Valuing Grid-connected Rooftop Solar

A Framework to Assess Costs and Benefits to Discoms

Executive Summary | September 2019

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


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The Council on Energy, Environment and Water (CEEW) is one of South Asia's leading not-for-profit policy research institutions. The Council uses data, integrated analysis, and strategic outreach to explain – and change – the use, reuse, and misuse of resources. The Council addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public.

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.

In nine years of operations, The Council has engaged in over 230 research projects, published over 160 peer-reviewed books, policy reports and papers, advised governments around the world nearly 530 times, engaged with industry to encourage investments in clean technologies and improve efficiency in resource use, promoted bilateral and multilateral initiatives between governments on 80 occasions, helped state governments with water and irrigation reforms, and organised nearly 300 seminars and conferences.

The Council's major projects on energy policy include India's largest multidimensional energy access survey (ACCESS); the first independent assessment of India's solar mission; the Clean Energy Access Network (CLEAN) of hundreds of decentralised clean energy firms; the CEEW Centre for Energy Finance; India's green industrial policy; the USD 125 million India-U.S. Joint Clean Energy R&D Centers; developing the strategy for and supporting activities related to the International Solar Alliance; designing the Common Risk Mitigation Mechanism (CRMM); modelling long-term energy scenarios; energy subsidies reform; energy storage technologies; India's 2030 Renewable Energy Roadmap; energy efficiency measures for MSMEs; clean energy subsidies (for the Rio+20 Summit); Energy Horizons; clean energy innovations for rural economies; community energy; scaling up rooftop solar; and renewable energy jobs, finance and skills.

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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."

Kumaresh Ramesh
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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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https://bit.ly/30Vv2wA

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.

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.

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

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.

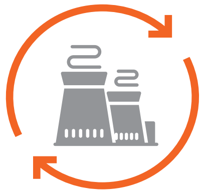
A comprehensive CBA-based VGRS framework for any discom will depend on three key parameters—time frame, location, and baseline. Rooftop solar PV systems have an estimated lifetime of 25 years. Thus, a 25-year period is the preferred duration for the framework. Since the consumer mix at the distribution 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)

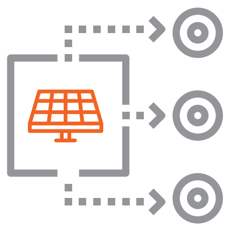
Generation from grid-interactive rooftop solar systems within the discom service area contributes towards the fulfilment of their RPO targets. Thus, by supporting the adoption and integration of rooftop solar, discoms can cut down on the purchase of renewable energy certificates. It is important to know 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

	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

Source: Authors' analysis

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.

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

Source: Authors' analysis

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.

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

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

Source: Authors' analysis

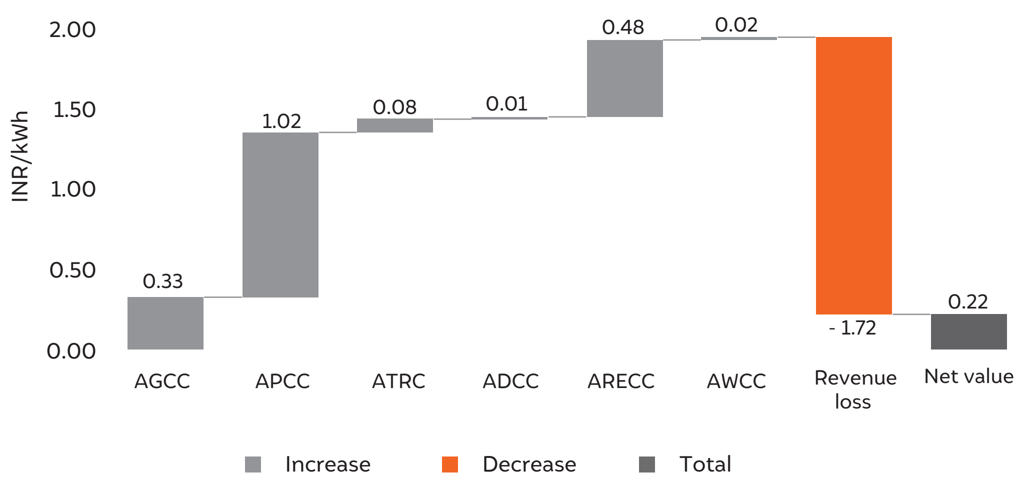
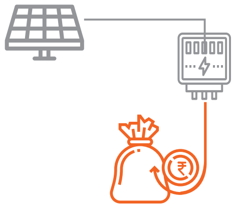


Figure ES1: Generation-normalised aggregate costs and benefits for selected ten DTs

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.

Image: BRPL

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.

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