International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 23s, 2025
https://www.theaspd.com/ijes.php

Assessing Consumer Adoption And Awareness Of Rooftop Solar Integration: A Case Study Of The Distribution System

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Abstract
*This study examines consumer awareness and adoption of rooftop solar power systems within the **Dis**tribution **Com**pany - DISCOM service area. A quantitative type of research approach was employed to investigate awareness levels, adoption rates across residential, commercial, and industrial sectors, barriers to adoption, consumer satisfaction, and perceptions of DISCOM's role. Stratified random sampling was used to get a proportional number of respondents from residential, commercial, and industrial areas. The finding of the study uncovered notable awareness gaps regarding rooftop solar power, particularly among residential consumers, highlighting a lack of sufficient knowledge about its benefits and installation processes. Additionally, a deficiency in accessible and clear information further hindered widespread adoption, leaving many consumers uncertain about available incentives, net metering policies, and technical feasibility. However, among those who had already adopted rooftop solar power, overall satisfaction levels were relatively high, indicating that once implemented, the system met user expectations in terms of performance and cost savings. These findings highlight the need for targeted awareness campaigns, financial incentives, and improved utility support to accelerate rooftop solar integration within the DISCOM distribution network.*
Keywords: Consumer awareness, rooftop solar power, adoption rates, DISCOM

1. INTRODUCTION

The global shift towards renewable energy is gaining momentum, largely driven by the pressing need to mitigate climate change and ensure long-term energy sustainability (Arndt, 2019). Among the various renewable energy solutions, rooftop solar power has emerged as a key contributor, allowing decentralized electricity generation while reducing dependence on fossil fuels (Elavarasan, 2019). India, with its vast solar potential, has set ambitious renewable energy targets to expand its solar capacity (Dalal, 2023). As part of this effort, the government has introduced policies and incentives to encourage the adoption of rooftop solar systems (Anjum, 2024). However, realizing these targets requires a deeper understanding of consumer behavior, particularly the factors influencing adoption decisions, awareness levels, and the barriers that deter widespread implementation (Kumar, 2024).

Existing research highlights several determinants of solar adoption, including financial incentives (Wani, 2020), environmental consciousness (Kumar, 2024), and technological feasibility (Elavarasan, 2019). While these studies provide valuable insights, there remains a notable gap in assessing consumer awareness and satisfaction at a localized level, particularly within specific utility service areas. Many consumers lack sufficient information about the benefits, installation processes, and regulatory policies associated with rooftop solar adoption. Furthermore, unclear incentive structures and limited consumer engagement have led to slow adoption rates in certain regions. Addressing these concerns requires a detailed analysis of consumer perceptions and challenges to ensure that policy interventions and market strategies align with consumer needs.

This study aims to fill this research gap by focusing on the DISCOM distribution system, providing an in-depth examination of consumer awareness, adoption barriers, and satisfaction levels. By analyzing data from residential, commercial, and industrial consumers within DISCOM's service area, the study offers localized insights to improve policy frameworks and utility strategies. Understanding consumer concerns and expectations will enable targeted interventions, such as enhanced awareness campaigns, streamlined regulatory support, and financial incentives tailored to different consumer segments. These findings will

contribute to accelerating the integration of rooftop solar power into DISCOM's energy distribution network, ultimately supporting India's broader renewable energy objectives.

2. METHODOLOGY

This research employed a quantitative research approach. A stratified random sample of residential, commercial, and industrial consumers within the DISCOM distribution area was surveyed. Stratification was based on consumer type (residential, commercial, industrial), ensuring proportional representation of each sector within the DISCOM consumer base according to publicly available data from DISCOM (e.g., annual reports, customer segmentation reports). This approach ensures the sample is representative of the diverse consumer landscape within the DISCOM distribution area (Wani, 2020). Random sampling within each stratum was achieved using a random number generator to select consumer accounts from DISCOM's customer database.

