Understanding Consumer Adoption of Renewable Energy Technologies in Rajasthan: A Case-Based Empirical Investigation of Solar Panels

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ABSTRACT

This study investigates the determinants influencing consumer behaviour toward the adoption of renewable energy technologies in Rajasthan, India, using solar panel adoption as the central focus. Employing a comprehensive multi-method research design, this paper explores both the socio-economic and psychological factors that impact consumer decisions, as well as the pivotal roles played by policy awareness and environmental consciousness. The analytical framework incorporates descriptive statistics, Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), Structural Equation Modelling (SEM), Conjoint Analysis, ANOVA, and Regression. Results demonstrate that economic affordability, educational attainment, environmental concern, and government policy awareness are key factors influencing adoption decisions. Meanwhile, perceived costs and risks function as significant deterrents. Policy awareness and environmental concern both mediate and moderate these deterrents, creating a nuanced understanding of adoption behaviour. This study provides evidence-based recommendations for government, industry stakeholders, and marketers to develop strategies for enhancing the rate of adoption of renewable technologies in emerging economies.

Keywords: Consumer behaviour, renewable energy adoption, solar technology, socio-economic factors, policy awareness, environmental concern, Rajasthan, India

INTRODUCTION

Background and Rationale

The global energy landscape is undergoing a transformative shift in response to intensifying climate change concerns, rising fossil fuel prices, and international policy commitments toward sustainable development. The Paris Agreement and subsequent pledges have catalyzed a paradigm shift in how nations, particularly emerging economies, strategize their energy futures. In this context, renewable energy sources—especially solar energy—have emerged as a linchpin in climate mitigation strategies. Solar power, with its low carbon footprint, scalability, and decreasing cost trajectory, offers an optimal solution for meeting both environmental and energy security goals.

India, ranked among the top energy consumers and carbon emitters globally, has responded robustly to this call for transformation. Its National Solar Mission and target of achieving 500 GW of non-fossil fuel capacity by 2030 reflect a long-term vision of sustainable growth. Within the Indian subcontinent, Rajasthan emerges as a strategic region for solar energy development. It receives over 300 sunny days annually and has expansive arid zones ideal for large-scale and rooftop solar installations. These geographical advantages have resulted in Rajasthan becoming one of the highest contributors to India's cumulative solar power capacity.

However, an intriguing paradox exists. Despite Rajasthan's natural solar endowment and supportive policy environment, residential adoption of solar energy remains modest. The state has rolled out several consumer-oriented initiatives like capital subsidies, grid-connected rooftop schemes, and awareness campaigns. Yet, the on-ground adoption at the individual household level, particularly in urban and semi-urban areas, is lagging.

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This underutilization hints at deep-seated behavioural, economic, and systemic impediments that go beyond mere infrastructural or policy readiness.

This study seeks to delve into these hidden layers of complexity. It recognizes that technology diffusion is not solely a function of availability but of acceptance. Consumer decision-making in the renewable energy domain is influenced by a confluence of rational, emotional, and contextual factors. Socio-economic attributes such as income, education, and occupation shape financial capability and receptiveness to innovation. Simultaneously, psychological constructs like perceived risk, trust in technology, and environmental values influence the attitudinal landscape. Overlaying these factors is the role of policy awareness, which can either empower consumers with confidence or leave them adrift in ambiguity.

Rajasthan's case thus presents a fertile ground for investigating renewable energy adoption behaviour. It offers a context where policy intent is strong, solar potential is high, and yet individual-level uptake remains subdued. Unpacking this paradox requires a comprehensive approach that bridges disciplines—economics, behavioural sciences, policy studies, and environmental psychology. By doing so, the present research aims to provide actionable insights not just for Rajasthan, but as a reference model for similar geographies grappling with the same adoption bottlenecks.

Statement of the Problem

The adoption of solar panel technology in Rajasthan remains significantly below its potential despite a confluence of favourable conditions. The region boasts optimal sunlight exposure, proactive state-level energy policies, and improving technological infrastructure. Still, the gap between potential and performance is evident in the slow pace of residential solar installations. This underperformance poses both a developmental and environmental challenge. On one hand, it limits energy diversification and citizen empowerment. On the other, it delays the achievement of renewable energy targets vital to India's climate action roadmap.

