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Valuing Grid-connected Rooftop Solar

A Framework to Assess Costs and Benefits to Discoms

Report | September 2019

Neeraj Kuldeep, Kumaresh Ramesh,
Akanksha Tyagi, and Selna Saji

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In 2019, CEEW once again featured extensively across nine categories in the *2018 Global Go To Think Tank Index Report*, including being ranked as South Asia's top think tank (15th globally) with an annual operating budget of less than USD 5 million for the sixth year in a row. CEEW has also been ranked as South Asia's top energy and resource policy think tank in these rankings. In 2016, CEEW was ranked 2nd in India, 4th outside Europe and North America, and 20th globally out of 240 think tanks as per the ICCG Climate Think Tank's standardised rankings.

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Neeraj Kuldeep has worked and published extensively on renewable energy markets. He is currently leading the rooftop solar programme at CEEW and piloting new utility-led business models to accelerate rooftop solar deployment. Neeraj holds an undergraduate degree in Energy Science and Engineering and an MTech in Energy Systems from the Indian Institute of Technology (IIT), Bombay.

"It is believed that rooftop solar systems only benefit consumers and result in a loss of revenue for utilities. However, the CEEW study will bring clarity on the inherent benefits of a rooftop solar system for the distribution grid. A greater understanding of the subject can lead to an equitable distribution of benefits and costs among stakeholders."

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Formerly a summer research intern at The Council, Kumaresh Ramesh is passionate about renewable energy and sustainability. He is currently pursuing his undergraduate degree in Energy Science and Engineering at IIT Bombay.

"In order to make a meaningful impact, any policy to increase the penetration of rooftop solar in India must recognise the discom as a legitimate stakeholder. This study creates a framework for policymakers to identify and address the discom's concerns regarding the economics of rooftop solar."

Akanksha Tyagi
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An experimental chemist by training, Akanksha contributes to the ongoing work on rooftop solar at CEEW. Currently, she is developing a tool to assess the monetary value of grid-connected rooftop solar for the discoms. Before joining The Council, she was a postdoctoral researcher at ESICB, Kyoto University, and holds a doctorate in Human and Environmental Studies from Kyoto University.

"The framework proposed in the study highlights the net impact of grid-integrated rooftop solar on discom revenues. It will empower discoms to identify profitable sites for future deployments and share net benefits with stakeholders equitably."

Selna Saji
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Selna is an energy and environmental analyst who focusses on renewable energy technologies. At The Council, she is working towards developing business models and tools that will facilitate the adoption of rooftop solar in India. Selna holds a dual postgraduate degree in Management and Engineering of Environment and Energy from Queen's University Belfast and Universidad Politécnica de Madrid.

"Distributed energy resources are an essential part of future energy systems. There need to be robust mechanisms that can evaluate their real value and develop a regulatory framework to facilitate the sustainable growth of the sector."

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Abbreviations

ADCC	avoided distribution capacity cost
AGCC	avoided generation capacity cost
APPC	avoided power purchase cost
ARECC	avoided renewable energy certificate cost
ARR	aggregate revenue requirement
ATC	avoided transmission charges
AWCC	avoided working capital requirement
BRPL	BSES Rajdhani Power Limited
CBA	cost and benefit analysis
CERC	Central Electricity Regulatory Commission
C&I	commercial and industrial
CPUC	California Public Utilities Commission
CUF	capacity utilisation factor
DCF	distribution coincidence factor
DTs	distribution transformers
GHS	group housing societies
IPTC	independent power transmission companies
JNNSM	Jawaharlal Nehru National Solar Mission
KVA	kilo volt ampere
MERC	Maharashtra Electricity Regulatory Commission
MSEDCL	Maharashtra State Electricity Distribution Co. Limited
O&M	operation and maintenance
PPA	power purchase agreements
PSC	Public Service Commission
PV	photovoltaic
REC	renewable energy certificate
RIM	ratepayer impact measure
RPO	renewable purchase obligation
RTS	rooftop solar
SCF	system coincidence factor
SCT	societal cost test
SERC	State Electricity Regulatory Commission
UCBA	utility cost and benefit analysis
UCT	utility cost test
VDER	value of distributed energy resource
VGRS	value of grid connected rooftop solar

Savings on power procurement and RPO fulfillment constitute about 77 per cent of the overall benefits of rooftop solar to discoms.

Image: iStock

Executive summary

India has set itself a lofty target of 40 GW of installed rooftop solar capacity by 2022, of which only a mere 3.8 GW was achieved as of March 2019. However, the declining cost of solar PV systems and effective implementation of net-metering policies are gradually improving the capacity deployments. In FY 2018–19, India achieved about 1,500 MW of rooftop solar capacity compared to 1,200 MW in the previous year—a 25 per cent year-on-year growth.

Impact of rooftop solar on discoms' revenue

As rooftop solar deployment increases, concerns about the loss of revenue to discoms also heighten. Higher electricity tariffs make rooftop solar systems more attractive to high-paying commercial and industrial consumers who currently cross-subsidise low-paying residential and agricultural consumers. Discoms will lose their best-paying consumers, who contribute to the cross subsidy, if more of these high-consumption categories reduce their reliance on grid-supplied electricity. Furthermore, greater penetration of rooftop solar technology at the distribution transformer level may require network upgradation on a case-to-case basis, to support the reverse flow of power from distributed solar generators, grid balancing, scheduling and forecast, and anti-islanding protection. This is an additional investment required to facilitate rooftop solar installations. These costs would then be passed on to non-solar consumers as part of the aggregate revenue requirement (ARR), which would lead to cross-subsidisation of solar integration costs by non-solar consumers.

However, rooftop solar also offers multiple inherent benefits to discoms, which are often overlooked. The installation of rooftop solar systems in the distribution grid contributes to—among other things—balancing demand at peak and off-peak hours, decongesting the distribution network, avoiding energy procurement from expensive generators, fulfilling the discom's renewable purchase obligation (RPO), and reducing transmission and distribution losses. Discoms realise these benefits through savings on capital expenditure and by postponing the investment required to cater to growing energy demands. Due to a poor understanding of the monetary value of rooftop solar, these benefits have not yet been adequately quantified in the Indian context. For example, some reports compare the societal benefits and costs of rooftop solar without assigning a monetary value to them (Natarajan and Nalini 2015). Others estimate the benefits of rooftop solar to the consumer while ignoring the associated costs/benefits to discoms (Pallav and Chakrabarti 2018) or oversimplifying the tariff structure (Mehebub 2017).

Due to a poor understanding of the monetary value of rooftop solar, its benefits have not yet been adequately quantified in the Indian context

Most Indian discoms are currently in a weak financial position. They suffer from high losses due to poor grid infrastructure, irregular peak demand patterns, electricity theft, and billing inefficiency. Burgeoning regulatory assets, deferred tariff hikes, and delays in the disbursement of the state subsidy also add to their poor financial health. Thus, the perception that rooftop solar will only further hurt their revenue makes them unwilling partners on the path to meet the ambitious target for rooftop solar.

Moving beyond net-metering

The current billing framework for rooftop solar energy favours consumers by offering them economic incentives to encourage adoption. In India, net-metering and gross-metering mechanisms have been adopted across discoms for metering and billing the electricity generated by grid-connected RTS systems. In both cases, the electricity generated by the rooftop solar system is fed into the grid, with some compensation accruing to the electricity producer, who, in this case, is also the consumer. The net-metering framework allows RTS consumers to substitute grid consumption with solar electricity, effectively awarding them compensation for solar electricity at the grid rate.

The real value of the inherent benefits that a rooftop solar system offers a discom depends on the location and time of generation

On the other hand, in the case of gross-metering, solar electricity is compensated at a pre-determined feed-in-tariff (FiT) rate. The real value of the inherent benefits that a rooftop solar system offers a discom depends on the location and time of generation. As current metering policies in most states do not consider the above two factors, they end up benefitting consumers disproportionately. Once the benefits and costs are properly quantified, it will become possible to develop a new tariff structure to fairly compensate RTS owners and the discom for the real value of the energy generated by the system.

Objectives of the study

Realising the need to accurately estimate the impact of grid integration of rooftop solar on discom finances, CEEW conducted a study to assess the economic value of integrating rooftop solar with discoms with the following objectives:

- To develop a detailed understanding of the associated costs and benefits of rooftop solar from the discom's perspective
- To develop a framework to assign monetary value to the associated costs and benefits of rooftop solar systems which can be used to develop more equitable billing and metering mechanisms

BSES Rajdhani Power Limited (BRPL), a Delhi-based discom, has been supporting us in this effort; they have provided technical guidance and the datasets required to undertake this quantitative assessment. This report presents a systematic methodology to assess the value of grid-connected rooftop solar (VGRS) for Indian discoms based on the simple cost and benefit analysis (CBA) method and discusses the results for selected service area of BRPL. The method could be extended to any utility provided the minimum required data is available.