The sample size was determined using G*Power software (Wani, 2020), a widely used tool for power analysis, which calculates the minimum sample size needed to achieve a desire level of statistical power (set at 80%) to detect meaningful differences between groups, considering the anticipated effect sizes and alpha level (set at 0.05). The specific sample size calculation was based on prior research on solar adoption rates and awareness levels in similar contexts and is justified by the need to ensure statistically significant results for each consumer type (Wani, 2020). The calculated sample size was 302, distributed proportionally across the three strata. A structured questionnaire was administered to the selected consumers, measuring awareness of rooftop solar systems and their benefits using a five-point Likert scale (1=strongly disagree, 5=strongly agree) (Warhade, 2024). A five-point Likert scale was used since it is important for measuring the attitudes and perceptions of respondents in a structured and quantifiable way. It provides a balanced range of responses, allowing respondents to express varying degrees of agreement or disagreement (Demissie et al., 2024). Questions on existing rooftop solar installations determined adoption rates.

The collected data using a questionnaire were cleaned and entered into SPSS software version 26. Descriptive statistics, including means, standard deviations, frequencies, and percentages were used to summarize the data. Inferential tests, such as ANOVA and t-tests, were employed to compare awareness levels and adoption rates across consumer types. Effect sizes were calculated to quantify the magnitude of the observed differences (Wani, 2020).

3. RESULTS

Awareness of Rooftop Solar Systems

The awareness of rooftop solar power systems plays a crucial role in their widespread adoption, as it directly influences consumer decision-making and investment in renewable energy solutions. Despite the growing global shift toward sustainable energy, many potential users remain uninformed about the benefits, installation processes, and financial incentives associated with rooftop solar technology. Factors such as inadequate promotional efforts, limited access to reliable information, and perceived technical complexity contribute to low awareness levels, particularly among residential consumers. Understanding these awareness gaps is essential for designing targeted outreach programs that enhance consumer knowledge and confidence in adopting solar energy. The following table shows the awareness level of respondents in the study area.

Table 1: *Consumer Awareness of Rooftop Solar Systems and Benefits*

Consumer Type	n	Mean	SD	F-statistic	p-value
Residential	164	2.8	1.2		
Commercial	96	3.5	1.0	40.07	0.000
Industrial	42	4.2	0.8		

Source: Survey Data, 2024

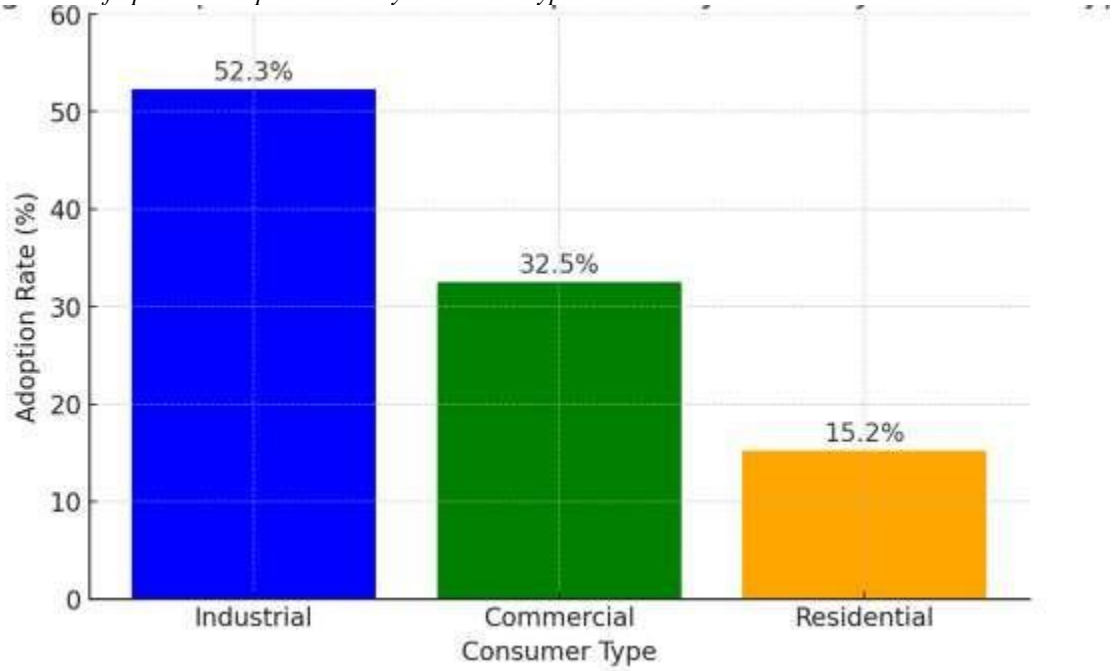
Table 1 displays the percentage of consumers aware of rooftop solar systems and their benefits, categorized by consumer type. The mean awareness score was highest among industrial consumers (4.2 ± 0.8), followed by commercial (3.5 ± 1.0) and residential (2.8 ± 1.2) consumers. A one-way ANOVA revealed

