Are Urban Microgrids Economically Feasible?

A study of Delhi's Discom and Consumer Perspectives for BYPL

Akanksha Tyagi, Neeraj Kuldeep, and Aarushi Dave

Report | October 2020

Solar-storage microgrids can assist discoms in managing the growing electricity demand in cities.

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The Council's major contributions include: The 584-page National Water Resources Framework Study for India's 12th Five Year Plan; the first independent evaluation of the National Solar Mission; India's first report on global governance, submitted to the National Security Adviser; irrigation reform for Bihar; the birth of the Clean Energy Access Network; work for the PMO on accelerated targets for renewables, power sector reforms, environmental clearances, Swachh Bharat; pathbreaking work for the Paris Agreement, the HFC deal, the aviation emissions agreement, and international climate technology cooperation; the concept and strategy for the International Solar Alliance (ISA); the Common Risk Mitigation Mechanism (CRMM); critical minerals for Make in India; modelling 222 scenarios for India's low-carbon pathways; India's largest multidimensional energy access survey (ACCESS); climate geoengineering governance; circular economy of water and waste; and the flagship event, Energy Horizons. It recently published Jobs, Growth and Sustainability: A New Social Contract for India's Recovery.

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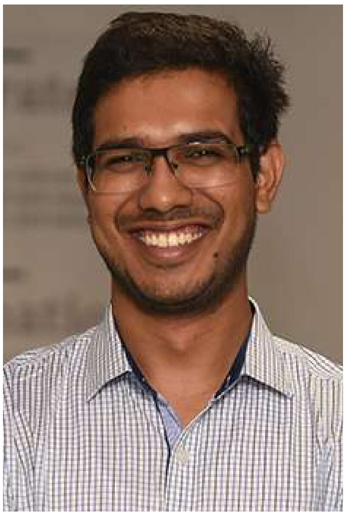
"Successful implementation of innovative demand-side management solutions like behind-the-meter storage by discoms needs a two-pronged approach involving appropriate system sizing based on demand patterns and system requirements, coupled with new business models to share the ensuing costs and benefits equitably with consumers."



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"Undoubtedly, urban microgrids (solar PV plus storage systems) are the backbone of a robustly distributed electricity market. Appropriate incentive structures and innovative business models on cost–benefit sharing would bring synergies between discom and consumer benefits and support urban microgrid deployments."

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"An important aspect of rooftop solar installations is how they financially benefit consumers. The purpose of this study was to understand how policy can support end-user confidence in solar power systems with storage facilities which balance environmental welfare with financial viability in the long run."

Energy storage technologies improve the availability and reliability of renewable energy.

Image: iStock

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Acronyms

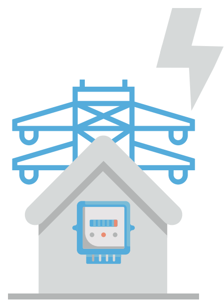
AC	alternating current
ADCC	avoided distribution capacity cost
ADSC	added distribution services cost
AGCC	avoided generation capacity cost
APPC	avoided power purchase cost
ARECC	avoided renewable energy certificate cost
ATRC	avoided transmission charges
AWCC	avoided working capital requirement
BESS	battery energy storage system
BYPL	BSES Yamuna Power Limited
CAGR	compounded annual growth rate
CEEW	Council on Energy, Environment and Water
CERC	Central Electricity Regulatory Commission
CF	coincidence factor
CUF	capacity utilisation factor
DC	direct current
DCF	distribution coincidence factor
DERC	Delhi Electricity Regulatory Commission
DRE	distributed renewable energy
DSM	deviation settlement mechanism
DT	distribution transformer
FY	financial year
GW	gigawatt
INR	Indian national rupee
kVA	kilovolt ampere
kVAh	kilovolt ampere hour
kW	kilowatt
kWh	kilowatt-hour
kWp	kilowatt peak
LCOE	levelised cost of electricity
LCOES	levelised cost of energy storage
MW	megawatt
NCT	national capital territory
NMC	nickel manganese cobalt oxide
NPV	net present value
PAC	programme administration cost
PPA	power purchase agreement
PV	photovoltaic
RE	renewable energy
REC	renewable energy certificate
RL	revenue loss
RPO	renewable purchase obligation
RTE	round trip efficiency
SCF	system coincidence factor
SOC	state of charge
VGRS	value of grid-connected rooftop solar

Urban microgrids could be a more convenient solution for electricity distribution companies to meet growing demand compared to traditional methods of capacity procurement and network augmentation.

Image: iStock

Executive summary

Urban microgrids with rooftop photovoltaic (PV) and battery energy storage systems can help power distribution companies (discoms) meet the accelerating electricity demand in cities. These may be a more convenient, less time-consuming alternative to procuring additional generation capacity, augmenting transmission and distribution networks, and building new infrastructure. For consumers, these systems offer multiple value propositions – more reliable power supply, reduced electricity bills, and earnings from the export of stored electricity.



A discom's load varies significantly throughout the year. Besides variations during peak hours, the baseload also changes dramatically across seasons

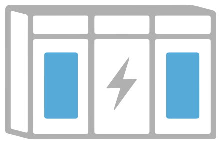
Solar storage microgrids could curb urban electricity woes; given the potential benefits, they offer for discoms and consumers. However, the high costs of energy storage may prove to be a deterrent. So, before installing and scaling these systems, it is necessary to understand better the impact of these systems on both the discom and consumer.

This report employs a cost–benefit analysis framework, value of grid-connected rooftop solar (VGRS) (Kuldeep, Kumaresh Ramesh, et al. 2019), to assess the economic viability of solar storage microgrids from the perspective of discoms. It also uses a discounted cash-flow analysis to estimate the financial impact on customers. These two approaches are applied to a case study of a pilot system installed by BSES Yamuna Power Limited (BYPL), a Delhi-based discom, in one of their offices. The unit consists of a 7 kWp (kilowatt peak) rooftop solar (RTS) PV system coupled with a 10 kWh (kilowatt-hour) behind-the-meter lithium ion BESS (battery energy storage system). These two components work in congruence with the grid to meet consumer demands.

While applying the VGRS framework, we analysed the load profile of the discom and consumer. We found that the discom's load varies significantly throughout the year. Besides variations during peak hours, the baseload also changes dramatically across seasons. The current practice of discoms dividing the year into two broad peak and off-peak periods to strategise their operations and use the microgrids is inefficient. Instead, using distinctive microgrid schedule and a battery dispatch for each season is more effective. Furthermore, there is a significant difference in the load profile of the discom and consumer. For BYPL, monsoon (July to September) is a peak period while winter (December to March) is the off-peak season. For the consumer, on the contrary, summer (April to June) is the peak season and demand tends to be softer during the monsoons. These differences make it challenging to schedule the dispatch of stored electricity from the battery such that it assists both stakeholders equitably.

To estimate the impact of these different demand curves, and the roles of PV and BESS, we developed four scenarios for the feasibility analysis. For the discom, these are PV only (Scenario 1/S_d1), PV-BESS (Scenario 2/S_d2), PV-BESS-Grid (Scenario 3/S_d3), and optimised PV-BESS-Grid (Scenario 4/S_d4).

- S_d1 assesses the impact of the grid-connected PV system on discom operations.
- S_d2 examines the impact of the coherence of PV and BESS on discoms, where the battery is restricted from charging using the grid supply.
- S_d3 represents the actual configuration of the pilot; the battery is allowed to charge on the grid when the PV system is unavailable.
- S_d4 is a modelled version of S_d3, where the battery dispatch across seasons is optimised to maximise the availability of the microgrid during the discom's peak hours.



Optimising battery usage according to the seasonal load experienced by the discom maximises the benefits

In these four scenarios, we calculated the impact PV and BESS have on discom revenues by considering different costs and benefits. Among the costs, we discussed revenue loss (RL) to discoms due to changes in the consumer's reliance on the grid. As for the benefits, we looked at the savings from reduced procurement of generation and transmission capacity (avoided generation capacity cost/AGCC and avoided transmission charges/ATRC, respectively), power (avoided power purchase cost/APPC), and renewable energy certificates (avoided renewable energy certificate cost/ARECC), along with deferred upgradation of the distribution network (avoided distribution capacity cost/ADCC). Lastly, we looked at the net impact of these expenses and earnings on discoms, as reflected in their working capital requirement (avoided working capital requirement/AWCC). Table ES1 summarises the results from the four scenarios in the form of generation-normalised net present value for 25 years (INR/kWh).

Parameters	PV (S_d1)	PV-BESS (S_d2)	PV-BESS-Grid (S_d3)	Opt. PV-BESS-Grid (S_d4)
AGCC	0.19	0.10	0.10	0.22
APPC	0.99	0.47	0.47	0.95
ATRC	0.08	0.05	0.05	0.10
ADCC	0	0	0	0
ARECC	0.49	0.23	0.23	0.47
AWCC	0.01	0.01	0.01	-0.01
RL	1.49	0.92	0.92	0.65
Net benefit	**0.27**	**-0.06**	**-0.06**	**1.08**

Table ES1
BYPL makes the highest profit in scenario 4 (S_d4)

Source: Authors' analysis

Among the different benefits, the savings from APPC represent 54 per cent of the cumulative benefits to the discom. This is driven by the increased export of solar electricity to the grid, which helps discom minimise their power procurement costs both from short-term purchases and scheduled procurements under long-term PPAs (power purchase agreements). Overall, in S_d1 (PV), BYPL makes a profit of INR 0.27 for each unit of solar electricity generated in its service area from the analysed 7 kW capacity. In contrast, in S_d2 (PV-BESS) and S_d3 (PV-BESS-Grid), BYPL loses INR 0.06, for each unit of solar electricity generated based on the analysed capacity. Finally, S_d4 (Opt. PV-BESS-Grid) yields the maximum profit of INR 1.08, indicating that optimising battery usage (charge–discharge intervals) according to the seasonal load experienced by the discom can enhance the benefits these systems offer discoms.

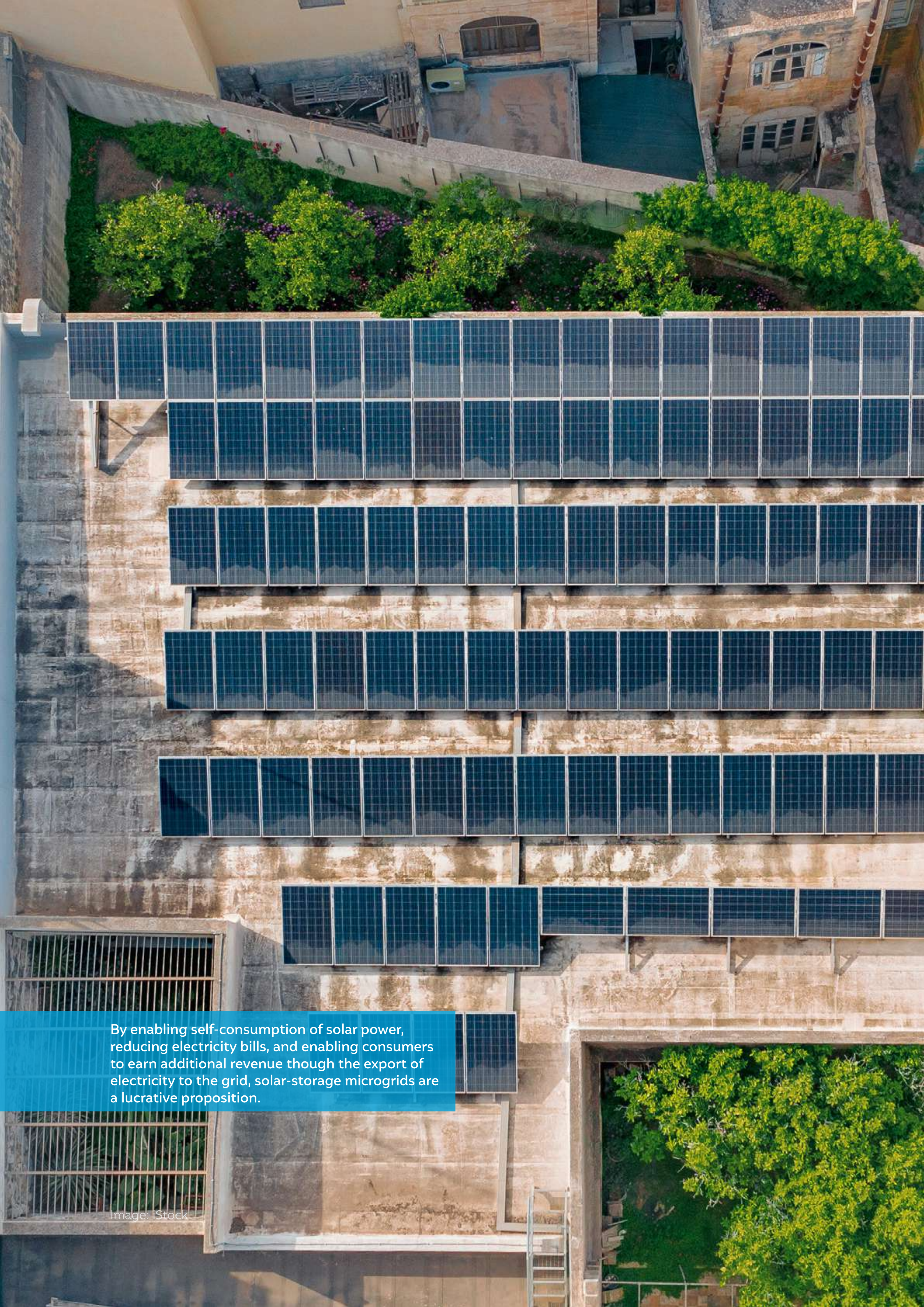
A similar procedure was adopted for the consumer. Here, the base scenario of the grid (S_c1) is compared to PV only (S_c2), PV-BESS-Grid (S_c3), and optimised PV-BESS-Grid (S_c4). The motivation was to estimate the impact of prioritising the operations of a microgrid for discoms over consumer finances. The economic viability of installing RTS and BESS for consumers was determined by the payback period and net present value (NPV). These parameters are essential to understand if the system will be economically lucrative or incur losses. Table ES2 shows various financial metrics over the lifetimes of microgrids. For the PV system alone (S_c2), the consumer can recover the installation cost within three years, and the NPV is INR 4,47,417. Here, the consumer saves an average of 69 per cent on their monthly electricity bills. In the case of PV-BESS-Grid (S_c3), the payback period increases to seven years. This is driven by reduced savings on the electricity bill (59 per cent) and the capital and replacement cost of the battery. As expected, the NPV is reduced to INR 1,30,782. The modelled optimised Opt. PV-BESS-Grid scenario (S_c4) has the longest payback period of ten years and an NPV of INR -8,859. The average electricity bill savings are reduced to 37 per cent. **These results indicate that the preferential utilisation of supply from microgrids for discoms leads to an increased financial burden for consumers.**

	PV-Grid (S_c2)	PV-BESS-Grid (S_c3)	Opt. PV-BESS-Grid (S_c4)
Payback period (years)	3.4	7.1	10
Net present value (NPV) (INR)	4,47,417	1,30,782	-8,859

Table ES2
Payback period for the consumer is shortest in scenario 2 (S_c2)

Source: Authors' analysis

This case study highlights some vital recommendations for future system design and deployment. First, we need regulatory provisions **to support dispatch by the consumers from behind-the-meter storage to the grid.** Such provisions would allow discoms to utilise the exported electricity to reduce power procurement, manage peak demand, and minimise transmission and distribution losses. At the same time, it is necessary to **optimise the permissible export of electricity to the grid.** Besides prioritising consumers for greater favourable gain, excess export to the grid might be challenging for discoms to manage. Therefore, to sustain equitable benefits for consumers and discoms alike, regulations should focus on restricting the permissible export of electricity to the grid to promote self-consumption by consumers, while ensuring access to electricity for discoms within the manageable technical limits. Next, to encourage uptake by consumers, we need **differential time-of-day tariffs for battery export for all consumer categories.** Such tariffs can be designed to incentivise consumers to export electricity to the grid during peak hours or to charge battery from the grid during off-peak hours. Lastly, to ease the financial burden imposed by high system costs on consumers, **discoms should implement new business models based on cost-sharing and leasing.** Such support policies and innovative market frameworks are a prerequisite for the proliferation of urban microgrids on a large scale.



By enabling self-consumption of solar power, reducing electricity bills, and enabling consumers to earn additional revenue though the export of electricity to the grid, solar-storage microgrids are a lucrative proposition.

Image: iStock

1. Introduction

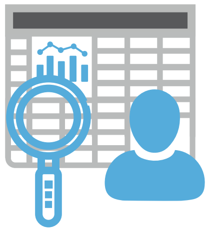
The developing Indian economy is becoming increasingly energy-intensive. Per capita electricity consumption increased from 631 kWh in FY (financial year) 2006 to 1,181 kWh in FY2019 (Central Electricity Authority 2020). Several factors, like improved energy access, rapid urbanisation, and the growing uptake of durable consumer electronics, have contributed to rising electricity use. Following the implementation of the Saubhagya Scheme in 2017, all households are now electrified (Central Electricity Authority 2020). Consumer ownership of high-end appliances, like air conditioners, is growing, and their sales have increased 15 times in 13 years (TERI, NRDC, and IGSD 2018). Electricity consumption by industries increased at an 8 per cent CAGR (compounded annual growth rate) between FY2008 and FY2017 (Central Statistics Office, Ministry of Statistics and Programme Implementation 2018). The sales share of electric vehicles is expected to reach 30 per cent by 2030 (NITI Aayog & World Energy Council 2018). All of these factors will further drive electricity consumption.

