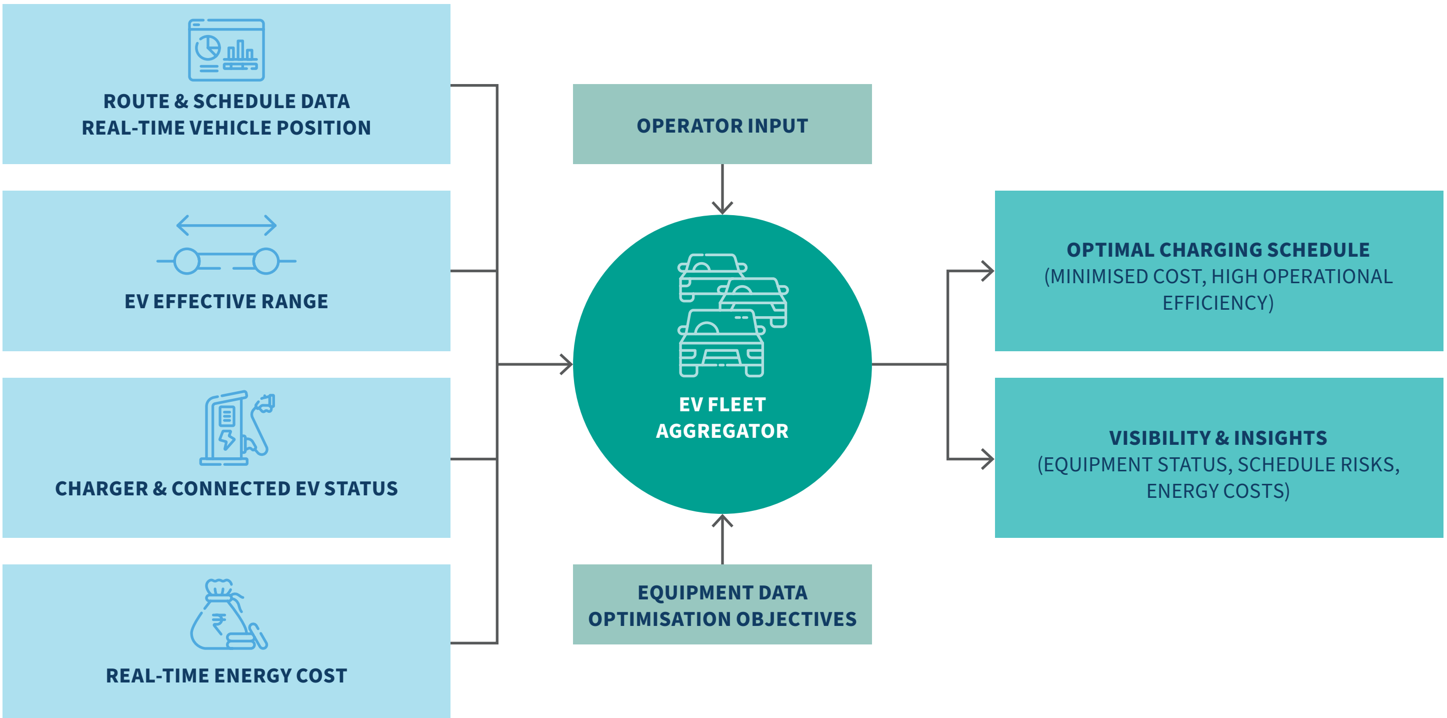
Participants are offered a monthly $20 (1,655 rupees) rebate for avoiding summer peak-hour charging and a $0.10/kWh (8 rupees/kWh) rebate for late-night charging. By actively engaging with the programme, consumers shifted a substantial portion of energy consumption from high-cost peak hours, characterised by elevated energy and transmission and distribution (T&D) expenses, to lower-cost periods. This transition resulted in a notable increase in net societal benefits, rising from $1,113 to $1,862 per vehicle (92,396–154,575 rupees per vehicle), indicating that the residents of the region recorded enhanced overall well-being as a direct outcome of this innovative programme.

Fleet Orchestration

Fleet aggregation combined with smart chargers play a crucial role in enhancing the benefits of managed EV charging programmes, allowing optimisation and orchestration of large fleets.[65] Without orchestration, the manual management of data essential for optimising EV charging poses significant challenges. Effective coordination is impeded by the lack of communication. Various entities, such as fleet management, building energy management, and EV charging controls, receive disaggregated data, which leads to suboptimal benefits.

Through orchestration, input of data like routes and schedules, real-time vehicle position, vehicle range, ToD tariffs, and charger status are consolidated into a central management system, allowing optimal charging schedules as well as visibility and insights to operations (see **Exhibit 41**).

Exhibit 41 EV fleet orchestration process



RMI Graphic. **Source**: RMI analysis

Fleet orchestration offers a multitude of benefits for establishing managed EV charging pilots. Because orchestration allows communication and coordinated charging of a large load, peak shaving can be optimised by shifting charging demand to off-peak hours. Discoms should work with fleet operators and bus depot operators to adopt fleet orchestration (or aggregation) software platforms to maximise benefits from electrified fleets and pave the way for future managed EV charging programmes. **Box 10** provides a case study for e-bus fleet aggregation.[66]

Box 10 Case study of e-bus fleet aggregation

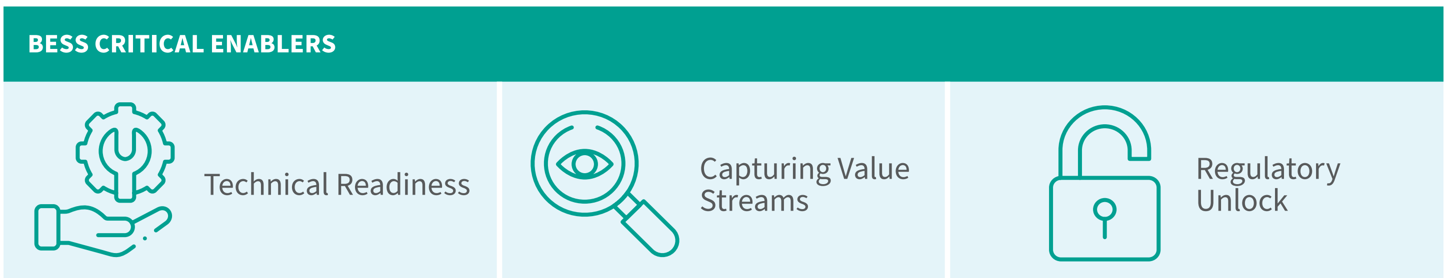
Smart charging paired with aggregation software can lead to significant savings in energy costs for fleets. A remarkable example is an electric bus fleet operator in the United States. Ampcontrol operates 100 buses that return to the depot between 9 and 11 p.m. for charging and must leave the next day by 9 a.m. Without optimisation, all buses would be charged simultaneously, leading to a power demand of 10 MW (100 kW per bus) and exorbitant electricity bills between $112,000 and $515,000 (9,296,784–42,748,605 rupees). However, using intelligent aggregation software to optimise charging, the buses are fully charged by the next morning with a total power demand of only 4 MW. In addition to substantial cost savings, this leads to a lower peak demand to be met by the utility, which can help defer infrastructure investments into the future.

Additionally, smart chargers are essential to managing EV charging programmes, serving as the hardware that enables aggregation software to communicate with the grid. By leveraging this software, fleet operators can access real-time data from chargers to automate and optimise operations. The coordination between smart chargers and aggregation software forms the foundation of efficient and scalable managed EV charging programmes.

BESS Enablers

The successful deployment and scaling of BESS hinges on addressing the following enablers that can lay the foundation for unlocking the full potential of energy storage: (a) technical readiness, (b) capturing value streams, and (c) regulatory unlock. This section lays out the role of these enablers for scaling BESS in Delhi.

Exhibit 42 BESS enablers



RMI Graphic. **Source**: RMI analysis

Technical Readiness

Discoms and regulators in Delhi need to have the technical capabilities to deploy BESS on a large scale as anticipated by 2030. The integration of BESS assets requires advanced monitoring and control software that can interface with the physical infrastructure and energy system operations to ensure reliability and safety. Specifically, the SCADA systems of Discoms must effectively communicate with the battery management system, power conversion system, and energy management system. Inadequately digitised infrastructure poses a challenge to efficient and safe BESS operation. State and central regulators should coordinate to identify legacy SCADA systems, assess distribution system technology readiness for BESS integration, and establish regulatory requirements for upgrades and automation.

Developing internal institutional capacity is crucial to facilitating the widespread adoption of BESS. Stakeholders like DERC, State Load Dispatch Centre (SLDC), and Discoms in Delhi will need further training and assistance to bridge knowledge gaps related to BESS project planning, grid services, operations, and BESS' contribution to ensuring resource adequacy and distribution deferral. Discoms and DERC should recognise that BESS can offer capacity and non-wire alternatives and employ appropriate benefit-cost analysis frameworks.

Capturing Value Streams

Regulators and Discoms can encourage BESS deployment by comprehensively capturing all value streams in their planning process. This signals to developers and project planners where battery storage is more critical, thereby increasing the economic viability of projects and making the technology appealing to stakeholders. BESS provides value in many areas, including energy arbitrage, ancillary services, capacity value, transmission, and distribution deferral and consumer energy management.[67]

> **BESS provides value in many areas, including energy arbitrage, ancillary services, capacity value, transmission, and distribution deferral and consumer energy management.**

Currently, energy arbitrage and tertiary reserve ancillary services value streams are easy to monetise for Discoms. CERC is working on enabling market-based participation in secondary reserve ancillary services. Regulators in Delhi can focus on setting up an appropriate regulatory framework for capacity value (in line with the MOP RA guidelines) and distribution deferral value.[68] As energy storage can provide multiple services simultaneously, its economic value needs to be enhanced by leveraging multiple revenue streams through value stacking or the bundling of grid applications (**see Appendix H for more information**).

