kWh from kW: Achieving Optimum Energy Generation from Rooftop Solar Systems

Insights from Field Visits in Delhi

November 2023 | Report


Image: iStock

Contents

Image: CEEW

1. About the study

Solarising rooftops provides an opportunity to reduce dependence on conventional energy sources

Establishing the need for rooftop systems (RTS)

- Building sector is one of India's leading electricity consuming sectors, contributing 40% in total electricity demand*
- Electricity demand is expected to grow manifold with growing urbanisation and penetration of appliances
- Shifting the existing and future electricity needs to clean energy is crucial for the deep decarbonisation of the economy in the long run

Performance monitoring is crucial for organic growth of the sector

- Monitoring is crucial to ensure systems delivers on promised benefits and contribution towards overall energy mix
- Poorly maintained solar system leads to- low energy output, increases payback period, make system economically unviable, reduces lifespan, increase safety concerns
- Unsatisfying experience impacts consumer sentiments and organic growth of sector in long run

Approach to assess the system performance

- CEEW partnered with BYPL and PV Diagnostics to evaluate the performance of rooftop solar systems installed in their license area in Delhi
- To assess the performance, a two-pronged approach adopted – desktop analysis and site visit
- Desktop analysis of generation data is complemented by site visits to evaluate system performance and identify the root causes of underperformance

Our study suggests policy recommendations to improve the systems performance in the long run.

 Source: *Indian Energy Outlook, International Energy Agency, 2021

2. Key highlights

Soiling and shadow
most recurring maintenance issue in rooftop solar systems

~ 10 million units
electricity lost annually due to underperformance of the RTS system

Low awareness on system maintenance, no proper documentation
leading factors causing maintenance issues

~70% Residential consumers
maintain the RTS system themselves

Commercial and industrial (C&I)
consumers **prefer third party AMC**

~ INR 2 crore (USD 250,000)[1]
savings realised by RTS consumers collectively just by cleaning RTS systems

Source: Authors' analysis

Note: 1. Retail electricity tariff considered for calculating the savings

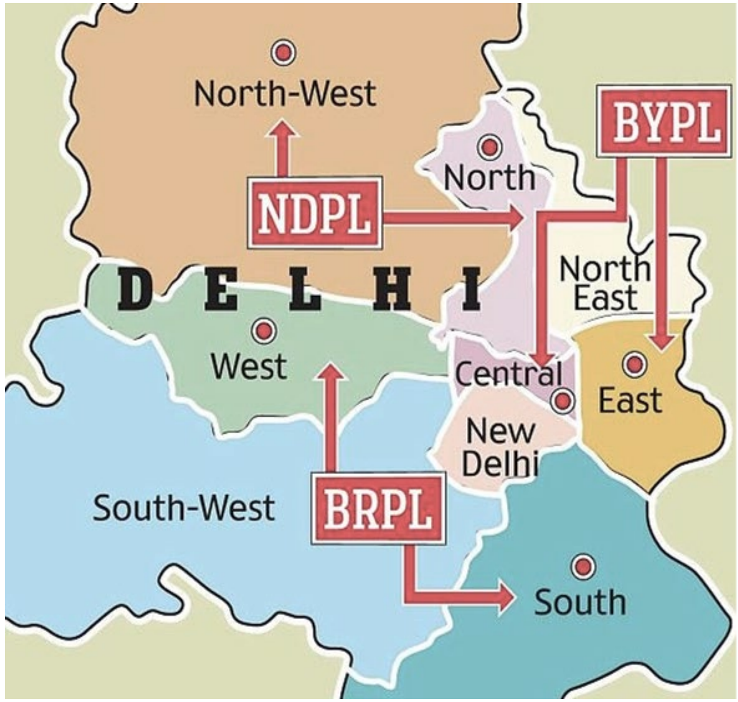
3.


Image: CEEW

RTS performance trends in Delhi

RTS installations in BSES Yamuna Power Limited (BYPL) area

Power distribution in Delhi



Images: BSES, Delhi

Power distribution by BYPL

Overview of RTS in BYPL area#

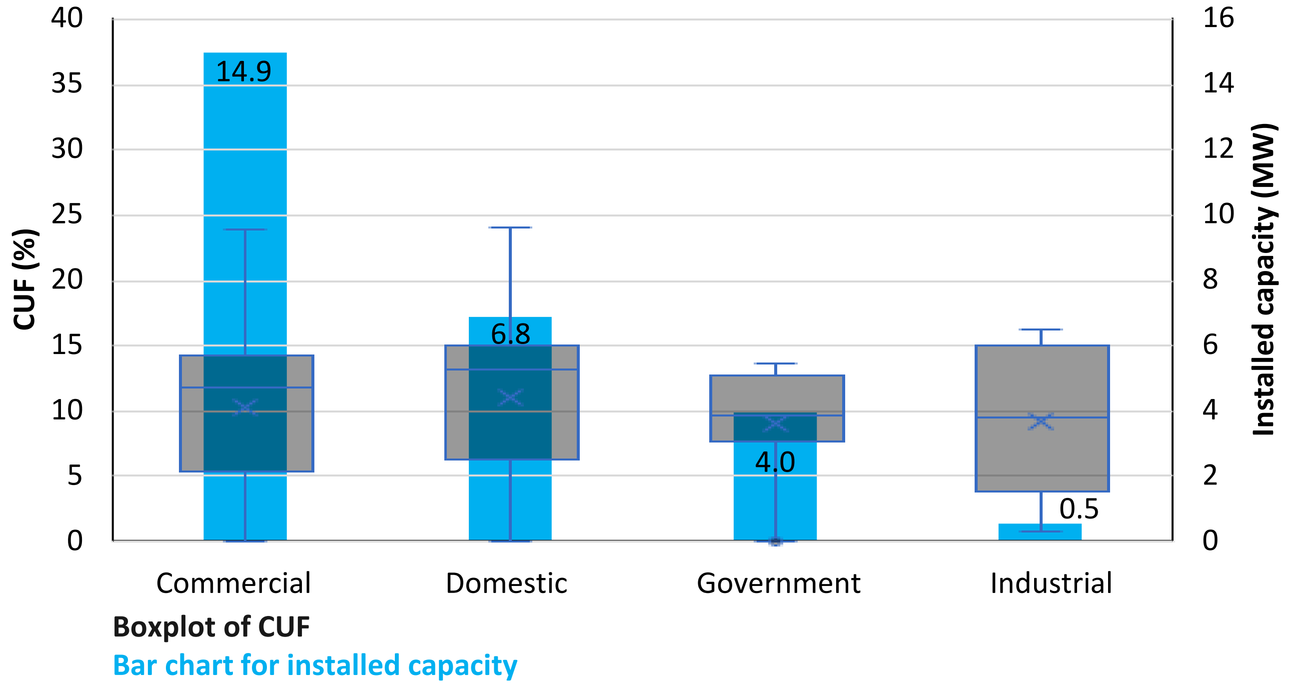
Total consumers – **681**
Total capacity – **27 MW**

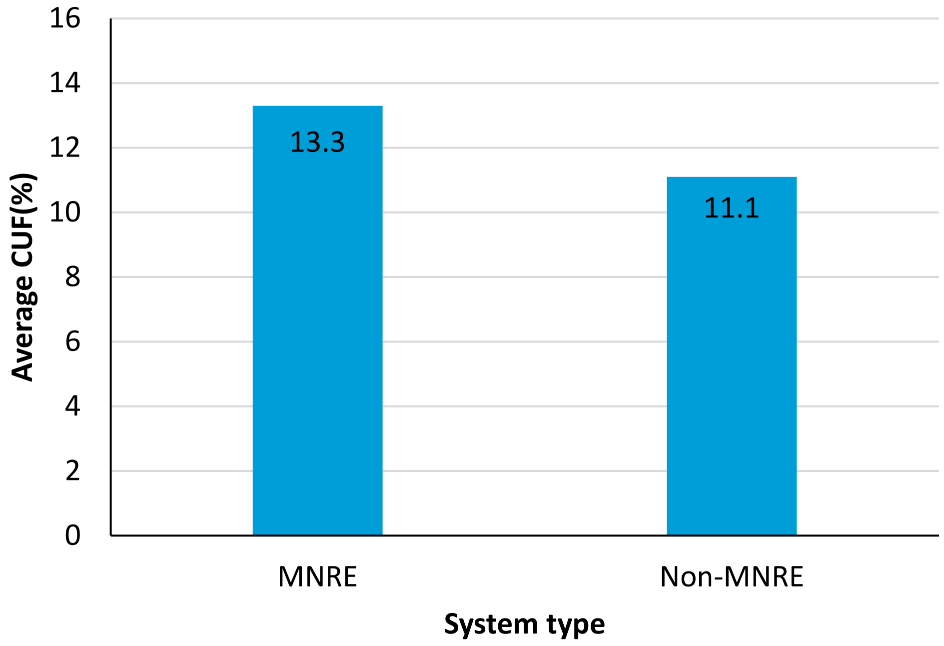
- 405 Domestic consumers **~6.9 MW**
- 10 Industrial consumers **~0.5 MW**
- 266 Commercial consumers **~20 MW**
- 123 System with MNRE subsidy **~2.4 MW**
- Average age of the plant in the area **3 years**

Rooftop solar installations are concentrated in domestic and commercial areas in Southeast, Northeast and Central parts of Delhi.