Distributed energy storage systems could potentially relieve the stress on distribution networks and support discoms

The government is striving to meet the growth in electricity demand by providing clean alternatives. The ambitious renewable energy (RE) targets of deploying 175 GW by 2022 and 450 GW by 2030 are a testimony to this commitment (PIB Delhi 2019). As of May 2020, India's cumulative RE capacity reached 87.3 GW (Ministry of New and Renewable Energy 2019) from a mere 34.9 GW in March 2014 (Central Electricity Authority 2015); this indicates that India is well on its way toward realising a clean energy transition. The concepts of hybrid power plants and microgrids with energy storage systems are gaining traction, which will ensure increased utilisation of these infrastructures, thus leading to reliable grid operations (Ministry of New and Renewable Energy 2018).

The increasing electricity demand puts enormous pressure on electricity distribution companies (discoms). Discoms have to adopt various measures to cater to consumer needs – for example, procuring additional generation capacity, augmenting transmission and distribution networks, and building new infrastructure. However, these measures are cost-intensive and put a significant financial burden on the discoms.

Rooftop solar (RTS) could potentially relieve the stress on distribution networks and support discoms. Reducing procurement of additional generation capacity, minimising short-term purchases of power, decreasing transmission and distribution losses, and deferring network augmentation are some of the direct benefits that rooftop PV (photovoltaic) systems offer to discoms (Kuldeep, Kumaresh Ramesh, et al. 2019). However, many discoms are sceptical about the rising adoption of solar PV systems. Their resentment stems from two issues: the intermittent nature of solar, which leads to fluctuation in electricity demand, and revenue loss (RL) due to consumer migration from the grid. Currently, it is difficult to forecast solar generation precisely due to its intermittency, making it tough for discoms to rely on it when planning their operations. Furthermore, decreasing the reliance of high-paying consumers on the grid reduces discom revenues. As a result of these technical and commercial concerns, discoms across the country are challenging the status quo by disrupting the adoption of renewable energy (The Times of India 2020; PV Magazine 2019).



Discoms across the country are beginning to explore the utility of energy storage in grid balancing and RE integration through pilot projects

Energy storage offers a promising solution to address these issues. It can help overcome intermittency and stabilise generation. Excess solar generation during the day can be stored and used for multiple purposes, such as meeting the night demand, optimising utilisation of electricity by time shift (energy arbitrage), and much more. Discoms across the country are beginning to explore the utility of energy storage in grid balancing and RE integration through pilot projects (Tata Power 2019; BSES Yamuna Power Limited 2019).

The high prices of technology make energy storage projects a cost-intensive investment for discoms. Hence, it is necessary to assess the economic impact of these systems on discom operations; this would also help discoms plan future deployments. Several studies have undertaken economic assessments of RTS with storage facilities (Anderson, et al. 2017; El Fathi and Outzourhit 2018; Adefarati and Bansal 2019; Deorah, et al. 2020). However, the main focus has been on estimating the levelised cost of electricity (LCOE) (Kumar, et al. 2019) or the levelised cost of energy storage (LCOES) (Comello and Reichelstein 2019). Successful scaling and promotion of these systems need a more comprehensive assessment of the revenues of both discoms and consumers, which LCOE and LCOES do not offer.

Study objectives

Acknowledging this information gap, the Council on Energy, Environment and Water (CEEW), in partnership with BSES Yamuna Power Limited (BYPL), a Delhi-based discom, has undertaken a feasibility assessment of energy storage systems using a comprehensive cost–benefit analysis framework. BYPL has recently commissioned four RTS PV systems with behind-the-meter battery storage in New Delhi (BSES Yamuna Power Limited 2019). These systems, called urban microgrids, have different solar and battery capacities and are located in the commercial offices of BYPL. The main objectives of this study are as follows:

- To assess the economic viability of urban microgrids from the discom and consumer perspectives.
- To develop insights on the effective utilisation of urban microgrids to improve their economic viability and guide future deployments.

Chapter 2 discusses the role of these systems in an evolving power sector. Chapter 3 gives an overview of these pilot systems, and Chapter 4 presents the methodology adopted to assess their economic feasibility for the discom and consumer. Chapter 5 discusses the performance of microgrids with respect to consumer demands. Chapters 6 and 7 present the results of the feasibility analysis, done from the discom and consumer perspectives, based on the BYPL case study. This is followed by conclusions and recommendations in Chapter 8.

2. The role of urban microgrids in an evolving power sector

Image: iStock

In cities, the daily peak of the electricity demand varies significantly. As a high proportion of the population is from the working classes, the daytime demand in residential areas is low while the commercial load is high. Conversely, at night, when offices and institutions close, the evening and night demand in residential areas increases because of a greater lighting load and the use of different appliances by a large part of the population. These variations are more pronounced across the year due to the seasonal use of cooling and heating appliances, which adds to the peak load.

Managing this fluctuating consumer demand in cities is a massive challenge for discoms. Generally, to maintain the local load balance, discoms augment their networks by laying new lines in the relevant areas and constructing new distribution transformers (DTs) or feeders. However, these measures are becoming increasingly challenging to implement in urban settings, where land availability is a huge constraint. Also, as the demand is intermittent, these new assets that discoms arrange for remain underutilised, resulting in a substantial economic burden and resource inefficiency. Moreover, improving solar penetration in cities adds to their woes. Besides managing the increased night load as a result of the unavailability of solar power, discoms have to accommodate surplus generation in the daytime. So, the issue of local spots of irregular loads worsens with increasing solar penetration.

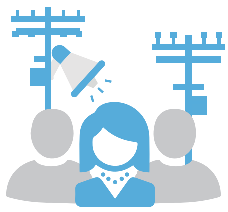
Cities have fluctuating power demands due to a diverse consumer base and a high proliferation of durable goods

Microgrids, a potential solution to urban electricity distribution issues, are smart grids with a confined generation source supporting a designated load. They can also be disconnected from the main grid and can operate autonomously for a specified time (intentional islanding). The size of a microgrid could be between 1 kW to a few MWs (megawatts). A microgrid can contain various types of generation sources, such as solar PV, wind, biomass, and hybrids like PV-diesel or PV-battery (Schnitzer, et al. 2014). Microgrids are easily integrable in urban settings with renewable generation sources like rooftop PV and battery storage systems. Such systems, called urban microgrids, offer discoms a vast potential to manage the local demand in cities. Some key benefits urban microgrids offer to discoms are as follows:

- **RE integration:** RE sources like solar PV offer cleaner power than conventional thermal power plants. However, their intermittent and variable nature restricts their uptake on a large scale. Dispatching RE with energy storage would help discoms overcome intermittency and will enable reliable support for grid operations. With solar PV-battery microgrids, discoms can efficiently integrate more RE in their service areas to meet their renewable purchase obligation (RPO) targets and reduce their dependence on conventional plants.

- **Deferred network upgradation:** Land availability is a massive constraint in cities; this deters discoms from upgrading the existing networks to cater to the rising consumer demand in particular areas. Empowering consumers in such regions with microgrids would serve two purposes. First, the grid dependence of these consumers would decrease with increased utilisation of solar electricity, which would reduce the overall load on the network. Second, discoms can utilise the stored electricity (surplus solar generation or off-peak grid electricity) during peak hours (energy arbitrage). As a result, discoms can accommodate peak demand without straining the network and constructing new components, thereby minimising their expenses and improving resource utilisation.

- **Efficient demand-side management:** The energy arbitrage offered by storage systems in microgrids can help with peak reduction and load levelling. Discoms invest significant efforts in maintaining a uniform load curve to ensure reliable power supply. However, various factors like consumer base and population density can make local demands vary considerably from the overall load curve of discoms. In such cases, battery integrated microgrids can support discoms with load levelling by allowing the flexible export of stored electricity to the grid to meet local or overall peak demands. Such flexible responses would reduce local peaks and level out discom demand.

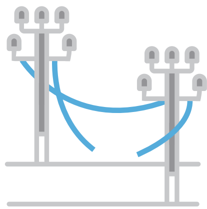


Dispatching RE with energy storage would help discoms overcome intermittency and will enable reliable support for grid operations

- **Savings from the deviation settlement mechanism (DSM):** A day-ahead demand forecast by discoms is crucial for the smooth functioning of the electricity grid. The actual demand, however, could be influenced by many factors which are hard to anticipate in advance. To streamline the process, the Central Electricity Regulatory Commission (CERC) has further amended DSM regulations (Central Electricity Regulatory Commission 2019). As such, discoms have to pay hefty penalties for any change in their scheduled dispatch of electricity. In the event of unexpected demands, microgrids can supply the necessary support and help discoms avoid load shedding and penalties.

- **Power backup during outages:** The electricity network is interconnected. Therefore, any local disruption or imbalance can spread to the broader area, thus affecting services. As microgrids can operate autonomously from the grid (islanding), they can ensure safe and a continuous supply of electricity to connected consumers in the case of an outage in the main network.

- **Miscellaneous benefits:** Urban microgrids can have other profound impacts on discom operations as well. First, transmission and distribution losses would come down. Second, the availability of a firm RE capacity would reduce their generation capacity procurements under power purchase agreements (PPAs) and, in turn, the fixed charges. Lastly, discoms could also cut the power procured from the contracted capacity to reduce variable costs.



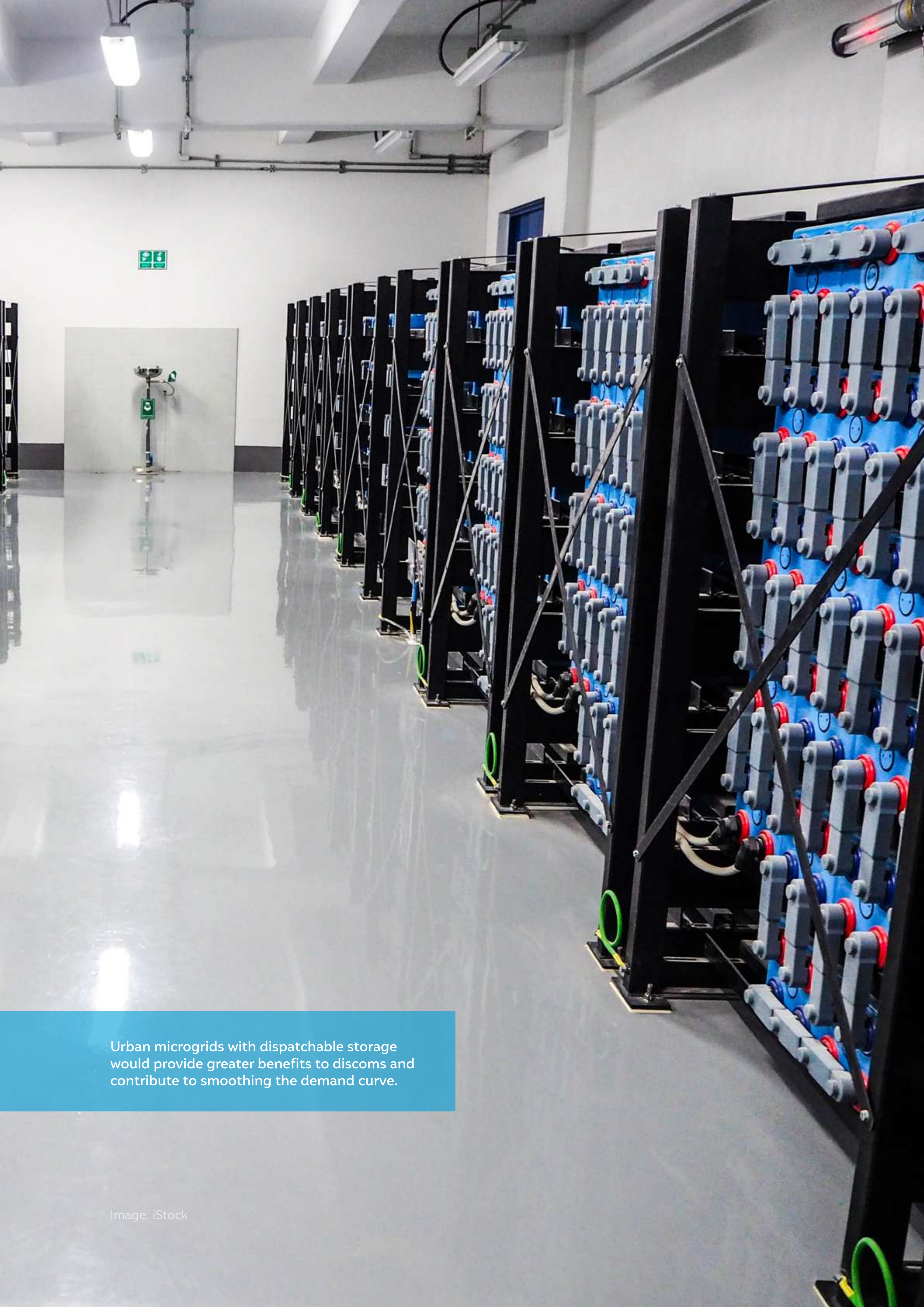
In the event of unexpected demands, microgrids can supply the necessary support and help discoms avoid load shedding and penalties

Urban microgrids offer an attractive value proposition to consumers, who can gain substantially from these systems. Some of the vital benefits microgrids offer to consumers are as follows:

- **Financial savings:** Microgrids help consumers reduce their dependence on the grid and cut their electricity bills. These savings are more pronounced for industrial and commercial consumers, who can optimise their grid usage to shave the peaks and minimise time-of-day charges (energy arbitrage).
- **Improved RE utilisation:** Storage systems in microgrids enhance the availability of renewable electricity, thus enabling efficient use by consumers. In the absence of storage, consumers have no other option but to export the excess generation to the grid. This is particularly useful in periods of low consumption, as consumers can store surplus generation reliably for self-use later.

- **Improved self-sufficiency:** As microgrids enable the efficient use of RE sources throughout the day, consumers can satisfy most of their demand through these systems. Such dynamic systems protect them from imbalances or outages in the grid. Hence, consumers continue to access an uninterrupted, safe electricity supply irrespective of local circumstances.

With these potential benefits to the discom and consumer, solar storage microgrids are a plausible way forward to curb some of the most prominent urban electricity woes.

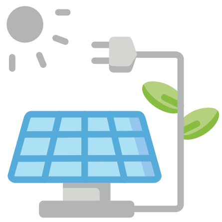


Urban microgrids with dispatchable storage would provide greater benefits to discoms and contribute to smoothing the demand curve.

Image: iStock

3. Urban microgrid pilot setup

BYPL is one of three electricity distribution companies in the NCT (National Capital Territory) of Delhi. It serves the central and eastern districts of the city and has some of the highest consumer densities among Indian discoms. The per capita consumption of electricity is about 3,871 kWh/consumer, and the consumer base is projected to have about a 5 per cent CAGR over between FY2020 and FY2025 (BSES Yamuna Power Limited 2019). Of late, Delhi's seasonal and overall demand for electricity has grown significantly. In FY2019, the peak demand in summer rose to 7,016 MW, a 20 per cent increase from FY2016 (State Load Despatch Center, Delhi 2019). In winter, it grew by 8 per cent between FY2016 and FY2019, from 4,125 MW to 4,472 MW. Additionally, BYPL recorded a maximum demand of 1,091 MW in the winter of FY2019. In the coming years, they expect the winter demand to reach 1,165 MW (BSES Yamuna Power Limited 2019).



The Green Division of BYPL is considering the benefits of demand-side management through storage-combined solar microgrids

The Green Division of BYPL is considering the benefits of demand-side management through storage combined solar microgrids (urban microgrids). BYPL, in association with Panasonic, has installed microgrid units with PV-battery energy storage systems (BESS) at four locations in Delhi. All installations are at BYPL offices, which is why BYPL is treated as a commercial consumer in this study. Table 1 mentions the specifications of these systems. The system sizing was pre-decided by BYPL and Panasonic; CEEW did not contribute to that phase of the project.

A. BYPL business office – Mayur Vihar (BO)
B. BYPL O&M (operations and maintenance) office – Mayur Vihar Phase 2 (PKT-C)
C. BYPL Trilokpuri dispensary (DSP)
D. BYPL O&M office – Sadar (SA)

System	PV capacity (kWp)	Battery capacity (kWh)	Connected load (kW)
BO	7	10.4	1.5
PKT-C	3	5.2	1.46
DSP	3	5.2	1.5
SA	3	5.2	1.32

Table 1
Four microgrids are piloted by BYPL in their service area

Source: BYPL

Figure 1 shows the schematic configuration of these urban microgrids. The rooftop PV produces a direct current (DC) output which, after conversion to alternating current (AC) by an inverter, passes over to the network to meet the load and is stored in the Li-ion NMC battery. The charge–discharge pattern is pre-defined algorithmically using fixed setpoints. The PV system is designated as the primary source of power for batteries, and based on the utilisation of batteries, grid power also supports battery charging. To maintain safety levels, a 15 per cent state of charge (SOC) serves as the lower end, beyond which batteries will enter the charging mode. Even though the buildings have higher sanctioned loads, the microgrid system is connected to only a fraction of the total sanctioned load, ranging between 1.3 to 1.5 kW, as shown in Table 1. This setup allows different types of electricity transactions, as mentioned in Table 2 and indicated in Figure 2. Our report focuses on examining the feasibility of the value of grid-connected rooftop solar (VGRS) framework for estimating the economic impact of urban microgrids on discoms. Therefore, only one of these pilots, installed at the BO, was studied.