1. **RA Considerations:** The RA framework guidelines, issued by the MOP in 2023, aim to ensure that Discoms procure sufficient capacity to meet expected demand reliably and cost-effectively. The Forum of Regulators has recommended model RA regulations, yet their adoption has yet to gain momentum across states. Madhya Pradesh stands out as the leading state in adopting these regulations.[69]

   The RA framework has the potential to significantly boost the economic viability of BESS assets, with capacity payments expected to account for 25%–30% of project revenues. Such payments have played a crucial role in the success of BESS initiatives in markets like California, where they supported the integration of 5 GW of BESS capacity within two years.[70] For the RA framework to reach its full potential in enhancing grid reliability and flexibility, Delhi regulators must provide additional guidance on its implementation, compliance mechanisms, and the inclusion of BESS and other flexibility resources as recognised capacity assets.

2. **Standardising Distribution Deferral Planning and Benefits Estimation:** Under existing DSM regulations, Discoms can potentially incorporate distribution deferral benefits into their planning process. However, there is no standardised practice and regulatory framework to enable it. Traditionally, as electricity demand and network congestion increase, Discoms invest in long-term distribution upgrades. This strategy could require substantial investments and may lead to tariff hikes for consumers. Additionally, planning and construction of distribution system upgrades can take years to complete.

Because BESS costs are expected to decline, BESS may add capacity to the grid much faster and at a lower cost than traditional upgrades or expansions.[71] This is especially valuable for dense megacities, such as Delhi, where space for system expansion is limited. BESS, as a non-wire alternative (NWA), is estimated to have 14,000 MWh of potential in Delhi by 2030, addressing the needs of over 6,000 km of overloaded lines.[72] In addition, with the improving power density of BESS, the physical footprint of the systems will shrink further, making them more suitable for space-constrained Delhi.

Discoms in Delhi could consider innovative NWAs, such as BESS, when planning distribution network expansion to meet increasing load and system peakiness. BESS can provide economic benefits, such as capital cost deferral, and distribution network performance benefits, such as voltage support, avoiding frequency deviations, minimising load loss, and avoiding scheduling expensive peaker plants through load shifting. Regulators should provide clear frameworks that enable Discoms to perform a benefit-cost analysis of NWAs that consider various economic and distribution network benefits. **Box 11** provides examples of regulations that capture the full value stack of BESS.[73]

Box 11 **Capturing BESS full value stack in regulation**

In 2018, the California Public Utilities Commission made a significant decision regarding the use of value stacking in Rulemaking 15-03-011, aiming to rectify the market rules that did not support energy storage at the time. This decision included 12 rules dictating battery value stacking to ensure that batteries are properly valued for the wholesale market, distribution grid, transmission system, resource adequacy requirements, and customers. These rules ensure that battery projects select the most cost-effective combination of services without compromising grid reliability, paving the way for batteries to be properly valued across sectors. This has proven successful, as California storage capacity has reached over 10 MW of capacity as of May 2024. Delhi regulators can utilise such regulations to gain insight into the parameters necessary to effectively capture all BESS value streams.

In 2017, the New York State Public Service Commission similarly established the Value of Distributed Energy Resources order. This order has been updated over time to appropriately account for the benefits of DERs, including BESS. DERs are incentivised accurately by permitting utilities to assign monetary value to benefits such as capacity, environmental impact reduction, demand reduction, and locational system relief, in addition to energy. Regulators in Delhi can draw insights from this regulation to define essential parameters to capture all BESS value streams effectively and promote widespread adoption.

Regulatory Unlock

Although regulations implicitly support grid flexibility and BESS, explicit regulations are needed in order to enable their wider adoption. By establishing clear rules, regulations create a favourable environment for BESS and facilitate project approval.

Recommended elements to be included in the regulatory framework:

1. **Standards for Reporting and Data Disclosure:** At present, data reporting for Discoms is inconsistent and inaccessible to project developers, primarily due to a lack of standardised public reporting procedures. Standardisation of critical data such as load profiles and the locations of overloaded substation and feeders are important to identify optimal locations for future siting of BESS. Additionally, Discoms could publish locations of distribution grid pockets that need upgrades, thereby identifying areas that would benefit the most from distribution improvements and consumer-sited BESS. Many US states have started publishing such electric distribution system hosting capacity maps.[74] Establishing a public data repository will facilitate the assessment of BESS effectiveness and inform best practices in Delhi. Regulators should provide guidelines to create a centralised data repository, distribution system hosting capacity maps, as well as standards for reporting this data.

2. **Innovation in Incentive Models:** Various incentive models could be piloted and then scaled to make BESS projects economically viable for both Discoms and consumers. The selection of a particular ownership option will depend on the requirements of the end-user. It is important to include ownership model guidelines in a regulatory framework because it can provide clarity on ownership rights, responsibilities, and financial implications. This clarity helps stakeholders make informed decisions based on their specific needs and preferences, ultimately leading to more efficient BESS deployment.[75]

   Additionally, more innovative approaches to BTM BESS ownership, like Sacramento Municipal Utility District's (SMUD) Energy Storage Shares programme in California, enable greater BESS adoption by enhancing accessibility and affordability. This programme allows commercial consumers to invest in an off-site BESS through the utility. In doing so, businesses receive energy cost savings without having to install BESS on-site.[76] Incorporating different avenues for ownership in Delhi will broaden BESS access to a wider consumer base, thereby fostering adoption.

   Consumer benefits for BTM storage should also be taken into consideration by regulation. BTM storage adds backup reliability and electricity bill savings for consumers. Additionally, BTM storage provides value to Discoms through aggregation. For example, SMUD also offers various incentives to support BTM storage for domestic consumers, depending on their level of participation. This participation level ranges from starter, in which the BESS is programmed to optimise to ToD rates, to Partner+, in which the utility optimises the BESS entirely for grid benefits.[77] Such programmes provide consumers with the same level of individual backup reliability and bill savings, while allowing the utility to harness the flexibility of BTM storage for broader grid benefits. **Box 12** provides an example a consumer-oriented BESS Bring Your Own Device programme.[78]

Box 12 Innovative incentives in Vermont to encourage BESS storage

Green Mountain Power (GMP) in Vermont has developed a pioneering home battery programme that serves as an exemplary model for enhancing grid reliability, which could be beneficial for Delhi Discoms to consider. Initiated in 2015 with pilot programmes and gaining regulatory approval in 2020, GMP's initiative includes the Powerwall and Bring Your Own Device programmes. These programmes allow customers to purchase a battery, either through GMP or from a local installer, and connect it to the grid to provide backup power during outages and reduce peak load demands.

The structure of GMP's programme is customer-centric, offering significant incentives for participation. In the Bring Your Own Device programme, customers who opt to share stored energy during peak times can receive incentives up to $10,500. The programme reduces overall energy costs and carbon emissions, benefiting all utility customers.

The impact of these programmes is substantial, providing reliable, seamless backup power and contributing to a more resilient grid. As of August 2023, 2,900 customers with more than 4,800 batteries were engaged in the programme, leading to customer savings of up to $3 million a year.

This model encourages the installation of BESS by demonstrating a successful, scalable approach to integrating individual energy storage solutions with the grid. It showcases how utilities can support grid stability, manage peak loads more efficiently, and reduce environmental impact through innovative customer partnerships and incentives. Adopting such a model could significantly aid Delhi Discoms in managing demand spikes and improving grid reliability.

Scaling Grid Flexibility in Delhi

Once the enablers are in place to amplify grid flexibility in Delhi, a strategic approach to implementing and scaling DR, managed EV charging, and BESS is essential (see **Exhibit 43**). This section outlines a deployment guide for stakeholders to help scale the proposed grid flexibility measures that can advance Delhi's grid flexibility needs.

Exhibit 43 Flowchart for scaling grid flexibility

RMI Graphic. **Source**: RMI analysis

Establish Evaluation Framework

Establishing a standardised framework to evaluate the value of grid flexibility measures is an essential step to determine its scaling potential. An evaluation framework can be developed using the proposed methodology, derived from the experiences of Delhi flexibility pilots to date and the success of similar programmes globally.

Standardising Metrics and Processes

Standardising metrics and regulatory processes can provide Discoms with a clear roadmap to evaluate grid flexibility measures and identify their potential in providing grid flexibility support. Establishing a clear set of processes from the technology evaluation stage to piloting and scaling demand flexibility-based programmes can enable Discoms to cost-effectively manage electricity procurement needs and new investments in distribution infrastructure upgrades.

Regulators play a necessary role in the development of these standards as they ensure that all Discoms under their jurisdiction follow the same protocols. Additionally, regulators could develop a long-term roadmap highlighting the role of these resources in providing grid flexibility and fostering a conducive environment for the growth of demand flexibility. This proactive approach by regulators can instil confidence in Discoms, investors, and industry players to develop effective long-term flexibility programmes.

Conducting a Benefit-Cost Analysis

To evaluate the potential of grid flexibility measures, identifying and quantifying their benefits relative to their costs plays a key role in demonstrating their value to the grid. Measuring key metrics highlighted in

Exhibit 44 can help develop a comprehensive benefit-cost matrix for individual grid flexibility measures. Discoms can perform benefit-cost analyses to identify their economic viability. A positive benefit-cost analysis, indicating that benefits outweigh costs, strengthens the case for demonstrating the technology via pilots in regulatory sandbox environments. Non-numeric benefits such as consumer empowerment and decarbonisation can also be considered to gain a comprehensive understanding of the impacts for all stakeholders.