Source: Authors' analysis based on BYPL data
Note: The numbers given in the slide are till December 2021.

Significant variation in capacity utilisation factor (CUF) in consumer categories





Capacity utilisation factor (CUF) among consumer categories shows significant variation ranging from 0 to 24 %

Systems installed under MNRE subsidy are comparatively better performing due to built-in O&M provisions

Poor CUF calls for further research through on-site performance measurement and data analysis to understand the reasons for variation in performance.

 Source: Authors' analysis based on BYPL data


Image: CEEW

4.

Approach

Data-driven analysis

Desktop analysis

- System level data
- Energy losses
- Financial losses and benefits

Sampling strategy for on-ground assessment

Site visits

- System performance
  - Electrical test (IV)
  - Thermal checks
  - Earthing checks
  - Soiling, air quality and water quality tests
- Visual inspections
- Validating desktop analysis

Technique: Purposive sampling

Key parameters

- Project location
- Age of the plant
- Consumer category
- MNRE vs Non-MNRE
- CAPEX vs RESCO
- System size
- Plant performance (CUF)

Projects considered for field assessment in Delhi are net-metered and at least a year old.

 Source: Authors' analysis based on BYPL data

Sample distribution

Sample

61 out of 681 sites in Delhi

(~9 MW out of 27 MW)

BYPL distribution Circle

Central
23 sites (7.8 MW)

North-East
16 sites (0.3 MW)

South-East
22 sites (0.7 MW)

Consumer category

Domestic
24 sites (0.2 MW)

Government
4 sites (0.3 MW)

Commercial
30 sites (8.3 MW)

Industrial
3 sites (0.1 MW)

Age of Plant

1-3 years
20 sites (0.4 MW)

3-5 years
27 sites (7.5 MW)

>5 years
14 sites (1 MW)

CUF

<5%
8 sites (7.5 MW)

5-8%
10 sites (0.2 MW)

10-13%
9 sites (0.2 MW)

13-17%
30 sites (1 MW)

>17%
4 sites (0.1 MW)

Installation type

Subsidised systems
6 sites (0.1 MW)

Non-subsidised systems
55 sites (8.8 MW)

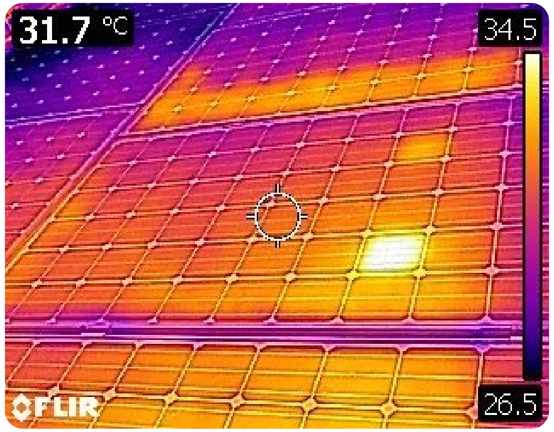
Source: Authors' analysis

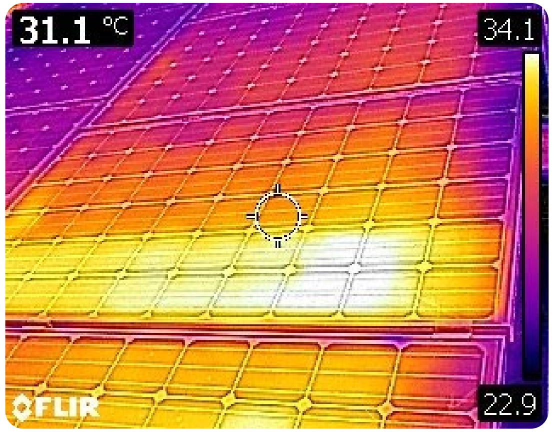
5.

Learnings from the field assessment

Key factors responsible for poor performance

Hotspots

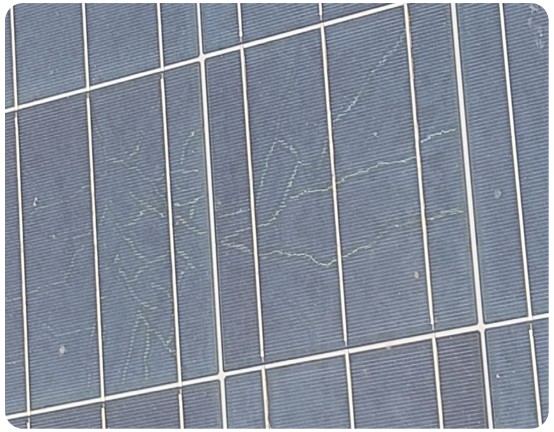


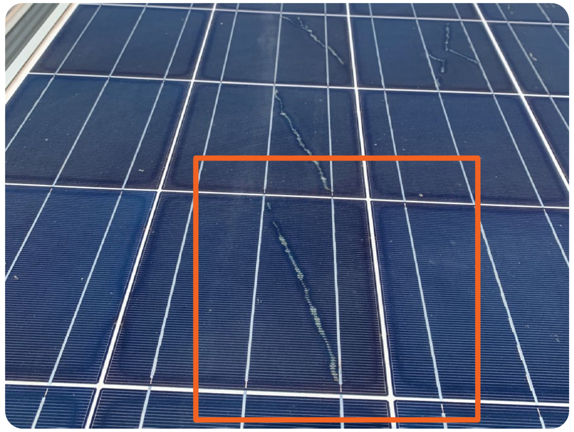


Hotspots damages solar cells, thus reducing the overall module performance

Possible causes cracked cell, defect in the solar cell, partial shading

Snail trails/Visual cracks





Images: CEEW and PV Diagnostics

Visible trail such as marking on the PV module caused due to underlying cell crack (extent of crack can impact cell performance) or at the frame of the solar cell

Possible causes cracked cell, moisture ingress

 Source: Authors' analysis

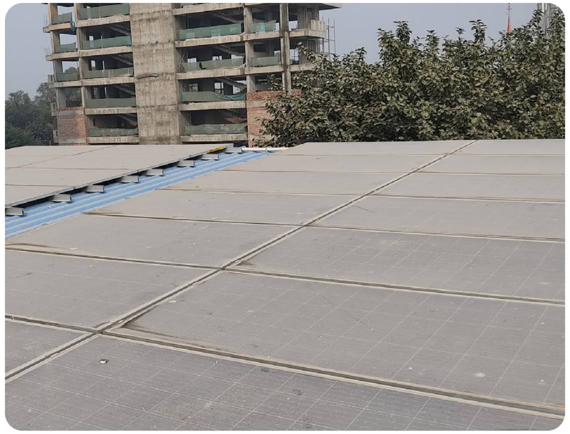
Key factors responsible for poor performance - O&M specific (1/3)

Shattered modules

If a **shattered module** is still attached to system, it causes low power production and is a high safety concern

Possible causes
projectile object, temperature shock, mishandling of modules

Dust deposition/Bird droppings



Images: CEEW

Dust deposition causes irradiation losses resulting in low energy production

Possible causes
bird droppings, nearby construction, poor air quality of the surroundings, road-side dust

 Source: Authors' analysis

Key factors responsible for poor performance - O&M specific (2/3)

Shadow effect

A shadow of objects falling over the module during peak sunshine hour lead to low energy production

Possible causes self shading, tree overgrowth, nearby vegetation (potted plants), nearby structure (building, pillar or water tank), clothes on rope or railing, and so on