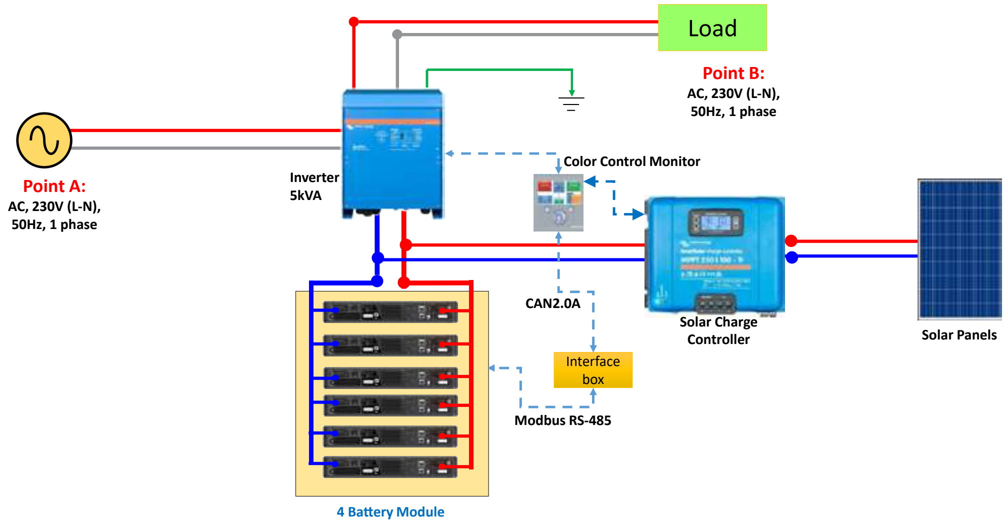


Figure 1
Schematic representation of a PV-BESS microgrid

Source: BYPL

Transaction	Notation
PV to battery	PV2B
PV to consumer	PV2C
PV to grid	PV2G
Battery to consumer	B2C
Battery to grid	B2G
Grid to consumer	G2C
Grid to battery	G2B

Table 2
Components of electricity exchange among PV, BESS, grid, and consumer in the configured microgrids

Source: Authors' compilation

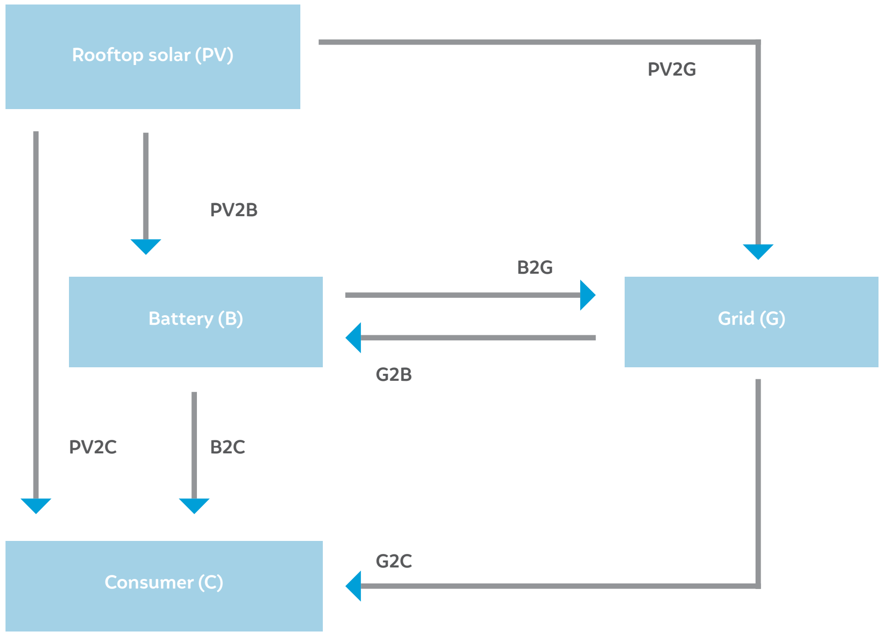
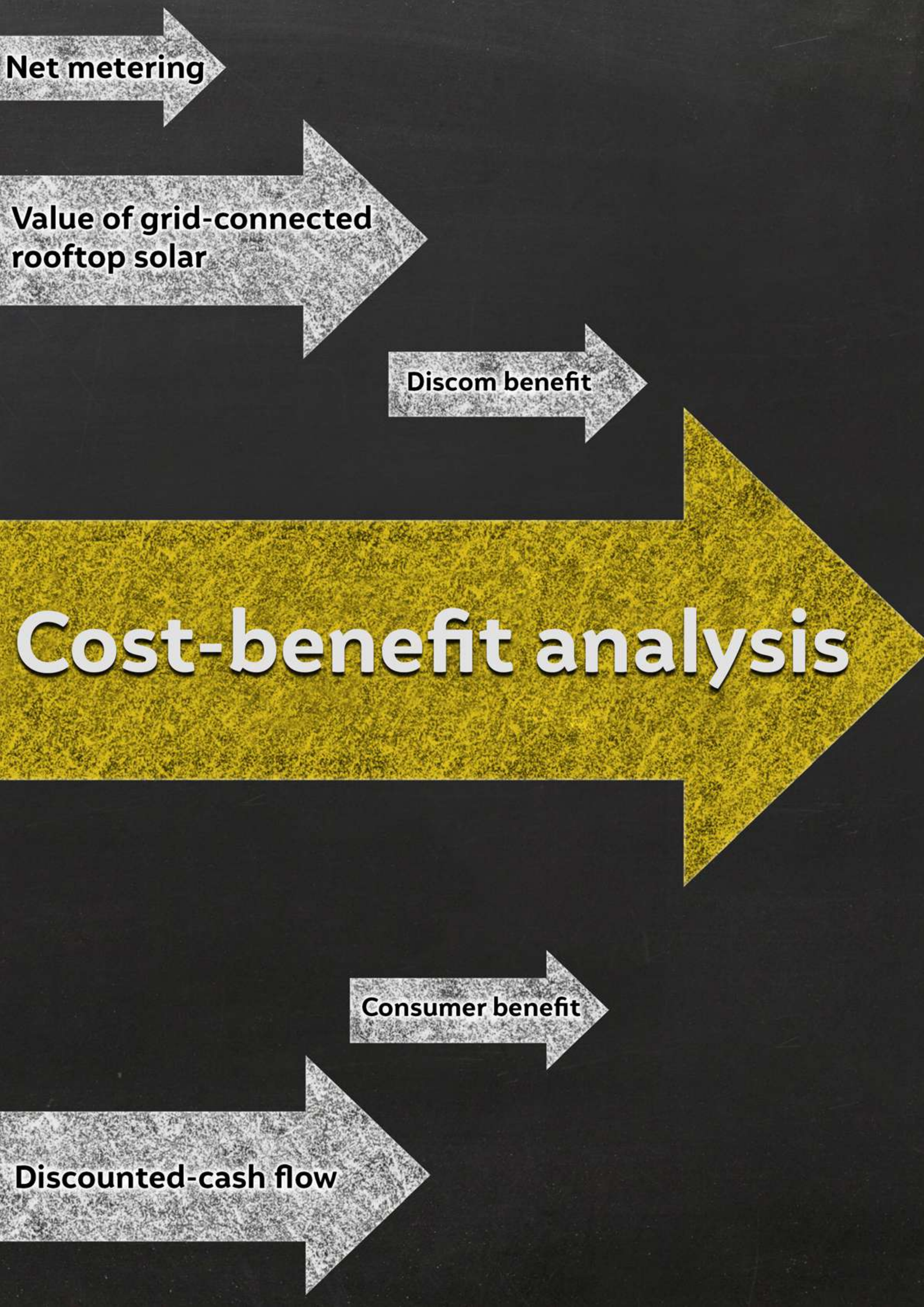


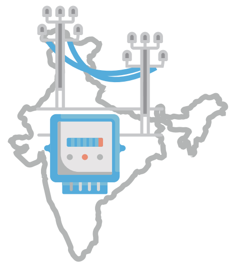
Figure 2
Schematic connection diagram showing various electricity transactions possible in a microgrid

Source: Authors' representation


Net metering
Value of grid-connected rooftop solar
Discom benefit
Cost-benefit analysis
Consumer benefit
Discounted-cash flow

4. Methodology

We examined the feasibility of urban microgrids for both discoms and consumers. The discom perspective was assessed using the VGRS methodology (Kuldeep, Kumaresh Ramesh, et al. 2019). For the consumer, we used a discounted cash-flow method. The following sections describe these two approaches in detail.



The VGRS framework accounts for various direct and indirect costs and benefits to assess the net impact of the microgrid on discom revenues

VGRS framework for the discom perspective analysis

VGRS is a cost–benefit analysis framework that assesses the economic impact of a distributed renewable energy (DRE) source on a specified stakeholder, like a discom. Although urban microgrids can benefit discoms in multiple ways, they are also expensive to implement and operate. Hence, the economic feasibility of these systems depends on a combination of costs and benefits. The VGRS framework considers both factors to estimate the net economic impact.

The period and location of analysis are vital considerations in this method. As the costs and benefits to the discom remain relevant only as long as the DRE source lasts, the analysis period is usually the system's lifetime. In this study, we applied the VGRS framework to an urban microgrid with a rooftop PV-BESS configuration; as such, the analysis time frame is 25 years (PV systems' lifetime). Also, the flexibility of an urban microgrid to utilise generated and stored electricity qualifies it to impact discom operations – across the entire power sector chain - generation, transmission, and distribution. Hence, the location of the analysis is vital to estimate a cost or benefit. Table 3 lists the various costs and benefits of urban microgrids identified in this study. Annexure 1 explains these parameters in detail. Some of these benefits are subject to regulatory provisions and discom operation strategies. Hence, such benefits are not realised during the entire analysis period. For instance, following the recent order of CERC to reduce the REC (renewable energy certificate) floor price to zero, the savings from avoided renewable energy certificate cost (ARECC) might not be significant (Central Electricity Regulatory Commission 2020). Furthermore, savings from avoided generation capacity (AGCC) and transmission capacity (ATRC) would be realised only if the capacity renegotiation, under a PPA or otherwise, falls during the system lifetime.

Benefit parameters	Generation (bulk) system	Avoided generation capacity cost (AGCC)
		Avoided power purchase cost (APPC)
	Transmission system	Avoided transmission charge (ATRC)
	Distribution system	Avoided distribution capacity cost (ADCC)
	Externalities	Avoided renewable energy certificate cost (ARECC)
		Avoided working capital requirement (AWCC)
Cost parameters	Programme administration costs (PAC)	
	Added distribution services costs (ADSC)	
	Revenue loss (RL)	

Table 3
Urban microgrids entail different types of benefits and costs to the discom

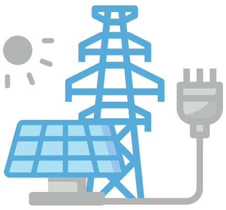
Source: Kuldeep, Ramesh, Tyagi, and Saji (2019)

Computing a particular cost or benefit needs the input of annual and hourly data from discoms and consumers. Annexure 2 contain details about some of these yearly data points, listed as follows:

- Cost of generation capacity procured under PPAs (fixed INR/MW and variable INR/kWh)
- Transmission charges (INR/MW)
- Cost of renewable energy certificates (RECs) (INR/kWh)
- Additional discom expenses to implement and manage the DRE programme (INR)
- Construction, operation, and maintenance cost of a new DT (INR)
- Consumers' electricity consumption data (kWh)

The magnitude of a benefit depends on the real-time availability of the DRE source during the system's peak hours. Coincidence factors (CFs) capture this information and indicate the contribution of the DRE source to peak reduction at the specified level relative to its rated capacity. In this study, we computed these factors at the generation, transmission, and DT levels, to understand the DRE contribution corresponding to the overall load, transmission load, and DT-specific load. We took the top 20 per cent of the discom's peak hours to calculate the CF. Therefore, the analysis considers both day and night peaks. Estimating the CFs requires a 30-minute profile (daily for a year) for the following data points:

- Overall and DT load profiles of the discom (MW)
- Quanta (kWh) and rate (INR/kWh) of the short-term power purchases from different sources
- Generation data from the solar PV system (kWh) and its export to the grid and consumers (kWh)
- Battery's charge–discharge profile (kWh) representing its interaction (export and import) with consumers, grid, and PV system



Coincidence factors reflect the availability of distributed powered generated during the discom's peak hours

These two sets of data points give the overall system profile, representing both discoms and DRE sources. The VGRS tool, developed on MATLAB, uses these system profiles to calculate the cost and benefit parameters individually and on an annual basis. It also gives the NPV of the cumulative costs and benefits at the end of 25 years. For the sake of better understanding, we report the numbers as either generation normalised (INR/kWh) or capacity normalised (INR/kW). It is essential to note that we have kept the consumer tariffs and power purchase cost constant for the entire analysis period. As such, the results reported are annualised numbers for the current year (FY19).

To estimate the feasibility of urban microgrids, we developed four scenarios in Microsoft Excel for the cost–benefit analysis; details on the scenarios are provided in Annexure 3.

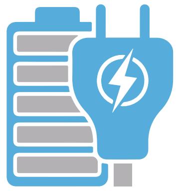
Each of these represents the interaction between the grid and the specified component of the microgrid. The VGRS approach enables us to understand the contribution of the microgrid components, individually and together, to grid operations and to optimise it to maximise the benefits. The four scenarios are as follows:

Scenario 1 (S_d1), PV: This contains the rooftop PV system and excludes BESS. It estimates the impact of the grid-connected PV system on the discom.

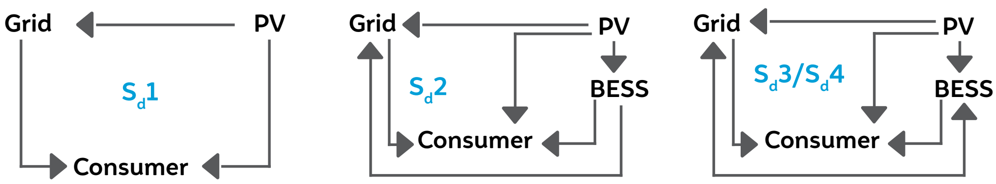
Scenario 2 (S_d2), PV-BESS: This contains PV and BESS connected to the grid, with the restriction that the battery cannot charge on the grid. The battery can only export stored electricity to the grid. Hence, this scenario tests the resiliency of the PV system in maintaining battery operations. It also assesses the contribution of the BESS to the performance of the PV system and the resulting impact on discom operations.

Scenario 3 (S_d3), PV-BESS-Grid: It contains a PV system, BESS, and the grid, which work in synergy to meet consumer and discom demand. The difference between S_d2 and S_d3 is that there is no restriction on battery and grid interaction; the battery can charge on both the PV system and grid. This scenario represents the actual configuration of the installed microgrids.

Scenario 4 (S_d4), Opt. PV-BESS-Grid: This is an optimised version of S_d3 in which we have modelled the battery charge–discharge cycles as per the discom load profile to achieve greater support from the microgrid. The other interactions from S_d3 remain unchanged.



In S_d4, the battery charge–discharge cycles are optimised as per the discom load profile to achieve greater support from the microgrid



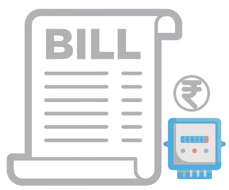
The discounted cash-flow method for the consumer perspective analysis

The discounted cash-flow method is a valuation method used to assess the economic feasibility of an investment based on the expected future cash flows. In this study, the CAPEX model is assumed where the consumer pays the entire system cost upfront. Future cash flows are represented as savings on the electricity bill because of reduced grid consumption and earnings from the export of surplus generation to the grid. The DCF method accounts for this total financial gain to give the NPV of the microgrid installed on the consumer's premises.

Calculation of the consumer's total financial gain

The cumulative monetary benefit to the consumer is a summation of savings from the electricity bill reduction and earnings from electricity export as per the net metering regulation (Delhi Electricity Regulatory Commission 2014).

To compute the savings on the electricity bill, we considered the difference in consumer bills before and after installing the microgrid. The monthly electricity bill of a consumer consists of fixed and variable energy charges, depending on its sanctioned load and consumed units, respectively. Further, as BYPL is a commercial consumer, the time-of-day tariff is applied to compute the total energy charges for consumption within peak and off-peak hours as



The consumer benefits from reduced electricity bills and earnings from the electricity export to the grid specified by the regulatory commission (BSES Yamuna Power Limited 2019). Specifically, it levies a 20 per cent surcharge and 20 per cent rebate for peak and off-peak hour consumption, respectively, in addition to the flat energy charge. To compute the monthly bill, grid units used by the consumer in a particular timeslot are offset against the exported electricity (direct export of solar generation or export of stored units from the battery) in the same slot. In other words, peak grid consumption is offset against export during peak hours, and so on. Remaining grid units, if any, are billed to the consumer and the surplus generation is carried forward to the next month. Similar iterations for each month of the year give the annual electricity bill of the consumer. The surplus generation at the end of the financial year is compensated at the tariff approved by the Delhi Electricity Regulatory Commission (DERC). Annexure 4 contains the remaining details of the analysis. As consumer benefits are computed over the entire lifetime of the system, we assume an annual escalation of about 2 per cent of the consumer's energy charges (Bharadwaj, Ganesan and Kuldeep 2017).