A significant advantage of conducting pilots based on benefit-cost analysis is that it establishes a benchmark against which the performance of the pilot can be evaluated. This validation can set the stage for scaling the grid flexibility measures as it helps develop confidence in the technology, thereby unlocking regulatory backing and attracting investments for a fully developed programme project.

Moreover, Delhi regulators can consider setting a benefit-cost framework based on the perspectives of different stakeholders, such as Discoms, participating consumers, and non-participating consumers. This framework would provide clarity on the cost-effectiveness metrics required for seeking regulatory approval of a grid flexibility programme. US state regulators (public utility commissions) typically employ the Total Resource Cost Test, Non-Participant Cost Test or Ratepayer Impact Measure, Participant Cost Test, and Programme Administrator Cost Test or Utility Cost Test to establish the cost-effectiveness of consumer-side programmes.[79] In India, the Maharashtra Electricity Regulatory Commission has adopted similar DSM cost-effectiveness tests, but other states lack regulatory clarity on these tests.

A comprehensive cost test methodology ensures a holistic evaluation of consumer-led demand flexibility initiatives, balancing benefits and costs from the perspectives of individual participants, non-participants, Discoms, and the grid system at large.

Exhibit 44 Metrics for formulating a benefit-cost analysis

COST	BENEFIT
Programme administration	Avoided T&D upgrades
Capital and financing	Avoided generation capacity
O&M[xiv]	Avoided fuel costs
	Avoided losses
	Consumer bill savings
	Emissions reduction
	Societal benefit

RMI Graphic. **Source**: E3, https://www.ethree.com/wp-content/uploads/2023/10/Regulatory-and-Business-Case-for-Distributed-Energy-Resources-in-India-Phase-2-Vol.-REPORT.pdf

xiv. Integrating new Discom processes can often be cumbersome as these programmes may be siloed. New software integration and additional processes will require training and collaboration among programmes.

Validating with Regulatory Pilots and Sandboxes

Once a framework with a comprehensive benefit-cost analysis is established, validation of these results can be tested in controlled regulatory sandboxes for a limited period with a limited number of participants.[xv] These pilots can also help implement programme structures, incentive frameworks, and consumer engagement strategies that can help improve the effectiveness of the larger programme rollout. Piloting a variety of programme structures that resonate with different consumer segments can inform the final design of a programme.

A standardised measurement and verification (M&V) protocol is essential to measuring the impact of and extracting learnings from the pilots. Consistent measurement of metrics is crucial in order to track progress, identify trends, and make informed decisions regarding programme adjustment and expansion. Stakeholders should work to implement a standardised M&V protocol to evaluate pilot outcomes. Processes put in place must be accurate, timely, and not susceptible to bias. M&V needs to be done reiteratively to effectively understand the impact of pilots, allowing Discoms to fine-tune strategies, identify areas for improvement, and make data-driven decisions to scale up successful initiatives.

> **Engaging with participants to collect feedback, understand consumer interests, and assess reactions on incentives and programme structures can be a key output from pilot programmes.**

Engaging with participants to collect feedback, understand consumer interests, and assess reactions on incentives and programme structures can be a key output from pilot programmes. Such interactions can help in adapting programme strategies to better align with consumer expectations and the goals of Discoms. Tailoring approaches to the unique preferences and requirements of different consumer groups can enhance attractiveness of grid flexibility programmes, encouraging broader adoption and facilitating successful programme rollout.

During this phase, establishing and testing models for aggregation can be prioritised. DERs can provide additional system flexibility when aggregated. Experimenting with models to meet grid and distribution needs would unlock these additional benefits. The US Department of Energy has established the following four models that regulators and Discoms can use to build programmes based on feasibility in the existing and future market:[80]

a. Aggregators bid directly into wholesale markets.
b. Aggregator sells services via bilateral contract with Discom.
c. Discom operates as an aggregator with third-party aggregation platform.
d. Discom operates as an aggregator.

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xv. A regulatory sandbox "creates a space where participating businesses won't be subject to onerous regulations — usually for a limited amount of time. The point is to allow these businesses to 'play' in the sandbox without regulations to see if innovative ideas and products can get traction and enter the market." See "Everything you need to know about regulatory sandboxes," State Policy Network, October 12, 2021 (spn.org).

Aggregation offers Discoms an alternative to traditional energy procurement methods by utilising aggregated resources to meet energy and capacity needs more flexibly and cost-effectively. Regulatory frameworks must be established to enable aggregators to independently participate in wholesale markets.

Discoms need to either develop internal expertise in aggregation or partner with third-party platforms to effectively manage and optimise aggregated BESS resources. Discoms can maximise the value and contribution of BESS technology to grid flexibility by creating multiple pathways for aggregated assets to provide grid services.

Discoms can prioritise the sharing of knowledge, lessons learned, and best practices from the pilot initiatives. This can help build greater confidence in the adoption of demand flexibility measures. This can be done through the establishment of working groups made up of various stakeholders, such as technological manufacturers, participants, academic professionals, and industry partners.

Scaling

Regulatory sandbox iterations allow Discoms to experiment with programme structure, incentive mechanisms, and stakeholder engagement. By disseminating the lessons learned, best practices can be extracted to inform how to proceed with scaling efforts. Successfully scaling grid flexibility requires a concerted effort from stakeholders to unlock the critical enablers highlighted earlier, coupled with the development of a roadmap that helps shape a well-informed programme. **Box 13** provides an example of a successful procedure for scaling.[81]

Box 13 **California's successful procedure for scaling**

California's Demand Response Auction Mechanism (DRAM) is an innovative scaling demand response model that offers value for regulators in Delhi seeking insights into standardised procedures for transitioning pilots to full-scale programmes. The project's primary goals include integrating DR resources into the energy market, facilitating third-party participation without utilities acting as intermediaries, and extending market access to residential resources. In the DRAM programme, sellers bid aggregated DR directly into the day-ahead market. This new approach allows distributed DR to compete with traditional generation and larger C&I DR portfolios. By transitioning from a utility-controlled demand response to a more inclusive system, DRAM removed barriers to widespread adoption. It achieved this by broadening value streams for participants and enabling added revenue through resource adequacy assets and wholesale market participation.

The steps for DRAM implementation are clearly laid out, offering insights into how Delhi regulators can support scaling DR programmes. The process shown in **Exhibit 45** highlights iterative pilot phases, comprehensive evaluation, and stakeholder engagement. Although this process is geared towards demand response, the lessons learned can be applied to offer benefits in scaling BESS projects and managed EV charging programmes as well.

Exhibit 45 Timeline of California's DRAM Programme Development

2014

California Public Utilities Commission (CPUC) issued a decision mandating all utilities to develop and execute a DRAM request for offers with plans to implement the pilot between 2016 and 2017. This marked the initial steps towards establishing the DRAM programme.

2016

A second significant decision was issued, calling for additional iterations of the pilots to be conducted in 2019. This decision aimed to further test and refine the DRAM programme.

2019

This year was marked by evaluation of the initial pilots and workshops, providing valuable insights into the programme's performance. Regulators also authorised an auction for deliveries in 2020 through 2023. Moreover, a decision was issued to adopt recommendations aimed at enhancing reliability and performance, based on a stakeholder working group report, leading to refinement of the programme beginning in 2021.

2022

Findings and recommendations from an evaluation report were presented in a virtual workshop. A scoping memo and ruling were issued, outlining a phasing schedule that focused on the future of the DRAM programme.

2023

CPUC issued a decision approving the 2024 pilots without modification, solidifying the programme's trajectory towards future scaling.

RMI Graphic. **Source**: PG&E

Conclusion and Path Forward

Delhi's electricity sector is undergoing a paradigm shift. The growth in peak demand — driven by rising cooling requirements and the electrification of the transportation sector, coupled with expanding RE penetration — will present challenges for the city's electricity grid throughout this decade. Grid operators and Discoms will face these challenges in the form of high-power procurement costs and frequent distribution infrastructure upgrades that can affect grid reliability and affordability of electricity for consumers. There is a need to rethink the architecture of Delhi's grid to enable seamless integration of future supply and demand trends. These trends provide Delhi with an opportunity to transform its power sector and design the country's first clean and modernised grid that empowers consumers and sets the benchmark for grid developments in other states.

Grid flexibility will be instrumental in the redesign of Delhi's grid, as it can help mitigate the impact of seasonal variations and intermittent peak demand, while also taking advantage of the increasing RE penetration on the grid. This report provides a comprehensive overview of the grid flexibility measures in Delhi and quantifies the peak savings and economic benefits that can be achieved by each measure. The analysis suggests that adopting grid flexibility measures can unlock a stack of benefits compared with the costs needed to implement them, highlighting that investments in scaling these measures can be lucrative.

As grid flexibility has yet to scale in Delhi, the critical enablers and stakeholders who can unlock these measures have been identified based on a global review of successful programmes. As the scaling of these measures requires a concerted effort from multiple stakeholders over a period, the report proposes a roadmap that can guide Discoms and regulators to mainstream grid flexibility measures in Delhi. **Exhibit 46** summarises the recommended path for each measure to mobilise grid flexibility in Delhi.