Uneven orientation

Images: CEEW

Uneven orientation leads to varying output from each module and overall system performance is limited by poorest performing module, resulting in lower energy output compared to its potential

Possible causes poor installation, low quality structure, limited by roof orientation (electrical connection should be such that the mismatch losses are minimum)

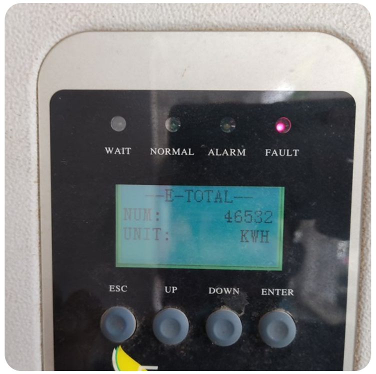
 Source: Authors' analysis

Key factors responsible for poor performance - O&M specific (3/3)

Scaling/cementation

Cable damage

Inverter not working



Images: CEEW

Deposition of dust layer due to improper cleaning or poor water quality resulting in low performance

Possible causes
poor water quality, improper cleaning

Damaged cable due to improper maintenance causing high resistance and safety concerns

Possible causes
improper structure for wiring, reckless activity near the wires

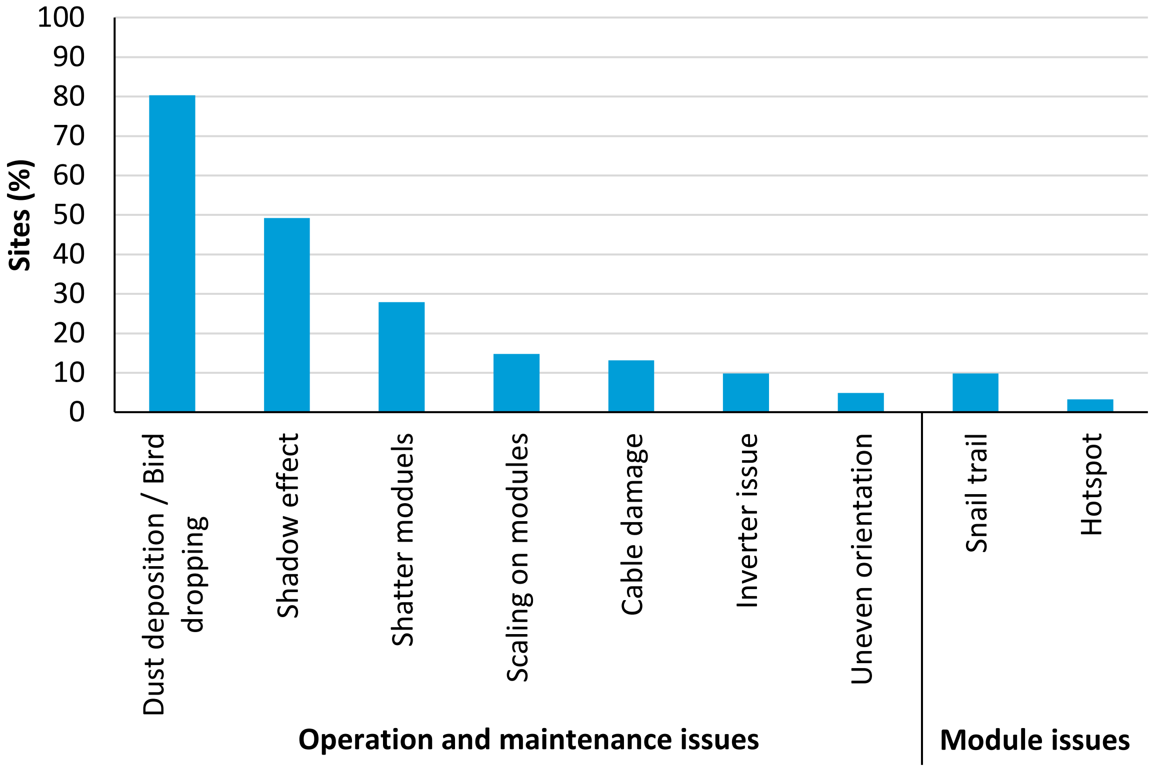
Non functioning inverter due to any internal cause resulting in system shutdown and no energy output

Possible causes
connection failure, component failure, readings outside any safety points provided in inverters.