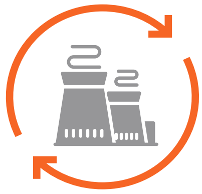
A comprehensive CBA-based VGRS framework for any discom will depend on three key parameters—time frame, location, and baseline. Rooftop solar PV systems have an estimated lifetime of 25 years. Thus, a 25-year period is the preferred duration for the framework. Since the consumer mix at the distribution transformer (DT) level varies significantly, the impact of rooftop solar in reducing peak demand and DT loading will vary by location. Thus, the framework evaluates different kinds of DTs to understand the real contribution of a solar system in peak reduction. The baseline estimates the scenario in the absence of rooftop solar. It includes all the actions and planned projects in the CBA time frame with the exception of those involving rooftop solar systems. It is later compared with the scenario when the technology is in place.

Assessing individual benefits and costs

Benefit parameters

Avoided generation capacity cost (AGCC)

Discoms procure power from generation companies by signing new or renewing long-term power purchase agreements (PPA). They also source power from the open market to meet peak demand. Fixed payments towards capacity procurement form a significant portion of the discom's expenses. Since the generation from rooftop solar can decrease the contracted capacity for a new PPA, discoms can reduce their fixed expenses significantly. These savings come with the benefit of avoided generation capacity cost. The magnitude of the benefit depends principally on the installed rooftop solar capacity and the system coincidence factor (SCF), which represents the fraction of system load supported by rooftop solar.



Rooftop solar electricity substitutes the most expensive energy procured by the discom at any given time interval if the discom follows a merit-order despatch

Avoided power purchase cost (APPC)

APPC refers to the variable part of the power purchase cost that the discom pays for the actual quantum of electricity procured from generators. However, as per the PPA contracts, discoms are bound to pay a fixed cost to generators. Rooftop solar electricity substitutes the most expensive energy procured by the discom at any given time interval if the discom follows a merit order despatch. Therefore, the magnitude of this benefit depends on the generation profile of the rooftop solar 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.

Avoided transmission charges (ATRC)

Transmission charges refer to the fixed payments that discoms make for the share of the transmission network they are allocated to transmit power from distant power generation stations. As higher rooftop solar capacities lead to avoiding procurement of additional transmission capacity, these savings are accounted for in the avoided transmission charges benefit. Similar to AGCC, the value of this benefit is decided by the installed rooftop solar capacity and the transmission coincidence factor.

Avoided distribution capacity cost (ADCC)

Rooftop solar does not require an elaborate distribution network, thereby relieving the load on the distribution system. Therefore, through rooftop solar power, discoms can bring down expenses related to the installation and maintenance of additional network components with simultaneous decongestion. The savings due to deferred capital investment resulting from the decongestion need to be estimated by factoring in the forecasted growth in the connected load. These savings, along with the reduced operations and maintenance costs, make up the avoided distribution capacity infrastructure and related costs.

Avoided renewable energy certificate cost (ARECC)

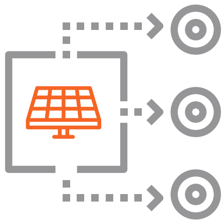
Generation from grid-interactive rooftop solar systems within the discom service area contributes towards the fulfilment of their RPO targets. Thus, by supporting the adoption and integration of rooftop solar, discoms can cut down on the purchase of renewable energy certificates. It is important to know that this benefit, with changes in RPOs and the significantly low prices of RECs in the exchange, may only be marginal over time. Also, with the increasing capacity of utility-scale solar energy, discoms may be able to procure 100 per cent of their required solar RPO from large-scale solar power plants, which again will make RECs obsolete.

Avoided working capital requirement (AWCC)

Reduced power purchases, avoided generation capacity, and revenue from the sale of electricity resulting from rooftop solar installations in the distribution grid reduce the discom's overall expenditure. This will be reflected as a reduction in the working capital requirement of the discom—which means the utility will have a lower debt servicing obligation.

Coincidence factors

Some of these benefits depend on the active contribution of rooftop solar during peak hours. Coincidence factors for any given network allow us to quantify the contribution of rooftop solar during peak hours. The framework requires the use of system (utility) (SCF), transmission, and distribution coincidence factors (DCF) which are calculated at the overall utility peak hours, transmission network peak hours, and DT loading peak hours, respectively. Since the utility demand and transmission network have nearly the same profiles, the system and transmission coincidence factors can be assumed to be equal.



Coincidence factors for any given network allow us to quantify the contribution of rooftop solar during peak hours

Cost parameters

Revenue loss

Depending on the category of the consumer, bills were calculated for scenarios with and without rooftop solar installations and in accordance with the current metering policy. The difference between these two amounts is the revenue loss to the utility.

Programme administration cost

Facilitating the deployment of rooftop solar can be a tedious process for discoms. The extant techno-operational regime may need to be overhauled if it is not compatible with the services necessary for rooftop solar, such as bidirectional metering. The discom will need to bear the expenses towards these procedures and an expert workforce, if required. These expenses are presented as the programme administration cost.

Added distribution services cost

Although the rooftop system is expected to work in congruence with the existing distribution network without any additional requirements, the implementation can entail the construction of new components or the upgradation of the existing system. These expenses, borne by the discoms, are covered in the added transmission and distribution services cost.

Case study for BRPL

We carried out an illustrative analysis for rooftop solar projects connected to nine different DTs and one group housing society (GHS) single-point delivery feeder (DT 10) in BRPL's licence area, which are in operation for over a year now. DTs are chiefly characterised by four attributes—rated capacity, loading, rooftop solar penetration (percentage of rated DT capacity), and consumer category (Table ES1). The study performs the VGRS analysis on ten different DTs with a mix of several values for these attributes. We used insights from these DTs to assess the aggregate impact of the total installed rooftop solar capacity on discom revenue. We considered all desired data related to DT loading, the discom load profile, solar generation, and power procurement etc. for the year 2018–19.

Table ES1: Specifications and performance characteristics of rooftop solar systems

Source: Authors' analysis

	DT capacity (KVA)	DT category	Total RTS capacity considered (kW)	Consumer categories	CUF (%)	SCF (%)	DCF (%)
DT 1	100	Industrial	35	Industrial	11.34	13.31	27.09
DT 2	630	Mixed	220	Government	11.76	13.71	33.57
				Commercial	13.45	14.64	36.114
DT 3	990	Institutional	102	Institutional	11.66	12.43	7.38
DT 4	100	Residential (Res)	10	Res	13.51	14.92	19.10
DT 5	100	Institutional	80	Institutional	10.32	11.51	37.25
DT 6	990	Res	10	Res	11.68	12.86	14.86
DT 7	990	Commercial	30	Commercial	13.90	15.35	20.02
DT 8	990	Institutional	63.3	Institutional	12.88	12.59	5.51
DT 9	630	Res	30	Res	16	16.2	8.3
				Res	15.8	15.9	7.8
				Res	15.5	16.6	8.5
DT 10	630	Group housing society (GHS)	120	GHS	13.2	11.2	9.1

The capacity utilisation factor (CUF) across systems is found to be low, with the minimum CUF at 10.3 per cent and the maximum at 16 per cent. The system coincidence factor (SCF) does not vary significantly, representing a similar generation profile across different systems. A higher SCF would lead to higher benefits, as the contribution from solar power increases during peak hours. We observe significant variation in the distribution capacity factor (DCF), which can be largely attributed to variations in DT load profiles.

Table ES2: Generation-normalised net value for each DT (all values in INR/kWh)

Source: Authors' analysis

	DT 1	DT 2	DT 3	DT 4	DT 5	DT 6	DT 7	DT 8	DT 9	DT 10
AGCC	0.38	0.36	0.33	0.35	0.35	0.35	0.35	0.31	0.32	0.26
APPC	1.01	1.02	1.02	1.02	1.02	1.02	10.2	1.01	1.02	1.02
ATRC	0.09	0.09	0.08	0.09	0.09	0.09	0.09	0.08	0.08	0.07
ADCC	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
ARECC	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
AWCC	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.00
Revenue loss	1.74	1.92	1.92	1.86	1.92	1.74	1.92	1.92	1.40	1.08
Net benefit	0.48	0.06	0.02	0.09	0.04	0.21	0.04	-0.02	0.51	0.75

Table ES2 shows the generation-normalised values of different benefit and cost parameters across the selected DTs. As expected, the revenue loss to the utility is much higher when non-domestic consumers—like commercial, industrial, and institutional ones—set up rooftop solar installations. However, in case of net export to the grid, the revenue loss would be lower since the excess solar electricity is compensated at the average power procurement cost—which is lower than the consumer's grid tariff. This is applicable only when average grid tariff for any consumer is higher than the average power purchase cost or any other tariff approved by the Hon'ble Commission to compensate solar export. Since the major benefits are quite similar, there is a strong correspondence between the revenue loss and the net benefit—the higher the revenue loss, the lower the net benefit. Table ES3 and Figure ES1 show aggregate generation-normalised benefits and costs across the ten DTs.

