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ADOPTION OF RESIDENTIAL RENEWABLE ENERGY: AN EMPIRICAL STUDY OF ROOFTOP SOLAR IN URBAN AND RURAL HOMES

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Abstract

In India, installing rooftop solar energy systems has become a crucial tactic for advancing decentralized, sustainable energy access. The socioeconomic, informational, and infrastructure aspects affecting rooftop solar adoption in urban and rural households were investigated in this study. In-depth interviews with important stakeholders were combined with survey data from 400 families (200 urban and 200 rural) as part of a mixed-methods approach. The findings showed that adoption was considerably greater in cities due to factors including greater income, education, and knowledge of government incentives. On the other hand, even though rural homes had excellent physical conditions, they encountered obstacles like lack of awareness, upfront expenses, and inadequate technical support. Adoption was strongly predicted by income, education, and policy knowledge, according to statistical analysis. According to the report, awareness campaigns, financial tools, and enhanced vendor networks are necessary for the inclusive and broad adoption of household renewable energy in India. It also emphasized the need for customized policy measures that address rural-specific obstacles.

***Keywords**: Rooftop solar, renewable energy adoption, urban-rural divide, residential energy, solar PV systems, government subsidy, energy policy, sustainable development.*

1. INTRODUCTION

Renewable energy technologies are now at the forefront of national energy strategy due to the worldwide trend toward sustainable energy systems. In nations like India, where both urban and rural populations deal with rising energy demands and erratic grid stability, rooftop solar photovoltaic (PV) systems have become a popular and decentralized energy option for residential sectors. By lowering reliance on traditional electricity sources, residential rooftop solar not only solves the dual problems of energy access and environmental sustainability, but it also has the potential to save households money.

Despite the acknowledged advantages, different geographies and socioeconomic classes continue to adopt rooftop solar at different rates. Rural families usually encounter financial, awareness-related, and infrastructure-related obstacles, whereas urban households frequently have easier access to information, funding, and installation services. This discrepancy emphasizes how crucial it is to comprehend the numerous social, economic, behavioral, and institutional elements that affect rooftop solar system adoption in distinct residential settings.

The purpose of this study was to investigate empirically how rooftop solar energy is being adopted by Indian homes, both urban and rural. It investigated the socioeconomic factors, knowledge levels, perceived obstacles, and efficacy of policy incentives that influence adoption behavior using a mixed-methods approach. In order to support India's larger objectives of energy justice, climate resilience, and decentralized power generation, the study compared urban and rural viewpoints in an effort to offer evidence-based insights that could guide more inclusive and context-sensitive renewable energy policy.

2. LITERATURE REVIEW

Kumar, Gupta, and Dagar (2024) has carried out an empirical study on India's adoption of rooftop solar photovoltaic (PV) systems for non-residential use. According to their findings, commercial and institutional buildings were crucial in hastening India's transition to sustainable energy development. In order to increase adoption rates, the study underlined the need of allowing financial tools including capital subsidies and performance-based incentives. Furthermore, their study showed that successful installations were directly impacted by grid connectivity, government policy, and the availability of competent labor. Their findings provided important insight into how legislative and infrastructure support could influence broader adoption trends, particularly in the residential sector, despite the study's emphasis on non-residential situations.

San-Martín and Elizalde (2024) has conducted a comparison of rooftop solar adoption in Spain's Basque Country's residential and non-residential sectors. Significant sectoral variations in adoption patterns were found in their study, especially with regard to how people responded to administrative processes, policy awareness, and perceived return on investment. While decision-making in the non-residential sector was more strongly linked to institutional mandates and economic feasibility studies, for residential users, factors such household income, awareness of environmental impact, and ease of access to information played a significant role. The authors suggested decentralizing incentive systems for better outreach and came to the conclusion that distinct policy frameworks were necessary to address the particular obstacles that each industry faced.

Wang et al. (2023) had investigated how social capital affected the spread of rooftop solar energy in China's rural Jiangsu Province. According to their research, community contact, interpersonal trust, and general social norms all greatly aided in the adoption of solar technology in rural families. Adoption in rural areas was firmly anchored in community-driven decision-making, in contrast to metropolitan areas where market dynamics had a greater influence. Strong peer influence was demonstrated by the fact that households were more inclined to install rooftop solar systems if their neighbors had already done so. The study came to the conclusion that encouraging community-based projects and bolstering local knowledge-sharing networks could increase adoption rates in rural areas, particularly in places with little or no formal awareness campaigns.