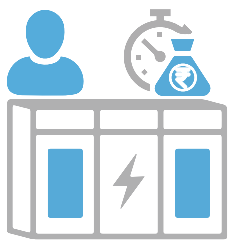
As the microgrid contains two components (PV and BESS), each of which imposes a considerable financial burden on consumers, it is necessary to assess their impact on consumers for a better understanding of the system's feasibility. To achieve this, we developed four scenarios.

S_c1, Grid: This is the base scenario to understand the consumer's electricity requirement. As all the electricity comes from the grid, the consumer makes no financial gain. This scenario is a reference from which to assess the benefits of the remaining three scenarios.

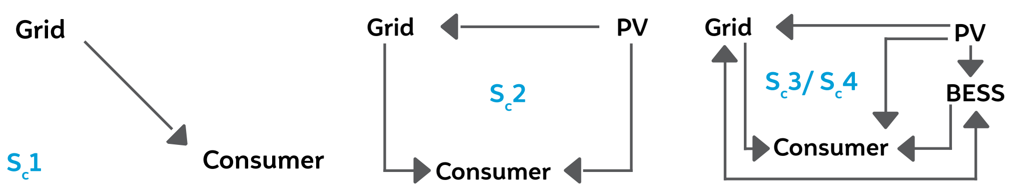
S_c2, PV-Grid: This case highlights the impact of grid-connected solar PV systems on consumers' electricity usage. With an alternative for procuring power, this case assesses the change in the consumer's grid dependence to gain financially and recover the upfront investment they made to install the PV system.

S_c3, PV-BESS-Grid: This case examines the role of the battery in the PV system's performance and consumer's grid dependence. As the battery provides flexibility to consumers to optimise their grid and PV usage, this scenario assesses financial gain and changes to capital costs in the payback period as compared to the base case (S_c1).

S_c4, Opt. PV-BESS-Grid: This is an optimised version of S_c3. Here the charge–discharge pattern of the battery is scheduled to support the discom load. The scenario assesses the impact of such a prioritised use of the battery on consumer savings and changes in the payback period compared to the S_c2 and S_c3.



The fourth scenario assesses the financial impact on consumers due to the preferential scheduling of battery to support the discom load



5. Contribution of the microgrid to consumer demand management

Image: iStock

This chapter discusses the overall contribution of urban microgrids to managing consumer demand in the current configuration (PV-BESS-Grid). For this purpose, we evaluated the performance of the PV and battery, and mapped it onto the consumer load. This mapping revealed the self-sufficiency of microgrids in meeting consumer demand. A detailed understanding of this self-sufficiency would allow for optimal utilisation of microgrids and the ability to reap the maximum benefits.

BYPL load profile

Discom demands vary significantly throughout the year and with changes in ambient temperature. Our study divides the year into four seasons: summer (April to June), monsoon (July to September), post-monsoon (October to November), and winter (December to March). In 2018–2019, the peak electricity demand in the BYPL license area was 1,185 MW, which occurred during the monsoon. The average demand throughout the year was 827 MW, and the minimum demand (baseload) was 289 MW. The magnitude and time of the peak demand varied dramatically across the four seasons. In summer, BYPL recorded afternoon and night peaks (1,166 MW); this continued in the monsoon as well (1,185 MW). However, in the post-monsoon season, the peak demand dropped significantly to 800 MW in the morning hours. A similar pattern continued during winter.

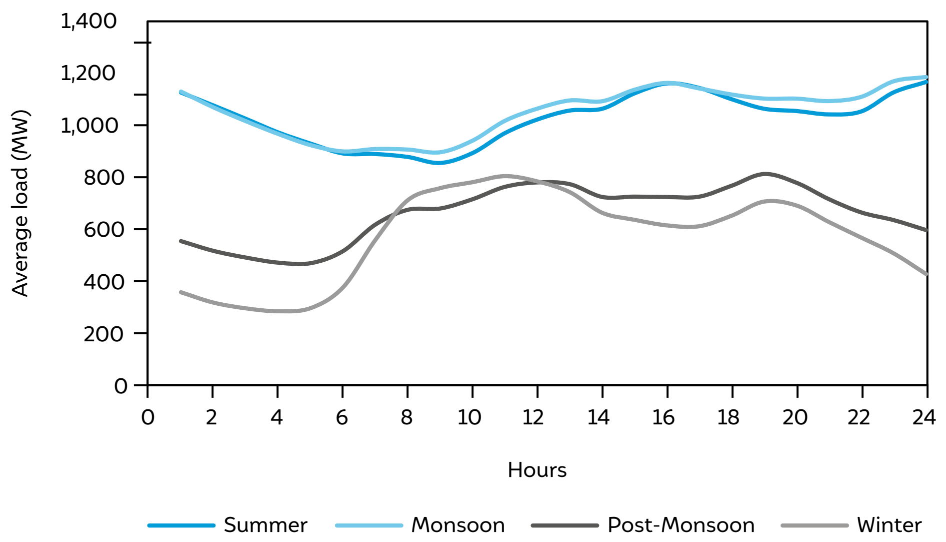


Figure 3
BYPL peak demands and baseloads varied drastically across seasons

Source: Authors' analysis

Consumer demand patterns

Figure 4 shows the average seasonal variations in the load supported by the microgrid installed at the BO of the BYPL (consumer under consideration for this analysis). The maximum demand of 1.2 kW occurred in summer, while the minimum demand of 0.1 kW was during the monsoon. The average annual baseload was 0.6 kW. As the individual consumer's electricity consumption is specific to their needs, it does not reflect the overall demand pattern that the discom records. Hence, the load curves of the consumer are strikingly different from those of the discom. For instance, discoms experienced peak demand in monsoon, which was an off-peak season for consumers. Similarly, winter was a lean period for discoms while for consumers it was a peak season.

The hourly consumer demand fluctuated significantly in peak seasons (summer and winter) but was comparatively uniform in the lean season (monsoon). Peak and off-peak hours differed for discoms and consumers. For instance, in winter, peak hours for discoms were between 8 am to noon. Consumers' demand peaks were early in the morning between 4 am to 7 am. Similar differences were observed in the post-monsoon season – discom loads peaked in the afternoon and continued till the evening. Consumer demand, on the contrary, was low during the day and high in the evening.

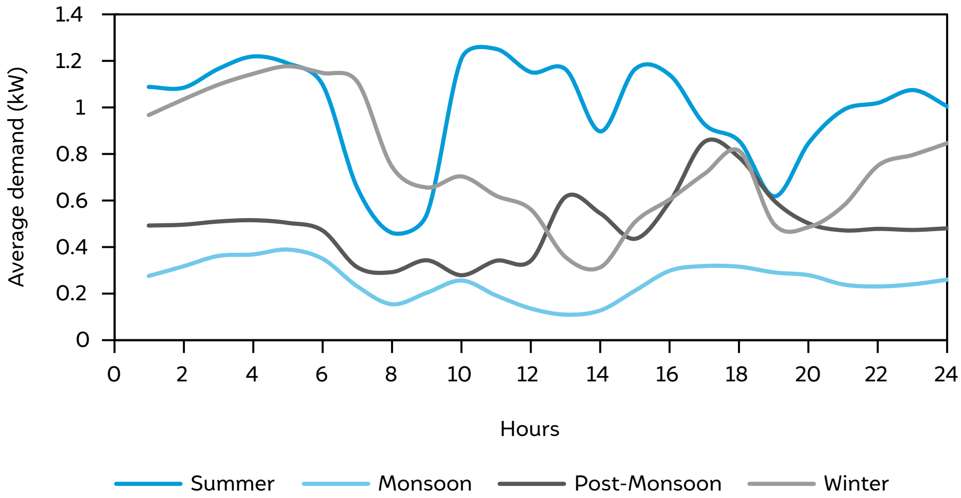


Figure 4
Hourly electricity demand of the consumer (BYPL BO) across seasons

Source: Authors' analysis

Performance of microgrids

Solar PVW

The microgrid contained a 7 kWp RTS system coupled with a 10.4 kWh battery. Figure 5 shows the seasonal variations in solar generation in the installed PV system during the day. Similar to solar irradiance, solar generation was highest in summer and least in winter.

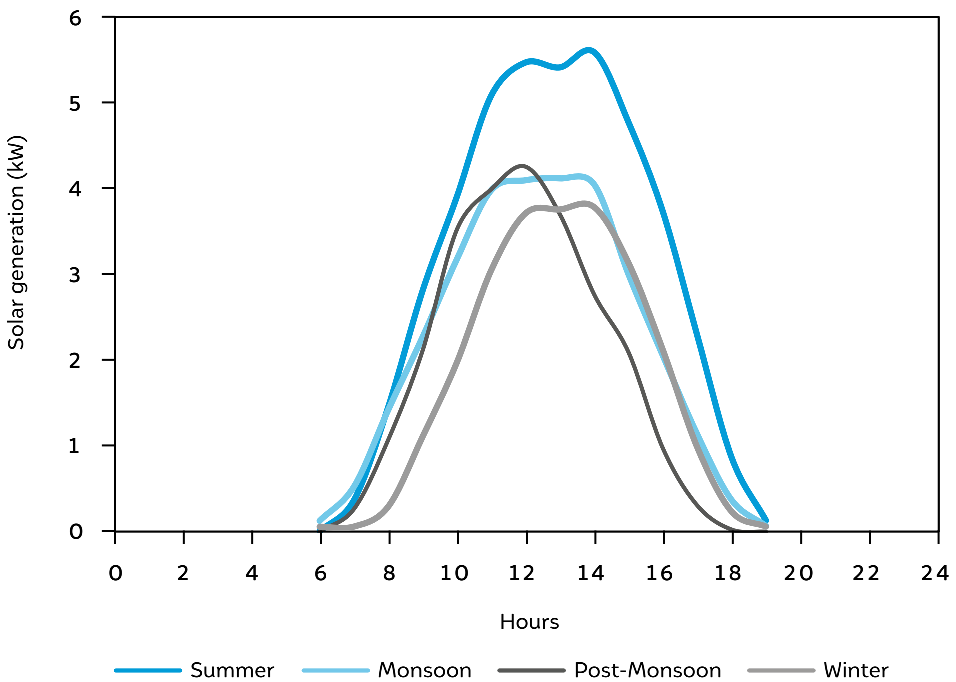


Figure 5
Solar generation by the rooftop PV system was highest in summer

Source: Authors' analysis

The annual average capacity utilisation factor (CUF) of the system was 18 per cent. The highest CUF was observed during the summer (April to June) and the lowest during the winter (December to March). The average CUF in summer was 25 per cent. Then it fell drastically to 18 per cent in monsoon, 15 per cent in post-monsoon, and 14 per cent in winter. These variations are shown in Figure 6.

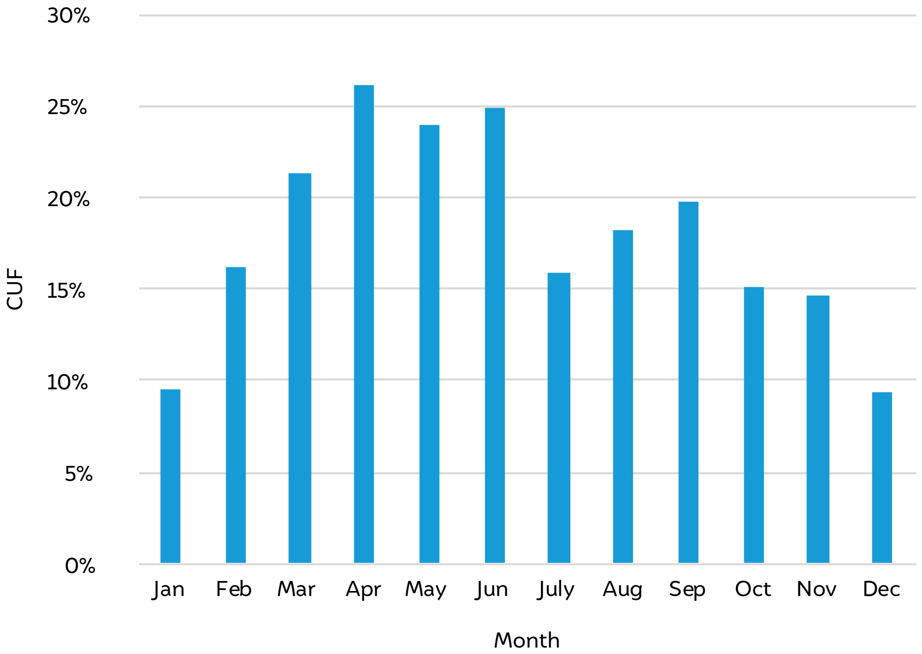


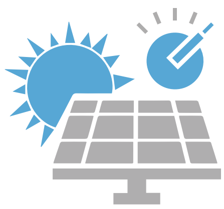
Figure 6
The capacity utilisation factor (CUF) of the rooftop PV system was highest in summer

Source: Authors' analysis

Battery

Round trip efficiency (RTE) is an important parameter to evaluate battery performance. It is the ratio of the total storage output to the total storage input. The RTE of the battery in the installed microgrid did not vary greatly across seasons – it remained at more than 90 per cent throughout the year. It had a -0.356 kW and -0.343 kW SOC at the start and end of the analysis period, respectively. The lowest efficiency of 92 per cent was observed in the post-monsoon season, while the highest, 97 per cent, was recorded during monsoon and winter.

The **degree of self-sufficiency** indicator highlights the fraction of the consumer demand which the microgrid fulfils. Solar generation is prioritised for battery charging. If the battery is fully charged, it is directed to the consumer. If any generation remains beyond that, it is exported to the grid. The objective of the microgrid is to maximise the self-consumption of solar, by charging the battery or through direct uptake by the consumer. Self-consumption of solar is calculated as the ratio of the total solar generation to its overall use (direct and indirect).[1]



A microgrid is designed to maximise the self-consumption of solar electricity

Figure 7 shows the seasonal variations in the utilisation of solar energy by the different components (grid, battery, and consumer). Throughout the year, more than 80 per cent of solar generation was self-consumed – the majority went to the battery (PV2B) followed by the grid. This was because of the consumer's low daytime demand for most of the year (see Figure 4). So except in summer, consumer demand was low during the day, when solar energy is available. Hence solar generation was not used directly and instead exported to the grid (PV2G) or stored in the battery.

1. Self-consumption of solar is calculated as (PV2C+PV2B)/total generation.

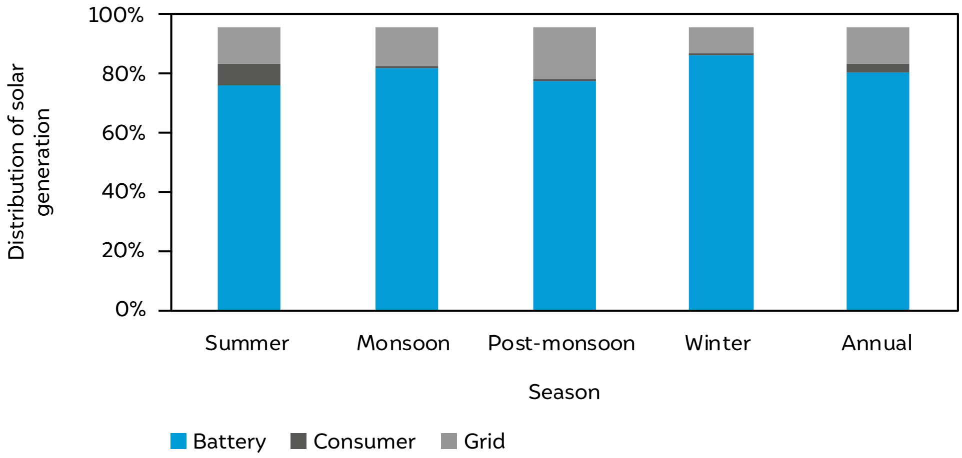


Figure 7
More than 80 per cent of solar generation is self-consumed via battery

Source: Authors' analysis

To calculate the degree of self-sufficiency, the direct consumption of solar (PV2C) is combined with battery charging (PV2B). This gives the cumulative assistance of the microgrid to satisfy consumer demand. Therefore, the degree of self-sufficiency is the ratio of the consumer demand met by solar (direct uptake) and battery to total consumption.[2] As Figure 8 shows, microgrids can fulfil more than half of the consumer demand for most of the year.