Exhibit 46 Path forward for grid flexibility initiatives

Technology	Initiative	Next Steps
DR	**Domestic BDR**	Several domestic BDR pilots have been conducted in Delhi to validate their concept and value. As smart metre deployment is gaining momentum, stakeholders can develop and deploy a large-scale, long-term programme based on a comprehensive benefit to cost. Iterative changes can be made to the programme based on participant and working group feedback.
	C&I and domestic ADR	An ADR pilot will require rollout of smart devices such as smart switches for ACs. Investments will be necessary to incentivise consumer participation in ADR pilots. It is also essential to focus on setting open technical standards and building technical capacity for pilots before scaling.
Managed EV charging	**Public bus fleet charging**	Discoms and bus depot operators should optimise the utilisation of current e-bus ToD tariffs to minimise their demand during peak hours. The savings potential can be tested via short-term pilots. Lessons from early programmes should be disseminated to ensure proof of concept. This can instil confidence in implementing technologies such as aggregation platforms and smart chargers to enable managed charging programmes for e-bus fleets.
	Commercial and domestic charging	Focus should be on building technological capacity in the domestic and commercial fleet segments through incentivisation and educational campaigns that underscore the benefits, facilitating programme testing. During the pilot phase, Discoms will need to adopt a standardised aggregation platform to maximise the programme benefits.
BESS	**Distribution-sited BESS**	Priority should be given to assessing the value of distribution-sited BESS projects in parts of the distribution grid that require significant upgrades, given the space constraints in Delhi. Based on the few pilots that have already taken place, a thorough M&V will enable learnings to be extracted and socialised. These learnings will inform the best practices and encourage scaling of distribution-sited BESS projects.
	Domestic and commercial BTM BESS	BTM BESS should be scaled to align with Delhi's future RE goals. Moreover, BTM pilot projects require aggregation and technical integration. The focus should be on innovative incentive mechanisms and ownership models to encourage adoption and participation of BTM BESS.

RMI Graphic. **Source**: RMI analysis

Appendices

Appendix A: 2030 Domestic Cooling Calculations

Delhi's 2019 AC penetration was calculated based on data from the 2020 BSES load research report.[82] The report states that 44% of installed ACs are non-star rated and provided data for the connected load of non-star ACs in the BSES territory. Using this data, the AC penetration for BSES was calculated to be 41% — assuming one registered consumer has one AC unit. To calculate the total number of domestic consumers with AC units, the 41% factor was applied to the total number of registered Delhi domestic consumers in 2019.

To calculate the Delhi peak AC demand in 2030, the 2019 AC demand was first calculated. The 2019 AC demand was calculated by finding the demand of the 44% non-star weighted ACs using the values and ownership data from the BSES load research report, and then finding the demand of the 56% star-rated ACs using a weighted average of Daikin star-rated ACs.[83] Assuming the overall average efficiency of 1.15 kW, the 2019 AC demand was calculated to be 2,748 MW. To project the 2019 AC load to 2030, the compound annual growth rate (CAGR) from the CEA 20th EPS load report between 2021 and 2030 was calculated to be 5.25%.[84] The same CAGR of 5.25% was applied to the domestic AC demand from 2019 to 2030. Using the 5.25% CAGR, the projected 2030 Delhi domestic AC demand was calculated to be 4,825 MW. Utilising an average of efficient ACs expected in 2030, 57% of Delhi domestic consumers would need to own an AC unit to produce a peak demand of 4,825 MW.[85]

The 2030 Delhi domestic AC demand curve was produced by applying the projected 2030 peak demand to the 2019 normalised hourly AC appliance working day usage curve from the 2020 BSES report. The 2030 peak demand represented 100% utilisation across the daily curve.

Appendix B: 2030 E-Bus Calculations

Based on stakeholder conversations, an e-bus to charger ratio of 4:1 will be assumed, requiring 4,000 chargers to support 12,000 e-buses in Delhi in 2030. First, the load profile of a single e-bus depot charger was determined. Then, the single charger load profile was multiplied by 4,000 to model the demand of the fleet of chargers needed to support the e-bus load in Delhi.

Appendix C: 2030 Commercial EV Calculations

As per stakeholder conversations, the EV to charger ratio is 3:1. Therefore, 26,287 chargers will be required to support 78,862 EVs in Delhi by 2030. The ratio of slow chargers (7 kW), medium chargers (22 kW), and fast chargers (50 kW) is assumed to be 2:5:3. Considering the existing situation, 80% of all chargers will operate at peak times; the peak demand of 26,287 chargers was calculated to be 576 MW. To calculate the hourly load profile of all the chargers, the existing load profile from the commercial fleet operator was extrapolated for the 26,787 chargers required to support commercial EVs in Delhi in 2030.

Appendix D: 2030 Supply Side Projections

We modelled FY23 and FY30 based on Energy Exemplar's PLEXOS India Dataset.[86] It simulates nationwide capacity expansion through 2040, as well as hourly security-constrained economic dispatch (SCED).

To model FY23, we conducted a production cost analysis using the existing generation mix (in-state + contracted resources by Delhi Discoms). To analyse FY30, we first generated a nationwide capacity outlook, using a pan-India capacity expansion model to simulate economically optimised generation resource additions. Our model allows for the selection of a wide variety of resources, including coal-fired steam turbines, gas-fired combined and simple cycles, solar, wind, hydro (run-of-river, reservoir, and pumped storage), nuclear, offshore wind, biomass, and utility-scale battery storage.

We incorporated the following assumptions and constraints beyond those represented in Energy Exemplar's base model: we assumed no development of new coal-fired or gas-fired generation within Delhi and we raised import/export capabilities into/out of Delhi to a level consistent with current physical transmission capacity, rather than the lower interface limits implemented by Energy Exemplar to reflect poor scheduling coordination.

Using the resultant generation builds and retirements from this capacity expansion model, we then conducted a base case production cost model to analyse hourly generation dispatch and energy costs. For each demand flexibility resource analysed, we then ran an additional production cost model, using the base case resource mix plus the demand flexibility resource. Total capacity by resource type in FY23 and FY30 is shown in **Exhibit 47**.

Exhibit 47 Base case generation capacity contracted to Delhi utilities, FY23 and FY30

	FY23 (MW)	FY30 (MW)
GAS	1,724	1,724
COAL	3,792	3,792
NUCLEAR	103	103
HYDRO	826	2,326
BIOMASS	40	40
SOLAR	2,045	10,839
WIND	521	3,521
BESS	10	10

RMI Graphic. **Source**: RMI analysis of Delhi SLDC data for FY23 and an illustrative portfolio projection for FY30

Hourly Generation

The production cost model yields hourly generation profiles for every generator represented in Energy Exemplar's India-wide data set. To demonstrate Delhi utilities' generation mix, we aggregated the energy output from every generator owned by or contracted to the utilities, scaling it by the utilities' ownership stake.[87] We assumed that the utilities carry their current contracts through to FY30, meeting increases in load through new contracted solar generation and increased market purchases. By FY30, we assume the utilities enter additional contracts for 7,500 MW of solar, 3,000 MW of wind, and 1,500 MW of hydro. This resource mix is based on discussions with Delhi utilities, the economically optimal outcomes modelled in capacity expansion (which favours contracted solar), and review of state and national policy goals.

Exhibit 48 shows average hourly generation profiles for Delhi's contracted resources across five seasons for FY23 and FY30 (base case, without grid flexibility measures): winter (December and January); spring (February and March); summer (April, May, and June); monsoon (July, August, and September); and fall (October and November).