statistically significant differences in awareness levels across consumer types ($F(2,299) = 40.07$, $p < 0.001$). The overall result indicated that industrial consumers exhibited significantly higher awareness compared to both commercial and residential consumers, while commercial consumers showed significantly higher awareness than residential consumers.

4. Rooftop Solar Adoption Rates

Rooftop solar adoption rates vary across consumer segments, influenced by factors such as awareness, financial capacity, and policy support. Industrial consumers typically exhibit the highest adoption due to cost savings and energy efficiency benefits, while commercial and residential sectors face barriers like upfront costs and regulatory complexities. Understanding these adoption patterns helps in designing targeted incentives and policies to accelerate solar integration across all sectors, promoting sustainable energy transitions. The following figure shows the rooftop solar adoption status of respondents in the study area.

Figure 1: *Rooftop Solar Adoption Rates by Consumer Type*



Source: Survey Data, 2024

Figure 1 presents the adoption rates of rooftop solar systems across different consumer types, highlighting significant variations in uptake. The highest adoption rate was observed among industrial consumers, with 52.3% having installed rooftop solar systems. This can be attributed to the substantial energy demands of industrial operations, where solar power provides a cost-effective and sustainable alternative to conventional electricity sources, leading to long-term savings and energy security. Commercial consumers followed with an adoption rate of 32.5%, benefiting from reduced electricity expenses and government incentives, though factors such as space limitations and initial investment costs may have influenced their relatively lower adoption compared to industrial users. Residential consumers had the lowest adoption rate at 15.2%, likely due to financial constraints, lack of awareness, and perceived complexities in installation and maintenance. These variations in adoption rates underscore the need for targeted awareness campaigns, simplified installation processes, and tailored financial incentives to encourage broader adoption across all consumer categories, ultimately promoting the widespread integration of rooftop solar power.

5. Barriers to Adoption

Despite the benefits of rooftop solar power, several barriers hinder widespread adoption across consumer segments. High initial costs, limited awareness, and complex regulatory procedures often discourage potential adopters, particularly in residential areas. Additionally, concerns about maintenance, technical

feasibility, and unclear financial incentives further slow adoption rates. Addressing these challenges through targeted policies, financial support, and streamlined installation processes is essential to accelerating the transition to solar energy.

Table 2: *Key Barriers to Rooftop Solar Adoption*

Barrier	Frequency (%)	Rank
High Upfront Costs	85	1
Maintenance Concerns	68	2
Lack of Information	62	3
Complex Installation Procedures	55	4
Uncertainty about Returns on Investment	48	5

Source: Survey Data, 2024

Table 2 summarizes the key barriers to rooftop solar adoption identified through the survey and interviews, ranked by frequency of mention. High upfront costs emerged as the most frequently cited barrier (85%), followed by concerns about maintenance (68%), lack of information (62%), complex installation procedures (55%), and uncertainty about returns on investment (48%).