Table ES3: Generation-normalised aggregate costs and benefits for selected ten DTs

Source: Authors' analysis

Parameter	AGCC	APPC	ATRC	ADCC	ARECC	AWCC	Revenue loss	Net benefit
Value (INR/ kWh)	0.33	1.02	0.08	0.01	0.48	0.02	- 1.72	0.22

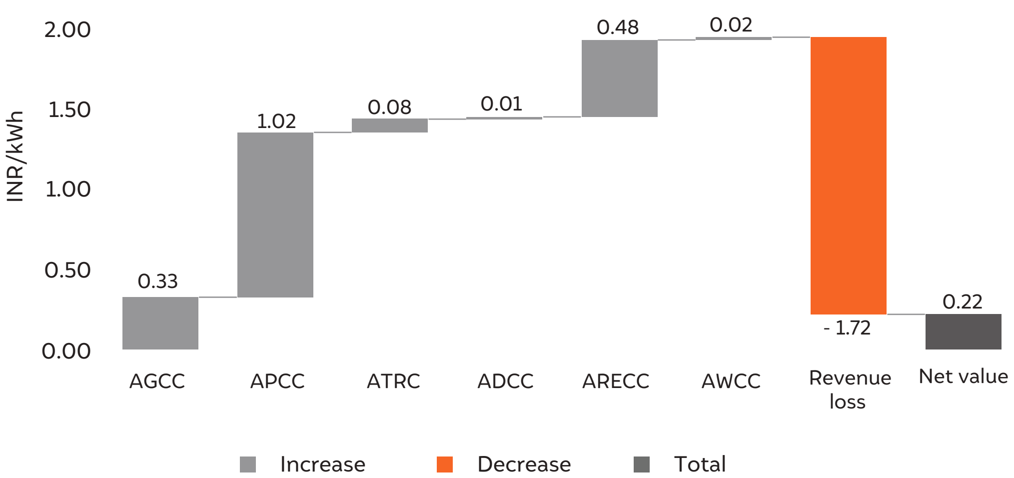
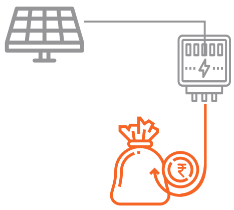


Figure ES1: Generation-normalised aggregate costs and benefits for selected ten DTs

Source: Authors' analysis

Key observations

- **The total inherent benefits of a rooftop solar system outweigh the revenue loss to the discom. The net gain amounts to INR 0.22 for every unit of electricity generated from a rooftop solar system.**
- The higher share of rooftop capacity in commercial and industrial categories, about 36 MW of total 45.18 MW capacity, limits overall benefits to discoms.
- Rooftop solar installations in the residential consumer category, in lower tariff slabs, tend to offer a greater benefit to discoms. Residential DTs in the BRPL area offered a maximum net gain of INR 0.75/kWh in case of high-rise societies with a single point delivery of electricity.
- Revenue loss in the residential category is the lowest among all consumer categories. BRPL loses INR 1.08–1.92 for every unit of solar electricity generated by a residential consumer compared to INR 1.74 and INR 1.92 in the industrial and commercial categories, respectively. Revenue loss in any consumer category is commensurate to their electricity tariff rate.
- Savings on power procurement and RPO fulfillment constitute about 77 per cent of the overall benefits to the discom.
- Increasing the share of rooftop solar capacity deployment in the residential category will lead to more significant benefits to discoms. To maximise their benefits, discoms should promote rooftop solar systems among their subsidised consumer categories.
- **Rooftop solar systems contribute to reducing a discom's peak demand by about 13 per cent of its rated capacity.**
- Increasing the rooftop solar penetration on a DT will increase the generation-normalised net value due to the increased impact of decongestion.



The total inherent benefits of a rooftop solar system outweigh the revenue loss to the discom. The net gain amounts to INR 0.22 for every unit of electricity generated from a rooftop solar system

Key recommendations

- Rooftop solar systems in the residential category provide maximum benefits to discoms; increased deployment will lead to higher benefits and savings on cross-subsidies.
- DTs with frequent overloading and day time peaks serve as useful targets for rooftop solar deployment to further improve the net benefit.
- Prioritise the net export of solar power into the grid, assuming net-metering based compensation. This could be achieved by targeting consumers with large roof areas and lower overall electricity demand.
- In view of the inherent benefits to the discoms, it would be prudent for the discom to promote installation of RTS systems through comprehensive and organised consumer outreach program, ensuring the discovery of most competitive cost / tariff. For these activities, additional suitable compensation mechanism to the discoms by the Government is recommended.

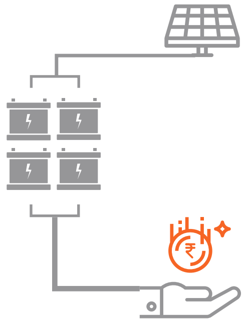
Rooftop solar systems in the residential category provide maximum benefits to discoms. Increased deployment will lead to higher benefits and savings on cross-subsidies.

Image: BRPL

1. Introduction

India has set itself the target of achieving 40GW of rooftop solar capacity by 2022. The cumulative installed capacity recently crossed the 3.8 GW mark, which is miniscule compared to the total target. However, with the improving cost completeness of rooftop solar PV systems and the on-ground operationalisation of net-metering policies, solar installations are expected to grow at a faster pace. In FY 2018–19, about 1,500 MW of rooftop solar capacity was achieved, compared to 1,200 MW in the previous year—a 25 per cent annual growth.

In recent years, discoms and state nodal agencies have undertaken multiple initiatives to promote roof top solar. BSES Rajdhani Power Limited (BRPL), under the Solarise Dwarka scheme, aims to support high-rise societies in installing rooftop solar systems under the Renewable Energy Service Company (RESCO) model. Similarly, Andhra Pradesh Eastern Power Distribution Company Limited (APEPDCL) has launched an on-bill financing scheme to encourage adoption of solar power among low-income groups. Concentrated efforts by discoms and state nodal agencies have been able to eliminate various market challenges such as high upfront costs and delays in the net-metering process and subsidy approvals while offering solar electricity at desirable tariffs. A recent rooftop solar tender in Madhya Pradesh is one such example, where the solar tariff reached a low of INR 1.58/kWh (Business Standard 2018).

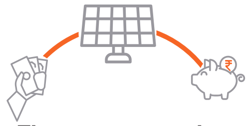


Net-metering is thought to present an additional cost to discoms, since solar consumers only pay for their net consumption but continue to use the distribution infrastructure to bank excess solar generation

As rooftop solar deployment increases, there are growing concerns around the loss of revenue for discoms. Current market prices make rooftop solar an attractive option for high-paying residential, commercial, and industrial customers. These consumers also cross-subsidise consumers in the residential and agricultural categories. Discoms will lose out on revenue and cross-subsidies as high-paying consumers start substituting a part of their electricity consumption with solar. The net-metering policy, which has been a key enabler for accelerating the rooftop solar market, is also contended by discoms. Net-metering is thought to present an additional cost to discoms, since solar consumers only pay for their net consumption but continue to use the distribution infrastructure to bank excess solar generation. It limits discoms' capacity to recover the fixed investment that they have already incurred in laying distribution infrastructure such as distribution transformers (DTs), substations, wires, etc.

In addition, the higher penetration of rooftop solar at the DT level would require network upgradation to support the reverse flow of power from distributed solar generators, grid balancing, scheduling and forecast, and anti-islanding protection. This is an additional investment required to facilitate rooftop solar installations. These costs would then be passed on to non-solar consumers as part of the aggregate revenue requirement (ARR), which would lead to the cross-subsidisation of solar integration costs by non-solar consumers.

In opposition to this, proponents of rooftop solar argue that rooftop solar offers inherent benefits, not just for consumers but also for discoms. Apart from savings on electricity bills for consumers, rooftop solar can contribute to balancing demand, decongesting the distribution network, avoiding energy procurement from generators, complying with renewable purchase obligations (RPOs), and reducing transmission and distribution losses. Discoms would be able to realise these benefits by saving on their capital expenditure and differing the investments required to cater to the growing energy demand. However, there is still a significant lack of understanding of methods to quantify these benefits.



There is a need to understand the associated costs and benefits of rooftop solar from the perspective of different stakeholders to avoid conflicts between discoms, non-solar consumers, and solar consumers

Such arguments will continue to emerge as the rooftop solar industry grows. There is a need to understand the associated costs and benefits of rooftop solar from the perspective of different stakeholders to avoid conflicts between discoms, non-solar consumers, and solar consumers. Essentially, what benefits consumers is usually a cost for discoms. The quantification of such benefits would lead to an equitable distribution of benefits and costs among the different stakeholders. This would also prevent discoms from imposing unprecedented charges to recover their costs, similar to the additional charges paid by open-access consumers for sourcing power directly from either generators or the electricity exchange. Such impositions could be deterrents for the rooftop industry and derail the ambitious target to achieve a 40GW rooftop solar capacity.