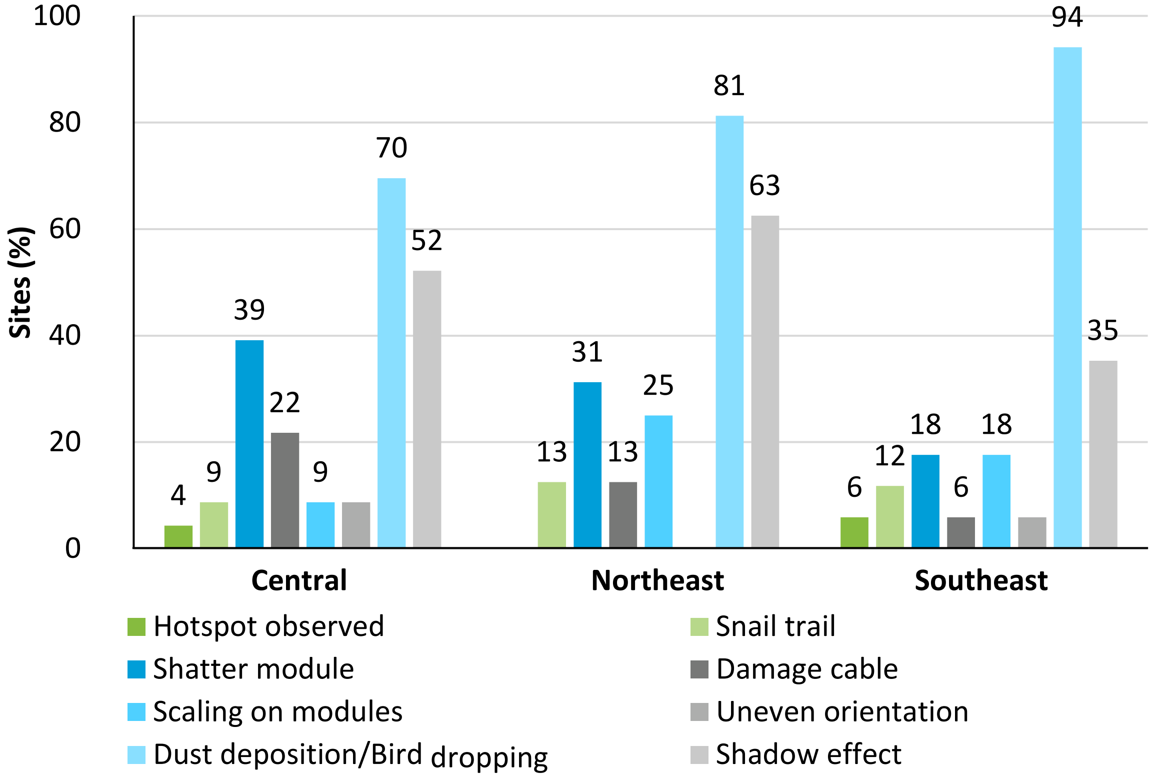
 Source: Authors' analysis

Dominant factors associated with poor system performance

Key factors responsible for the poor performance of RTS in Delhi



Variation in dominant factors across circles

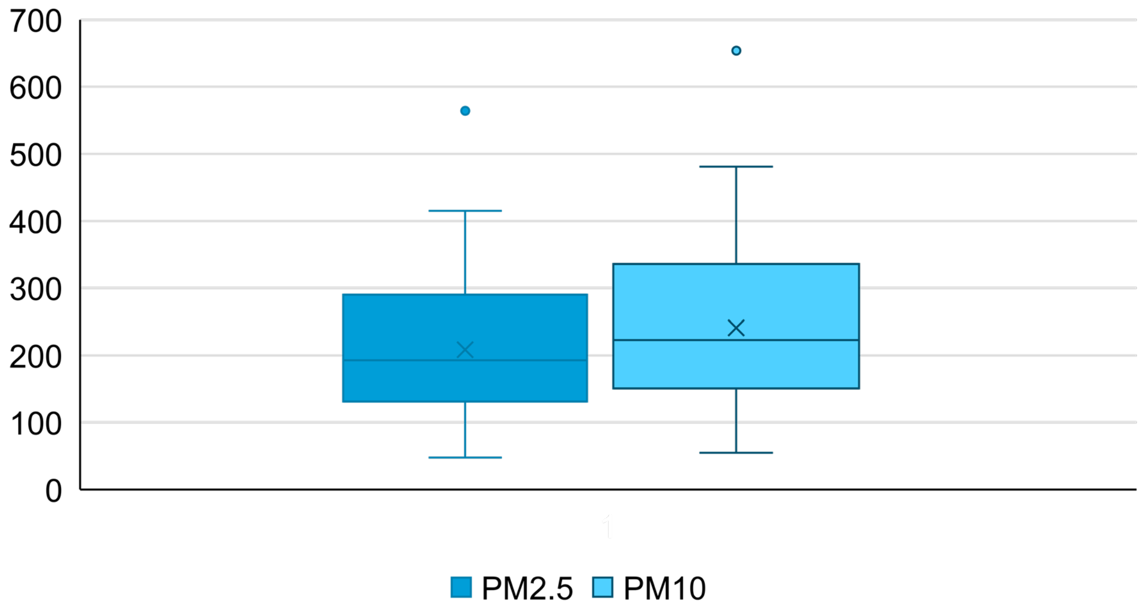


High soiling is observed across all the regions, which is largely due to construction activity in the surrounding areas, followed by shadow effect.

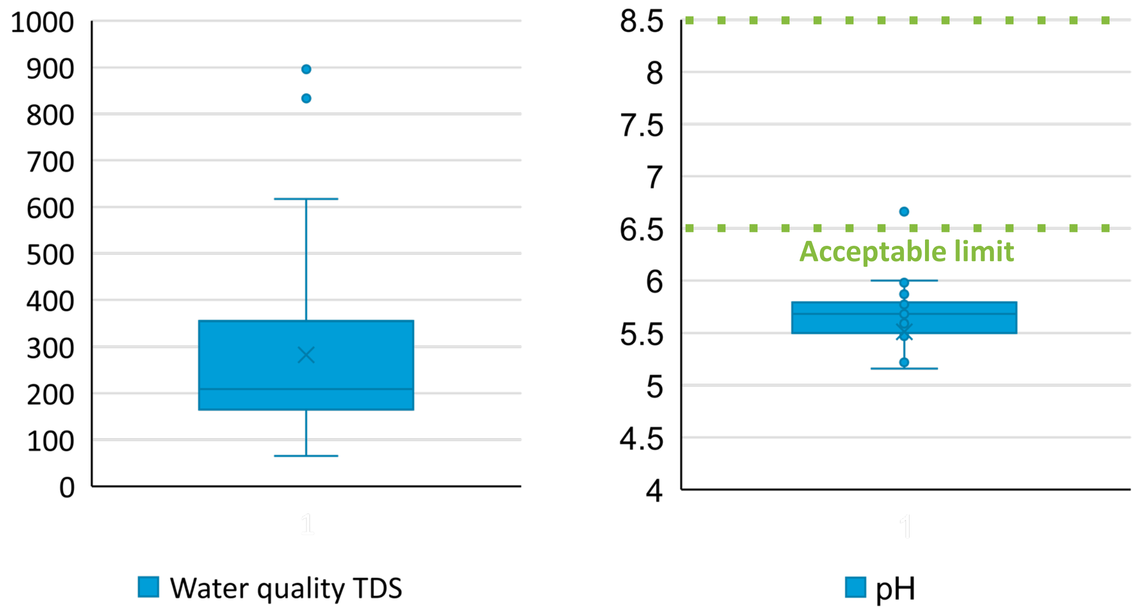
 Source: Authors' analysis

Local air and water quality impact the system performance

Air quality



Water quality



Poor air quality across the area contribute significantly to high soiling observed during the site visits

The issue of scaling / cementation on PV modules may be due to poor quality of water and improper cleaning of modules

Air pollution and water quality impacts the system performance in Delhi, necessitating proper maintenance for better performance of the RTS systems.

Source: Authors' analysis

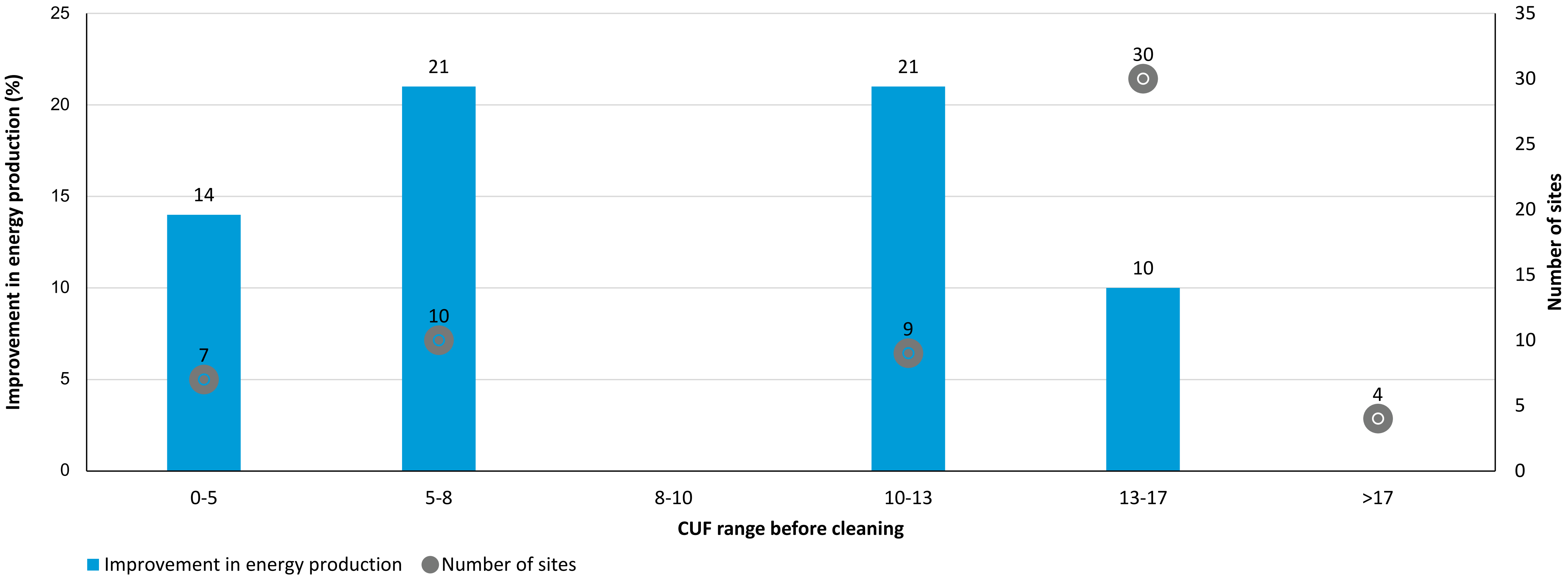
Note: "The Acceptable limit" is based on the stakeholder consultations. Use of RO water provides the best results.

6.