6. Consumer Satisfaction

Consumer satisfaction with rooftop solar power systems is a key indicator of their long-term viability and impact. Satisfaction levels are influenced by factors such as system performance, cost savings, ease of maintenance, and support from utility providers. While adopters generally report positive experiences, issues like inadequate after-sales service, unclear billing mechanisms, and occasional technical difficulties can affect overall satisfaction. Understanding consumer feedback helps in refining policies, improving service delivery, and enhancing the overall adoption experience, ultimately fostering greater trust in solar energy solutions.

Table 3: *Consumer Satisfaction with Rooftop Solar Systems*

Aspect	Residential		Commercial		Industrial	
	Mean	SD	Mean	SD	Mean	SD
Energy Cost Savings	4.5	0.7	4.8	0.5	4.9	0.4
Environmental Benefits	4.3	0.8	4.6	0.6	4.7	0.5
System Reliability	4.0	0.9	4.3	0.7	4.5	0.6
DISCOM Support Services	3.2	1.1	3.5	0.9	3.8	0.8

Source: Survey Data, 2024

Table 3 presents consumer satisfaction levels with various aspects of installed rooftop solar systems and the overall satisfaction was high, with consumers across residential, commercial, and industrial sectors expressing positive views on energy cost savings and environmental benefits, which received the highest ratings. However, satisfaction with DISCOM's support services was notably lower, with mean scores ranging from 3.2 to 3.8, suggesting gaps in customer service, installation assistance, and ongoing maintenance support. This discrepancy points to a crucial area for improvement, as efficient post-installation support and responsive utility services play a significant role in sustaining consumer trust and encouraging further adoption. Addressing these service-related concerns through enhanced communication, streamlined regulatory processes, and better consumer engagement can significantly improve user experience and boost confidence in rooftop solar technology, ultimately contributing to its wider acceptance and integration within the DISCOM service area.

7. Before solar and after solar voltage profile.

In one of the distribution system, x nos of consumers reading were taken and voltage before solar and after solar were calculated. The study was carried out for impact of Solar Power Injection at Load Factor on Voltage Profile.

International Journal of Environmental Sciences
ISSN: 2229-7359
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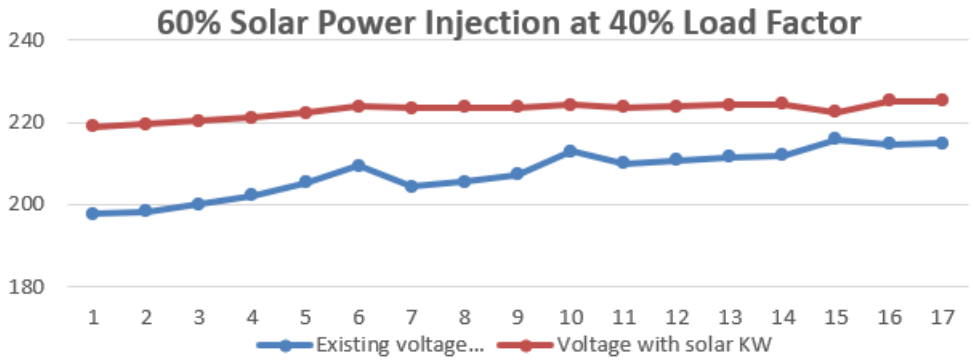
Table 4: Impact of 60% Solar Power Injection at 40% Load Factor on Voltage Profile