Exhibit 48 Seasonal average generation stacks for Delhi, FY23 and FY30

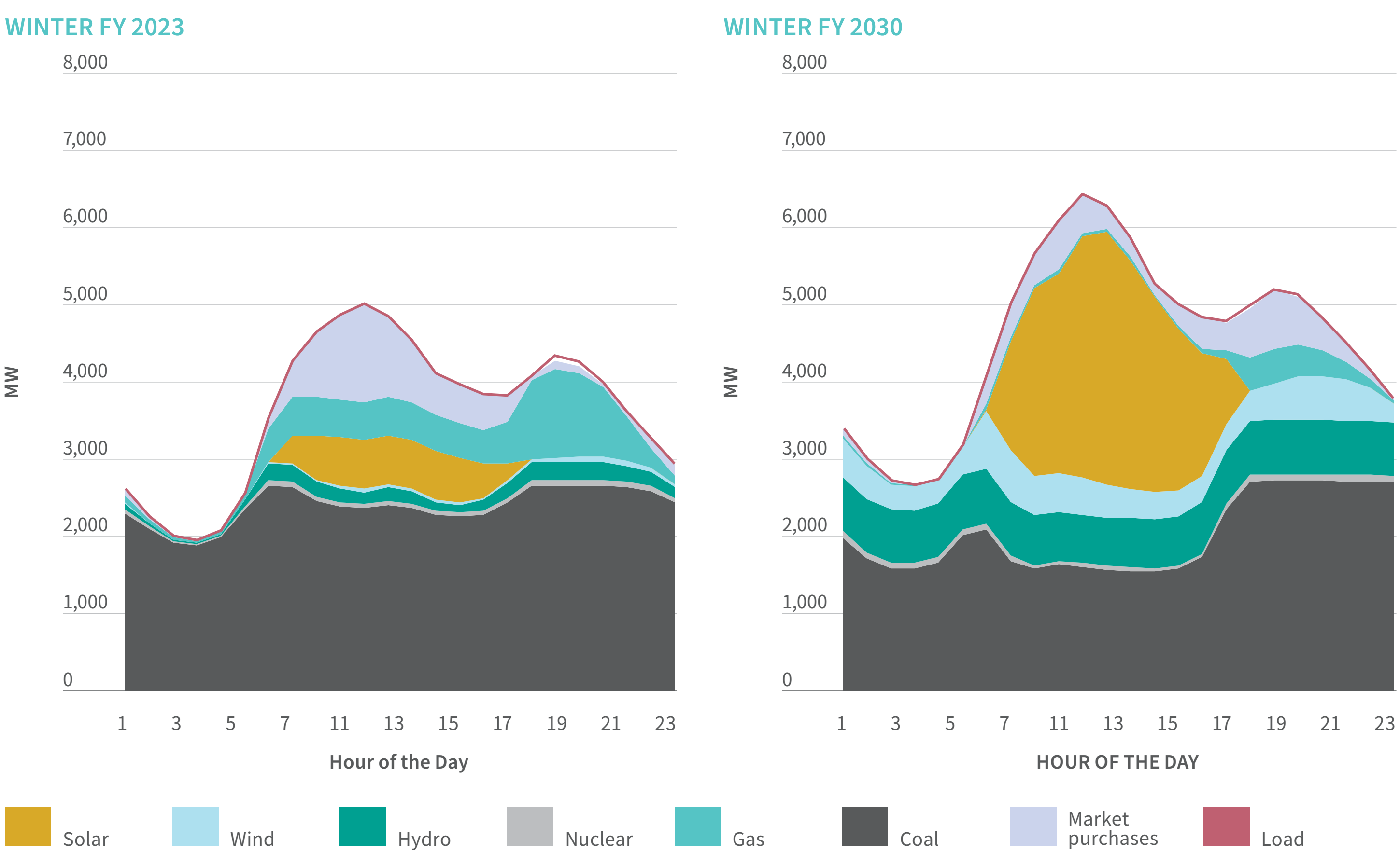
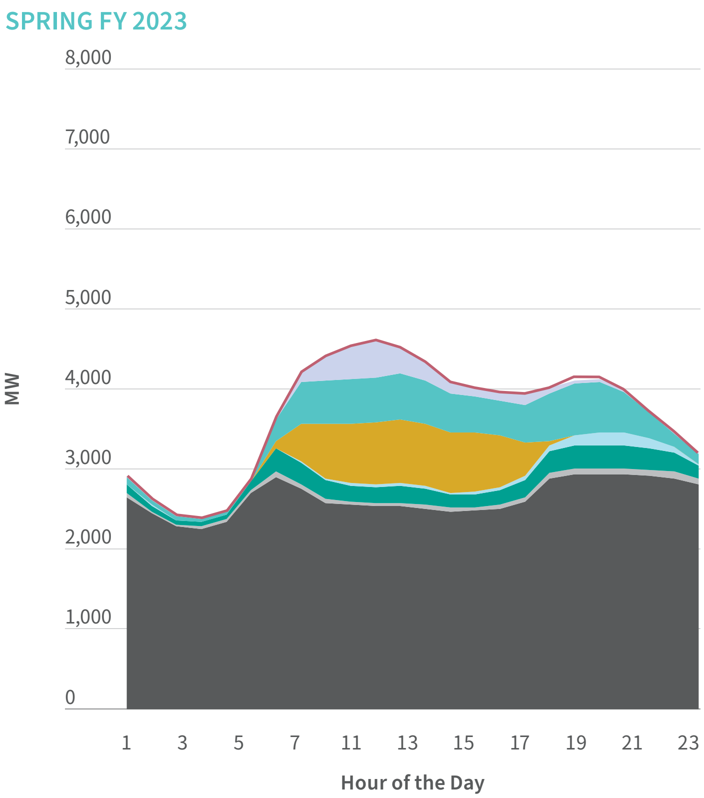
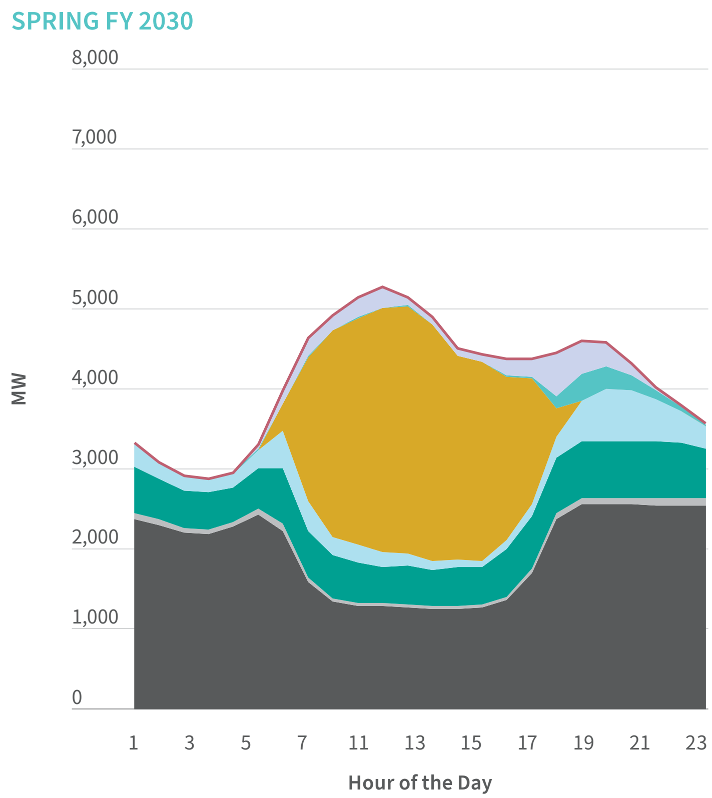
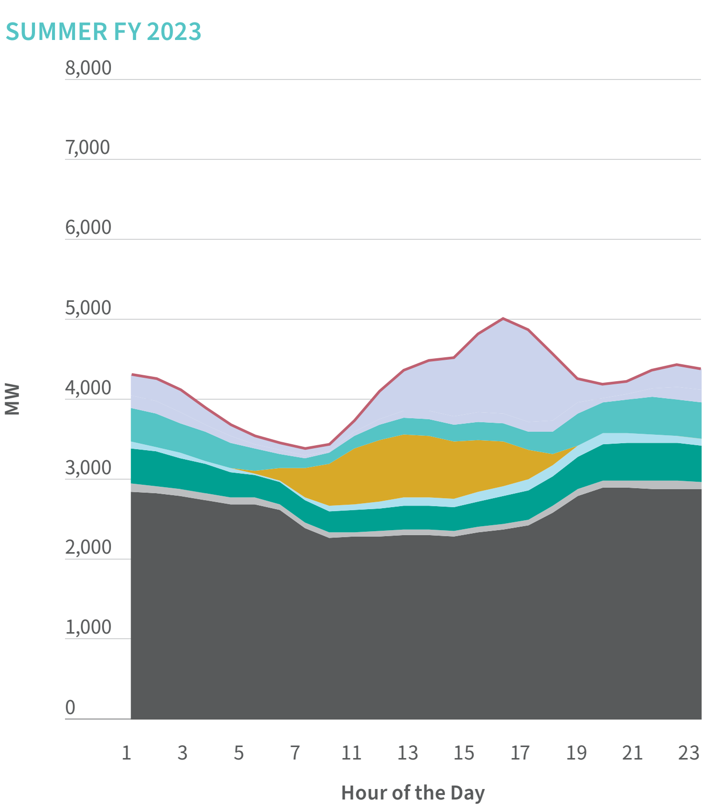
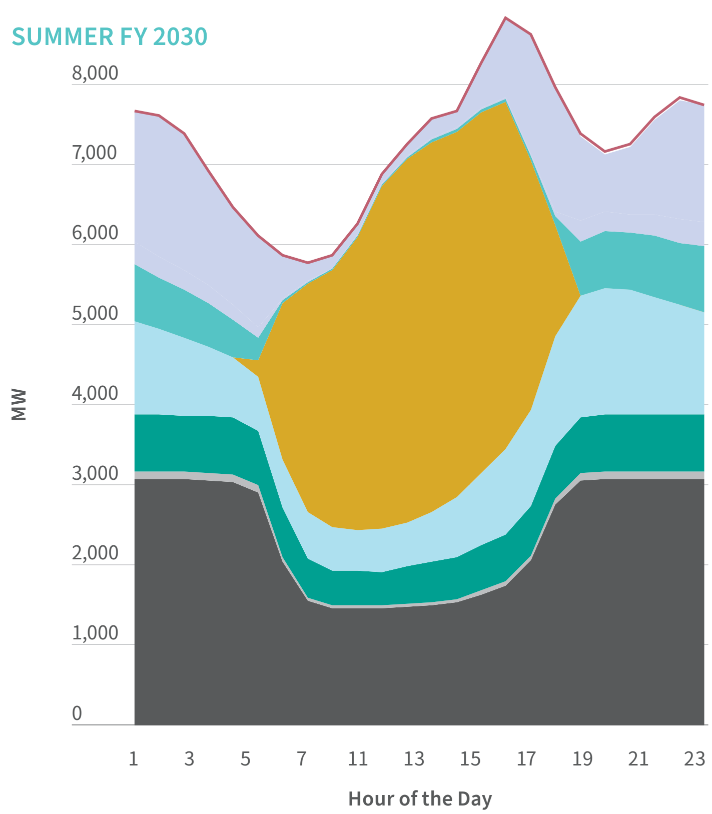


Exhibit 48 Seasonal average generation stacks for Delhi, FY23 and FY30 (Contd.)