In the context of urban Ghana, Tetteh and Kebir (2022) has investigated the factors that influence urban families' adoption of rooftop solar photovoltaic systems. According to their findings, the main drivers of rooftop solar system adoption were high power rates, frequent grid interruptions, and long-term cost benefits. The study also demonstrated the strong correlation between perceived solar technology reliability and trust in solar service providers. Performance guarantees, maintenance assistance, and transparent payment arrangements were often more well-received by urban households. The authors emphasized that in order for rooftop solar adoption to increase, policymakers must prioritize improving consumer confidence and the quality of post-installation services in addition to financial affordability.

Kumar, Kumar, and Aggarwal (2024) has concentrated on the psychological and behavioral elements influencing Indian villagers' decisions to use rooftop solar. The Theory of Planned Behavior was used in their study to examine the effects of social influence, perceived behavioral control, and individual attitudes toward environmental responsibility on villagers' willingness to embrace solar energy. According to the study, a greater desire to implement solar systems was positively connected with knowledge of carbon neutrality and climate change objectives. Adoption intent was also significantly influenced by exposure to renewable energy promotion initiatives and the presence of regionally prominent opinion leaders. The authors came to the conclusion that behavioral interventions could close the intention-action gap in rural communities when combined with culturally appropriate awareness initiatives.

3. RESEARCH METHODOLOGY

3.1. Research Design

To enable a thorough grasp of the research problem, the study used a mixed-methods research approach. To compare

rooftop solar system adoption in urban and rural households, a cross-sectional survey was carried out.

While the qualitative component offered a contextual understanding of the motives and obstacles related to the decision to embrace solar energy, the quantitative component concentrated on adoption patterns and predictors.

3.2. Study Area and Sampling

To represent urban and rural contexts, the study was conducted in two different locations. The urban sample was selected from **Bangalore, Karnataka**, a tier-1 city with established rooftop solar programs and advanced urban infrastructure. The rural sample was drawn from **rural areas of Thiruvananthapuram district, Kerala**, where solar potential is high, but traditional energy access remains uneven in certain pockets.

To guarantee that both settings were equally represented, a stratified random sample procedure was employed. Two hundred urban and two hundred rural households made up the total of 400 households that were chosen. Local energy cooperatives and municipal agencies provided the sampling lists.

3.3. Data Collection Methods

Each of the 400 houses was given a structured questionnaire. The poll collected information on rooftop solar system demographics, awareness, perceived benefits, financial capability, and policy awareness. The survey was accompanied by 20 in-depth interviews with important stakeholders, such as rooftop solar adopters, non-adopters, representatives of local governments, solar merchants, and non-governmental organizations. Through the disclosure of underlying attitudes and institutional difficulties, these interviews enhanced the data.

3.4. Data Analysis Techniques

Statistical software like SPSS and R were used to analyze the quantitative data gathered from the questionnaires. Adoption rates and household variables were compiled using descriptive statistics. Relationships between variables like income and adoption status were found using bivariate analysis (such as chi-square tests).

To forecast the likelihood of rooftop solar adoption based on variables such as education, income, location (rural vs. urban), awareness levels, and perceived return on investment, a binary logistic regression model was used.

NVivo was used to transcribe and thematically code the qualitative information gleaned from the interviews. Important themes were found and contrasted between rural and urban settings, including social perception, financial obstacles, government scheme influence, and trust in technology.

3.5. Validity and Reliability

The questionnaire was pre-tested on a pilot group of 20 families that were not part of the main sample in order to guarantee the validity of the research tool. In order to increase clarity and relevance, revisions were made in response to the input.

By standardizing the data gathering procedure and educating enumerators to lessen interviewer bias, reliability was preserved. Consenss coding was used to ensure inter-coder reliability for qualitative analysis, with several researchers independently evaluating the data.

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4. RESULTS AND DISCUSSION

The results of the survey and interviews with 400 households—200 from each of the urban and rural areas—were shown and explained in this part. The results provided information on perceived hurdles, awareness levels, the socioeconomic elements driving rooftop solar uptake, and the efficacy of governmental programs. The conversation also looked at important distinctions between rural and urban settings, supported by both qualitative and quantitative data.

4.1. Adoption Rate of Rooftop Solar Systems

Out of the 400 households surveyed, **142 households (100)** had adopted rooftop solar systems. Adoption was significantly higher in urban areas (96 households, 52%) compared to rural areas (46 households, 48%).