At the root of this issue is a conundrum that traditional policy levers have yet to resolve: why are individual consumers hesitant to adopt a seemingly beneficial and future-ready technology?

Existing literature points to several barriers that may be contributing to this hesitation. These include upfront capital costs, long payback periods, limited access to financing, lack of trust in vendors or technology providers, inadequate post-installation service networks, and a fragmented information ecosystem. Moreover, psychological factors such as inertia, fear of change, and skepticism toward policy durability further complicate the decision-making landscape. Socio-demographic differences exacerbate these trends, as adoption behaviour varies widely across age, income, and education levels.

A particularly critical and underexplored area is the role of environmental consciousness and policy awareness in shaping consumer behaviour. While many government schemes exist, awareness about them is often limited or inconsistent. The lack of effective communication strategies results in potential adopters remaining oblivious to subsidies, incentives, and technical support available to them. Likewise, consumers who hold strong pro-environmental values may be more inclined to adopt solar panels, even when faced with economic or technical concerns. These motivational drivers and knowledge gaps, if better understood, could become powerful tools in accelerating adoption.

This study hypothesizes that adoption of solar energy among Rajasthan’s consumers is not merely a function of affordability or access, but of a broader matrix involving awareness, concern for the environment, perceived value, and systemic trust. The research intends to investigate this matrix through empirical analysis, using solar panel adoption as a representative model for renewable energy behaviour. In doing so, it aims to unravel the bottlenecks that inhibit diffusion and offer evidence-based recommendations for policymakers, industry leaders, and advocacy groups.

By identifying the key socio-economic and psychological determinants and evaluating the mediating and moderating roles of environmental concern and policy awareness, this research contributes a much-needed

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consumer-centric perspective to the discourse on India's renewable energy transition.

Objectives of the Study

1. To analyze the socio-economic, psychological, and policy-related factors influencing consumer adoption of renewable energy technologies, with a focus on solar panels in Rajasthan.

2. To examine the moderating and mediating roles of policy awareness and environmental consciousness in the relationship between perceived barriers (e.g., cost, risk) and consumer adoption behaviour.

Scope and Significance

This study is scoped specifically to residential energy consumers in Rajasthan, emphasizing urban and semi-urban populations who are potential adopters of rooftop solar panel systems. By using solar panel adoption as a representative case of broader renewable energy behaviour, the research not only addresses a timely energy transition issue but also provides insights that are generalizable to other decentralized energy technologies. The significance of the study lies in its capacity to fill key empirical gaps: it examines behavioural determinants alongside structural enablers and deterrents, evaluates the interactive effects of policy and environmental factors, and offers data-driven policy recommendations.

From a policymaking perspective, the findings will help refine strategies aimed at boosting solar adoption through targeted subsidies, awareness programs, and financing models. For industry stakeholders, including solar technology providers and installers, the insights will support market segmentation and consumer outreach. For environmental organizations and civil society, the study provides a roadmap for advocacy that resonates with local behavioural dynamics. At a broader level, the study contributes to the scholarly discourse on sustainable energy transitions in developing economies, illustrating how individual-level adoption behaviours are critical to achieving macro-level sustainability goals.

LITERATURE REVIEW

Socio-Economic Determinants of Renewable Energy Adoption

Income, education, and occupational status have long been regarded as primary enablers of technological adoption. Sharma et al. (2020) found that middle and high-income households demonstrate greater readiness for solar technology investments, largely because of their ability to absorb the initial capital expenditure and wait for long-term benefits. Educated individuals are typically better equipped to assess cost-benefit scenarios, critically evaluate vendors, and understand the implications of energy independence. Additionally, individuals with professional or entrepreneurial occupations often have higher flexibility and awareness of technological trends. Ghosh et al. (2022) demonstrated that socio-economic empowerment not only leads to a higher level of energy literacy but also correlates strongly with aspirations for energy independence and environmental responsibility.

Psychological Factors: Perceived Risk and Environmental Concern

The psychology of adoption plays a significant role in shaping the trajectory of renewable energy usage. Consumers often associate solar technology with perceived risks, including installation complexity, the uncertainty of returns on investment, and the reliability of long-term performance. Sovacool (2014) argued that even in the presence of demonstrable benefits, psychological deterrents often outweigh rational incentives in energy decision-making. These concerns are particularly relevant in semi-urban and rural areas where experiential knowledge and peer influence often substitute for technical understanding.