60 % Load Factor and 20 % Solar power Injection										
Location		**Single phase load**	**Single phase load**	**Difference in Load**	**Three phase load**	**Three phase load**	**Difference in Load**	**Existing Voltage W/O Solar**	**Voltage with solar**	**Difference in Voltage**
		KW	KW	KW	KW	KW	KW	KW	KW	**KW**
1		9	2	7	21.5	0	21.5	181.72	213.569	**-31.849**
2		3	0	3	61	14.1	46.9	182.72	214.408	**-31.688**
3		0.5	0	0.5	0	0	0	185.12	215.404	**-30.284**
4		0	0	0	15	5.28	9.72	188.5	216.806	**-28.36**
5		1	0	1	9.5	3.2	6.3	192.96	218.502	**-25.542**
6				0			0	199.96	220.721	**-20.761**
	6.1	4.5	0	4.5	32	8.97	23.3	192.77	220.357	**-27.587**
	6.2	18	5.93	12.7	20	12.81	7.19	194.6	220.387	**-26.327**
	6.3	3.5	0	3.5	8.5	5.85	2.65	195.96	220.491	**-24.531**
7				0			0	204.32	221.153	**-16.833**
	7.1	6	2.1	3.9	26	0	26	194.71	220.406	**-25.696**
	7.2	6	0	6	21.5	1.98	19.52	195.85	220.806	**-24.956**
	7.3	5	0	5	0	0	0	197.11	221.336	**-24.226**
	7.4	19.5	0	19.5	12.5	0	12.5	202.99	221.624	**-18.634**
8				0			0	208.81	223.362	**-14.552**
	8.1	4.5	0	4.5	12	0	12	207.2	222.776	**-15.756**
	8.2	0	0	0	37	6.89	30.11	207.45	222.944	**-15.494**



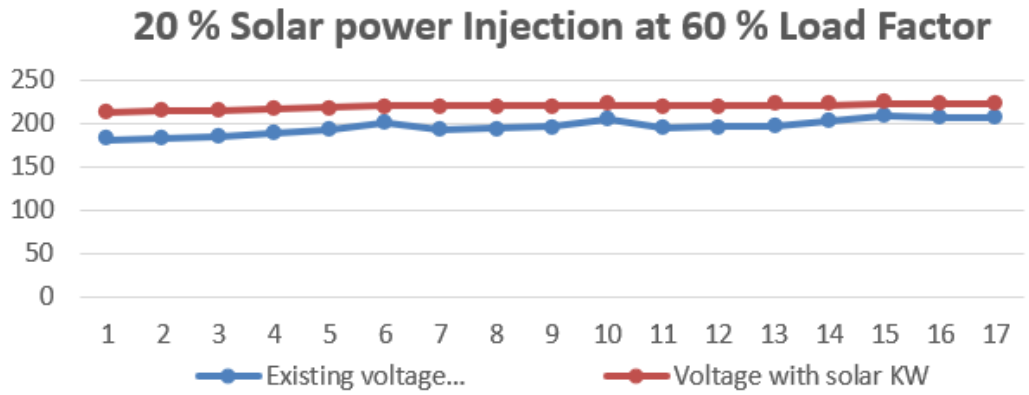
This study analyzes the effect of 60% solar power injection on voltage performance under a 40% load factor across various single-phase and three-phase loads. Observations reveal that solar integration consistently improved system voltage, raising it from a range of 197–215 V (without solar) to 219–225 V (with solar). The voltage rise varied between 6.7 V and 21.3 V, with the maximum improvement occurring at higher load reductions, particularly where three-phase loads decreased by up to 46.9 kW. Single-phase load reductions were recorded up to 19.5 kW. Instances with negligible load variation exhibited comparatively lower voltage gains. The results demonstrate that solar power injection mitigates low-voltage conditions, enhances grid

stability, and supports load management by reducing overall demand on the system.

This highlights the potential of distributed solar generation to act as a voltage support mechanism, particularly in networks experiencing fluctuating industrial and residential loads. The findings support the integration of photovoltaic systems as a strategic approach for improving power quality and reliability in low- to medium-voltage networks.

Table 5: Impact of 20% Solar Power Injection at 60% Load Factor on Voltage Profile