Image: CEEW

Potential gains to consumers and discoms with improved system performance

Module cleaning led to a 10-20 % increase in energy production

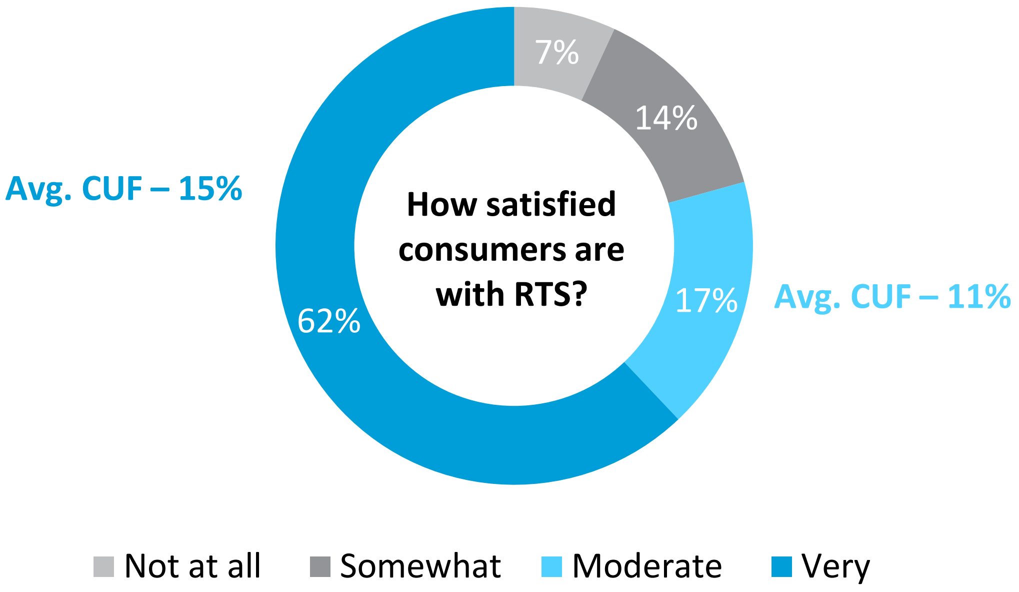


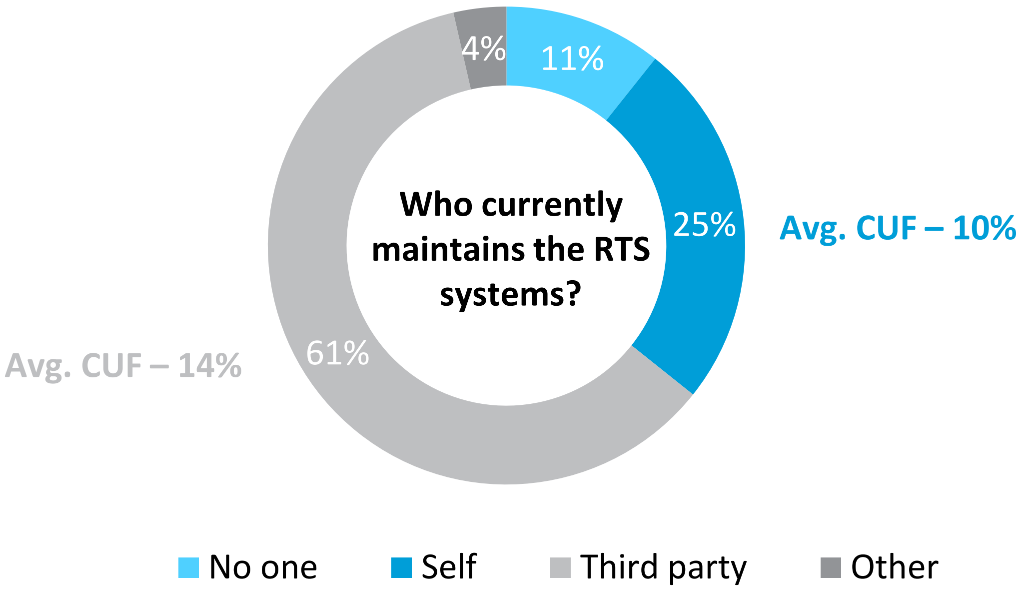
System performance improves by more than 10% with onsite cleaning. Due to poor air quality, modules have to be cleaned periodically. There is a further scope for improvement in performance, if a proper O&M system is in place.

Source: Authors' analysis

Note: The improvement is limited to the impact of cleaning done by the team during site visits. Proper operation and maintenance will cover other issues such as non-functioning of the inverter, damaged cables, among others.

System performance impacts consumer confidence in RTS





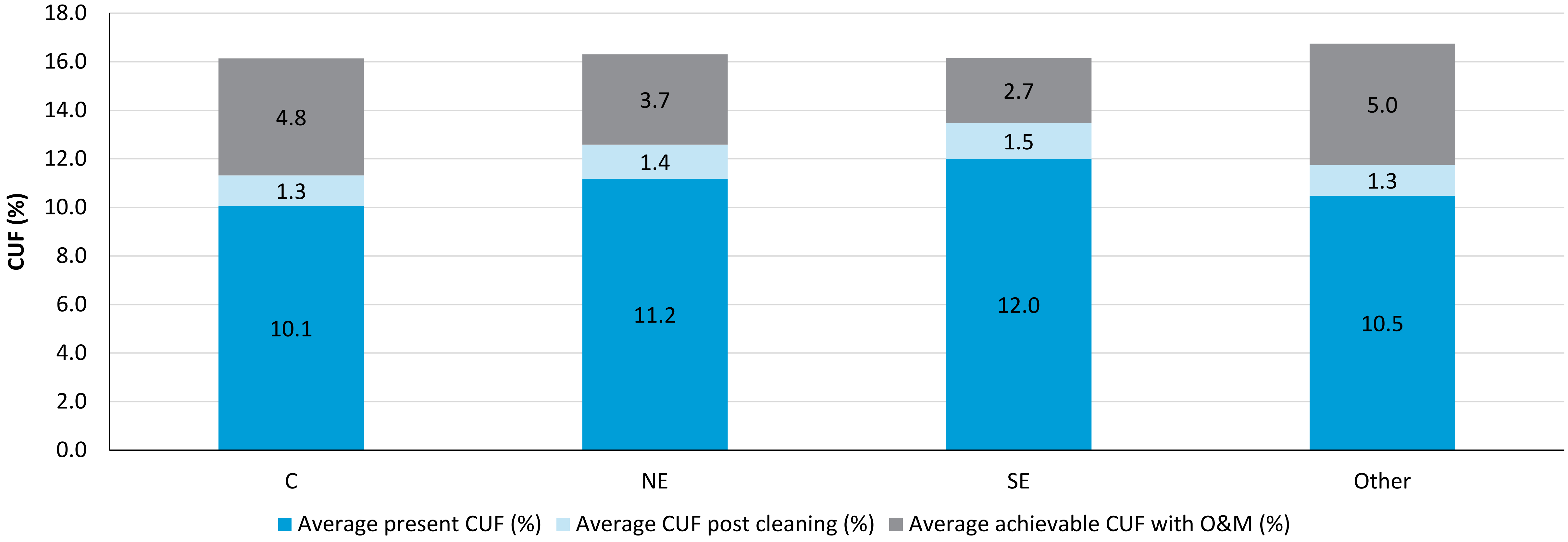
Consumers owning better performing systems (62%) tend to be very satisfied with RTS and expressed their willingness to recommend the RTS system to others

RTS system covered by third party O&M service contracts has a cleaning frequency of 15 - 30 days and offers better performance. These services are mainly used by non-domestic consumers.

Both domestic and non-domestic consumers, irrespective of whether availing third party O&M services or not, lack the necessary knowledge about maintaining the RTS system for an optimal performance.
The system performance creates the long term perception of consumers about the technology and its potential benefits.