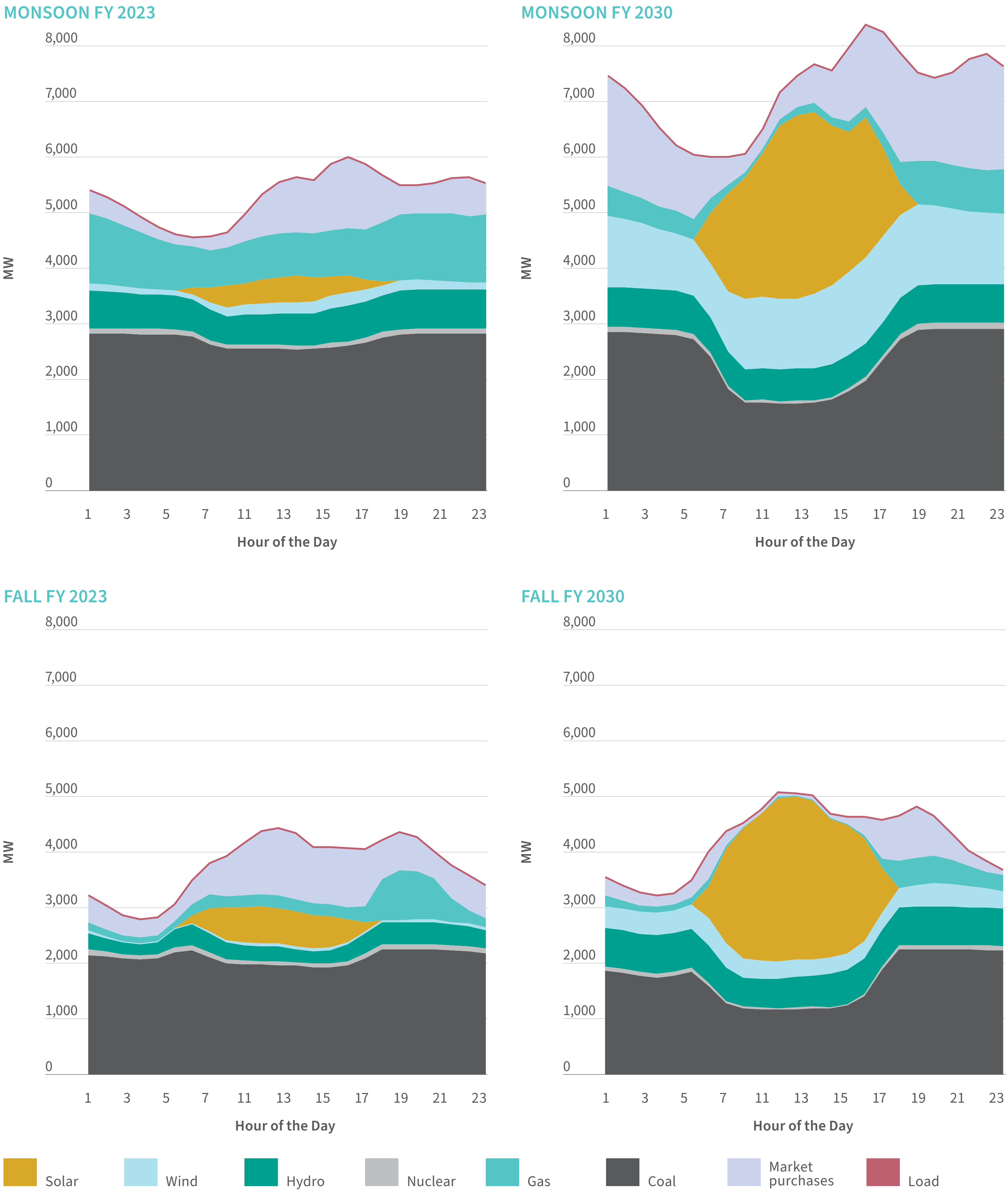






Solar | Wind | Hydro | Nuclear | Gas | Coal | Market purchases | Load

Exhibit 48 Seasonal average generation stacks for Delhi, FY23 and FY30 (Contd.)



RMI Graphic. **Source:** RMI analysis

Appendix E: DR Modeling Assumptions

The following assumptions are used to understand the potential for demand flexibility based on programme offerings, participation rates, and number of events (see **Exhibit 49**). Other assumptions such as the number of consumers, savings per participant, event times, and season are held constant.

Programme offerings are determined based on the feasibility of implementation for Delhi. In the low-case scenario, only a domestic BDR programme is assumed to be offered, as it has already been piloted in Delhi and proven feasible. The mid-case scenario assumes domestic BDR as well as commercial and industrial ADR, as C&I consumers are more likely to have adopted AMI and other smart technologies by 2030 and therefore have the technical feasibility to implement an ADR programme. Lastly, the high-case scenario assumes domestic BDR, C&I ADR, and domestic ADR to fully encapsulate the benefits of AC DR when domestic consumers reach the technical readiness to implement more advanced programmes.

Participation rates are based on a feasible range extracted from established programmes. For the low-case scenario, a 7% domestic BDR participation rate is assumed based on PG&E's national (US) estimate, as reported in *Utility Dive* in 2019.[88] For the mid-case scenario, a 17% domestic BDR participation rate is assumed based on the Association of Energy Services Professionals 2017 survey as reported in *Utility Dive* in 2019.[89] A 10% C&I ADR participation rate is assumed as a low range, given that C&I participation depends largely on incentives, Discom outreach, etc.

For the high-case scenario, a 24% domestic BDR participation rate is considered based on a Tata Power Delhi Distribution (TPDDL) Behavioural DR Pilot as reported in a 2021 AEEE/AutoGrid Study.[90] A 25% C&I ADR participation rate is assumed to reflect a much higher range of participation compared with the mid-case scenario. A 5% domestic ADR participation rate is assumed based on PG&E's SmartAC programme as presented in 2023.[91]

The number of events called during a season is determined based on the AC DR programme data from the US Department of Energy.[92] Events range from 10 to 20 from low to high cases, respectively, to capture a feasible yet comprehensive range.

The number of consumers in 2030 for domestic and C&I sectors is based on RMI analysis using data from Delhi's *2023 Statistical Handbook*, assuming a consistent growth rate.[93]

Savings per participant for domestic BDR is assumed to be 0.5 kW based on a TPDDL Behavioural DR Pilot, as reported in a 2021 AEEE/AutoGrid Study. Savings per participant for C&I ADR is assumed to be 5 kW based on BSES Yamuna AC demand flexibility programme, as reported in a 2021 AEEE/AutoGrid Study. Savings per participant for domestic ADR is assumed to be 0.2 kW based on PG&E's SmartAC programme, as presented in 2023. Event times and season are based on a TPDDL Behavioural DR Pilot, as reported in a 2021 AEEE/AutoGrid Study.

Based on these assumptions, electricity demand for 2030 is calculated using the following formula:
2030 Demand with AC DR = PLEXOS 2030 Project Load – (Number of Consumers x Participation Rate x Savings Per Participant)

Exhibit 49 DR modeling assumption

	Low	Mid	High
Domestic BDR	Y	Y	Y
Domestic ADR	N	N	Y
C&I ADR	N	Y	Y
Domestic BDR			
Number of consumers in 2030	7,441,811	7,441,811	7,441,811
Participation rate	7%	17%	24%
Savings per consumer (kW/participant)	0.5	0.5	0.5
Event time	10:30 p.m.–12:30 a.m.	10:30 p.m.–12:30 a.m.	10:30 p.m.–12:30 a.m.
Season	April–Sept	April–Sept	April–Sept
Number of events per season	10	15	20
Domestic ADR			
Number of consumers in 2030			7,441,811
Participation rate			5%
Savings per consumer (kW/participant)			0.2
Event time			10:30 p.m.–12:30 a.m.
Season			April–Sept
Number of events per season			20
Commercial and industrial ADR			
Number of consumers in 2030		1,095,777	1,095,777
Participation rate		10%	25%
Savings per consumer (kW/participant)		5	5
Event time		2:30–5:30 p.m.	2:30–5:30 p.m.
Season		April–Sept	April–Sept
Number of events per season		15	20

RMI Graphic. **Source**: Government of NCT of Delhi, https://des.delhi.gov.in/des/statistical-hand-book; *Utility Dive*, https://www.utilitydive.com/news/portland-general-pilot-proposes-reward-to-customers-for-reducing-energy-use/546095/; AutoGrid, https://www.auto-grid.com/resources/white-papers/roadmap-demand-flexibility-india/, CPUC, https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/demand-response-workshops/2023-load-impact-protocol-workshops/py2022-smartac-load-impact-presentation-final.pdf

Appendix F: Benefit-Cost Analysis Methodology

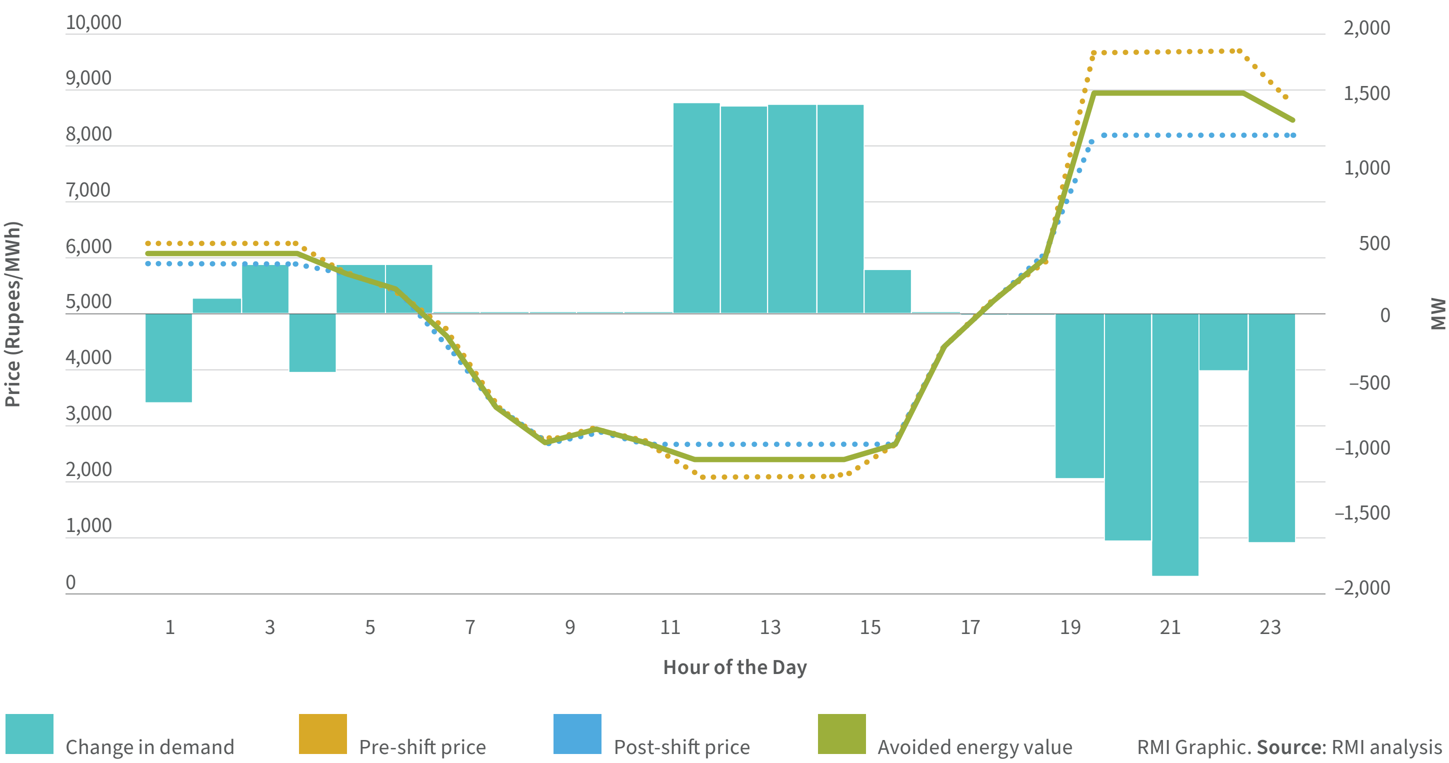
We quantify three additive (stacked) benefits for grid flexibility measures: avoided energy value, avoided generation capacity/RA value, and distribution system deferral value.[94] Costs include equipment, programme administration, and incentives. This benefit-cost framework is widely consistent with the Total Resource Cost Test used by regulators internationally.[95]