20 % Solar power Injection at 60 % Load Factor										
Location		**Single phase load**	**Single phase load**	**Difference in Load**	**Three phase load**	**Three phase load**	**Difference in Load**	**Existing voltage W/O Solar**	**Voltage with solar**	**Difference in Voltage**
		KW	KW	KW	KW	KW	KW	KW	KW	**KW**
1		9	2	7	21.5	0	21.5	181.72	213.569	**-31.849**
2		3	0	3	61	14.1	46.9	182.72	214.408	**-31.688**
3		0.5	0	0.5	0	0	0	185.12	215.404	**-30.284**
4		0	0	0	15	5.28	9.72	188.5	216.806	**-28.306**
5		1	0	1	9.5	3.2	6.3	192.96	218.502	**-25.542**
6				0			0	199.96	220.721	**-20.761**
	6.1	4.5	0	4.5	32	8.97	23.03	192.77	220.357	**-27.587**
	6.2	18	5.93	12.07	20	12.81	7.19	194.06	220.387	**-26.327**
	6.3	3.5	0	3.5	8.5	5.85	2.65	195.96	220.491	**-24.531**
7				0			0	204.32	221.153	**-16.833**
	7.1	6	2.1	3.9	26	0	26	194.71	220.406	**-25.696**
	7.2	6	0	6	21.5	1.98	19.52	195.85	220.806	**-24.956**
	7.3	5	0	5	0	0	0	197.11	221.336	**-24.226**
	7.4	19.5	0	19.5	12.5	0	12.5	202.99	221.624	**-18.634**
8				0			0	208.81	223.362	**-14.552**
	8.1	4.5	0	4.5	12	0	12	207.02	222.776	**-15.756**
	8.2	0	0	0	37	6.89	30.11	207.45	222.944	**-15.494**



This study investigates the impact of 20% solar power injection on voltage stability under a 60% load factor for mixed single-phase and three-phase loads. Results show a notable improvement in system voltage, with levels increasing from 181–209 V (without solar) to 213–223 V (with solar). Voltage rise ranged from 14.55 V to 31.85 V, with the highest improvement observed during heavy three-phase load reduction of up to 46.9 kW. Single-phase load reductions reached up to 19.5 kW, while several instances exhibited minimal or zero load variation, leading to relatively smaller voltage gains. Compared to higher solar penetration (e.g., 60% injection), the 20% injection still provided significant voltage uplift, though with relatively larger negative differences at lower voltages, indicating under-compensation in some high-load scenarios. The findings emphasize that even moderate solar integration contributes to mitigating low-voltage conditions, improving grid performance, and supporting demand management, especially in areas with substantial industrial or commercial loads. These insights reinforce the role of distributed solar systems as a complementary tool for power quality enhancement in low- and medium-voltage distribution networks.

The study of above two cases can be summarized as follows :

At 20% solar injection (60% load factor), voltages rose from 181–209 V to 213–223 V (increase: 14.5–31.8 V). At 60% solar injection (40% load factor), voltages improved from 197–215 V to 219–225 V (increase: 6.7–21.3 V). Higher solar penetration provided more stable and moderate voltage correction, keeping levels closer to nominal, while lower penetration caused larger swings under heavy loads due to limited compensation.

This comparison shows that greater solar injection enhances voltage stability and reduces fluctuations, whereas lower injection, though beneficial, may be insufficient during peak demand. Optimizing solar capacity according to load profiles is essential for reliable grid performance.

8. Perceptions of DISCOM's Role

Consumer perceptions of DISCOM play a crucial role in shaping the adoption and success of rooftop solar power systems. As the primary electricity distributor in the region, DISCOM is responsible for providing clear information, facilitating smooth grid integration, and ensuring regulatory support for consumers transitioning to solar energy. While some consumers recognize DISCOM’s efforts in promoting renewable energy, others express concerns about bureaucratic delays, insufficient communication, and a lack of proactive engagement. Strengthening DISCOM’s role through improved customer support, transparent policies, and efficient service delivery can enhance consumer trust and accelerate the adoption of rooftop solar power.

Table 6: *Consumer Perceptions of DISCOM's Role*

Perception	**n**	**%**
Helpful in providing information	217	72
Streamlined connection process	196	65
Could improve communication	145	48
Could improve support services	127	42
Unhelpful or obstructive	24	8

Source: Survey Data, 2024

Table 6 summarizes consumer perceptions of DISCOM's role in facilitating rooftop solar adoption. While a majority viewed DISCOM as helpful in providing information (72%) and streamlining the connection process (65%), a substantial proportion felt that DISCOM could improve its communication (48%) and support services (42%). These findings highlight the importance of proactive utility engagement in fostering consumer confidence and accelerating solar adoption. The relatively low percentage (8%) who found DISCOM unhelpful or obstructive suggests that with improved service provision, DISCOM could play a more significant role in driving wider adoption.