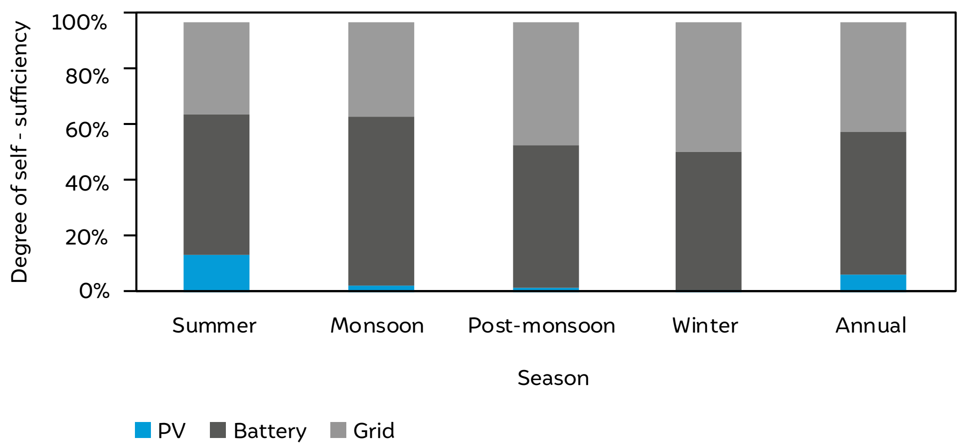


Figure 8
Self-sufficiency of the microgrid remains at more than 50 per cent throughout the year

Source: Authors' analysis

Throughout the year, the direct contribution of PV to meet consumer demand is less under the current configuration of the microgrid. The highest self-sufficiency was attained in summer (66 per cent) while the lowest was in winter (52 per cent). The microgrid supported 59 per cent of the consumer demand (53 per cent from the battery and 6 per cent from direct PV consumption) and the grid took care of the remaining 41 per cent. These results indicate that the microgrid has a considerable degree of self-sufficiency.

2. Self-sufficiency is calculated as (PV2C+B2C)/total consumption.

Battery as load is another factor that evaluates the self-sufficiency of microgrids. It is the ratio of the energy that the battery requires from the grid (G2B) to the total demand on the grid (G2C+G2B). This ratio signifies the battery's dependence on the grid to charge itself; a lower value indicates that the microgrid is a self-sustaining. In the current configuration of the microgrid, the battery charges first from PV solar generation. If solar energy is unavailable, then the battery charges on the grid.

Figure 9 shows the distribution of the grid load between the battery and the consumer. Close to 99 per cent of the load was imposed by the consumer and the remaining 1 per cent by the battery when it charged on the grid during the non-summer seasons, or when there was less solar generation (see Figure 10). In summer, PV solar generation was sufficient to charge the battery and meet the consumer demand. These results indicate that the battery does not add a significant load to the grid.

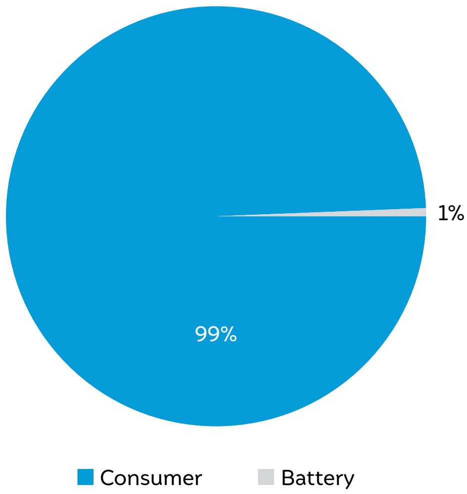


Figure 9
Battery does not impose additional load on the grid

Source: Authors' analysis

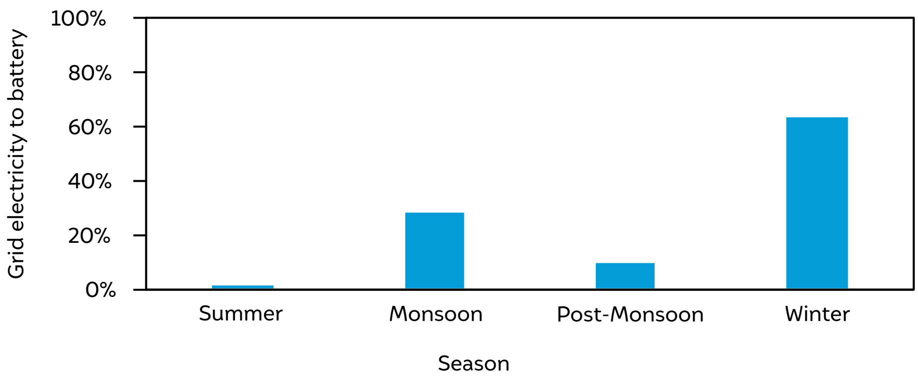


Figure 10
Battery relies on the grid for charging during the winter season

Source: Authors' analysis

Key Observations

- The demand of discoms varied significantly throughout the year. The peak demand was 1,166 MW in summer; this increased to 1,185 MW in the monsoon. Peak demand dropped to 808 MW in the post-monsoon season and was lowest in winter, at 800 MW.

- The baseload for discoms, indicated by the minimum demand, also varied significantly throughout the year. In summer it was 851 MW and it increased to 893 MW in monsoon. Baseload decreased to 470 MW in the post-monsoon season and was lowest in winter, at 289 MW.

- The peak and lean seasons differ significantly for discoms and consumers. For discoms, monsoon was a peak season, while winter was an off-peak season. For consumers, however, summer and winter was a peak season, while monsoon was a lean season.

- The rooftop PV system had an annual CUF of 18 per cent. However, it varied between 25 per cent in summer and 12 per cent in winter.

- More than 80 per cent of solar generation was self-consumed by the consumer (directly and via the battery).

- In the current configuration, the battery did not act as a load on the grid; it drew a mere 1 per cent of electricity annually.

- The microgrid supported about 59 per cent of the consumer's annual demand. It was driven by an oversized PV capacity, which was almost five times that of the load connected to it.


Discoms can potentially benefit by promoting distributed energy sources in their service area.

Image: iStock

6. Impact of solar microgrids on discom revenue: a case study of BYPL

Increasing the adoption of urban microgrids can help discoms manage the electricity demand. However, as microgrids are cost-intensive, it is imperative to do a comprehensive feasibility study that captures all possible benefits and costs to make strategic deployments. This chapter discusses the results of the feasibility analysis for discoms using the VGRS framework. First, we explain the four scenarios we developed for the analysis. This is followed by a comparison of different parameters, like self-consumption of solar, export of electricity to the grid, etc., to understand the dynamics between the PV system, battery, and grid in each scenario. Lastly, the results of the cost-benefit analysis are presented, followed by a discussion.

For this report, we chose to analyse the microgrid installation at the BYPL BO. It has a 7 kWp RTS system combined with a 5 kW/ 10.4 kWh battery. The microgrid supports only a fraction (1.5 kW) of the consumer's total sanctioned load. The system is connected to a 630 kVA DT. Table 4 summarises this information.

PV capacity (kWp)	Battery capacity (kWh)	Connected load (kW)	DT capacity (kVA)
7	10.4	1.5	630

Table 4
Technical details of the microgrid installed at the BYPL BO

Source: BYPL

To estimate the impact of PV-BESS systems on discoms, we developed four scenarios for the cost–benefit analysis. The scenarios were designed to understand the additional value that the battery system offers the discom.

S_d1, PV: This is the PV-only case. The consumer satisfies their demand from the available solar generation and obtains the rest from the grid. Surplus solar generation is exported to the grid.

S_d2, PV-BESS: It contains a PV system with a battery, which operates independently of the grid. More specifically, all the PV solar generation goes to the battery and then to the consumer; the remaining (if any) is exported to the grid. Any instance of battery charging on the grid was not considered in the analysis; we assumed that the battery charges solely on the PV system. In this scenario, the consumer meets their demand from the PV system (PV2C), battery (B2C), and the grid (G2C).

S_d3, PV-BESS-Grid: This scenario includes the PV system, battery, and grid working together to meet consumer demand. The distinction from S_d2 is that the three components interact without any restriction. So the battery can charge on either the PV system or the grid, depending on its requirements and the availability of electricity.

S_d4, Opt. PV-BESS-Grid: This is a modelled scenario, developed to maximise the contribution of PV solar generation to discom peaks.[3] The modelling was done in Microsoft Excel. The battery charges on the PV system or the grid during off-peak hours and discharge happens during peak hours. The remaining solar generation is directed to consumers or the grid, depending on consumer demand at that instant. Here, only one charge–discharge cycle is allowed of the battery per day. Further, the battery cycle is optimised, depending on the peak and off-peak hours in different seasons, to maximise the availability of the microgrid at the discom's peak hours. Annexure 3 contains more details on this scenario.

Results

Three parameters – self-consumption of solar energy, export of solar electricity to the grid, and coincidence factors – explain these four scenarios. The first reflects the impact of the microgrid on consumers, while the latter two indicate the effects on discoms.

Self-consumption of solar energy

Self-consumption of solar energy is the ratio of the solar generation that consumers use to the total solar generation. High self-consumption of solar indicates that consumers are able to utilise solar electricity to meet their needs, while low self-consumption signifies that the majority of the solar electricity is exported to the grid. Figure 11 shows the seasonal variations in the self-consumption of solar in the four scenarios. S_d1 (PV) and S_d4 (Opt. PV-BESS-Grid) have low self-consumption rates throughout the year, unlike S_d2 (PV-BESS) and S_d3 (PV-BESS-Grid), in which self-consumption (directly by consumer or via the battery) is almost 80 per cent.

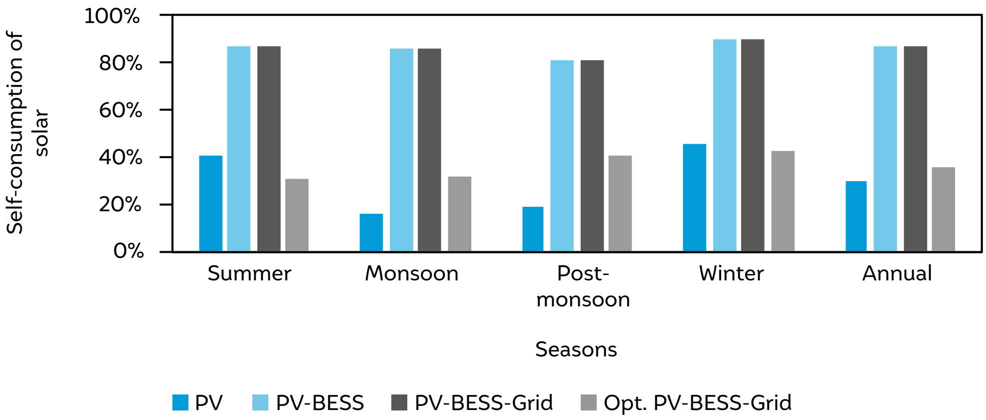


Figure 11
Self-consumption of solar is least in S_d4 (Opt. PV-BESS-Grid)

Source: Authors' analysis

In S_d1, consumers do not have the option of storing excess generation for later use. So, the PV system exports all the excess electricity to the grid. Consequently, self-consumption of solar is low, and consumers rely on the grid to satisfy their demand when solar energy is unavailable. In S_d2 and S_d3, self-consumption of solar is significantly higher. This is because the battery can store excess solar generation, which can be used during non-solar hours. Finally, in S_d4, despite the battery, the self-consumption rate of solar is low. As explained, this scenario focuses on improving the availability of solar during the discom's peak hours.

3. The top 10 per cent of hours in each season were defined as peak hours.

To achieve this, we scheduled battery charging on the grid (G2B) during the discom's off-peak hours, thus rendering solar generation available for direct uptake by the consumer (PV2C) or export to the grid (PV2G). As the charged battery can fulfil the consumer demand (B2C), the consumer's direct consumption of solar (PV2C) is low. Consequently, more solar is exported to the grid (PV2G) in S_d4 as compared to S_d2 and S_d3. Therefore, a reduced net draw of solar generation by the battery (PV2B) and direct consumption of solar (PV2C) result in lower self-consumption of solar in this case compared to S_d2 and S_d3.

Export of solar electricity to the grid

The export of solar electricity to the grid indicates how much of the total generation is available for utilisation by the grid. Figure 12 compares the annual profile of self-consumption of solar electricity and export to the grid in the four scenarios. In S_d1 (PV), there is no option to store excess solar energy, so naturally, export to the grid is high. S_d2 (PV-BESS) and S_d3 (PV-BESS-Grid), on the contrary, prioritise self-consumption over export to grid. Lastly, in S_d4 (Opt. PV-BESS-Grid), grid export is preferred over self-consumption.

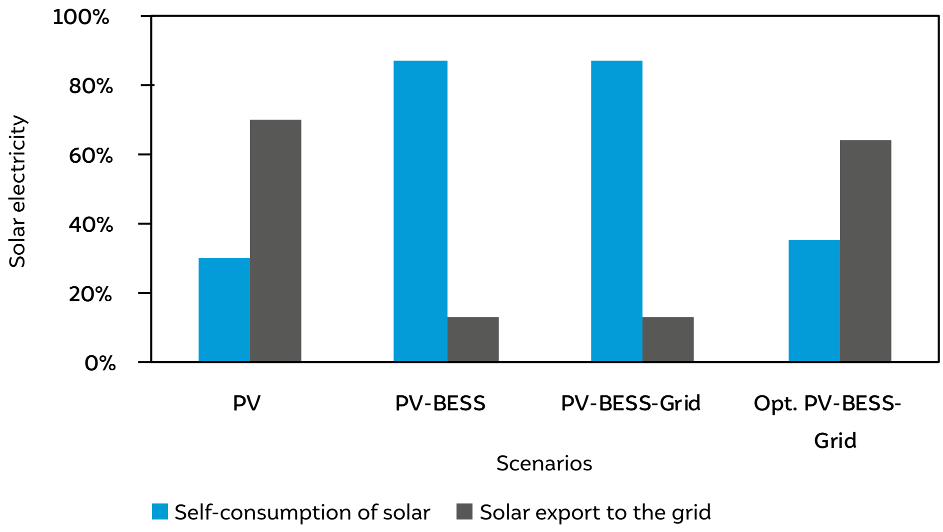


Figure 12
Export of solar generation to the grid is maximum in S_d1 (PV)

Source: Authors' analysis

Coincidence factors (CFs)

CFs indicate how much of the total solar generation is available during the discom's peak hours. A CF is the fraction of the discom's peak load that is supported by the microgrid.[4] The higher the CF, the more beneficial the installed solar capacity. There are three types of CFs used in this analysis – system, transmission, and distribution – each corresponding to the three segments of the power grid. As discoms plan for generation, transmission, and distribution based on their system-wide peaks, any contribution by a microgrid to reduce peak demand would directly benefit discoms. In this study, the transmission and system CFs are the same as they correspond to the discom's peak demand.

4. We used the top 20 per cent of the discom's peak hours to calculate CFs, which signify the ratio of the actual solar electricity generated to the rated output.

Table 5 shows the system coincidence factor (SCF) and distribution coincidence factor (DCF) in the four scenarios. Compared to the PV-only base scenario (S_d1), both factors decrease with the introduction of BESS in S_d2 and S_d3. Further, the allowance of grid interaction in S_d3 does not enhance the CFs. As the battery does not impose an additional load on the grid while charging (see Figure 9), the CFs in S_d2 and S_d3 are the same. In S_d4, the optimised scenario developed based on the discom load profile, the two CFs increase significantly.

Scenario	PV (S_d1)	PV-BESS (S_d2)	PV-BESS-Grid (S_d3)	Opt. PV-BESS-Grid (S_d4)
SCF	18.8	10.1	10.1	21.9
DCF	22.7	10.6	10.6	25.4

Table 5
SCF and DCF are maximum in the optimised scenario (S_d4)

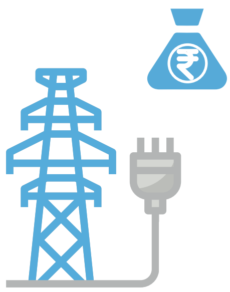
Source: Authors' analysis

These numbers indicate that the mere installation of a BESS cannot improve the contribution of a PV system in reducing the peak demand. Battery usage must be carefully optimised to achieve significant benefits. S_d1 has no battery, so there is no control over electricity export to the grid. Therefore, whenever the consumer demand drops, excess generation is exported to the grid. However, the inclusion of a battery without the clear objective of relieving the discom peak demand or increasing self-consumption does not help either. In S_d2 and S_d3, the battery is optimised to maximise the self-consumption of solar (see Figure 11) instead of exporting it to the grid. As the local demand of consumers differs significantly from that of discoms (see Figures 3 and 4), reducing the local peak does not contribute much to lowering that of discoms. So, even after battery installation, the CFs drop. In S_d4, a deliberate comparison of the discom load profile and PV generation enables the optimised scheduling of battery charge–discharge, thereby improving solar availability during the discom's peak hours. As a result, the CFs in S_d4 are the highest of all the scenarios.

Cost-benefit analysis

The cost-benefit analysis uses the VGRS framework, which accounts for various direct and indirect costs and benefits to assess the net impact of the microgrid on discom revenues (see Table 3 in Chapter 4). The NPV of these components, normalised by generation across the four scenarios, is presented in Table 6 and Figure 13.

PV (S_d1): Of the developed scenarios, the CFs, in this case, are the second-highest (close to 19 per cent at the system level and 23 per cent at the DT level). Consequently, the benefits are high. The maximum benefit is from APPC (56 per cent), which represents both short-term purchase and savings from the variable component of the PPA. ARECC also makes up a significant fraction of the discom's savings (28 per cent). The RL is considerably high, as consumers benefit from being able to export solar electricity to the grid. This is discussed more in the next chapter, which focuses on consumer perspectives. The cumulative benefits offset the RL, resulting in a net benefit of INR 0.27/kWh over 25 years.