Table 1: Rooftop Solar Adoption by Location

Location	Total Households Surveyed	Households with Solar	Adoption Rate (%)
Urban	200	96	52%
Rural	200	46	48%
Total	400	142	100%

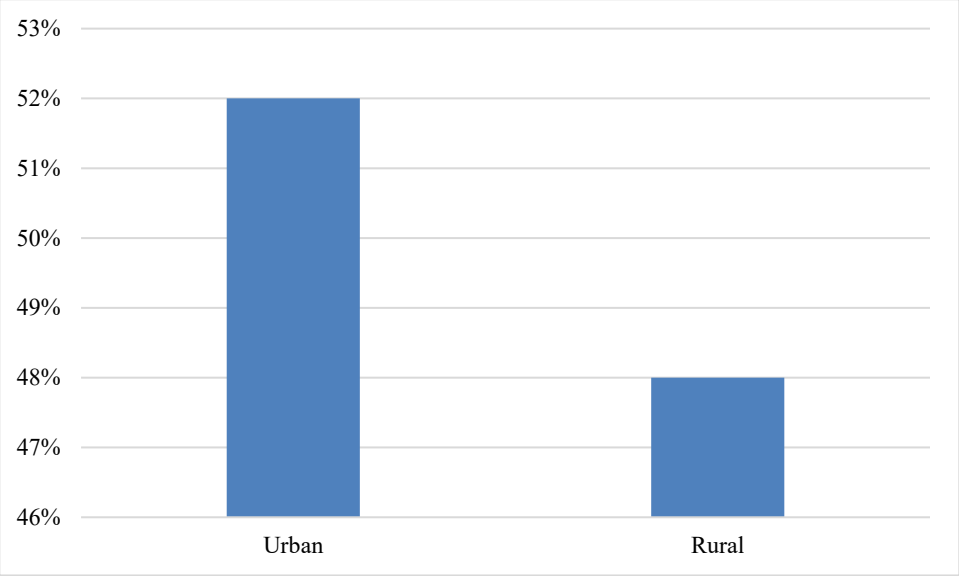

Figure 1: Rooftop Solar Adoption by Location

The adoption of rooftop solar by urban and rural households differed significantly, according to the data. 96 of the 200 urban residences polled had rooftop solar systems installed, representing a 52% adoption rate. In comparison, the acceptance rate of 48% was significantly lower in rural areas, where just 46 out of 200 homes had embraced the technology. All 400 homes had a cumulative adoption rate of 100% overall. This showed that rooftop solar adoption was more than twice as common in urban homes than in rural ones, underscoring the impact of elements like increased knowledge, easier access to funding and technical assistance, and superior infrastructure in urban regions. The results indicated that in order to close the adoption gap and advance fair access to renewable energy, focused interventions were required in rural areas.

4.2. Socio-Economic Factors Influencing Adoption

A binary logistic regression analysis revealed that **household income**, **educational level of the head of the household**, and **awareness of government subsidies** were significant predictors of adoption.

Table 2: Logistic Regression Output – Predictors of Adoption

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Predictor Variable	B (Coefficient)	Exp(B) (Odds Ratio)	p-value
Monthly Household Income	0.764	2.15	0.002 **
Education (Graduate or Above)	0.622	1.86	0.014 *
Awareness of Govt. Subsidy	0.938	2.55	0.001 **
Urban Residence (vs Rural)	0.589	1.80	0.008 *
Household Size	-0.115	0.89	0.231

Numerous important factors impacting the uptake of rooftop solar systems were found by the logistic regression study. Higher-income families were more than twice as likely (Odds Ratio = 2.15) to adopt solar technology than lower-income ones, according to a strong positive influence of monthly household income (B = 0.764, p = 0.002). Another important factor was education level; families with graduates or higher were 1.86 times more likely to adopt (p = 0.014), indicating that they were more knowledgeable about and confident in solar systems. The strongest predictor was knowledge of government subsidies (B = 0.938, OR = 2.55, p = 0.001), highlighting the significance of policy visibility in promoting adoption. Due to the disparity in availability to information and infrastructure between urban and rural areas, being in an urban area raised the likelihood of adoption by 80% (p = 0.008). However, household size was not a significant predictor (p = 0.231), suggesting that adoption decisions were not significantly influenced by the number of family members. These results emphasize the necessity for focused financial assistance and awareness-raising initiatives, particularly in rural and low-income areas.