Study objectives

Realising the need to accurately estimate the impact of grid integration of rooftop solar on discoms' finances, Council on Energy, Environment and Water (CEEW), in partnership with BRPL, is conducting a study to assess the economic value of integrating rooftop solar for discoms. This report aims to develop a systematic methodology to assess the value of grid-connected rooftop solar (VGRS) systems with the following objectives:

- Develop a detailed understanding of the associated costs and benefits of rooftop solar PV systems from the discom's perspective
- Develop a framework to assign a monetary value to the associated costs and benefits of rooftop solar PV, which can be used to develop more equitable billing and metering mechanisms

There are several studies that have undertaken a hyphenate analysis (CBA) for distributed solar energy in different American states like Arizona (Beach and McGuire 2013), Colorado (Xcel Energy Services 2013), New York (Patel, et al. 2015), and California (Cohen, Kauzmann and Callaway 2016). However, a similar analysis for the Indian power sector is much needed. In the Indian context, most of the existing reports focus on specific aspects of rooftop solar. For example, some reports compare the societal benefits and costs of rooftop solar without assigning a monetary value to them (Natarajan and Nalini 2015). Others estimate the benefits of rooftop solar to the consumer while ignoring the associated costs and benefits for discoms (Pallav and Chakrabarti 2018) or oversimplifying the tariff structure (Mehebub 2017). This report is a seminal work in determining the value of rooftop solar PV systems for Indian discoms. It proposes a simple utility cost and benefit analysis (UCBA) method tailored for the Indian electricity system and summarises the key parameters that discoms should consider to embrace and benefit from this revolutionary change in the Indian power sector.

2. Implications of rooftop solar on discom revenues

The persistent reluctance of discoms to integrate rooftop into the grid primarily from the anticipated financial loss. To meet the increasing electricity demand, most discoms have long-term power purchase agreements (PPAs) with various generation companies (gencos). Due to the capacity charges specified in the PPA, the discom must pay a fixed amount for the allocated capacity even if a portion of the energy requirement is fulfilled by rooftop solar.

Other expenses associated with upgrading the system can be expected. The grid integration of rooftop solar might require the construction of additional infrastructure like smart meters or the upgradation of the distribution network, the cost of which would be borne by the discoms either directly or indirectly. Finally, the intermittent nature of rooftop solar is detrimental to its adoption. Power generation from rooftop solar is highly variable and affected by natural and technical issues. This means that discoms cannot rely entirely on it to fulfil their requirements. This also implies that they would have to set up additional resiliency services in case of situations when rooftop solar is unavailable. These added services and costs translate to increased expenses for discoms, which explain their unwillingness to adopt rooftop solar.

However, this is only one side of the story, as there are ample benefits to rooftop solar that are often overlooked by the discoms. First, by procuring power from rooftop solar, discoms can reduce their capacity requirements, and at times, substitute energy procurement from expensive power plants and power exchanges. Second, they can reduce their transmission and distribution losses; since power generation stations are located far from points of consumption, discoms lose huge amounts of power while delivering it to consumers. Thus, they often purchase more power than the actual requirement to account for these losses. Rooftop solar, however, has the advantage of coincident generation and consumption points. This minimises the transportation and distribution of electricity considerably, thereby minimising power loss. Third, rooftop solar can reduce congestion in distribution networks. Increased adoption of rooftop solar in areas with congested networks can reduce the load demand and help defer discoms' investment in network upgradation. This is especially valuable in areas where there are land constraints. Thus, adopting rooftop solar will help

Increased adoption of rooftop solar in areas with congested networks can reduce the load demand and help defer discoms' investment in network upgradation

discoms minimise their capacity and power procurement expenses, while also reducing transmission and distribution losses and network congestion.

Another potential benefit of adopting rooftop solar for discoms is fulfilling their RPO. The Government of India, under its *Jawaharlal Nehru National Solar Mission* (JNNSM) initiative to promote renewable energy, has mandated that all discoms should procure a fixed fraction of their total power from renewable sources. At present, due to technical and non-technical factors like the current capacity of renewable power sources, this requirement remains unfulfilled. Thus, discoms purchase renewable energy certificates (RECs) to meet their RPOs. By purchasing power from rooftop solar, they can fulfil their RPOs and avoid purchasing RECs.

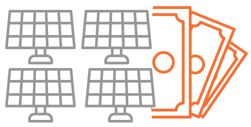
Although various costs and benefits have been described, these are variable and not necessarily applicable to all discoms throughout the lifetime of a rooftop solar system. For instance, the proposed benefit of avoiding capacity procurement from generation stations by adopting RTS systems will be applicable only if no new PPAs are signed in the year following the implementation of the rooftop solar (RTS) system. The same applies to potential reductions in distribution and transmission losses. These losses are huge, and the current capacity of rooftop solar systems might not have any significant impact in minimising them. Similarly, discoms would not have to endure all the costs listed above to integrate rooftop solar. For example, some locations may already be capable of incorporating rooftop solar, in which case the construction of new transmission and distribution infrastructure can be avoided. Thus, it is crucial to develop a quantitative method like VGRS that clearly defines the analysis timeline, sets geographical boundaries, and gives reasonable weightage to the different benefits and costs to determine the overall impact grid-integration solar on discoms.

3. Need to look beyond net-metering

Image: iStock

Most Indian discoms are currently in a poor financial position. They suffer large losses due to various reasons like poor grid infrastructure, irregular peak demand, electricity theft, and billing inefficiency. Burgeoning regulatory assets, deferred tariff hikes, and delays in disbursing state subsidies also consistently add to their poor financial health. Further, the electricity tariff being lower than the average cost of supply (ACoS) in the residential and agriculture consumer categories restricts discoms' capacity to recover their cost. Discoms, to compensate for the deficit between ACoS and consumer tariffs, impose cross-subsidies on commercial and industrial consumers. However, with declining rooftop solar tariffs, discoms' high-paying consumers—industrial, commercial, and institutional consumers—are becoming early adopters, thus reducing their dependence on the grid. Discoms fear that this is worsening their financial situation as they are losing out on cross-subsidies and revenue from high-paying consumers.

The current billing framework for rooftop solar also favours consumers, offering economic incentives for early adopters . In India, net-metering and gross-metering mechanisms have been adopted by discoms for metering and billing the electricity generated by grid-connected RTS systems. The net-metering framework allows RTS consumers to substitute grid consumption with solar electricity and receive compensation for it at the grid rate. Whereas, in case of gross-metering, solar electricity is compensated at a pre-determined feed-in-tariff (FiT) rate. In either case, the existing mechanism follows a volumetric approach to compensate solar electricity at a fixed rate, irrespective of whether it was consumed at the source or was exported to the grid. This does not account for the real costs and benefits incurred by the discom depending on the location and the time of generation or the consumers' tariff slab. However, with a VGRS-based compensation mechanism, it is possible to develop a new tariff structure to compensate the rooftop solar owners as well as the discom for the real value of the energy generated by the system.



The existing mechanism follows a volumetric approach to compensate solar electricity at a fixed rate, irrespective of whether it was consumed at the source or was exported to the grid

The various benefits of rooftop solar for discoms include avoidance of costlier power purchases during peak demand, reductions in transmission and distribution losses, decongestion of the distribution network, reductions in working capital requirements, avoidance of capacity procurement, etc. The costs associated with supporting rooftop solar would include loss of cross-subsidies and revenues from high-paying consumers, costs of grid integration, and any administrative expenditure borne by the discoms. Hence, to ensure a sustainable scaling up of rooftop solar technology, it is necessary to develop an accurate analysis framework for the equitable distribution of the associated costs and benefits among all the stakeholders, including discoms and solar consumers, solar consumers, and non-solar consumers..

Electricity utilities (discoms) in the west are already taking the lead on this. The states of New York and California conducted studies to assess the value of integrating different distributed energy resources (DERs) into the grid, including rooftop solar. The methodology, termed as value of distributed energy resource (VDER), is a cost and benefit analysis (CBA) for the concerned distributed energy resource, specific to the location and perspective of the stakeholder, which could be the utility, installer, or society.

In 2016, the California Public Utilities Commission (CPUC) issued an assigned ruling to use a locational net benefit analysis (LNBA) to evaluate the value of different DERs (California Public Utilities Commission 2016). Similarly, in March 2017, the Public Service Commission (PSC) of New York approved Phase 1 of VDER and implemented it in September that year as a new method for compensating owners for the electricity generated from rooftop solar (State of New York Public Service Commission 2017).Although subsequent developments relating to both methods have shown that the tools require further development to meet market requirements, the initiative to transition from net-metering is a prudent step to ensure fair compensation for solar energy.

