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Adoption and Economic Analysis of Rooftop Solar Photovoltaics: A Consumer-Centric Approach

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ABSTRACT:
The rapid growth in energy demand has made renewable energy adoption a necessity for sustainable development. This study examines the adoption of rooftop solar photovoltaic (PV) systems among private property owners in India, focusing on consumer perceptions, technological innovations and economic feasibility. It highlights benefits such as environmental sustainability, bill savings and enhanced energy awareness, while also identifying barriers like high costs, perceived risks and lack of workforce reliability. Using a consumer-driven model, the study evaluates savings and utility benefits across different PV capacity ranges (1–4 kW, 4–6 kW and 6–9 kW) for two Indian utilities—MSEDCL and Tata Power. Results indicate that larger PV capacities yield greater savings and utility benefits, with optimal feed-in tariff (FiT) rates enhancing profitability. The study emphasizes the importance of policy support, awareness programs and technological advancements to accelerate solar adoption and ensure long-term energy sustainability.

KEYWORDS: Rooftop Solar, Photovoltaic Adoption, Renewable Energy, Consumer Perception, India, Feed-in Tariff, Energy Economics

INTRODUCTION:

Energy is seen as a basic necessity in today's world since it is necessary to daily activities. Every aspect of existence involves energy or is affected by it. Adopting and supporting energy sources that can fulfil all energy requirements and preserve energy for future generations is necessary due to the growing demand for energy. Renewable energy (RE) projects and cleaner creation are significantly impacted by green innovation. Right present, any country can accelerate its economic growth by skillfully preserving its energy resources and interest.

The most popular method of "going solar" for a private property owner is a complicated decision. Studies on the diffusion of innovation suggest that the development of a broad innovation arrangement is largely influenced by individual independent direction; this is especially evident for the private solar PV industry.

Previous study has attempted to gain a better understanding of the elements that promote and hinder the usage of solar photovoltaics in order to allow a wider adoption of rooftop solar. Buyers see a number of benefits from solar PV investments, according to this analysis: a positive net energy life cycle, increased energy awareness, the ability to view the outside of the home as a sign

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of financial stability, bill savings and environmental benefits such as a decrease in nearby contamination. Mortgage holders may be deterred from going solar for a number of reasons, such as perceptions of innovative risk and complexity, worries about the nature of PV frameworks, uncertainty about bill savings owing to changes in administrative systems, ignorance of the underlying mechanical subtleties and lack of confidence in the workforce for hire. High actual and visible costs, an uncomfortable feeling of being on the roof and the irregular and insufficient character of the labour force engaged for the job all serve to dissuade mortgage holders from making purchases. Early studies on the adoption of solar photovoltaics (PV) frequently examined rooftop solar buying incentives and barriers without providing detailed information about the solar module itself. This most likely happened as a result of consumers' limited capacity to select features like board and mounting type due to the limited item availability in the solar PV industry. Recent industry initiatives to remove adoption hurdles have led to significant mechanical developments in componentry, including board type and mounting method, which have increased consumer choice.

Consumers have options regarding, among other things, various module materials, innovative lightweight flexible modules versus conventional rigid modules and building-integrated photovoltaics (BIPV) versus building-applied photovoltaics (BAPV), all of which have an effect on expenses and productivity. In order to verify that the new products address the critical adoption obstacles and make sure that these agreements don't unintentionally generate new barriers that, if overlooked, can impede organisation, more research into customer perceptions is necessary in light of these innovative and novel innovations. This study focuses on US mortgage holders' adoption of solar PV. A locally customised example was utilised to gain insights that might be applicable to various geographic districts. Research writing draws attention to similarities between places, as well as at the public and global levels, given that the reasons and concerns for moving to solar power are similar.

In any event, members in different states may have a positive attitude towards solar adoption due to local differences, such as government subsidies or neighbouring impacts.

LITERATURE REVIEW

Aklin, Cheng and Urpelainen (2018) examine how social recognition of new energy innovation varies across developing countries. The review emphasises how important it is to comprehend public opinions and judgements regarding energy innovations because these factors taken together have a significant impact on the successful implementation of sustainable advancements. The authors investigate the implications of different informational introductions about new energy technologies for public recognition by utilising a framing test. The results highlight the need for specific correspondence strategies to enhance the social acceptance of renewable energy initiatives in developing regions.

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Duan et al. (2021) contribute to the literature. The review presents a nuanced perspective on the relationship between energy and carbon costs across different quantiles using a quantile-on-quantile method. The analysis provides evidence of how energy costs impact carbon pricing schemes, illuminating the complex relationship between natural policy and economic considerations. Comprehending these relationships is essential to developing effective carbon pricing models that account for the various impacts on various sectors of the economy.

Elavarasan et al. (2021) look into how innovations in renewable energy can be integrated into a network-related environment. The review focuses on a PV-diesel-hydrogen energy unit-based design for a building intended for institutional use, utilising cost enhancement estimates and the Best-Most Effective Strategy (BWM) approach. The analysis highlights the importance of sustainable energy systems and suggests a comprehensive approach to address upgrading from both an economic and environmental standpoint. The evaluation provides a methodical approach to assessing and concentrating on different energy possibilities by considering the Building with Various Points of View (BWM) framework. This ensures a comprehensive analysis of renewable energy solutions for academic buildings.