Savings on reduced power procurement and REC represent 84% of total benefits

PV-BESS (S_d2): The CFs drop significantly in this scenario, to 10 per cent, at both the system and DT levels. In this scenario, the battery cannot charge on the grid, and any such instance is eliminated from the analysis (see Table A2 in Annexure 2). The reduced CFs decrease the benefits. However, among all the benefits, APPC and ARECC still contribute the most. The overall reduction in benefits is more than the RL, leading to a net loss of INR -0.06/kWh over 25 years.

PV-BESS-Grid (S_d3): In this case, the CFs are similar to those in S_d2 – close to 10 per cent at both levels. However, due to the restoration of grid charging for the battery, the overall benefits are slightly greater than those in S_d2. This is especially true for APPC and ARECC, which depend directly on the solar generation. Here, the RL trumps the cumulative benefits, and the discom faces a net loss of INR -0.06/kWh over 25 years.

Opt. PV-BESS-Grid (S_d4): This scenario has the highest CFs – close to 22 per cent at the system level and 25 per cent at the DT level. Consequently, the benefits are the highest among the four scenarios developed while the RL is lowest. These variations result in a considerable profit of INR 1.08/kWh over 25 years to the discom.

Results

In S_d1 (PV), BYPL makes a profit of INR 0.27 for each unit of solar electricity generated in its service area from the analysed 7 kW capacity. On the contrary, in S_d2 (PV-BESS) and S_d3 (PV-BESS-Grid), BYPL loses INR 0.06 for each unit of solar electricity generated by the analysed capacity. Finally, S_d4 (Opt. PV-BESS-Grid) yields the maximum profit of INR 1.08 per unit, indicating that optimising the battery cycle (charge–discharge) as per the discom's seasonal load can enhance the benefits that these systems offer discoms. Indeed, the magnitude of many of these benefits depends on the SCF and DCF. Therefore, the benefits are highest in S_d4 and lowest in S_d2 and S_d3.

High coincidence factors in S_d1 and S_d4 indicate that a considerable fraction of discom peak hours fall during the day

Several insights emerge from these scenarios. First, the high CFs observed in S_d1 and S_d4 suggest that a considerable number of discom peak hours fall during the daytime when solar generation is available. Therefore, directly utilising the available solar electricity by consumers instead of storing it in the battery for consumer uptake (like in S_d2 and S_d3) seems more beneficial to the discom. Second, the ADCC benefit is zero in all cases. This indicates that the considered DT is not overloaded and that the microgrid is not being utilised to its full potential, for instance, to defer network upgradation. Lastly, the trade-off between solar consumption by consumers and export to the grid significantly alters the RL to the discom. RL includes consumer savings from the reduction in electricity bills and earnings from electricity export to the grid; these two factors interchange across the scenarios. In S_d4, grid export is prioritised but the RL is the smallest. This is because, compared to other cases, consumers rely more on the grid to meet their demand in S_d4. Chapter 7 discusses this grid reliance aspect in more detail.

Parameters	PV (S_d1)	PV-BESS (S_d2)	PV-BESS-Grid (S_d3)	Opt. PV-BESS-Grid (S_d4)
AGCC	0.19	0.10	0.10	0.22
APPC	0.99	0.47	0.47	0.95
ATRC	0.08	0.05	0.05	0.10
ADCC	0	0	0	0
ARECC	0.49	0.23	0.23	0.47
AWCC	0.01	0.01	0.01	-0.01
Total benefits	**1.76**	**0.86**	**0.86**	**1.73**
RL	1.49	0.92	0.92	0.65
Net benefit	**0.27**	**-0.06**	**-0.06**	**1.08**

Table 6
Scenario 4 gives the highest generation-normalised net profit across the four scenarios (INR/kWh)

Source: Authors' analysis

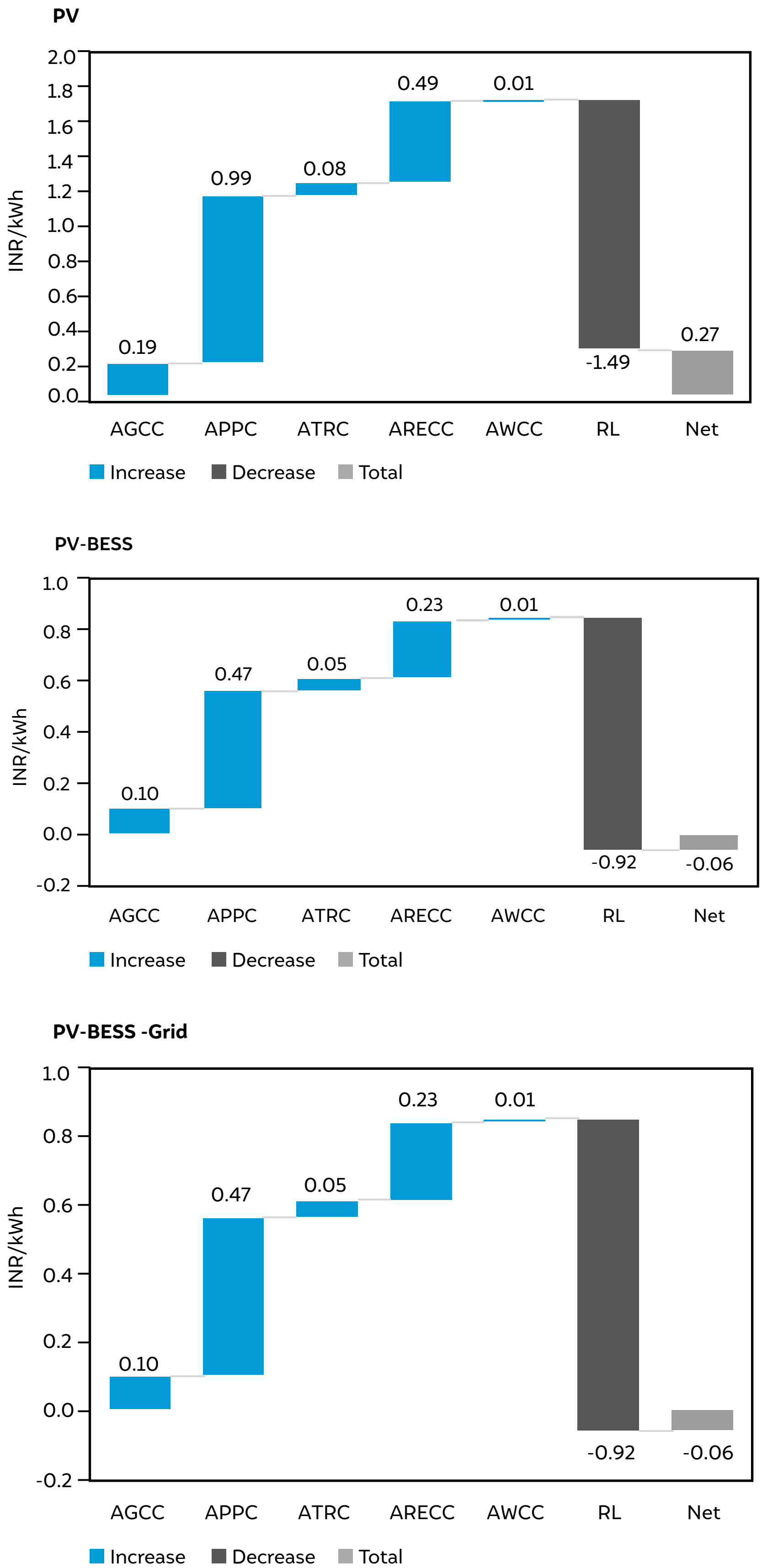
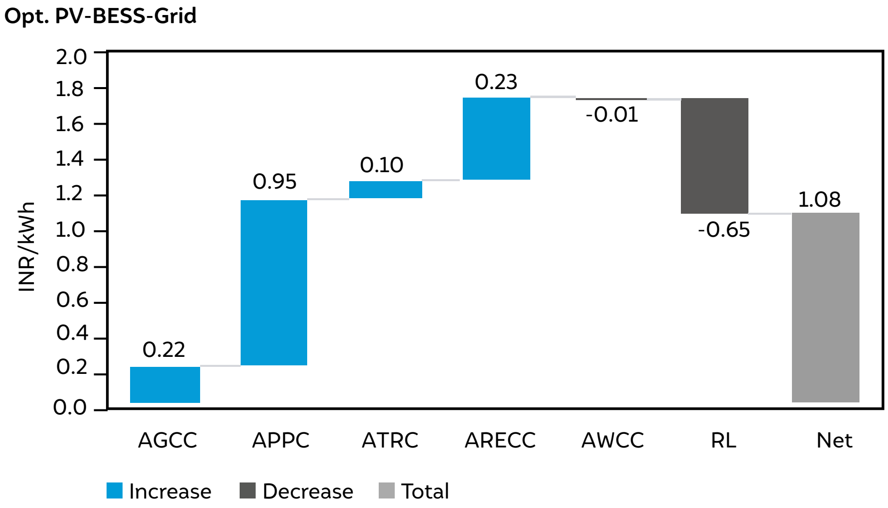


Figure 13
BYPL makes the maximum benefit in S_d4 (Opt. PV-BESS-Grid)

Source: Authors' analysis



Key observations

- The discom benefits the most in S_d4 (gaining INR 1.08/kWh), in which the urban microgrid is optimised to reduce the overall peak demand of the discom.

- Greater export of solar electricity to the grid during the discom's peak hours – 70 per cent in S_d1 and 65 per cent in S_d4 – results in a net benefit to the discom.

- On the contrary, increased self-consumption of solar electricity by consumers – 87 per cent in S_d2 and 87 per cent in S_d3 – results in a net loss to the discom, as local peaks are different to and smaller than system peaks. Hence, using microgrids to reduce these local peaks does not significantly impact discom operations but does significantly affect their revenues.

High upfront cost of microgrid systems deters its uptake by the consumers.

Image: iStock

7. Impact of solar microgrids on consumers: a case study of BYPL

While consumers are growing increasingly aware of the environmental benefits of renewable energy installations, there is still little awareness about the associated financial gains. Regardless, the high upfront cost of a PV-BESS system and the lack of knowledge about the system's technical and financial performance are often hindrances to its uptake. This chapter elaborates on the financial benefits of urban microgrids to consumers over the system's lifetime. Our analysis assumes the CAPEX (capital expenditure) model for consumers, which involves an upfront payment of the system cost. The system's economic feasibility is determined by the payback period and NPV. These parameters are essential to understand if the system will be economically lucrative or incur losses.

We developed four scenarios to estimate the economic impact of microgrids on consumers. Apart from the base case, the scenarios are identical to those developed for the analysis from the discom perspective.

S_c1, Grid is the base case in which the consumer satisfies its entire demand from the grid.

In **S_c2, PV-Grid**, rooftop PV and grid work together to meet the consumer demand.

S_c3, PV-BESS-Grid is the present case, in which the consumer fulfils their demand from the grid, rooftop PV system, and battery (BESS).

S_c4, Opt. PV-BESS-Grid is the modelled version of S_c3, as explained in the previous chapter. Here, the utilisation of solar energy and battery charge–discharge scheduling are as per the discom's peak demand. So, the export of solar generation to the grid is maximised during peak hours. The battery charges on the grid during off-peak hours and meets the consumer demand. Only one charge–discharge cycle is permitted per day. Hence, in the absence of battery and solar power, the consumer draws electricity from the grid.

Figure 14 shows the consumer's consumption profile and the export of solar electricity to the grid in the four scenarios. In S_c1, the grid is the consumer's only source of electricity. With the inclusion of the PV system in S_c2, the consumer can reduce their grid dependence by 71 per cent, mostly during the day. Almost 70 per cent of solar generation is exported to the grid in this case, as there is no option to store the surplus. The inclusion of the battery in S_c3 decreases the consumer's direct consumption of solar energy (PV2C) to 6 per cent. Here, the battery takes care of 53 per cent of the consumer's demand. The remaining 41 per cent is still provided by the grid. The discrepancy between the overall solar electricity utilisation in S_c2 and S_c3 is due to efficiency losses in battery operations. A part of the solar electricity stored in

With the inclusion of the PV system in S_c2, the consumer can reduce their grid dependence by 71 per cent, mostly during the day the battery is lost while delivering to the consumer. As the battery charges on the PV system, the fraction of solar generation exported to the grid reduces drastically to 13 per cent. Lastly, in the optimised scenario S_c4, the consumer's grid dependence increases to 56 per cent; the microgrid fulfils the remaining 44 per cent. This facilitates maximising solar availability during the discom's peak hours and, in turn, directing the consumer to the grid. The high export of solar generation to the grid (64 per cent) corroborates the modelled scenario.

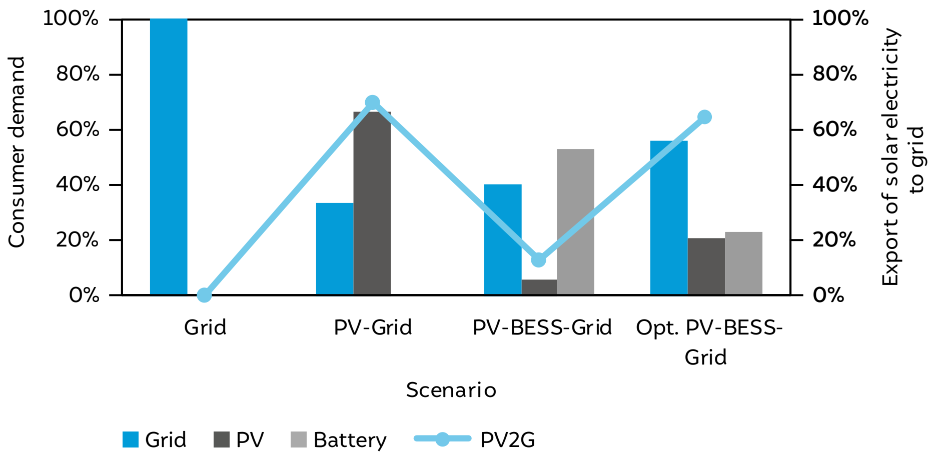


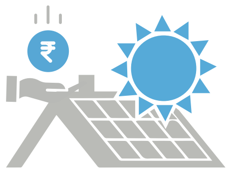
Figure 14
Grid dependence of the consumer is least in S_c2 (PV-Grid)

Source: Authors' analysis

Figure 14 sheds some light on the self-sufficiency of microgrids. It indicates what fraction of the consumer demand these microgrids meet directly. Self-sufficiency is the ratio of the consumer demand met by solar and battery power to total consumption.[5] As the PV system and battery are present together in S_c3 (BESS-PV-Grid) and S_c4 (Opt. BESS-PV-Grid), only these two cases are relevant to this discussion. Evidently, self-sufficiency is higher in S_c3 (59 per cent) than in S_c4 (43 per cent).

Results

Table 8 shows the annual financial savings that microgrids provide consumers. On average, consumers save about 69 per cent per month by installing a rooftop PV system (S_c2). These savings include a reduction in the monthly electricity bill and earnings under the net metering regulation. As a significant fraction of solar generation is exported to the grid, the financial gain is highest in S_c2. The introduction of a BESS in S_c3 decreases the monthly savings (to 59 per cent) as well as the total earnings. The small financial gain is due to a drastic reduction in the net export of solar generation and efficiency losses during battery performance.



On an average, consumers with a rooftop PV system can save 69% on their monthly electricity bill

Optimising the microgrid's performance in S_c4 to reduce the discom's peak demand improves customer earnings under the net metering regulation (INR 7,328), as compared to S_c3. The reduced savings are attributed to the consumer's increased dependence on the grid as solar generation is prioritised for export to the grid. As a result, the RL to the discom, represented by 'Total financial gain' in Table 8, is lowest in the optimised scenario (S_c4).

5. Self-sufficiency of microgrids is calculated as (PV2C+B2C)/total consumption

Parameter	PV-Grid (S_c2)	PV-BESS-Grid (S_c3)	Opt. PV-BESS-Grid (S_c4)
Savings on the electricity bill (INR)	46,211	36,648	21,878
Average monthly savings on the electricity bill (%)	69	59	37
Earnings under the net metering regulation (INR)	20,768	4,708	7,328
Total financial gain (INR)	**66,979**	**41,357**	**29,206**

Table 7
Annual financial gain for consumers with microgrids

Source: Authors' analysis

Table 8 shows the various financial parameters over the lifetime of the microgrid. The NPV represents the net benefit to the consumer after accounting for CAPEX costs (PV system, BESS, and battery replacement costs) and returns over the system's lifetime. The consumer can recover the installation cost of the PV system alone under four years; the NPV is INR 4,47,417. With the addition of the BESS (S_c3), due to reduced savings and increased capital costs, the payback period increases to about seven years. However, the NPV is decreased to INR 1,30,782. In S_c4, modelled to benefit the discom, the reduced financial savings (Table 7) result in an increased payback period of ten years and an NPV of INR -8,859.

Parameter	PV-Grid (S_c2)	PV-BESS-Grid (S_c3)	Opt. PV-BESS-Grid (S_c4)
Payback period (years)	3.4	7.1	10
Net present value (NPV (INR))	**4,47,417**	**1,30,782**	**-8,859**

Table 8
Scenario 2 results in shortest payback period and highest financial gain

Source: Authors' analysis

Key observations

- The consumer benefits the most from directly consuming the solar electricity, as in S_c2, instead of a redirected use via the battery, as in S_c3 and S_c4.