 Source: Authors' analysis

Significant potential to improve system performance with O&M

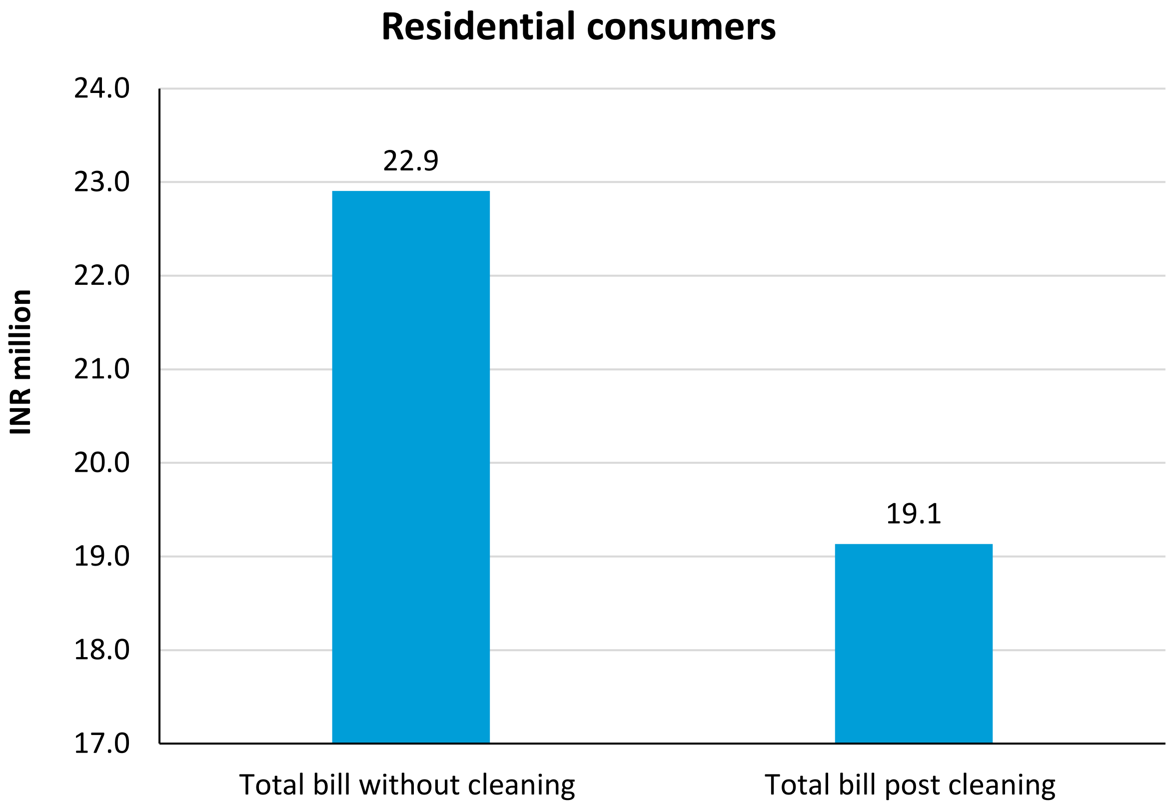


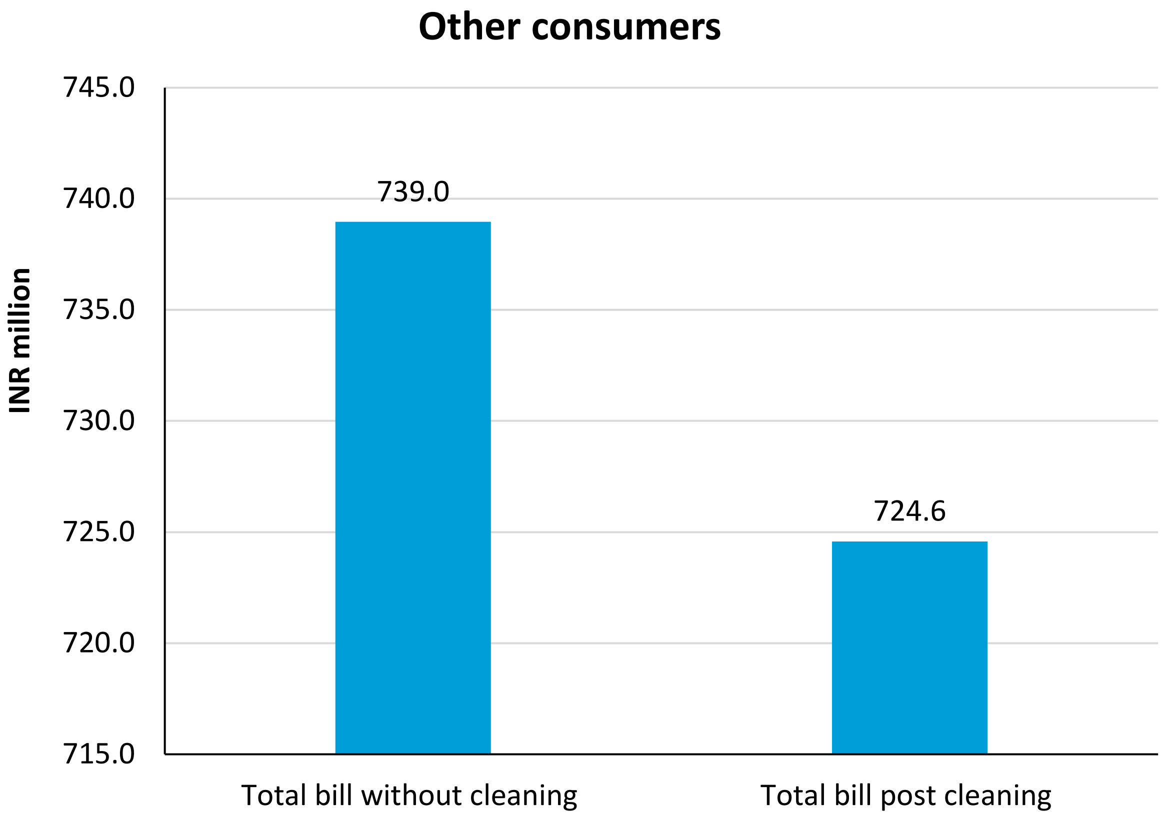
The performance of the RTS system can be increased by 4-6% with regular maintenance (considering all issues that can be resolved with proper O&M). This will lead to 35 – 60% more energy production from the existing systems.

Source: Authors' analysis

Note: The three scenarios are explained in the Annexure

Potential benefits to consumers

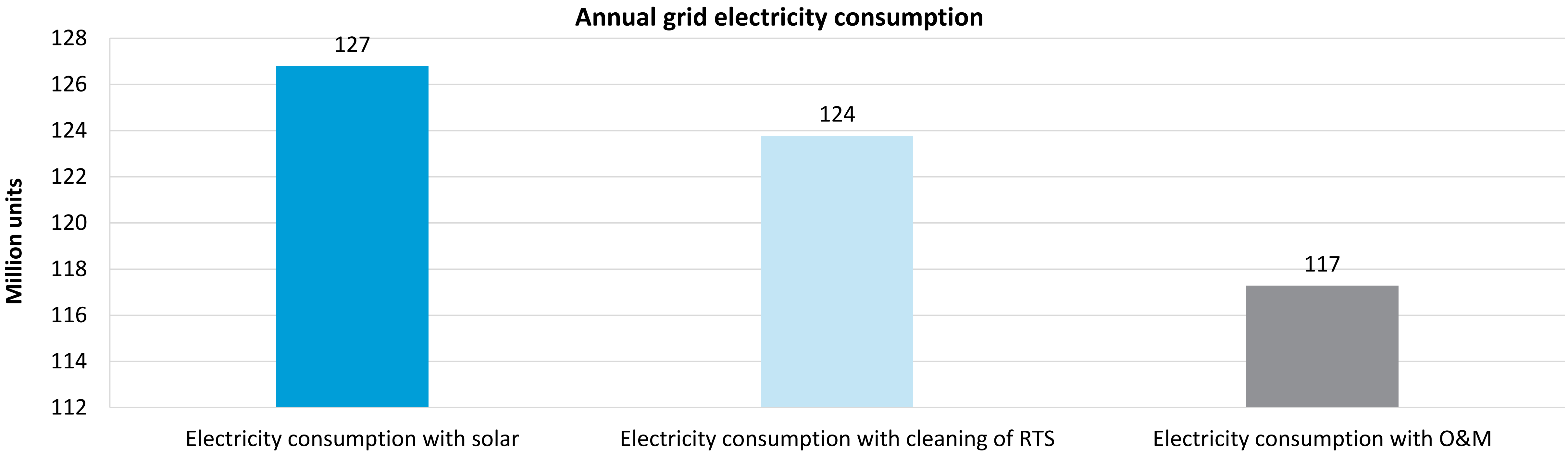




With potential improvement in system performance, consumers can save on their electricity bill with reduced dependence on the grid. **Residential consumers will save INR 3.8 million (USD 48,000), whereas the non-residential consumers will save INR 14 million (USD 175,000) annually.**

 Source: Authors' analysis using tariff rates from tariff order, 2021.