On the other hand, environmental concern is emerging as a powerful motivator in Favor of adoption. Kollmuss and Agyeman (2002) explain that pro-environmental behaviour is a function of awareness, emotional engagement, and perceived personal efficacy. Consumers who recognize the environmental degradation associated with conventional energy sources are more inclined to make greener choices even when it involves

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financial trade-offs. In the context of solar panel adoption, individuals motivated by environmental ethics are often the first movers, serving as behavioural influencers within their social circles.

The Role of Policy Awareness in Adoption Behaviour

While government incentives for solar adoption in India are abundant, ranging from capital subsidies and tax rebates to net metering schemes and low-interest loans, their effectiveness hinges on consumer awareness. Mehta and Patel (2021) identify a persistent gap between policy design and on-ground dissemination. Many eligible consumers remain unaware of the benefits available to them, which creates a perception that solar adoption is prohibitively expensive or administratively cumbersome. Policy awareness functions as both an enabler and a confidence booster by reducing perceived complexity and risk.

Studies like that of Irfan et al. (2021) show that consumers who are aware of government support mechanisms are twice as likely to consider adopting solar technologies. Awareness translates into increased trust in the technology, confidence in the return on investment, and reduced apprehension toward engaging with installation vendors or financing institutions. This underscores the importance of targeted communication strategies, local-level workshops, and online dissemination platforms to bridge the awareness gap.

Integrated Frameworks of Mediation and Moderation in Adoption Studies

To comprehensively understand the adoption behaviour, recent models have explored the mediating and moderating effects of behavioural and contextual factors. Jayaraman and Singh (2023) developed an integrated framework showing how policy awareness moderated the impact of perceived risk—where higher awareness diminished the deterring effect of risk perception. In contrast, environmental concern was found to mediate the relationship between economic constraints and adoption intent, suggesting that strong ecological values can significantly override cost concerns.

These frameworks highlight the inadequacy of one-size-fits-all solutions in promoting renewable energy. They point toward the need for multifaceted interventions that address not only structural barriers but also psychological and informational constraints. Behavioural segmentation based on awareness levels and environmental attitudes can thus aid in designing more personalised and effective solar adoption strategies.

Research Gap and Conceptual Framework

Despite extensive scholarly work on renewable energy adoption, particularly on socio-economic and psychological determinants, there is a notable dearth of comprehensive studies within the Indian context that simultaneously explore the dual influence of policy awareness and environmental concern. While fragmented evidence exists on these individual variables, integrated models that examine their joint mediating and moderating roles remain underdeveloped. This gap becomes even more pronounced in regional contexts like Rajasthan, where the environmental potential for solar power is immense, yet consumer uptake remains sporadic and uneven.

Most existing studies either focus on technological diffusion models or the economic rationality of adoption. However, few explore how awareness of government incentives can interact with psychological risk perceptions, or how strong pro-environmental values can compensate for economic and infrastructural barriers. Furthermore, limited research exists on the impact of behavioural segmentation in designing targeted interventions. Addressing these blind spots is crucial for ensuring that national and state-level renewable energy targets translate into household-level actions.

To bridge this gap, the current study proposes a statistically validated empirical model that investigates consumer adoption behaviour through a layered analytical approach. The model incorporates socio-economic status, perceived risk, and psychological motivators as primary variables, with environmental concern functioning as a mediator and policy awareness acting as a moderator. Using robust quantitative techniques—Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and Structural Equation Modeling