- Earnings under the net metering regulation increase with the export of solar electricity to the grid and reduced self-consumption.

- Inclusion of the battery significantly increases the consumer's payback period. The maximum savings and shortest payback period are possible in S_c2, which does not include the battery.

- Prioritising battery usage for grid support, as in S_c4, reduces consumer savings by 37 per cent.

Discoms should focus on combining multiple applications from microgrids to receive maximum benefits.

Image: iStock

8. Conclusion and recommendations

Urban microgrids have applications in managing intermittent solar generation and in reducing solar export to the grid with increased self-consumption. These applications lead to many indirect benefits to discoms, including reduced peak demand, lower transmission and distribution losses, distribution network upgrade deferral, etc. Greater transparency regarding these benefits, from discom and consumer perspectives, is essential to devise innovative policy, regulatory, and market interventions to support the higher uptake of microgrids. The following section outlines some of the key findings from the BYPL case study. A detailed assessment of the economic viability of installed microgrids provided the following insights:

BYPL gains the most by optimising electricity dispatch from microgrids to support its peak load

- **The benefit to BYPL increases by almost four times with battery storage:** The benefits that urban microgrids offer to discoms vary depending on the utilisation of the storage capacity. Solar generation alone offers a net benefit of 0.27 INR/kWh ($S_{d}1$); this improves to 1.08 INR/kWh in $S_{d}4$, in which battery storage is optimised for grid application. This is achieved by scheduling electricity export during peak hours and battery charging during off-peak hours simultaneously through the grid and solar.

- **The increased financial burden on consumers:** With energy storage, prioritising the export of solar electricity during the discom's peak hours over self-consumption by consumers decreases the latter's savings by 37 per cent. Under these circumstances, the payback period for microgrids increases to a little over nine years.

- **Urban microgrids can reduce discom peak demand:** Urban microgrids with energy storage can reduce the peak demand by 21 per cent of the rated solar PV capacity, as compared to an 18 per cent reduction without energy storage. This is achieved by prioritising the export of solar electricity to the grid during peak hours and altering the consumption patterns of consumers.

- **Peak demand reduction offers the maximum benefit:** The export of solar electricity to the grid helps discom minimise their power procurement costs, both from short-term purchases and variable components of scheduled procurements under long-term PPAs. Savings from APPC represent 55 per cent of the cumulative benefits to the discom.

- **Battery storage may yield a net loss to BYPL if not optimised for grid application:** Energy storage brings additional benefit to discoms by increasing solar export during discom peaks. However, in the case of an afternoon discom peak, using the energy storage lowers the overall benefit due to a loss in battery efficiency.

- **Enhanced self-sufficiency of consumers:** Urban microgrids with battery storage significantly improve the self-sufficiency of consumers and reduce their grid dependence. Consumers can satisfy 59 per cent of their total demand with energy storage, as compared to 66 per cent with solar generation alone. The battery provides consumers the flexibility to store and later utilise solar electricity.

Recommendations

The discom peak demand in urban centres, with the increased penetration of air conditioners and electric vehicles, is likely to rise sharply in the coming years. This would also shift demand patterns from having uniform peak and off-peak periods to featuring intermittent peak and off-peak hours. As discussed, urban microgrids with dispatchable storage would provide greater benefits to discoms and contribute to smoothing the demand curve. The proliferation of urban microgrids, however, is contingent on various support policies and innovative market frameworks:

- **Regulatory provisions to support dispatch from behind-the-meter storage:** The energy storage system of the microgrid would be placed behind the meter in the consumer's premises. Such storage installations actively interact with the grid in order to charge and export electricity to it. Although many state regulations recognise such grid-interactive systems, none explicitly mentions export from the battery to the grid. Hence, regulations supporting dispatch from behind-the-meter storage would support urban microgrid deployment.

- **Grid tariff for battery charging and export to the grid:** Differential or time-of-use/-day tariffs for all consumer categories can be designed to incentivise consumers to export electricity to the grid during peak hours or charge batteries on the grid during off-peak hours.

- **Redesigning the restrictions on the sanctioned PV capacity of urban microgrids:** At present, most states have put restrictions on permissible installed PV capacity based on the sanctioned load. Often, solar generation from rooftop systems is not enough to meet consumer demand and restricts the utilisation of solar energy for the discom's benefit. The restrictions on sanctioned load could be revised in the case of urban microgrids, and they could be imposed on the overall export of solar power. Further, the time-of-day concept, based on the overall discom load profile and seasonality, can also be used to restrict export of electricity.

- **New business models:** The high upfront cost of batteries drastically increases the payback period for consumers, as compared to investing in a solar PV system alone. Discoms could develop new business models to ease the financial burden of microgrids on consumers. Such business models could include cost-sharing and leasing.

- **Value-stacking the benefits:** Urban microgrids offer numerous applications to discoms. Battery discharge can be scheduled to support load levelling (peak shaving), minimise power procurements from expensive sources (short-term purchases), or defer network upgradation. For each of these factors, systems have to be configured and sized depending on the local or overall load profile. Discoms should undertake studies like ours to ensure the deployment of urban microgrids with optimal benefits.

Successful scaling of urban microgrids needs regulatory support, incentivising tariff structures, and innovative business models

- **Strategic dispatch from the battery:** In the present case study, there is a conflict of interest between discoms and consumers in terms of the benefits derived from urban microgrids. Prioritising self-consumption of solar electricity benefits consumers more than discoms, which benefit from the maximisation of solar export. Hence, a cautious choice needs to be made to optimally schedule dispatches from the battery, based on time-of-use/-day tariffs, in order to benefit both stakeholders equitably.

Annexures

Annexure 1

Benefits and costs considered in the VGRS framework

Benefit components

Discoms can accrue the **avoided generation capacity cost (AGCC)** benefit by contracting less capacity from generation companies and signing a PPA due to the installed PV capacity. AGGC benefit essentially refers to the avoided fixed cost payment for each MW of generation capacity. Besides the installed PV capacity, the magnitude of this benefit depends on the SCF, which represents the fraction of the system load that the PV system supports. This benefit would be applicable from the year following a PPA renegotiation; until then it wouldn't apply.

Working formula

$$AGCC = \sum \frac{RTSoutput}{(1\text{-}TL\%)} \times SystemCoincidenceFactor \times DegradationFactor \times Capacity\ Cost$$

Description

RTSoutput (kW): The rated capacity of the RTS system.

SystemCoincidenceFactor (dimensionless): Fraction of the rated RTS output that supports the system at its peak. It is the ratio of the RTS output (kW) at the discom's peak supply hour to its rated output (kW).

DegradationFactor (dimensionless): Factor to account for the decrease in the RTS system's performance over the years.

CapacityCost (INR/kW): Fixed cost of additional contracted capacity as decided by the regulatory commission.

TL%: Transmission loss per cent.

The **avoided power purchase cost (APPC)** benefit captures the potential savings from the variable part of the power purchase cost that the discom pays generators for the actual quanta of units procured. RTS electricity substitutes the most expensive energy that the discom procures at the given time interval, if the discom follows a merit order dispatch, i.e., dispatch of electricity from contracted sources in increasing order of the power purchase cost. Therefore, the magnitude of this benefit depends on the generation profile of the RTS system, the load profile of the discom, its power procurement strategy, and the variable power purchase cost of electricity from different sources in each time interval.

Working formula

$$APPC = \sum \frac{RTSEnergy}{(1\text{-}TL\%)(1\text{-}DL\%)} \times VariablePowerPurchaseCost$$

Description

RTSEnergy (kWh): Actual electricity the RTS system produces.

VariablePowerPurchaseCost (INR/kWh): Variable component of the power purchase cost of the discom as set by the regulatory commission.

TL%: Transmission loss per cent.

DL%: Distribution loss per cent.

The **avoided transmission charges (ATRC)** benefit captures the potential benefit by avoiding payment for using the transmission network, as solar electricity has coincident generation and consumption points. The magnitude of this benefit depends on the installed PV capacity and the transmission CF. This benefit would be applicable from the year following a capacity renegotiation; until then it wouldn't apply.

Working formula

$$ATRC = \sum \frac{RTSoutput}{(1\text{-}TL\%)(1\text{-}DL\%)} \times TransmissionCoincidenceFactor \times DegradationFactor \times TransmissionCapacityCost$$

Description

RTSoutput (kW): The rated capacity of the RTS system.

TransmissionCoincidenceFactor (dimensionless): Fraction of the rated RTS output that supports the transmission system at the latter's peak. It is the ratio of the RTS output (kW) at the transmission load's peak hour to its rated output (kW).

DegradationFactor (dimensionless): Factor to account for a decrease in the performance of the RTS system over time.

TransmissionCapacityCost (INR/kW): Fixed capacity charge payable to the transmission licensee as per the commission.

TL%: Transmission loss per cent.

DL%: Distribution loss per cent.

The **avoided distribution capacity cost (ADCC)** benefit refers to the potential savings from deferring the network upgradation due to the installed PV-BESS system. As these systems can take the load off the distribution system, the life of the network components can be enhanced with simultaneous decongestion. Hence, the discom can minimise expenses associated with network augmentation and maintenance. The magnitude of this benefit depends on the DCF and installed PV capacity.

Working formula

$$ADCC = \sum \frac{RTSoutput}{(1\text{-}TL\%)(1\text{-}DL\%)} \times DistributionCoincidenceFactor \times DegradationFactor \times DistributionCapacityCost$$

Description

RTSoutput (kW): The rated capacity of the RTS system.

DistributionCoincidenceFactor (dimensionless): Fraction of the rated RTS output that supports the distribution system at the latter's peak. It is the ratio of the RTS output (kW) at the DT's peak hours to its rated output (kW).

DegradationFactor (dimensionless): Factor to account for the decline in the RTS system's performance over time.

DistributionCapacityCost (INR/kW): Sum of the annual expenses for the discom to install the new capacity, upgrade the network, and operate and maintain the network.

TL%: Transmission loss per cent.

DL%: Distribution loss per cent.

The **avoided renewable energy certificate cost (ARECC)** benefit refers to the savings from meeting the RPO. Generation from rooftop PV systems within the discom boundaries counts towards the fulfilment of this requirement. In the event of nonfulfillment, discoms can purchase RECs to meet their RPO targets. Thus, by supporting the adoption and integration of microgrids, discoms can achieve their annual RPO targets and cut down their expenditure on RECs. This benefit is subject to the applicability of RECs in the future and would be considered zero if these certificates were discontinued.

Working formula

$$ARECC = \sum RTSEnergy \times RECCost$$

Description

RTSEnergy (kWh): Actual electricity the RTS system produces.

RECCost (INR/kWh): The cost of purchasing an REC.

The **avoided working capital requirement (AWCC)** benefit represents the net of savings from reduced discom expenses towards generators (fixed and variable charges) and losses because of the migration of consumers from the grid to PV-BESS. It reflects the disparity between its total revenue and expenses. It is reviewed every year to monitor increases and requires the approval of the state regulator. The working capital amount for BYPL is equivalent to the difference between two months' revenue from electricity sales and one month's power purchase cost.

Working formula[6]

$$AWCC_Y = \sum \frac{((2\times RevenueLoss)-(AGCC+APPC+ATRC+ADCC+ARECC))}{12} \times DebtRate$$

Description

AGCC (INR): Avoided generation capacity cost in the respective year.

APPC (INR): Avoided power procurement cost in the respective year.

ATRC (INR): Avoided transmission charges in the respective year.

ADCC (INR): Avoided distribution capacity cost in the respective year.

ARECC (INR): Avoided REC cost in the respective year.

RL (INR): Revenue loss to the discom.

DebtRate (%): Debt financing rate approved by the regulator.

Coincidence factors

Some of the listed benefits depend on the active contribution of the PV-BESS system during peak hours. CFs for any given network (generation, transmission, and distribution) allow us to quantify the contribution of these systems during peak hours. The analysis uses two types of CFs – SCF and DCF – which are calculated for the overall discom peak hours and DT loading peak hours, respectively. Since the discom demand and transmission networks have nearly the same profiles, the system and transmission CFs can be assumed to be equal.

6. The formula was developed based on the working capital formula defined by the Delhi Electricity Regulatory Commission (DERC). It would have to be updated for each discom based on the relevant regulation.

Cost components

Revenue loss refers to the difference in the discom revenue due to a reduced dependence of the consumers on the grid. In this analysis, it includes savings from bill reduction and earnings under the net metering regulation from exporting excess solar power to the grid. Bill savings are equal to the difference in consumer bills with and without the PV-BESS system. As the VGRS analysis computes the costs and benefits for the current year, the consumer's energy tariffs and APPC cost are assumed to be constant throughout the analysis.

Programme administration cost captures various additional measures that discoms take to support the installation and operation of PV-BESS systems. It includes efforts like hiring an expert workforce, conducting technical feasibility studies, installing bidirectional meters, inspecting plants, among others.

Added distribution services cost represents any additional network-related modification that discoms might have to do to support PV-BESS systems. Although the microgrid is expected to work in congruence with the existing distribution network, without any additional requirements, its implementation can require constructing new components or upgrading the existing system. These expenses, borne by discoms, are accounted for in the ADSC.

Annexure 2

Data inputs and assumptions considered in the VGRS framework

- The analysis was done for a 25-year period (a PV system's lifetime), assuming a battery replacement in the fourteenth year since installation.
- This cost–benefit analysis needs two system profiles for each scenario: solar and consumption. Table A1 shows these two profiles for the four scenarios. In S_d1 (PV), the solar profile represents the total solar generation available to the discom service area. The consumption profile is the consumer demand from the grid, PV system, and battery. In S_d2 (PV-BESS), the component of PV generation transferred to the battery (PV2B) is replaced by the consumer demand supported by the battery (B2C) and excess exported to the grid (B2G). Any possibility of the battery charging on the grid (G2B) is excluded to ensure the self-sufficiency of the PV-BESS system. The consumption profile is the same as the solar profile in S_d1. In S_d3 (PV-BESS-Grid), we allow for interactions between the battery and grid. Correspondingly, the consumption includes the additional load that the battery imposes on the grid (G2B). The last scenario, S_d4 (Opt. PV-BESS-Grid) is the optimised version of S_d3, in which we have modelled the battery charging and discharging profiles to match availability of solar electricity at discom peak hours.

Scenario	Solar profile	Consumption profile
PV (S_d1)	∑(PV2C, PV2G, PV2B)	∑(PV2C, G2C, B2C)
PV-BESS (S_d2)	∑(PV2C, PV2G, B2C, B2G–G2B)	∑(PV2C, G2C, B2C)
PV-BESS-Grid (S_d3)	∑(PV2C, PV2G, B2C, B2G)	∑(PV2C, G2C, B2C, G2B)
Opt. PV-BESS-Grid (S_d4)	∑(PV2C, PV2G, B2C, B2G)	∑(PV2C, G2C, B2C, G2B)

Table A1
Overview of the four scenarios developed for the VGRS analysis for discoms

Source: Authors' analysis

Table A2
Data inputs and assumptions considered to estimate the net impact of the PV-BESS system

Parameter	Approach and assumption
Coincidence factors - SCF - DCF	• The top 20 per cent of the load duration curve is identified as peak demand and, consequently, the RTS output in those intervals is mapped to estimate CFs. • Since the loading profile of the transmission system is the same as the discom demand profile, the transmission CF was considered to be the same as the SCF. • A similar procedure was followed for the DCF, except that the loading of the concerned DT was used.
Avoided generation capacity cost	• Long-term PPAs cover only the baseload requirements of BYPL. However, during peak hours (i.e., the peak 20 per cent of the load duration curve), BYPL procures power from short-term markets. • Since short-term contracts are more flexible and can be renegotiated, the true value of these benefits (as per the formula) was considered. • The rated output of an RTS system would fall consistently every year due to the continuous degradation of PV. Therefore, the magnitude of the annual contribution would be limited by the value in the previous year, as the discom's plans would consider the minimum contribution from the RTS system. • This benefit would be considered if the PPA renegotiation falls during the system's lifetime. Hence, the benefit would be zero until the renegotiation happened.
Avoided power purchase cost	• Discoms in India follow a merit order dispatch, which is a variable component. Additionally, during peak demand, the discom resorts to buying electricity from the open market as well. • The tool estimates the avoided purchase cost for every hour individually, based on the hourly solar generation profile and power procurement from different sources.[7] • It is assumed that solar energy will replace the most expensive source of power in any given interval as per the merit order dispatch. • Data on the power purchase cost for every 15-minute interval are used for procurement from the open market, and merit order dispatch is used for long-term contracts.
Avoided transmission charges	• The benefit is calculated based on ATCs and unit charges that BYPL pays for each kW of additional transmission capacity. • This benefit is considered if the transmission capacity renegotiation falls during the system lifetime; hence, it would be zero until the negotiation happened.

7. As an example, let us assume that the RTS system generates 100 units of electricity in one interval, with transmission and distribution losses equal to 5 per cent each. Thus, the discom can reduce its procurement in that interval by 111 (= 100/0.952) units. If 111 units or more are procured via the open market, the benefit in that interval is simply 111 x open access procurement cost per unit. However, say the discom procures only 70 units, then the remaining 41 units are eliminated from sources that are contracted under long-term PPAs. The benefit in this case will be 70 x open access procurement cost per unit + 41 x long-term PPA procurement cost per unit. Thus calculated, the value of the benefit can be summed up for all intervals in a year.