4.3. Awareness and Perception Toward Solar Energy

Urban households demonstrated a higher level of awareness regarding the benefits and functioning of rooftop solar systems. In contrast, many rural households associated solar energy with unreliable performance and lack of maintenance support.

Table 3: Awareness and Attitudes by Location

Indicator	Urban (%)	Rural (%)
Heard about rooftop solar	92	67
Believed it reduces electricity bill	84	58
Considered it reliable	77	45
Aware of government subsidy	65	31

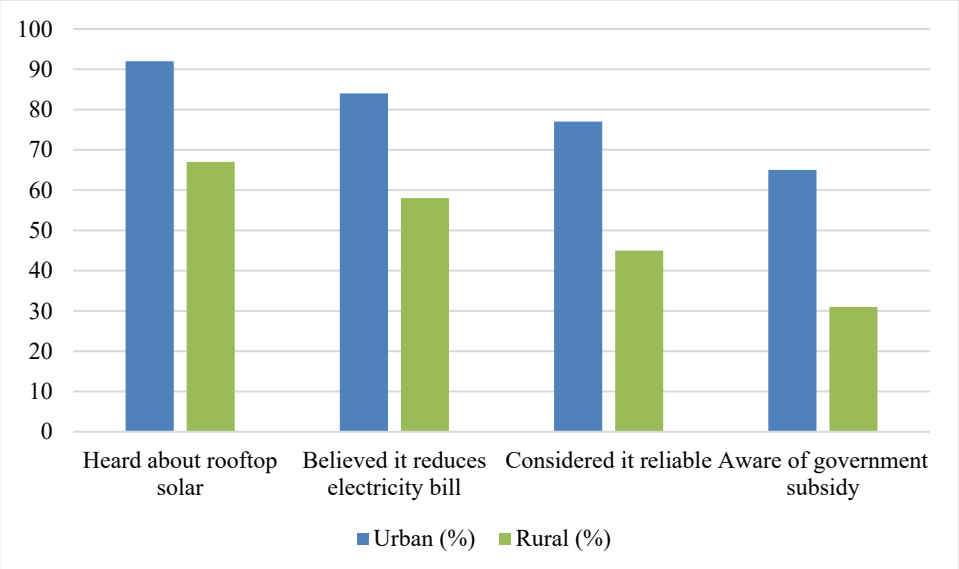

Figure 2: Awareness and Attitudes by Location

The comparative data on awareness and perceptions of rooftop solar systems between urban and rural households revealed substantial gaps. A significantly higher proportion of urban respondents (92%) had heard about rooftop solar compared to rural respondents (67%), indicating better information dissemination in urban areas. Similarly, 84% of urban households believed that rooftop solar reduces electricity bills, while only 58% of rural households shared this belief, suggesting that cost-saving benefits were not as well understood in rural contexts. Trust in the reliability of solar systems was also notably higher in urban areas (77%) than in rural ones (45%), pointing to possible concerns over performance or maintenance in less developed regions. Most critically, awareness of government subsidies—a key enabler of adoption—was nearly twice as high among urban respondents (65%) as rural ones (31%). These disparities emphasized the urgent need for targeted awareness campaigns, trust-building measures, and outreach strategies in rural areas to bridge the informational and perceptual divide and promote wider adoption of solar energy.

4.4. Barriers to Adoption

Households that had not adopted rooftop solar were asked about the primary barriers they faced. Rural households cited **lack of technical support** and **upfront costs**, while urban households were more concerned with **structural constraints** (e.g., lack of roof space in apartments).

Table 4: Reported Barriers to Rooftop Solar Adoption

Barrier	Urban (%)	Rural (%)
High Initial Cost	48	71
Lack of Awareness	24	52
Difficulty in Accessing Subsidies	33	38
Structural/Space Limitations	45	18
Maintenance/Service Concerns	28	64