Potential benefits to discoms (1/2)



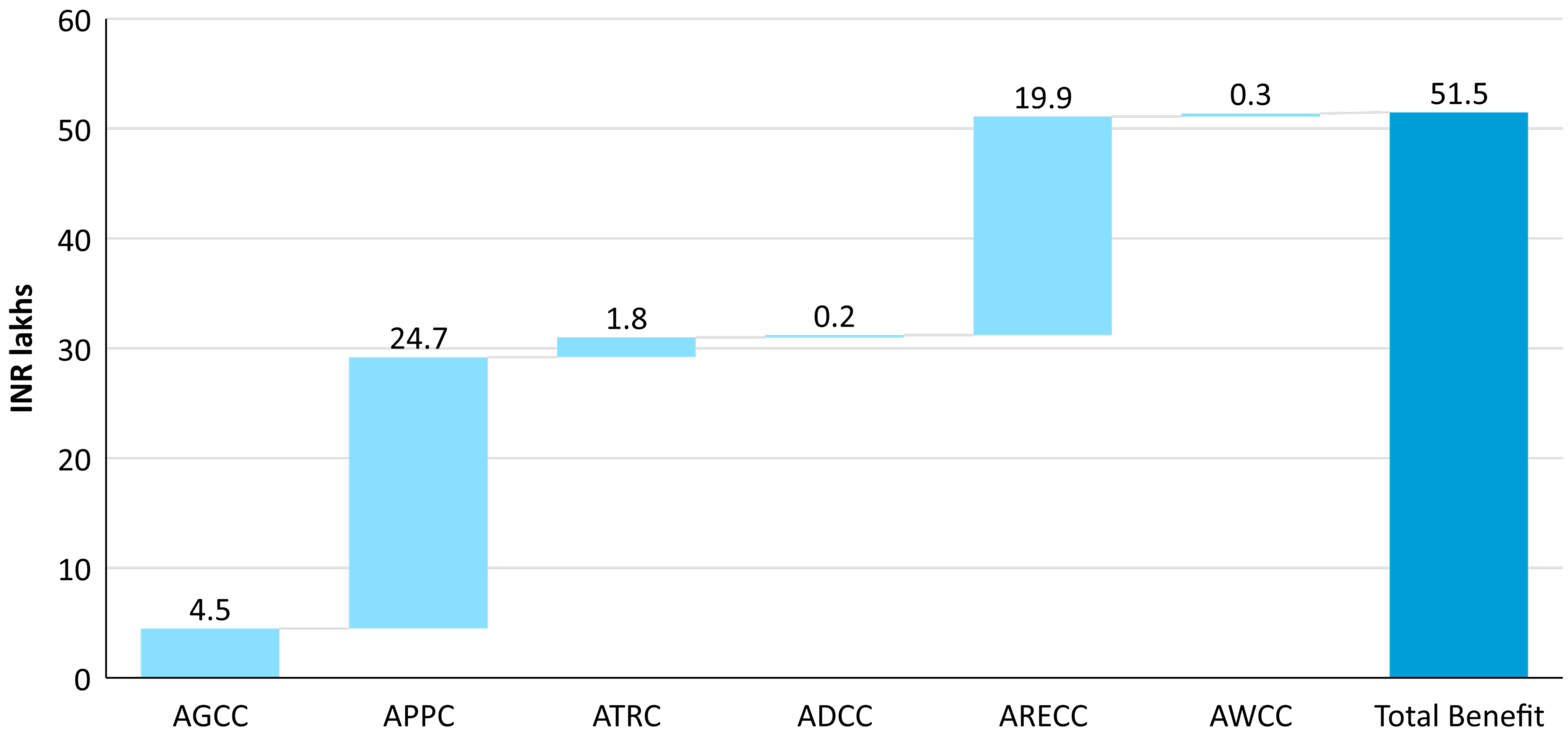
Annual grid electricity demand from RTS consumers decline by 3 million units if systems are properly cleaned.
Further, reduction of 7 million units can be realised if systems are well maintained.

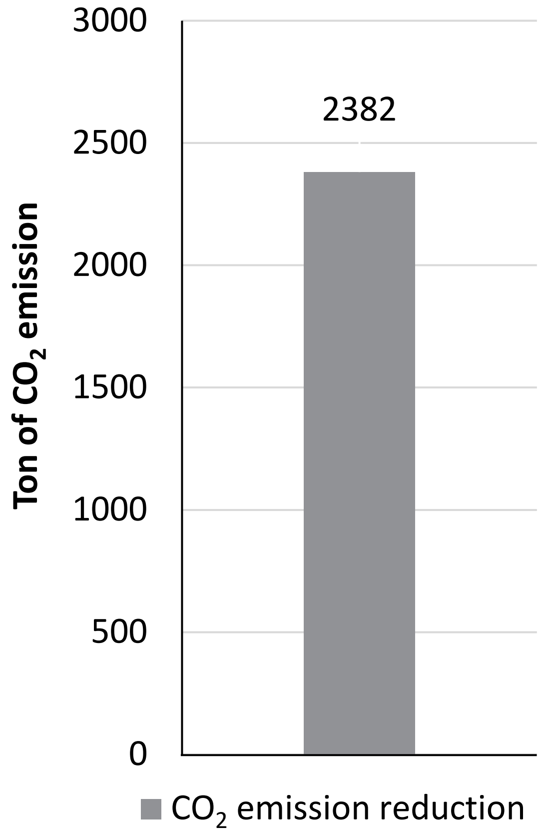
Discoms can target at least 7% reduction in electricity demand from solar consumers if RTS systems are performing optimally.

Source: Authors' analysis

Note: Potential gains are calculated for the system that are operating for more than one year.

Potential benefits to discoms (2/2)





Discoms can save an additional ~INR 5 million and ~2300 ton of CO_2 emissions from existing RTS capacity with proper O&M schedules.

Source: Authors' analysis

Notes: 1. Avoided generation capacity cost (AGCC), avoided power purchase cost (APCC), avoided transmission capacity cost (ATRC), avoided distribution capacity cost (ADCC), avoided renewable energy certificate cost (ARECC), avoided working capital requirement (AWCR)

2. Benefits are calculated using: Kuldeep, Neeraj et al. 2019. Valuing Grid-connected Rooftop Solar: A Framework to Assess Costs and Benefits to Discoms. New Delhi: Council on Energy, Environment and Water.

3. All the cost values are discounted at 16.5 % for 25 years. The graph captures the benefits that can be realized from cleaning the system.

7.

Recommendations

Recommendations

01

Create standard operating procedures (SoP) for consumers post the AMC period

Systems installed under MNRE subsidy are covered under AMC for a period of five years. **There is a need to create an SoP for consumers for post the AMC period. This could be part of the post-installation documents.** This will facilitate smooth transition from the developer to the consumer and ensure optimum performance of the solar photovoltaic (PV) system. This could include the information on responsibility of manufacturers or developers in case of failure/damage of PV modules, cleaning process, handing over of warranty certificates for different components, point of contacts, and training of consumers, among others.

02

Increase accountability of developers to ensure optimum performance of system

To increase accountability of developers, the **discoms should keep a rating mechanism for vendors**, which is published on the discom's website. The rating should be based on feedback from verified consumers. It is also recommended that the document should highlight the criteria to ascertain the rating of empaneled vendors including the **optimum performance of system, handover of documents, explaining consumers on the maintenance, among others**. This will be critical to identify those vendors with complaints and encourage them to perform well otherwise consumers will not choose them.

Recommendations

03

Simplify the guidelines for the maintenance of the system to increase consumer satisfaction about the technology

MNRE has published detailed guidelines on the do's and don'ts for consumers to maintain their system post-installation. However, **it should be converted into a simpler language as the document is intended for consumers.** Also, it could be **supported by explainer videos** showing steps to maintain the system or through infographics.

04

Roll out AMC services led by discoms

The improvement in system performance provides potential gains to discoms. The **discoms could potentially offer the annual maintenance services in their license area to their consumers**. This helps discoms in generating additional revenue, improve the system performance and retains consumer confidence in the technology. This will ensure the maximum contribution of clean energy in the overall mix as envisaged.

1000 GWh
Potential increase in generation with proper cleaning[1]

0.8 MT CO_2
Additional carbon emission saving with proper cleaning[2]

>700 crore
Total market size for basic packages[3]

Source: Authors' analysis

Notes: [1] Considering 9 GW of installed RTS, Bridge to India, December 2021. [2] CO2 Baseline Database for the Indian Power Sector, CEA; [3] Calculated based on basic package price INR 1,025 + INR 768 with increase per kW

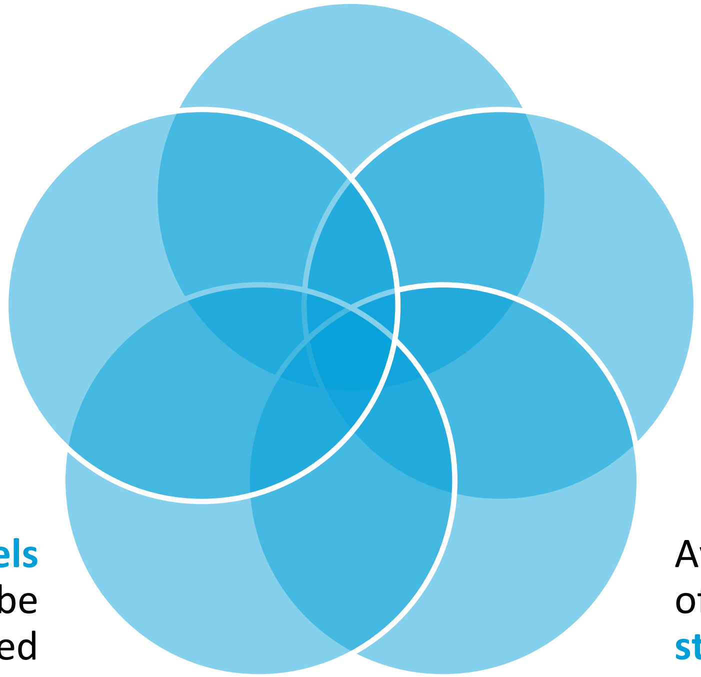
8.