Avoided Energy Value

We estimate avoided energy costs using a modified marginal pricing approach. Under a traditional marginal approach, hourly energy value would be calculated as the change in net demand from the grid flexibility measure, multiplied by the base case energy price (i.e., marginal cost of energy in Delhi). However, at large penetrations of grid flexibility, the grid flexibility measures may change the marginal generator. In such situations, valuing the change in net demand at the base case energy price would overvalue demand reductions and undercount the costs of demand increases (e.g., from battery storage charging).

An alternative approach would be to use the price output from the case with the grid flexibility measures. But this approach would undervalue the grid flexibility measures, as it would ignore any savings from replacing the original marginal generator. Therefore, to approximate the cost savings most accurately, it is appropriate to use the average of prices before and after introducing the grid flexibility measure. **Exhibit 50** shows how grid flexibility-induced changes in net demand affect hourly energy value for an example summer day.

Exhibit 50 Impact of grid-flexibility-induced changes in net demand on hourly energy value for an example day (VPP mid case)



RMI Graphic. **Source**: RMI analysis

To ensure that we do not overestimate energy savings from grid flexibility using the marginal approach, we assess the depth of the energy supply stack in each season.[xvi] We assume that savings come only from avoiding non-contracted or sufficiently flexible resources (i.e., market purchases and gas). We approximate the depth of potential savings by comparing the ratio of total possible energy saved each season to the average energy procured from market purchases and gas generation.

In the spring, demand is low and contracted and renewable resources are available; therefore, the depth of potential savings is low. This affects BESS and VPPs, as they are the resources capable of saving the most energy (we assume the BESS cycles once per day). The result is that in the mid-adoption case, BESS and VPP revenues are adjusted downward 22% in spring. In the high-adoption case, they are adjusted downward 53%. In every other season, the pool of potential savings is sufficiently deep so that no cuts to modelled revenue are necessary.

Our approach is conservative in that it overlooks two possible streams of additional value for grid flexibility resources. The first is value from managing price volatility. Production cost models are known to understate price volatility, leading to systematic undervaluing of quick-responding flexible resources such as battery storage, controlled vehicle charging, and ADR.[96] By basing avoided energy costs on production cost outputs, we likely understate the true value of grid flexibility.

The second additional value stream comes from price effects. Load reductions from flexible resources depress market prices. This means that all residual market purchases cost less than they would have otherwise. The savings from these price effects could be quite large. However, these benefits are contingent on Delhi utilities purchasing energy from the market. Because the future extent of market purchases is uncertain, we excluded these benefits from our results.

Avoided Generation Capacity/RA Value

The MOP has released the Guidelines for Resource Adequacy Planning Framework for India, and the Forum of Regulators has developed model RA regulations.[97] If state regulators adopt the RA regulations framework by 2030, Delhi utilities will be tasked with meeting planning reserve margin requirements and fulfilling capacity obligations, either by building new generating resources or securing bilateral contracts. Given that our model displays relatively high reliance on market purchases for energy in 2030, we believed it was appropriate to estimate generation capacity value through avoided bilateral contracts.

To estimate the rupees/kW-year generation capacity value per grid flexibility measure, we need three parameters: the price of capacity per bilateral contract, the grid flexibility measure's capacity accreditation, and the transmission and distribution losses avoided by securing capacity from demand-side resources rather than traditional generators. A given measure's RA value is then the price of capacity multiplied by its capacity accreditation, grossed up for avoided transmission and distribution losses.

xvi. Winter (December and January); spring (February and March); summer (April, May, and June); monsoon (July, August, and September); and fall (October and November).

The price of capacity is calculated using a net cost of new entry (CONE) methodology.[98] We calculated the net CONE as the capital cost and fixed O&M cost for a resource built in 2030, minus its net revenues in the energy market,[xvii] as simulated in our production cost model. We compared net CONE values for open cycle and combined cycle gas turbines and found the combined cycle to have a lower net CONE, and therefore to be the expected marginal capacity resource. The net CONE of the combined cycle is 2,793 rupees/kW-year (US$33.5/kW-year) (see **Exhibit 51**).

Exhibit 51 **Net CONE Estimation for open-cycle gas turbine (OCGT) and combined cycle gas turbine (CCGT)**

	OCGT	CCGT
[1] Capital cost (rupees/kW)	50,000	34,700
[2] Capital cost (rupees/kW-y)	5,508	3,823
[3] Fixed O&M (rupees/kW-y)	1,800	2,900
[4] = [2] + [3] Gross CONE (rupees/kW-y)	7,308	6,723
[5] Net energy revenues (rupees/kW-y)	2,335	3,930
[6] = [4] – [5] Net CONE (rupees/kW-y)	4,973	2,793

RMI Graphic. **Source**: Capital cost and fixed O&M from CEA's Indian Technology Catalogue.[99] We levelised to an annual cost using the CEA assumed lifetime (25 years) and a 10% weighted average cost of capital (WACC). Net energy revenues are estimated by RMI.

Capacity accreditation per resource is tabulated in **Exhibit 52**. Four-hour batteries are given full capacity credit, in accordance with the methodology utilised in California.[100] Because AC DR and e-bus load reductions are fixed, capacity credits are calculated based on the coincidence of demand reduction with the top 20 net peak load hours of the year. This methodology is widely accepted as a high-quality approximation for more complex probabilistic accreditation analyses such as effective load carrying capacity.[101] VPP credits are calculated as the weighted average of capacity credits across measures.

Transmission and distribution losses are assumed at 8%, based on the most recent aggregate technical and commercial (AT&C) losses reported for Delhi utilities in the Power Finance Corporation of India's *Report on Performance of Power Utilities 2021–22*.[102]

xvii. Where net revenues are revenues from energy market sales minus variable O&M, fuel costs, and startup costs.

Exhibit 52 Capacity accreditation by resource

RESOURCE	CAPACITY CREDIT
Four-hour storage	100%
AC DR – low	19%
AC DR – mid	37%
AC DR – high	36%
E-bus	17%
VPP – mid	72%
VPP – high	79%

RMI Graphic. **Source**: RMI analysis

Distribution Deferral Value

We calculate distribution deferral value by estimating the contribution of each resource to avoid distribution circuit investments such as transformer upgrades. We assume distribution investments of 500 rupees/kW-year (US$6/kW-year), based on the midpoint of costs estimated in E3's Regulatory and Business Case for Distributed Energy Resources in India.[103] We use a mid-level cost due to the wide range of potential distribution deferral values across the system. Although some locations will have much higher values than 500 rupees/kW-year, others will have none. Detailed utility studies can better estimate the value for specific projects. We assume that batteries can be dispatched to fully reduce distribution-coincident peak, i.e., they earn 100% capacity credit for distribution deferral.

To calculate the contribution of AC DR programmes to distribution deferral, we count the ability of AC DR to reduce the total annual system peak demand. Implicitly, we are making the simplifying assumption that Delhi system-wide peak demand and distribution-circuit level peak demand are coincident. We observe that the low-participation case reduces peak demand by 0 MW, the mid-participation case by 553 MW, and the high-participation case by 944 MW. This leads to corresponding capacity credits of 0%, 87%, and 70%, respectively. We assume the e-bus managed charging programme has no distribution deferral value, due to the costs involved with upgrading the distribution system to accommodate bus depots.

Ancillary Services Value

We do not model ancillary services explicitly in our benefit-cost analysis framework. Therefore, we do not attribute any ancillary service value to the grid flexibility measures. At low saturation levels, flexibility measures such as battery storage can earn much of their revenues through ancillary services. However, as penetration level increases, the relatively shallow markets for ancillary services saturate, and grid flexibility measures must rely on avoided energy, transmission and distribution deferral, and generation capacity benefits to be cost-effective.