9. DISCUSSION

This study reveals significant variations in rooftop solar awareness and adoption across different consumer segments within the DISCOM distribution area. Residential consumers exhibit notably lower awareness and adoption rates compared to commercial and industrial consumers, highlighting the need for targeted interventions to address specific barriers within this sector (Warhade, 2024). Residential consumers may face challenges such as limited access to information, lack of technical knowledge, or space constraints, which hinder their ability to adopt solar technology. Tailored educational campaigns, community outreach programs, and simplified information dissemination could play a pivotal role in bridging this gap and fostering greater engagement among residential consumers (Warhade, 2024).

A key finding across all consumer types is the consistent ranking of "high upfront costs" as a major barrier to rooftop solar adoption. This underscores the crucial role of financial incentives and innovative financing mechanisms in making solar technology more accessible. Studies have demonstrated the significant impact of government subsidies on consumer purchase intentions, as they reduce the financial burden and make solar installations more appealing (Wani, 2020). Additionally, exploring alternative financing models such as solar leasing, pay-as-you-go schemes, or low-interest loans could further alleviate cost concerns and encourage wider adoption, particularly among cost-sensitive residential consumers (Varghese, 2024).

The study also emphasizes the importance of addressing information gaps and simplifying installation procedures to reduce perceived complexity and risk. Simplifying processes, providing clear guidelines, and offering robust technical support can significantly enhance consumer confidence and satisfaction (Baldwin, 2015). While overall satisfaction with installed rooftop solar systems is generally high, the lower satisfaction with DISCOM's support services suggests an opportunity for the utility to enhance its communication and technical assistance programs (Kureel, 2022). Improved customer service, proactive engagement, and reliable post-installation support could strengthen consumer trust and encourage broader adoption. These findings highlight the synergistic relationship between consumer awareness, perceived benefits, financial accessibility, and utility support in shaping rooftop solar adoption (Kumar, 2024). A holistic approach that addresses these interconnected factors is essential to overcoming existing barriers and driving wider adoption.

10. CONCLUSION AND RECOMMENDATIONS

The study revealed significant awareness gaps in rooftop solar power, especially among residential consumers, due to insufficient knowledge about its benefits and installation processes. Lack of clear information on incentives, net metering policies, and technical feasibility further hindered adoption, leaving many consumers uncertain about the process and benefits. The findings suggest a multi-faceted strategy. This should include:

- **Targeted Awareness Campaigns**: Public awareness campaigns should specifically target residential consumers, addressing concerns about high upfront costs, maintenance, and perceived complexity. The campaigns should highlight the long-term economic benefits and environmental advantages of rooftop solar systems, utilizing various channels, including community outreach programs, social media, and collaborations with local influencers.
- **Enhanced Financial Incentives**: DISCOM and the government should explore expanded financial incentives, including subsidies, tax breaks, and innovative financing options such as leasing or power purchase agreements. These should be tailored to the financial capacity of different consumer segments to ensure equitable access to rooftop solar technology.

- **Improved DISCOM Support Services**: DISCOM needs to invest in improving its communication and support services for rooftop solar customers. This includes providing clear information on net metering policies, simplifying the installation and connection process, offering technical assistance, and establishing readily accessible customer support channels.
- **Simplified Regulatory Framework**: Streamlining the regulatory framework for rooftop solar installations will reduce bureaucratic hurdles and incentivize greater adoption. This involves simplifying permitting processes, establishing clear guidelines for grid integration, and ensuring timely processing of applications.
- **Community-Based Initiatives**: Promoting community-based solar projects and fostering peer-to- peer learning can leverage social influence and reduce perceived risks associated with rooftop solar adoption. Sharing success stories and testimonials from early adopters can build community trust and encourage wider participation.

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