To ensure a sustainable scaling up of rooftop solar technology, it is necessary to develop an accurate analysis framework for the equitable distribution of the associated costs and benefits among all the stakeholders, including discoms and solar consumers, solar consumers, and non-solar consumers.

4. Value of grid-connected rooftop solar (VGRS)

Image: iStock

As discussed before, rooftop solar offers multiple benefits for discoms; however, these benefits would depend on the solar generation profile and its contribution to the DT load as well as the discom load profile. The VGRS approach takes this into consideration and estimates the benefits rooftop solar could potentially offer the electricity grid and the discom. It employs a CBA to determine the net economic impact of a rooftop solar system.

Based on real grid data, the framework provides the net value added under each cost and benefit parameter; this can be used by the discom to provide monetary credits for the quantum of electricity exported to the distribution grid instead of providing a fixed compensation under the net-metering and gross-metering mechanisms. Such a framework would facilitate the equitable distribution of benefits and costs between the discom and rooftop solar owners. Since discoms would be able to recover their input cost by providing grid infrastructure for energy export, it would lead to sustained growth in rooftop solar installations.

Before developing a comprehensive CBA-based VGRS framework for a discom, the following pertinent considerations should be addressed:

Timeframe: Rooftop solar PV systems have an estimated lifetime of 25 years. Thus, the implementation costs and potential benefits are time dependent. Hence, before starting the analysis, it is crucial to decide on the analysis period and whether the estimates will be on an annual basis or for the entire life of the system.

The timeframe is also relevant while calculating the benefits of avoided power purchase costs (APPC) and capacity reductions. In a real scenario, the cost of power will vary based on the total power demand (load profile) as per the merit order despatch. Evaluating solar energy's contribution in 15-minute or 30-minute intervals would provide a more realistic estimation of savings.

Location: Since the consumer mix at the DT level varies significantly, the overall load profile also differs. Hence, the impact of rooftop solar in reducing peak demand and DT loading will differ across locations. For instance, an industrial DT might be overloaded at night; in this case, the decongestion benefit of a solar system will be zero. Thus, the analysis should consider different DTs to understand the real contribution of solar systems in peak demand reduction.

Baseline: The baseline predicts what the scenario would be in the absence of rooftop solar; it includes all other actions and planned projects in the CBA timeframe. It is later compared with the scenario that has the technology in place.

Perspective: Rooftop solar deployment in distribution grids impacts three different stakeholders: discoms, rooftop solar owners, and non-solar consumers. A universal CBA considers the perspectives of all stakeholders in the rooftop solar project by conducting specific cost-effective tests. The main categories of cost-effective tests recommended in a CBA (Edison 2018) are:

- **Utility cost test (UCT):** This test reflects the perspective of discoms and compares their loss of revenue with the benefits they avail from rooftop solar installations in their distribution area.
- **Ratepayer impact measure (RIM):** This test analyses the impact of increased rooftop solar adoption on non-solar consumers due to change in grid electricity tariff as the rooftop solar impacts the discom revenue. The test compares increased utility cost and avoided investment by not installing a rooftop solar system.
- **Societal cost test (SCT):** This test analyses the overall impact of adopting rooftop solar on the society after considering the impacts on utility and non-solar consumers. It also includes environmental benefits while assessing the CBA.

A universal CBA considers the perspectives of all stakeholders in the rooftop solar project by conducting specific cost-effective tests

5. Assessing discom losses and gains from rooftop solar

Due to its very nature, a grid-connected rooftop solar system will impact generation (or bulk generators), transmission, and distribution. This will, in turn, have a bearing on the discom's operations, which will be reflected in its ARR, and will be passed on to consumer tariffs. Thus, precisely defining the different benefits and costs of rooftop solar to the discom is of utmost importance to the power sector value chain. Table 1 lists the components applicable to the UCT for discoms. The following sections discuss each parameter in detail and present a working formula for computation. The formulas, originally from the CBA whitepaper (Edison 2018), have been modified for the Indian power sector.

Table 1:
List of benefits and costs considered in the UCT

Source: Authors' analysis

Benefit parameters	Generation (bulk) system	Avoided generation capacity cost
		Avoided power purchase cost
	Transmission system	Avoided transmission charges
		Reduced transmission losses
	Distribution system	Avoided distribution capacity cost
		Reduced distribution losses
	Externalities	Avoided renewable energy certificate cost
		Avoided working capital requirement
Cost parameters	Programme administration costs	
	Added distribution services costs	
	Revenue loss	

5.1 Avoided generation capacity cost (AGCC)

Discoms procure power from gencos (by signing PPA) and the open market to meet peak demand. These fixed payments towards capacity procurement are a significant portion of the discom's expenses. Some conventional power plants have a higher cost of electricity than rooftop solar power. For example, the solar tariff at the auctions in Madhya Pradesh in August 2018 reached INR 1.58 per kWh after the 50 per cent subsidy provided by the government. Contrarily, the average variable price of electricity from thermal power stations in Madhya Pradesh, as per the ARR and retail supply tariff order of Madhya Pradesh Electricity Regulatory Commission (MPERC) for FY 2018–19, was INR 2.12 per kWh. When coupled with fixed charges, the electricity from thermal plants becomes much more expensive than that from rooftop solar. Therefore, if the power generation from rooftop solar systems is enough to deter discoms from signing new PPAs, then the discoms can reduce their expenses significantly. These savings are categorised as the benefit of AGCC.

However, the contribution of this benefit depends on when a PPA is due. A rooftop solar system has an operational lifetime of 25 years. If a discom already has sufficient power to cater to its demand and does not plan to sign any PPAs during this analysis period, the AGCC benefit is irrelevant. They will keep paying the gencos irrespective of the solar penetration in their service area. The magnitude of the benefit depends on several factors like the output, efficiency, and availability of rooftop solar, transmission and distribution losses, and coincidence factor. The coincidence factor is the fraction of the system peak load supported by rooftop solar. A higher coincidence factor translates to more support and thus an increased benefit. The availability of load profile data and solar generation data for every 15-minute interval is crucial for a precise determination of the AGCC benefit.

Working formula:

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

Description:

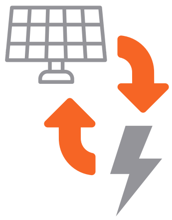
RTSoutput (kW): Rated capacity of the RTS

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



Depending on the discom's load profile and the time of the day, power generated from rooftop solar serves as a substitute for power procurement from base load plants, power exchanges, or other sources

5.2 Avoided power purchase cost (APPC)

This refers to the variable part of the power purchase cost, or the amount the discom pays for the actual quantum of electricity procured from the genco. The power procurement portfolio varies across discoms. But generally, the base load is covered by long-term PPAs and the intermediate and peak loads are covered by medium- and short-term purchases. Depending on the discom's load profile and the time of the day, power generated from rooftop solar serves as a substitute for power procurement from base load plants, power exchanges, or other sources. Since rooftop solar reduces demand at the source, it can be assumed that the power generated by it substitutes the most expensive energy procured by the discom at any given time, if the discom follows the merit order despatch method.

Therefore, the magnitude of this benefit depends on the generation profile of the rooftop solar system, the load profile of the discom and its power procurement strategy, and the variable power purchase cost of electricity from different sources in each time interval.

Working formula:

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

Description:

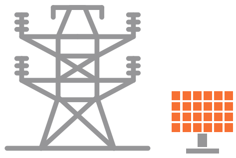
RTSEnergy (kWh): Actual electricity produced by RTS system

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

5.3 Avoided transmission charges (ATRC)



An increase in rooftop solar capacity within a discom's distribution network reduces its overall power requirement

Transmission charges refer to the fixed payments made by the discoms for their allocated share of the transmission network, which they use to transmit power from distant power generation stations to the point of consumption. An increase in rooftop solar capacity within a discom's distribution network reduces its overall power requirement. If this reduction in load leads to avoiding the procurement of additional transmission capacity, then these savings are accounted in the ATRC benefit.

An accurate estimation of this benefit requires data regarding the annual transmission capacity procured by the discom, the electricity production from rooftop solar, and the fraction of transmission peak load met by rooftop solar (transmission coincidence factor).

Working formula:

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

Description:

RTSoutput (kW): Rated capacity of the rooftop solar system

TransmissionCoincidenceFactor (dimensionless): Fraction of 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 hours to its rated output (kW)

DegradationFactor (dimensionless): Factor to account for the decrease in performance of the rooftop solar system over the years

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

TL%: Transmission loss per cent

DL%: Distribution loss per cent

5.4 Reduced transmission and distribution losses

Conventionally, electricity generating stations are located far away from consumption/ load centres. Transferring power from the generating station to the receiving sub-station at the discom periphery and then to the end consumer leads to inter-state and intra-state transmission and distribution losses. To make up for these losses, discoms buy more power than required, which increases their expenses. Due to its coincident generation and consumption points, rooftop solar energy is free from these losses. Thus, adopting rooftop solar can help discoms avoid transmission and distribution losses and improve their efficiency.