Costs

AC DR programme costs are estimated at 600–879 rupees/kW-year (US$7.2 – 11.6/kW-year). These approximations are derived from a review of existing literature, though programme development can help better determine costs for Delhi utilities. We assume that every customer participating in automated demand response programmes receives a Wi-Fi-enabled smart thermostat, with costs taken from E3's analysis for TPDDL. Programme administration and marketing costs are estimated at 600 rupees/kW-year (US$7.2/kW-year), in keeping with E3's estimate for the programme administration and inconvenience costs for its modelled distribution hot spot demand response programme.[104]

Managed e-bus charging costs are estimated at 865 rupees/kW-year (US$10.4/kW-year). This data was collected from e-bus managed charging solution providers. Costs are primarily related to software investments necessary to manage existing e-bus depot charging equipment and Discom programme administration costs.

Battery cost forecasts are assumed to remain at the real level discovered in the recent Phase III Gujarat Urja Vikas Nigam Ltd (GUVNL) tender.[105] The cost for this project is rupees 3.72 lakhs per MW per month (US$4,450/MW-month). We convert from two-hour to four-hour battery cost using ratios from the CEA Technology Catalogue and adjust for inflation using an estimated 5% per year inflation rate. [106] The resultant real (2020 currency) cost is rupees 6,273/kW-year (US$75/kW-year).

Exhibit 53 Net benefits summary

	AC DR			E-BUS	BESS			VPP	
	Low	Mid	High	Mid	Low	Mid	High	Mid	High
Energy benefits (rupees/kW-y)	210	446	549	3,173	7,608	6,776	6,119	4,522	4,342
Generation capacity benefits (rupees/kW-y)	567	1,125	1,084	522	3,020	3,020	3,020	2,170	2,379
Distribution deferral benefits (rupees/kW-y)	0	437	352	0	500	500	500	409	445
Total costs (rupees/kW-y)	600	700	879	865	6,273	6,273	6,273	4,015	4,415
Net benefits (rupees/kW-y)	177	1,308	1,106	2,830	4,854	4,023	3,336	3,086	2,752
Max shift/shave (MW)	261	633	1,340	399	500	1,500	2,500	2,510	3,870
Net benefits (crore rupees/y)	5	83	148	111	243	603	841	775	1.065

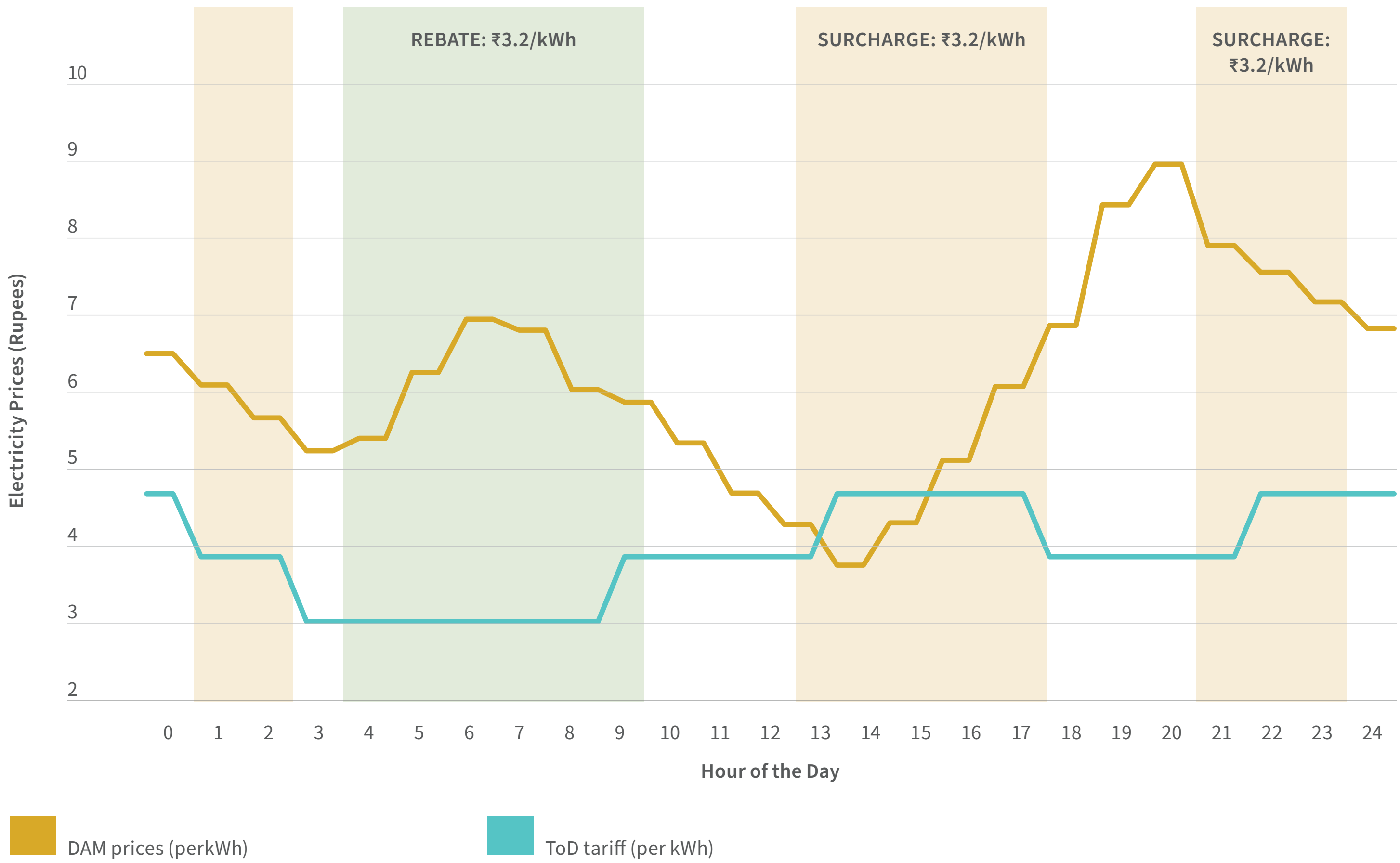
RMI Graphic. **Source**: RMI analysis

Appendix G: Managed E-Bus Charging

Potential savings: Optimisation using historical energy market prices (2023 Indian Energy Exchange DAM)

The adoption of managed EV charging for buses presents a significant opportunity for Discoms to realise substantial economic benefits. Discoms incur higher electricity procurement costs during peak hours compared with non-peak hours as highlighted in the earlier sections. Despite the imposition of a 20% surcharge on electricity tariffs during peak hours, the gap between tariffs and costs remains considerably higher than during peak demand periods, as highlighted in **Exhibit 54.**

Exhibit 54 Average hourly electricity price in DAM and e-bus tariffs (2023)



RMI Graphic. **Source**: RMI analysis

By optimising demand, the peak demand of e-buses shifts from 8 p.m.–midnight to after 1 a.m. During this off-peak period, Discoms can procure power at cheaper rates of around 6 rupees/kWh (US$0.07/kWh). Although the power purchase cost is still higher than the electric tariff, Discoms can save around 2 rupees/kWh (US$0.02/kWh) through demand optimisation.

Appendix H: Potential BESS Value Streams and Ease of Monetisation

Exhibit 55 Distribution-located storage (DLS) value streams and ease of current and future market monetisation for Discoms

DLS VALUE STREAMS AND EASE OF CURRENT AND FUTURE MARKET MONETISATION FOR DISCOMS				
Direct control of DERC	**DLS value streams**	**Current ease of monetisation (2023–24)**	**Expected future ease of monetisation (2025–26)**	**Considerations for optimisation/revenue stacking**
N/A	Energy arbitrage	Relatively easy to monetise	Will further streamline with increase of price caps / more clearance through markets	DLS asset operator to optimise and schedule between real-time market (RTM), DAM, and HP-DAM
No	Ancillary services: primary reserve ancillary services	Not allowed by the CERC 2022 AS regulation	Likely to remain difficult to shift to market-based procurement	
No	Ancillary services: secondary reserve ancillary services	Allowed by CERC AS regulation, but no clarity yet on prices and DLS participation process	Expected to move to market based procurement in a year; clarity expected on DLS participation process	Not easily stackable with energy revenues (as SRAS up may be required at the same time as high energy prices, and conversely for SRAS down)
N/A	Ancillary services: tertiary reserve ancillary services	Allowed by CERC AS regulation, some clarity on prices and DLS participation process	Further clarity is expected on prices and DLS participation process	DLS asset operator can optimise between energy and TRAS markets
Yes	Distribution capex deferral	Discoms and state regulators need to identify and implement deferrals proactively	Needs detailed local network analysis for proactive planning	Operating DLS asset to provide local peak reduction while balancing market participation
Yes	Reducing DSM penalties	Value of DSM penalty reduction via DLS is unclear to external stakeholders	Early pilots to establish DLS value for reducing DSM; states rich in variable renewable energy going first	No clarity on whether it could be co-optimised/stacked with other value streams
Yes	Resource adequacy	RA regulation still in the early stages of formulation; no clarity yet on Discom RA obligations and the value of capacity credits DLS can provide	Successful implementation of RA framework expected with participation from CEA, Grid-India, and state Discoms	Easily stackable value stream with energy and AS participation opportunities

Easy to monetise

Partially monetisable: Need further clarity on the participation process

Non-monetisable: Regulation exists, but no clear price signals

RMI Graphic. Source: https://rmi.org/insight/powering-progress-batteries-discoms-india/

Appendix I: Cost Share of Gas Generator in the Overall Portfolio of Discoms

As per the data received from BSES, they procure around 8,482 MU from various generating companies (through power purchase agreements) at a total cost of 3,830 crore rupees (US$460 million). Of this, the quantity of gas purchased is approximately 650 MU at a total cost of 914 crore rupees (US$110 million). This implies that although gas generators met about 8% of the annual electricity demand, these generators accounted for about 25% of the Discoms' annual power procurement costs.

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