Parameter	Approach and assumption
Avoided distribution capacity cost	• The ADCC calculation has two components: – Normative expenses incurred during the maintenance of the distribution network (excluding DTs). – Cost of DT upgradation and related O&M expenses. • The first component has not been taken into consideration as the cost structure for the discom is independent of system loading. • Determining whether a DT is due for upgrade is calculated based on the pattern and growth rate of the peak load and the **cost** from solar generation. • Historical DT load patterns are used to estimate future growth in demand. • Avoided interest payment due to the deferment of DT upgradation is calculated based on predictions for the year in which the DT is due for upgradation.
Avoided REC cost	• If the discom is already purchasing electricity from a solar plant, then this benefit is applicable for the actual generation from RTS or the shortfall required to be made up, whichever is lower. This benefit is subject to the relevance of RECs in the future and can become obsolete if regulations change.
Reduced working capital requirement	• As per the DERC, working capital is considered to be the difference between two months' revenue of the discom from energy sales and one month's power purchase cost and must be completely sourced through debt. • The reduction in working capital is equal to the interest to be paid on the difference between two months of RL and one month of avoided costs.
Revenue loss	• RL is taken as the financial gain to consumers. The consumer's financial gain, in turn, is a summation of savings from electricity bill reduction and earnings from the export of surplus electricity to the grid, in accordance with the current net metering policy. In S_d1 for the discom (PV), consumer savings in S_d2 (PV-Grid) are taken as the RL. In S_d2 (PV-BESS) and S_d3 (PV-BESS-Grid) for the discom, consumer savings in S_c3 (PV-Grid-BESS) are taken as the RL. Lastly, the RL in S_d4 for the discom is equal to savings in S_c4 for the consumer.
Net present value	• Each of the costs and benefits is calculated annually and discounted to the present year. • The interest rate used for the NPV is the same as the discom's weighted average cost of capital (WACC) rate of 16.64%.

Table A3
Cost components as taken from the BYPL FY2018-19 ARR

Parameter	Cost	Unit
Capacity cost	7,452.229	INR/kW
The average variable component cost of the five most expensive long-term PPAs (coal/gas)	3.44	INR/kWh
Transmission cost	2,970.154	INR/kW
REC cost	2,000	INR/MWh
DT upgradation cost		
Standard cost of the augmentation of a 400 kVA DT to 630 kVA	9.36	INR lakh
Standard cost of the augmentation of a 630 kVA DT to 990 kVA	12.83	INR lakh
Standard cost of the augmentation of a 400 kVA DT to 990 kVA	12.89	INR lakh
Variable component of the tariff structure	8.50	INR/kVAh
Average power purchase cost	3.5	INR/kWh
Transmission loss	2.63%	
Distribution loss	11.69%	
Discount rate	16.64%	

Annexure 3

Modelling details for Opt. PV-BESS-Grid

Table A4
Modelling of the battery usage in Opt. PV-BESS-Grid (S_d4/ S_c4)

Parameter	Value		
Battery capacity (kWh)	10.4		
Power rating (kW)	5		
Cycles/day	1		
Energy in the battery (kWh/day)	10.4		
Depth of discharge (%)	85		
Efficiency (%)	96		
Available energy in the battery (kWh)	9.98		
Battery operational characteristics across seasons			
Season	Charging time (hours)	Discharging time (hours)	Idle time (hours)
Summer (April to June)	11 (midnight to 1100)	8 (1600 to midnight)	5 (1100 to 1600)
Monsoon (July to September)	10 (midnight to 1000)	8 (1600 to midnight)	6 (1000 to 1600)
Post-monsoon (October to November)	10 (midnight to 1000)	8 (1600 to midnight)	6 (1000 to 1600)
Winter (December to March)	7 (midnight to 0700)	8 (0700 to 1000 and 1500 to 2000)	9 (1000 to 1500 and 2000 to midnight)

Annexure 4

Details of the consumer perspective analysis

Table A5
Data inputs and assumptions considered for the consumer perspective analysis

Parameters	Assumption
Electricity duty	5% of fixed charges + energy charges for each month
Average Power Purchase Cost	INR 3.5/kWh for the base year; no change for the remaining 24 years
Energy Charges	INR 8.5/kWh for the base year; 2% year-on-year increase for the remaining 24 years (Bharadwaj, Ganesan and Kuldeep 2017)
PV performance degradation factor	0.5% per year
Discount Rate	10%[8]
Cost of the PV system	INR 2,45,000
Cost of the battery system	INR 68,600
NPV of the battery replacement cost	INR 983

Table A6
Time-of-day schedule and tariff charges

Months	Peak hours	Surcharge on energy charges (%)	Off-peak hours	Rebate on energy charges (%)
May to September	1400 to 1700 and 2200 to 100	20	0400 to 1000	20

8. Equivalent to the bank's Marginal Cost of Funds based Lending Rate (MCLR) for commercial consumers.

References

Adefarati, Temitope, and Ramesh C. Bansal. 2019. "Reliability, economic and environmental analysis of a microgrid system in the presence of renewable energy resources." Applied Energy 236 (C): 1089-1114.

Anderson, Kate, Nick DiOrio, Dylan Cutler, Bob Butt, and Allison Richards. 2017. "Increasing Resiliency Through Renewable Energy Microgrids." Journal of ENergy Management 22-38.

Bangash, Kashif N., Mohamed Emad A. Farrag, and Ahmed H. Osman. 2017. "Impact of Energy Storage Systems on the Management of Fault Current at LV Network with High Penetration of Distributed Generation." Interna tional Journal of Smart Grid and Clean Energy 6 (3): 195-206.

Bharadwaj, Kapardhi, Karthik Ganesan, and Neeraj Kuldeep. 2017. Retail tariffs for electricity consumerd in Delhi: A forward looking assessment. New Delhi: Council on Energy, Environment and Water.

BSES Yamuna Power Limited . 2019. About BSES. Accessed June 22, 2020. https://www.bsesdelhi.com/web/bypl/about-bses.

BSES Yamuna Power Limited. 2019. "BSES Commissions Solar Micro Grids With Energy Battery Storage." March 12, 2019. https://www.bsesdelhi.com/documents/73527/626545808/Micro_Solar_Grid_eng.pdf.

BSES Yamuna Power Limited. 2019. BSES Fully Geared-Up For The Winter Months. December 3, 2019. https://www.bsesdelhi.com/documents/55701/1218289262/Winter_Arrangements_031219_Eng.pdf.

BSES Yamuna Power Limited. 2019. "BYPL tariff order 2019-20." September. Accessed January 21, 2020. https://www.bsesdelhi.com/documents/73527/75014/BYPL_TARIFF_ORDER_2019_20.pdf/92414ea2-1b68-d98d-f8ae-0ba9d039b8d9.

Central Electricity Authority. 2019. "CEA reports." December. Accessed January 21, 2020. http://www.cea.nic.in/reports/monthly/hydro/2019/pump_storage-12.pdf.

Central Electricity Authority. 2020. "Executive Summary on Power Sector." CEA. January. Accessed March 19, 2020. http://cea.nic.in/reports/monthly/executivesummary/2020/exe_summary-01.pdf.

Central Electricity Authority. 2015. "Executive Summary Power Sector: January 2015." Accessed January 21, 2020. http://cea.nic.in/reports/monthly/executivesummary/2015/exe_summary-01.pdf.

Central Electricity Authority, Ministry of Power. 2010. "Annual Report 2009-10." www.cea.nic.in. September. Accessed January 21, 2020. http://www.cea.nic.in/reports/annual/annualreports/annual_report-2010.pdf.

Central Electricity Regulatory Commission. 2019. CERC. 28 May. Accessed February 16, 2020. http://www.cercind.gov.in/2019/regulation/DSM(5th%20Amendment)149.pdf.

Central Electricity Regulatory Commission. 2020. "CERC Orders." 31 March. http://www.cercind.gov.in/2020/orders/5-SM-2020.pdf.

Central Statistics Office, Ministry of Statistics and Programme Implementation. 2018. "Energy Statistics 2018 (Twenty Fifth Issue)." March. http://mospi.nic.in/sites/default/files/publication_reports/Energy_Statistics_2018.pdf.

Comello, Stephen, and Stefan Reichelstein. 2019. "The emergence of cost effective batter storage." Nature Communications.

Commission, Central Electricity Regulatory. 2017. CERC web site. January. Accessed January 21, 2020. http://www.cercind.gov.in/2017/draft_reg/SP.pdf.

Delhi Electricity Regulatory Commission. 2014. "DERC renewable energy net metering regulations 2014." September. Accessed January 2020. https://mnre.gov.in/file- manager/UserFiles/Grid-Connected-Solar-Rooftop-policy/DERC_Renewable_ Energy_Net_Metering_Regulations_2014.pdf.

Deorah, Shruti M., Nikit Abhyankar, Siddharth Arora, Ashwin Gambhir, and Amol Phadke. 2020. Estimating the Cost of Grid-Scale Lithium-Ion Battery Storage in India. California: Lawrence Berkeley National Laboratory.

El Fathi, A, and A Outzourhit. 2018. "Technico-economic assessment of a lead-acid battery bank for standalone photovoltaic power plant." Journal of Energy Storage 185-191.

Energy, Ministry of New and Renewable. 2020. MNRE web site. 2 January. Accessed January 14, 2020. https://mnre.gov.in/sites/default/files/webform/notices/The___Draft%20 RTC%20Scheme%20for%20MNRE%20Website.pdf.

Gulia, Jyoti, and Shilpi Jain. 2020. Solar+Battery Storage: Assessing vability in India. Gurugram: JMK Research & Analytics.

Kuldeep, Neeraj, Kumaresh Ramesh, Akanksha Tyagi, and Selna Saji. 2019. Valuing Grid- connected Rooftop Solar: A Framework to Assess Costs and Benefits to Discoms. Council on Energy, Environment and Water, New Delhi: Council on Energy, Environment and Water.

Kuldeep, Neeraj, Selna Saji, and Kanika Chawla. 2018. Scaling Rooftop Solar: Powering India's Renewable Energy Transition with Households and DISCOMs. New Delhi: Council on Energy, Environment and Water.

Kumar, Jitendra, B V Suryakiran, Ashu Verma, T S Bhatti, and Kumar Jitendra. 2019. "Analysis of techno-economic viability with demand response strategy of a grid-connected microgrid model for enhanced rural electrification in Uttar Pradesh, India." Energy 176-185.

Ministry of New and Renewable Energy. 2018. "National Wind-Solar Hybrid Policy, 2018." August. http://www.cbip.org/Policies2019/PD_07_Dec_2018_Policies/1_MNRE/1- Wind%20Solar/1%20Summary%20National%20 Wind-Solar%20Policy.pdf.

Ministry of New and Renewable Energy. 2018a. "Press release: PIB." 14 May. https://pib.gov.in/newsite/PrintRelease.aspx?relid=179270.

Ministry of New & Renewable Energy. 2019. "Programme/Scheme wise Physical Progress in 2019-20 & Cumulative upto Dec,2019." Physical Progress (Achievements). December. Accessed January 21, 2020. https://mnre.gov.in/physical-progress-achievements.

National Sample Survey Office, National Statistical Organisation. 2012. "Household Consumption of Various Goods and Services in India: NSS 66th round." February.

NITI Aayog & World Energy Council. 2018. "Zero Emission Vehicles (ZEVs): Towards a Policy Framwork." https://niti.gov.in/writereaddata/files/document_publication/EV_ report.pdf.

PIB Delhi. 2019. September. https://pib.gov.in/PressReleasePage.aspx?PRID=1585979.

PIB. 2019. Press Release. March. https://pib.gov.in/PressReleaseIframePage. aspx?PRID=1567807.

Press Information Bureau, Government of India. 2019. "Press release: PIB." PIB. 07 March. Accessed Januray 2020. https://pib.gov.in/PressReleaseIframePage. aspx?PRID=1567807.

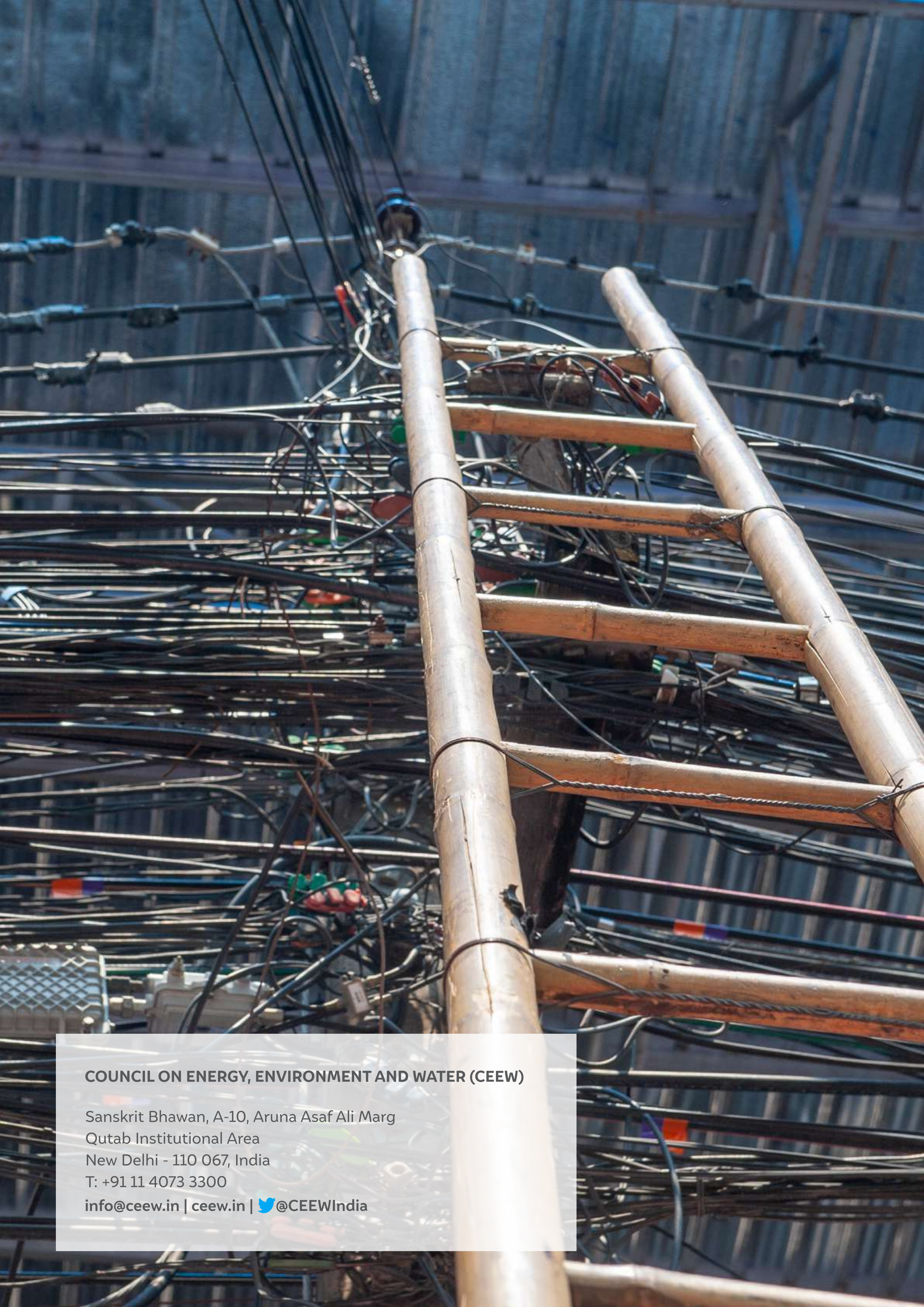
PV Magazine. 2019. Lobby group demands expansion of net metering in Uttar Pradesh. 12 February. Schnitzer, Daniel, Deepa Shinde Lounsbury, Juan Pablo Carvallo, Ranjit Deshmukh, Jay Apt, and Daniel M. Kammen. 2014. Microgrids for Rural Electrification: A critical review of best practices based on severn case studies. Review, United Nations Foundation. Accessed July 20, 2020.

State Load Despatch Center, Delhi. 2019. "Annual Report 2018-19." https://www. livemint.com/news/india/delhi-electricity-demand-touches-record-7-241-mw-amid-heatwave-1561990772257.html.

Tata Power. 2019. "Tata Power Collaborates with AES and Mitsubishi Corporation to Power Up South Asia's Largest Grid-Scale Energy Storage System in India." February. https://www.tatapower.com/media/PressReleaseDetails/1617/tata-power-collaborates-with-aes-and-mitsubishi-corporation-to-power-up-south-asias-largest- grid-scale-energy-storage-system-in-india.

TERI, NRDC, and IGSD. 2018. "Improving Air Conditioners in India: Cooling India with Less Warming Series-Affordable and Efficient Room Air Conditioners." Accessed April 16, 2020. https://www.teriin.org/sites/default/files/2018-04/improving-air-conditioners-in-india.pdf.

The Times of India. 2020. MSEDCL proposes astronomical Grid Support Charge for solar rooftop. Nagpur, 16 January, 2020.



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