The benefits associated with reduced transmission and distribution losses are already accounted for in the AGCC and APPC sections. One should always be careful while estimating this benefit to avoid double counting. If the rooftop solar system changes the topology of the distribution system to decrease transmission and distribution losses substantially, one should count this benefit separately. However, the present scale of these losses and the low penetration of rooftop solar suggests that any noticeable reduction in the losses is a distant reality.

5.5 Avoided distribution capacity cost (ADCC)

By procuring power from rooftop solar, discoms can reduce the expenses associated with installing and maintaining additional network components, while simultaneously benefitting from decongestion

An efficient distribution network is imperative to ensure reliability in electricity supply. Due to its large scale, the network faces several issues. For instance, the timely installation and maintenance of network components at specific locations is a huge technical challenge. Furthermore, overloading and congestion of the network decreases the efficiency and lifetime of these components. Maintaining the network is an integral part of the discoms' responsibilities and consumes a part of their revenues. Rooftop solar can help discoms tackle these issues and cut down on these expenses.

The rooftop solar system does not require an elaborate distribution network. Besides, switching to rooftop solar in areas of high demand will relieve the load on the transmission system. Therefore, by procuring power from rooftop solar, discoms can reduce the expenses associated with installing and maintaining additional network components, while simultaneously benefitting from decongestion. Three components should be assessed to estimate the avoided distribution capacity infrastructure and related costs—savings from deferred capital investment, reduced operations and maintenance, and improved life of network infrastructure due to the reduced load on the network.

The benefit is calculated for each sub-station, due to the varying nature of network requirements. Its magnitude depends on the output, availability, and the fraction of the distribution system load supported by rooftop solar. The component-wise cost of all the elements in the distribution network is also required for the accurate estimation of this benefit.

Working formula:

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

Description:

RTSoutput (kW): Rated capacity of the rooftop solar systems

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

DegradationFactor (dimensionless): Factor to account for the decrease in the performance of the rooftop solar system over the years

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

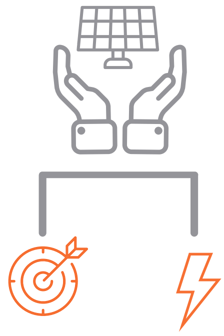
TL%: Transmission loss per cent

DL%: Distribution loss per cent

5.6 Avoided renewable energy certificate cost (ARECC)

The RPO regulation obligates Indian discoms to purchase a fixed proportion of their annual electricity demand from renewable energy sources such as solar and wind. Generation from rooftop solar 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 rooftop solar, discoms can achieve their annual RPO targets and cut down their expenditure on RECs.

It is important to know that this benefit might become irrelevant in the future with changes in RPO regulations. Also, as the capacity of utility-scale solar energy increases, discoms will be able to procure 100 per cent of their required solar RPO from large-scale solar power plants, which again will make RECs obsolete. Thus, at some point, this might not be applicable as a benefit to adopting the rooftop solar.



By supporting the adoption and integration of rooftop solar, discoms can achieve their annual RPO targets and cut down their expenditure on RECs

Working formula:

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

Description:

RTSEnergy (kWh): Actual electricity produced by the rooftop solar system

RECCost (INR/kWh): The cost to purchase REC

5.7 Avoided working capital requirement (AWCC)

The working capital requirement of a discom reflects the disparity between its total revenue and its expenses. It is a function of the discom's revenue from energy sales and its power purchase cost. The working capital requirement is reviewed every year for any increases and requires the approval of the state regulator. The working capital amount for BRPL is equivalent to the difference between two months' revenue from electricity sales and one month's power purchase cost.

The installation of rooftop solar in the distribution grid would reduce overall expenditure for discoms due to reduced power purchases and avoided purchase of generation capacity. However, discom revenue from electricity sales will also decrease, since solar generation will lead to reduced electricity consumption from the grid. The net effect of these changes would be reflected in the change in the working capital requirement of the discom.

Working formula[1]:

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

Description:

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

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

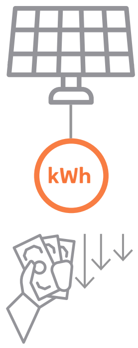
ATRC (INR): Avoided transmission charges in the respective year

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

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

RevenueLoss (INR): Revenue loss to the discom

DebtRate (%): Regulator-approved debt financing rate



Migrating to rooftop solar does not change the sanctioned load, but it allows consumers to save on the payment of the variable component, by reducing electricity consumption from the grid

5.8 Revenue loss

Revenue from consumers is crucial for discoms to recover their annual expenses. The Indian tariff structure is a cross-subsidy model in which agriculture and residential consumers pay a subsidised or lower tariff than industrial and commercial consumers, who bear the cost of the subsidy by paying higher tariffs. The consumer tariff has a fixed and variable component, corresponding to the sanctioned load and the consumed units. Migrating to rooftop solar does not change the sanctioned load, but it allows consumers to save on the payment of the variable component, by reducing electricity consumption from the grid.

Increased migration to rooftop solar among consumers can decrease the discoms' revenue in two ways. First, the reduced grid consumption will lower the consumer's electricity bill and, eventually, the discoms' revenue. Second, discoms will lose on cross-subsidy gains from high-paying commercial and industrial consumers as they switch to rooftop solar due to the

1 The formula is 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.

high grid tariff. The revenue loss can be calculated based on the difference between the net electricity bill of the consumer before and after rooftop solar installation.

Working formula:

$$RevenueLoss = \sum(consumer\ bill\ without\ rooftop\ solar - consumer\ bill\ with\ rooftop\ solar)$$

5.9 Programme administration cost

Facilitating the deployment of rooftop solar in the distribution grid can be a tedious process for discoms. They will have to administer the existing network and check its compatibility with the new system simultaneously. It includes procedures like analysis of the technical feasibility of the DT, technical evaluation of the plant design and installation parameters, plant inspection, and installation of bidirectional meters. The cost of these procedures, along with an expert workforce (if required), would have to be borne by the discoms. It is presented as the programme administration cost (PAC).

Working formula:

$$PAC = \sum_{M} MeasureCost$$

Description:

M: Measure taken to implement rooftop solar

MeasureCost (INR): The cost to execute the concerned measure—can refer to the instrument cost, salary of the employees, or incentives

5.10 Added distribution services cost

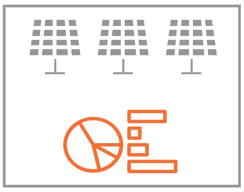
Although the rooftop system is expected to work in congruence with the existing distribution network, without any additional requirements, its implementation can require the construction of new components or the upgradation of the existing system. These expenses, borne by the discoms, are accounted for in the added transmission and distribution services cost.

Rooftop solar systems contribute to reducing a discom's peak demand by about 13 per cent of its rated capacity.

Image: BRPL

6. BRPL case study

The benefits and costs mentioned above capture the impact of grid-connected rooftop solar on discom revenue. The working formulas, however, do not account for all the variables specific to the discoms' regulatory environment. Thus, there cannot be a one-size-fits-all VGRS tool without compromising on accuracy. An illustrative analysis was carried out for rooftop solar projects connected to ten different DTs in BRPL's licence area. DTs are chiefly characterised by four attributes—rated capacity, loading, rooftop solar penetration, and consumer category. The VGRS analysis for these ten DTs was performed, which represent the residential, commercial, industrial, institutional, and governmental consumer categories.



Insights from the systems are used to assess the aggregate impact of the total installed rooftop solar capacity on discom revenue

Insights from the systems are used to assess the aggregate impact of the total installed rooftop solar capacity on discom revenue. The assessment period is assumed to be 25 years, corresponding to the life of a rooftop solar system. The VGRS tool is developed on MATLAB; it calculates the costs and benefits parameters individually on an annual basis. All the required data related to DT loading, discom load profile, solar generation, power procurement, etc. are considered for the year 2018–19.

6.1 Data inputs and assumptions

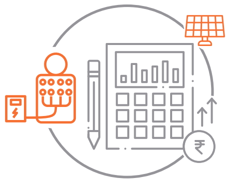
This section elaborates on the data inputs and assumptions considered to estimate the net impact of a rooftop solar PV system, based on the VGRS approach.

Table 2: **List of input parameters and associated assumptions**

Source: Authors' analysis

Parameter	Approach and assumption
Coincidence factors • System coincidence factor (SCF) • Distribution coincidence factor (DCF)	• The top 20 per cent of the load duration curve is identified as peak demand and, consequently, the rooftop solar output in those intervals is mapped to estimate coincidence factors. • Since the loading profile for the transmission system will be the same as the discom demand profile, the transmission coincidence factor was considered to be the same as the SCF. • A similar procedure was followed for the distribution coincidence factor (DCF), except that the loading of the concerned DT was used.
Avoided generation capacity cost	• For BRPL, the long-term PPAs cover only its base load requirements. However, during peak hours (i.e., the peak 20 per cent of the load duration curve), BRPL procures power from short-term markets. • Since the 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 a rooftop solar system would consistently fall every year, due to the continuous derating of modules. Therefore, the magnitude of the annual contribution would be limited by the value in the last year, as the utility's plans would consider the minimum contribution from the rooftop solar system.