AMC model for improved performance

Why do we need AMC services?

Losses in energy due to dust **reported to be 13.4%**

Other challenges observed are loose cables, **inverter shutdown, panel orientation**



80% of the sites reported soiling issues impacting their performance.

28% of the panels found to be damaged

Average annual degradation rate of **2% is higher than the industry standard**

There are benefits to the discom and consumers if the RTS system performs optimally. Given their easy access to consumers and as a trusted source, discoms become a potential candidate to offer AMC services to the consumer.

 Source: Authors' analysis

Types of AMC packages and services offered

Advanced package

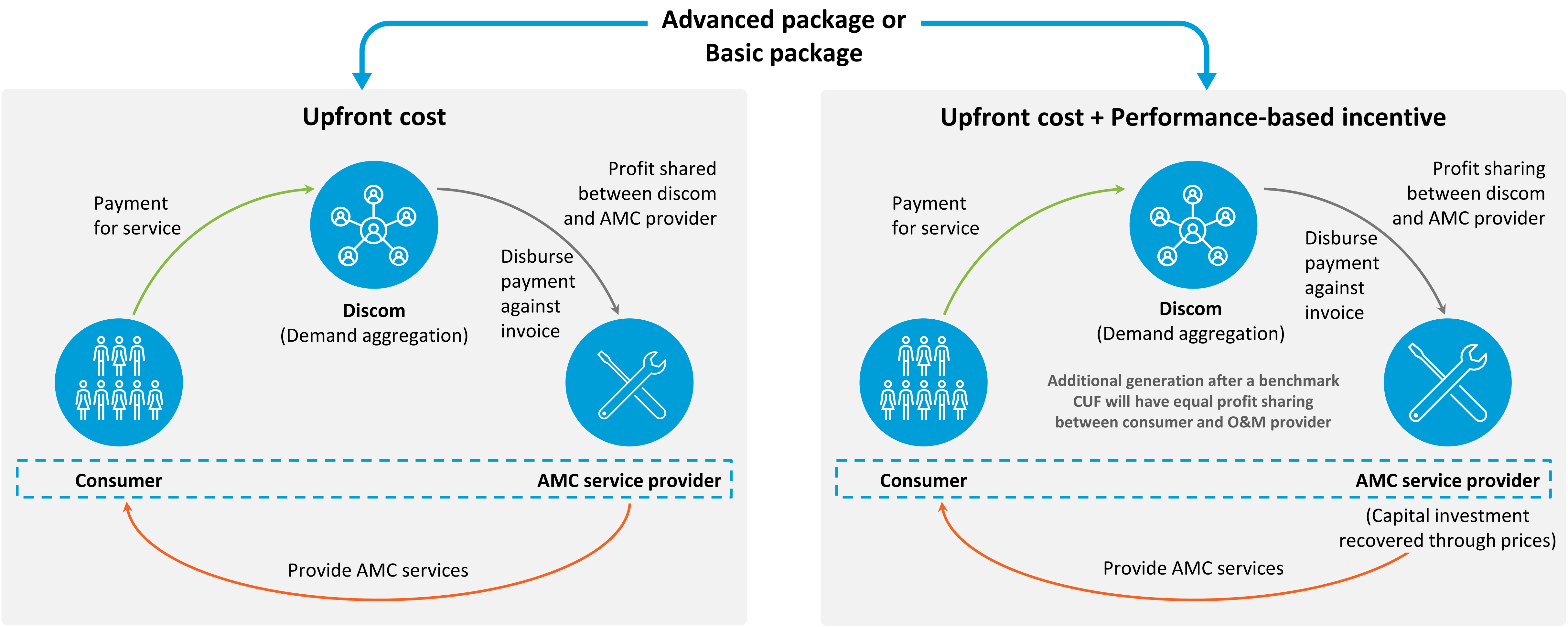
- Cleaning of panels
- Clearing vegetation, shading from nearby trees, plants etc.
- Electrical checks, loose connections (thermal imaging), string current, voltage, etc.
- Checking inverter functionality (servicing), junction box servicing and diagnosing abnormal behaviour in the power plant, system monitoring
- Notifying manufacturing faults, management of repairs/upgrades, warranty claim assistance

Basic package

Annual Maintenance Contract (AMC) refers to the business arrangement between service provider and the consumer to undertake maintenance of the product and ensure its optimum performance.

Source: Authors' analysis

Proposed AMC models



Incentive/disincentive linked to benchmark CUF: If annual CUF is less than benchmark CUF, 10 % penalty on every 0.5 % drop and if higher, equal profit sharing between consumer and developer compensated at the average power procurement cost (APPC).

Source: Authors' analysis

Note: Colour code (for the interaction between): green (consumer and discom); blue (discom and vendor); orange (consumer and vendor)

CEEW and PV Diagnostics team members interact with the rooftop system owner to understand their experience in Paharganj, New Delhi.

9.

Annexures

Key challenges experienced during the field visits

Consumer unavailability

In many cases, consumers agreed to the visit but declined or rescheduled the programme time of visit.

High travel time

Travelling between different locations were difficult due to irradiation time colliding with peak traffic hours, especially in populated areas.

Image: CEEW

Irradiation challenge

As visits were conducted in the months of November and December, weather conditions or very low irradiation also impacted the visit. In some cases, sites visits were undertaken twice to complete the assessment.

Accessibility issues

To conduct the assessment, sites needs to be accessible to clean and perform the test. In a few cases, sites were inaccessible as shown in figures on the right.

Image: CEEW

Source: Authors' analysis

Acronyms

ADCC	avoided distribution capacity cost
AGCC	avoided generation capacity cost
AMC	annual maintenance contract
APCC	avoided power purchase cost
ARECC	avoided renewable energy certificate cost
ATRC	avoided transmission capacity cost
AWCR	avoided working capital requirement
BYPL	BSES Yamuna Power Limited
C&I	commercial and industrial
CUF	capacity utilisation factor
O&M	operation and maintenance
MNRE	Ministry of New and Renewable Energy
SoP	standard operating procedure
Achievable with O&M	Address all the maintenance-related issues such as cable damage, inverter shutdown, shadow effect, among others

Source: Authors' analysis

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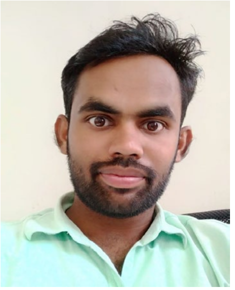

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Organisations

The **Council on Energy, Environment and Water (CEEW)** is one of 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. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public.

BSES Yamuna Power Limited (BYPL) is a joint venture of Reliance Infrastructure Ltd., (a 80 year old power utility) and Govt. of NCT of Delhi,donning the mantle of distributing electricity to East and Central part of National Capital Territory of Delhi. Catering Electricity to geographical areaof around 200 sq kms. The company supplies electricity to over 10.46 lakh customers as on date, covering a population base of nearly 42 lakh in Central and East Delhi.Since taking over distribution in July 2002, BYPL singular mission has been to provide reliable and quality electricity supply. BYPL has achieved a record reduction in AT&C losses from a high of 63.1 % in 2002 to 23% in less than 8 years of its existence.

PV Diagnostics is a solar-tech consultancy, founded in 2017. Our services lie at the forefront of tech and innovation in the solar industry. PVD aim is to improve the performance of solar plants and assists in quality inspection, monitoring and testing from the inception to the O&M stage of the plant. It offers services across the solar value chain. PVD also offers product integration for its clients in form of microservices and independent plant assessment tools for various stages of plant life. PVD have evaluated more than 6 GW of solar assets which constitutes over 100 projects in India and abroad (USA, South Africa and South East Asia). PVD top existing customers include Tata Power, Renew Power, ACME, Adani, KKR, Indigrid, Cleantech Solar, Sterling Wilson, Tata Power, Adani to name a few. PVD is now an ISO 9001:2005 certified.

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