Gandini and Almeida (2017) explore the usage of direct current (DC) microgrids as a tool for realistic rustic shock. The assessment places a strong emphasis on the development of capacity frameworks to improve the efficiency and dependability of the energy supply outside of network areas. Through the use of a solar-powered methodology, the authors offer a workable solution for supplying electricity to regional networks, thereby promoting a sustainable trajectory and improving living conditions. The results highlight DC microgrids' potential as a clever and trustworthy solution for rustic shock.

Hossain et al. (2019) provide a framework and cost analysis of independent solar housing frameworks. The research looks into the technical and financial aspects of setting up solar home systems to supply off-network households with electricity. The authors conduct a thorough analysis to evaluate the feasibility and economics of autonomous solar systems, highlighting the challenges and opportunities associated with implementing such systems for rural electricity generation in developing countries.

Iqbal and colleagues (2018) contribute to the literature by investigating the potential of biomass energy in Pakistan's energy components. The evaluation delves into biomass's potential as a renewable energy source, considering its role in meeting the nation's energy needs. Through an analysis of the current energy landscape, the authors provide useful insights into the challenges and opportunities associated with biomass energy, providing a comprehensive overview of its potential in relation to Pakistan. The discussion on increased energy hotspots for sustainable turn of events gains important new information from this study.

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2. METHODOLOGY

The three most popular business models in India for rooftop solar installations are utility-partnered, buyer-driven and based on Renewable Energy Service Companies (RESCO). The buyer-driven paradigm outlined in this article places all responsibility for the framework, as well as for the rooftop installation's financial and functional needs, on the client. Prosumer properties—those with installed rooftop solar PV boards—and shopper properties—those without any neighbouring self-age—are the two categories of private properties taken into consideration. There are three categories for prosumers based on the range of installed PV limits. In India, the maximum allowable PV constraints are restricted to 9–11 kW, depending on the utility. There are three categories: 1-4 kW, 4-6 kW and 6-9 kW. The succession is required since a single policy proposal spanning the entire range of 1-9 kW would be unreasonable given the large variations in capital investment costs. The best way to see the advantages of becoming a prosumer is to look at the savings obtained from installing rooftop solar power after deducting the system's interest payments and the money made from selling privately generated rooftop solar energy. The profit from the energy offer at ABR is the utility's advantage, after deducting the cost of obtaining energy.

3. RESULTS AND DISCUSSION

Three consumers and two prosumers, whose heap request is dictated by their service bills, are assessed using the proposed methodology. The search space of the multi-objective enhancement computation is defined by the limitations of the choice parameters FiT, PV size and Ed p, as indicated in Table 2. Two Indian utilities, MSEDCL and Goodbye Power, are considered for the study based on their present upsides of ABR and ACoS. In a similar manner, ABR values between 100 and 120% of ACOS are used to repeat the test.

3.1. MSEDCL (Maharashtra) Case No. 1

The range of 6-9 kW PV limits offers the best trade-offs for overall utility benefit and prosumer savings. However, PV restrictions of 1-4 kW result in reasonable rate compromises (see Table 6).

3.2. TATA power in case two (Delhi)

Such a pattern If 1 is observed, this indicates that the optimum rate compromises for PV limits within the range of 1–4 kW are found. However, a win-win situation occurs when PV restrictions are reached, specifically between 6 and 9 kW. Table 8 shows that the optimal Ed p increases from 51% to 61% of Egp for the current ABR and ACoS values. Additionally, the ideal FiT ranges from Rs 1 to 1.4 per kWh for the majority of lowest PV restrictions of 1-4 kW and from Rs 1 to 1.6 per kWh for bigger PV limits of 4-9 kW. Table 9 illustrates how the benefit over PV restrictions rises from 9%–14% to 21%–49% when ABR is valued at 120% of ACoS. Benefits are rising since the utility is getting more revenue from the increase in ABR. As of this now, the ACoS is 7.31 Rs/kWh and the ABR is 4.96 Rs/kWh for goodbye power. Because the prevailing ABR in this instance is

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far lower than ACoS for Goodbye Power, the prosumer savings and utility benefits are less than those of MSEDCL.

CONCLUSION:

The analysis concludes that rooftop solar PV adoption among residential consumers offers significant economic and environmental benefits, particularly when supported by flexible FiT structures and utility partnerships. The 6–9 kW range consistently showed optimal trade-offs between consumer savings and utility revenue. The study also reveals that technological innovation (such as flexible modules and BIPV) can address adoption barriers, but requires greater awareness and consumer trust. Utility policies must ensure competitive FiT rates, simplified procedures and training programs to improve workforce reliability. Given India's growing energy demand, proactive measures in policy design, subsidy frameworks and community engagement will be critical for scaling rooftop solar PV and achieving sustainable energy goals.

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