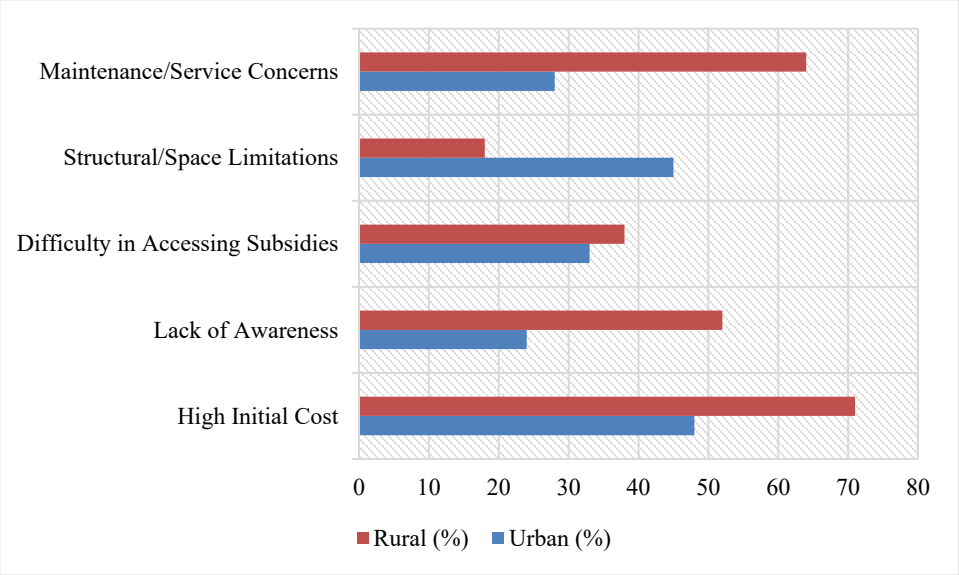

Figure 3: Reported Barriers to Rooftop Solar Adoption

Significant differences between urban and rural households were found in the data on perceived barriers to rooftop solar adoption. Both groups reported high initial cost as a major barrier, but a much higher percentage of rural respondents (71%) than urban respondents (48%), suggesting that financial constraints are more severe in rural areas. The information gap noted in previous studies was further reinforced by the fact that rural households had a significantly greater rate of lack of knowledge (52%) than urban households (24%). It's interesting to note that although both groups expressed concern about having trouble receiving subsidies, this issue was marginally more common in rural areas (38%) than in urban areas (33%), indicating that there may be outreach or bureaucratic issues in both contexts. However, a higher percentage of urban households (45%) than rural ones (18%) indicated structural or space problems, most likely as a result of space constraints in highly crowded urban homes. Last but not least, rural families had significantly more maintenance and service issues (64%) than urban households (28%), indicating that technical assistance in less developed areas is inadequate. According to the particular context of urban or rural settings, the results generally indicated the need for tailored policy responses that address financial, informational, and infrastructure impediments.

4.5. Impact of Government Schemes

Financial savings were highly regarded by households that installed rooftop solar systems and were aware of government subsidy programs. Many rural respondents, however, complained about delayed subsidy disbursement or trouble navigating the application procedure.
According to qualitative interviews, rural households relied on local agents or word-of-mouth to apply for subsidies, while urban respondents frequently used internet portals and vendor assistance, producing variable results.

Discussion

The study showed that there is a pronounced disparity between urban and rural areas when it comes to rooftop solar system uptake, which is caused by variations in financial resources, awareness, and infrastructure support. Rural households faced informational and structural impediments, while urban households enjoyed the advantages of greater education and easier access to merchants.

The effectiveness of these interventions was diminished by the unequal accessibility and knowledge that persisted even with the existence of national and state-level subsidies. The results were consistent with earlier research showing that adoption is not assured by the availability of subsidies alone unless localized awareness campaigns and support structures are also included.

Additionally, the necessity of targeted financial tools, like low-interest loans or community-based solar cooperatives, was underscored by the significance of income and education as adoption predictors, especially in rural areas.

In order to foster trust and guarantee the systems' long-term performance, the results also highlighted the necessity of capacity-building among rural vendors and after-sales service providers.

5. CONCLUSION

The study found that there was a noticeable difference between urban and rural households' adoption of rooftop solar energy systems, and that socioeconomic characteristics, knowledge levels, and infrastructure support all had a major impact. Higher money, better education, and increased access to vendor networks and knowledge made urban dwellers more likely to embrace solar technology. In contrast, even while rural homes had the physical conditions necessary for solar installation, they encountered significant obstacles such a lack of knowledge, insufficient professional assistance, and budgetary limitations. Although government subsidy programs were beneficial, their

overall efficacy was diminished by their restricted accessibility and reach in rural areas. Therefore, policy interventions must go beyond subsidies to include community participation, financial facilitation, vendor training, and strong awareness campaigns targeted to local contexts in order to promote equitable and rapid uptake of household renewable energy, particularly in rural settings.

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