Parameter	Approach and assumption
Avoided power purchase cost	• Discoms in India follow merit order despatch, i.e., despatch of electricity from the contracted sources in increasing order of the (variable component of) the power purchase cost. Additionally, during times of high demand, the utility 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.[2] • It is assumed that solar will replace the most expensive source of power in any given interval as per the merit order despatch. • Data on the power purchase cost for every 15-minute interval is used for procurement from the open market and merit order despatch is used for long-term contracts.
Avoided transmission charges	• The transmission coincidence factor is assumed to be equal to the SCF. • The benefit is calculated based on avoided transmission capacity and unit charges paid by BRPL for each kW of additional transmission capacity.
Avoided distribution capacity cost	• The ADCC calculation has two components: – Normative expenses incurred in the maintenance of the distribution network (excluding DTs) – Upgradation cost for DTs and related operations and maintenance (O&M) expenses • The first component has not been taken into consideration since the cost structure for the utility is independent of the system loading. • Determining whether a DT is due for upgradation is calculated based on the pattern and growth rate of the peak load and the contribution from solar. • Historical DT load patterns are used to estimate the future growth in demand. • Avoided interest payment due to deferred investment in DT upgradation is calculated based on predictions of the year in which the DT is due for upgradation.
Avoided REC cost	• If the utility is already purchasing electricity from a solar plant, then this benefit is applicable for the actual generation from rooftop solar or the shortfall required to be made up, whichever is lower.
Reduced working capital requirement	• As per DERC, working capital is considered to be the difference between the discom's two months' revenue from energy sales and one month's power purchase cost and must be completely sourced through debt. • The reduction in working capital will be equal to the interest to be paid on the difference between two months' worth of revenue loss and one month's worth of avoided costs.
Revenue loss	• Depending on the category of the consumer, the bill is calculated for the scenarios with and without rooftop solar installation, in accordance with the current net-metering policy. The difference between these two amounts is the revenue loss to the utility.
Net present value	• Each of the costs and benefits parameters is calculated annually and discounted to the present year. • The interest rate used for this is the same as the utility's weighted average cost of capital rate.



Determining whether a DT is due for upgradation is calculated based on the pattern and growth rate of the peak load and the contribution from solar

2 As an example, let's assume that the rooftop solar system generates 100 units of electricity in one interval, with transmission and distribution losses equal to 5 per cent, each. Thus, the utility can now reduce its procurement in that interval by 111 (= 100/0.952) units. If 111 units or more are procured via open access, the benefit in that interval is simply 111 x open access procurement cost per unit. However, say it procures only 70 units, then the remaining 41 units are eliminated from the sources that have been 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.

6.2 Key observations and recommendations

This section presents the findings from the BRPL case study across ten different DTs along with the aggregate results for the entire solar generation capacity. BRPL has a total of 45.18 MW of rooftop solar capacity across approximately 1,380 individual systems in their distribution geography. Of the total installed capacity, residential consumers consist of 18 per cent, the government and institutional category contribute about 67 per cent, and the remaining is comprised of the commercial and industrial category.

	DT capacity (KVA)	DT category	Total RTS capacity considered (kW)	Consumer categories	CUF (%)	SCF (%)	DCF (%)
DT 1	100	Industrial	35	Industrial	11.34	13.31	27.09
DT 2	630	Mixed	220	Government	11.76	13.71	33.57
				Commercial	13.45	14.64	36.114
DT 3	990	Institutional	102	Institutional	11.66	12.43	7.38
DT 4	100	Residential (Res)	10	Res	13.51	14.92	19.10
DT 5	100	Institutional	80	Institutional	10.32	11.51	37.25
DT 6	990	Res	10	Res	11.68	12.86	14.86
DT 7	990	Commercial	30	Commercial	13.90	15.35	20.02
DT 8	990	Institutional	63.3	Institutional	12.88	12.59	5.51
DT 9	630	Res	30	Res	16	16.2	8.3
				Res	15.8	15.9	7.8
				Res	15.5	16.6	8.5
DT 10	630	Group housing society (GHS)	120	GHS	13.2	11.2	9.1

Table 3: **Specifications and performance characteristics of rooftop solar systems**

Source: Authors' analysis

The total installed rooftop solar capacity across ten DTs is 700 kW and total DT capacity is 6,150 KVA. Much of the capacity is installed on DTs in the institutional and commercial categories.

The capacity utilisation factor (CUF) across systems is found to be on the lower side, with the minimum CUF at 10.3 per cent and maximum at 16.2 per cent. The system coincidence factor (SCF) does not vary significantly across systems, representing a similar generation profile across different systems. A higher SCF would lead to higher benefits as the contribution from solar increases during peak hours. Significant variations in the distribution coincidence factor (DCF) are observed, which can be largely attributed to a variation in DT load profiles.

Results

	AGCC	APPC	ATRC	ADCC	ARECC	AWCC	Revenue loss	Net benefit
Capacity (INR/kW)	8,383	25,794	2,119	319	12,150	431	43,626	5,572
Generation (INR/kWh)	0.33	1.02	0.08	0.01	0.48	0.02	1.72	0.22

Table 4: Capacity and generation-normalised aggregate costs and benefits for selected ten DTs

Source: Authors' analysis

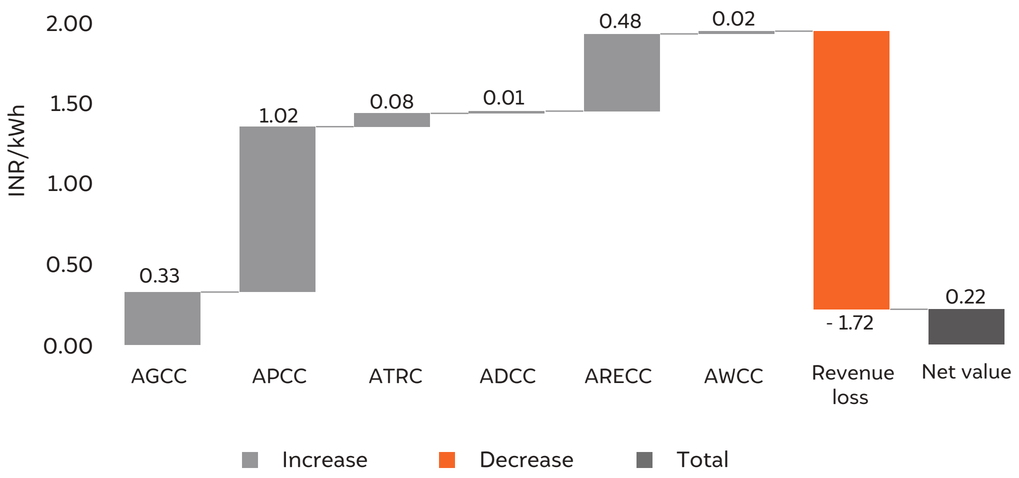


Figure 1: Generation-normalised aggregate costs and benefits for selected ten DTs

Source: Authors' analysis

	DT 1	DT 2	DT 3	DT 4	DT 5	DT 6	DT 7	DT 8	DT9	DT 10
AGCC	8,789	8,924	8,043	9,653	7,446	8,324	9,933	8,149	10,550	7,257
APPC	23,716	25,068	24,609	28,356	21,690	24,598	29,277	26,917	33,426	27,930
ATRC	2,221	2,255	2,033	2,440	1,882	2,104	2,511	2,060	2,667	1,834
ADCC	5,633	120.88	-	-	-	-	-	-	-	-
ARECC	11,224	11,793	11,539	13,374	10,218	11,565	13,761	12,753	15,708	13,193
AWCC	391	517.74	517	556	453	413	611.98	587	318	88.5
Revenue loss	40,685	47,173	46,158	51,824	40,871	41,926	55,042	51,013	45,966	29,685
Net benefit	11,291	1,506	585.43	2,555	819	5,080	1,052	-545	16,703	20,619

Table 5: Capacity-normalised values of costs and benefits (all values in INR/kW)

Source: Authors' analysis

Since the avoided generation capacity and transmission charges are dependent on system performance during peak demand hours, they vary linearly with the SCF; in contrast, avoided power purchase and REC costs are almost directly related to the CUF. The ADCC is significant only for the first two DTs. For the remaining eight, either the solar penetration is too low to impact the upgradation schedule or the loading is too low to necessitate an upgrade within the timeline of the analysis.

	DT 1	DT 2	DT 3	DT 4	DT 5	DT 6	DT 7	DT 8	DT 9	DT 10
AGCC	0.38	0.36	0.33	0.35	0.35	0.35	0.35	0.31	0.32	0.26
APPC	1.01	1.02	1.02	1.02	1.02	1.02	10.2	1.01	1.02	1.02
ATRC	0.09	0.09	0.08	0.09	0.09	0.09	0.09	0.08	0.08	0.07
ADCC	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-
ARECC	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
AWCC	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.00
Revenue loss	1.74	1.92	1.92	1.86	1.92	1.74	1.92	1.92	1.40	1.08
Net benefit	0.48	0.06	0.02	0.09	0.04	0.21	0.04	-0.02	0.51	0.75

Table 6: **Generation-normalised values of costs and benefits (all values in INR/kWh)**

Source: Authors' analysis

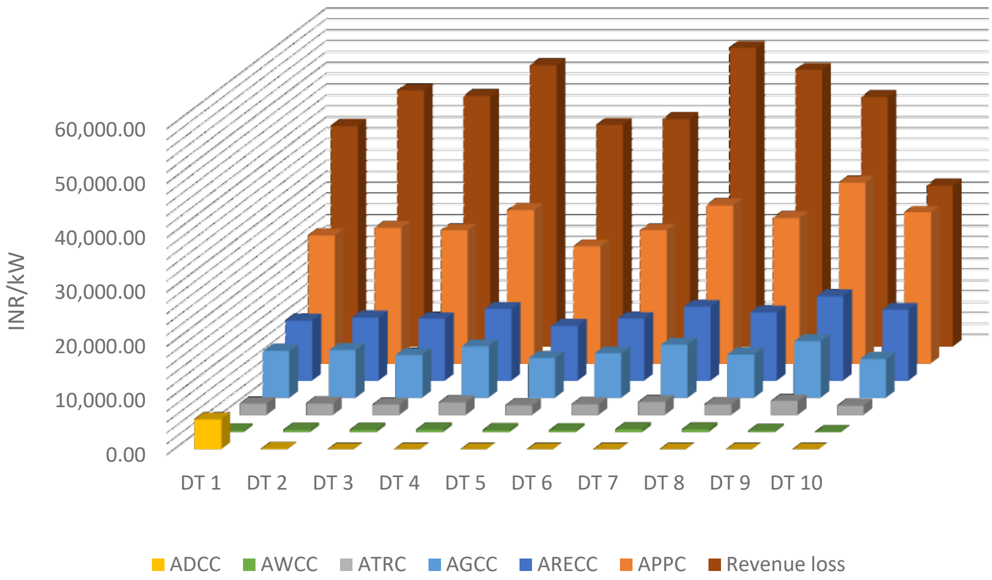


Figure 2: **Capacity-normalised values for individual costs and benefits parameters**

Source: Authors' analysis

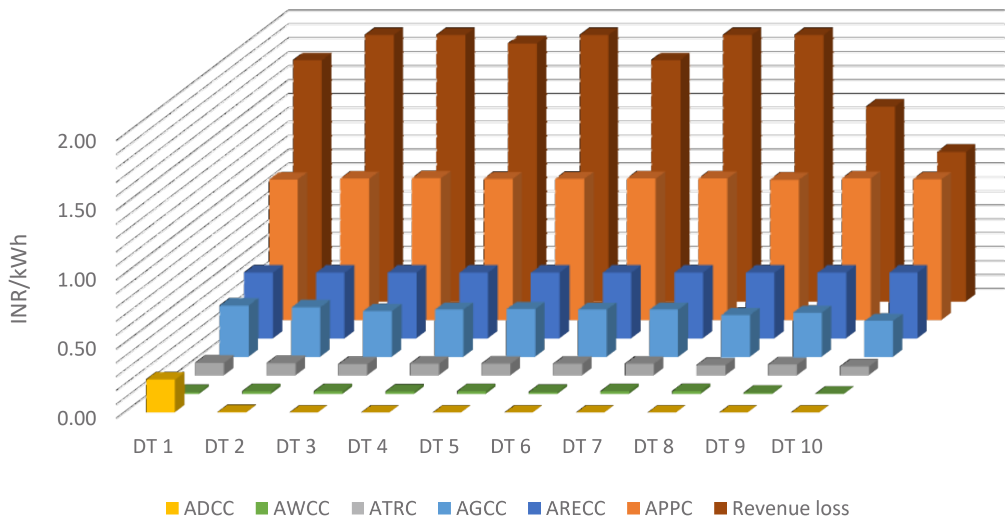


Figure 3: **Generation-normalised values for individual costs and benefits parameters**

Source: Authors' analysis

As expected, the revenue loss for the utility is much higher when non-domestic consumers (i.e., commercial, industrial, and institutional consumers) set up rooftop solar installations. However, regarding net export to the grid, the revenue loss would be lower since the excess solar electricity is compensated at the average power procurement cost, which is lower than the consumer's grid tariff. The major benefits like AGCC, APPC, and ARECC are quite similar across these consumer categories. However, there is a strong correspondence between the revenue loss and the net benefit—the higher the revenue loss, the lower the net benefit, as evidenced from DTs 2, 3, 5, 7, and 8.

Key observations

- The total inherent benefits of a rooftop solar system outweigh the revenue loss for discoms. BRPL's gains amount to INR 0.22 for every unit of electricity being generated from rooftop solar.
- The higher share of rooftop capacity in commercial and industrial categories, about 36 MW of the total 45.18 MW capacity, limits the overall benefits to discoms.
- Rooftop solar installations in the residential consumer category (in lower tariff slabs) tend to offer greater benefits to discoms. Residential DTs in the BRPL area provided a maximum net gain of INR 0.75/kWh in case of high-rise societies with single-point delivery of electricity.
- Revenue loss in the residential category is the lowest among all consumer categories. BRPL loses INR 1.08–1.92 for every unit of solar electricity generated by a residential consumer compared to INR 1.74 and INR 1.92 in the industrial and commercial categories, respectively. Revenue loss in any consumer category is commensurate to their electricity tariff rate.
- Savings on power procurement and RPO fulfillment constitute about 77 per cent of the overall benefits to discoms.
- Increasing the share of rooftop solar capacity deployment in the residential category will lead to more significant benefits for discoms. To maximise their benefits, discoms should promote rooftop solar systems among their subsidised consumer categories.
- Rooftop solar systems contribute to reducing a discom's peak demand by about 13 per cent of its rated capacity.
- Increasing the rooftop solar penetration on a DT will increase the generation-normalised net value due to the increased impact of decongestion.

Key recommendations

- Grid integrated rooftop solar systems can influence the Indian power sector in many ways. This impact will increase as rooftop solar deployment increases in the future. Thus, it becomes necessary to ensure that all stakeholders are compensated fairly. The proposed VGRS framework is a comprehensive approach to assess the value of grid integrated rooftop solar for discoms. It is tailored for the current Indian power sector and accounts for all potential costs and benefits of rooftop solar to give its net present value. This analysis will enable discoms to strategically deploy rooftop solar in their licensed areas in a way that limits their losses and maximises their benefits.
- Rooftop solar systems in the residential category provide the most benefits to discoms; increased deployment among residential consumers will lead to higher benefits and savings on cross-subsidies.

- DTs with frequent overloading and day-time peaks serve as useful targets for rooftop solar deployment to further improve the net benefit.
- The net export of solar power into the grid should be prioritised, assuming net-metering based compensation. This could be achieved by targeting consumers with large roof areas and overall lower electricity demand.
- In view of the inherent benefits that the discoms will receive, it would be prudent for them to promote the installation of RTS systems through comprehensive and organised consumer outreach programmes, while ensuring the discovery of the most competitive cost/tariff. Additional and appropriate compensation mechanisms for the discoms could be devised for these activities.

Increasing the rooftop solar penetration on a congested DT will increase the net benefit to a discom by decongesting the DT's load.

Image: iStock

Annexure

Cost components as taken from the ARR/BRPL data

Capacity cost	7452.229 INR/kW
Average variable component of the five costliest long-term PPAs (coal/gas)	3.44 INR/kWh
Transmission cost	2970.154 INR/kW
REC cost	2000 INR/MWh
DT upgradation cost	
Standard cost of augmentation of 400 KVA to 630 KVA DT	9.36 INR lakh
Standard cost of augmentation of 630 KVA to 990 KVA DT	12.83 INR lakh
Standard cost of augmentation of 400 KVA to 990 KVA DT	12.89 INR lakh
Variable component of tariff structure	
Residential (GHS) category	4.50 INR/kWh
Industrial category	7.25 INR/kVAh
Commercial/institutional category	8.00 INR/kVAh
Transmission loss	3.30%
Distribution loss	9.50%

Source: BRPL

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In view of the inherent benefits that acrue to discoms through RTS, it would be prudent for them to promote RTS installations through comprehensive and organised consumer outreach programmes.

Image: BRPL

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