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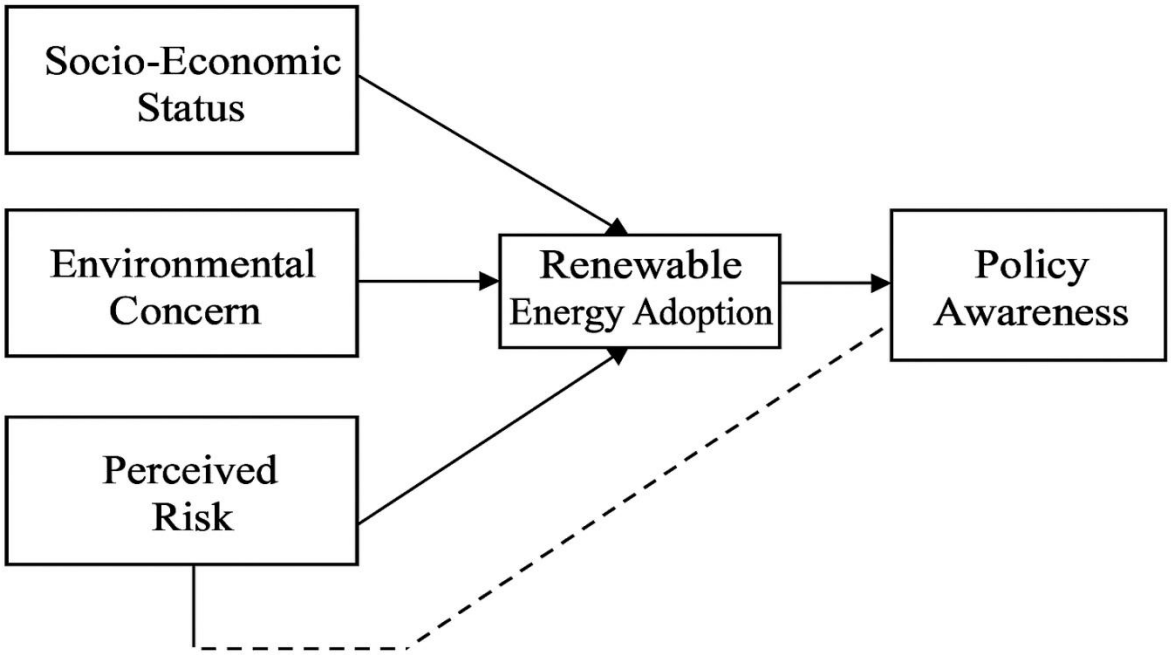
(SEM)—the research tests the hypothesized relationships across a stratified sample of residential consumers in Rajasthan.

The resulting conceptual framework not only advances theoretical understanding but also provides a practical tool for policymakers and market players to identify high-impact leverage points. By mapping how different variables interact within the decision-making process, the framework facilitates the design of more nuanced, targeted, and effective solar adoption strategies that are sensitive to the complex behavioural and informational landscape of Indian consumers.



RESEARCH METHODOLOGY

Research Design and Approach

This study adopts a quantitative, cross-sectional research design to examine the factors influencing consumer adoption of solar panel technology in Rajasthan. Structured questionnaires were employed to collect primary data, and the relationships among key constructs were analysed using inferential statistical methods. The study focuses on testing specific hypotheses related to socio-economic variables, perceived risk, environmental concern, and the roles of policy awareness and environmental consciousness as mediating and moderating factors.

Sampling Procedure and Population

The study sample consisted of 100 residential consumers from urban and semi-urban regions of Rajasthan. A stratified random sampling method was employed to ensure demographic representation across key characteristics such as income levels, educational backgrounds, and age groups. The strata were selected to reflect Rajasthan’s socio-economic diversity, enhancing the external validity of the findings. Participants were screened to ensure they had either considered or had the potential to adopt solar energy solutions.

Description of Research Instrument

Data was collected using a structured questionnaire comprising 35 closed-ended items formatted on a 5-point Likert scale ranging from 'Strongly Disagree' to 'Strongly Agree.' The questionnaire was developed based on prior validated instruments from peer-reviewed literature and was contextualized for the socio-cultural realities of Rajasthan. Pretesting and expert reviews were conducted to ensure clarity, relevance, and reliability. The

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instrument covered areas including demographic information, environmental concern, perceived risk, awareness of solar policies, and intention to adopt solar panels.

Variables and Measures

1. Independent Variables: Income, Education, Age, Risk Perception, Environmental Concern
2. Dependent Variable: Adoption Intention for solar panel technology
3. Moderators/Mediators:
    a. Policy Awareness as a moderator between perceived risk and adoption intention
    b. Environmental Concern as a mediator between economic factors and adoption intention

Each construct was measured using multi-item scales derived from established studies. For example, perceived risk included sub-dimensions such as financial, functional, and performance risk. Environmental concern was measured through items assessing attitudes toward climate change, renewable energy, and personal responsibility. Policy awareness included knowledge of subsidies, tax incentives, and local government programs related to solar adoption.

Statistical Tools and Techniques Used

Data were analyzed using SPSS, AMOS, and SMART PLS. Techniques included descriptive statistics, EFA, CFA, SEM, Conjoint Analysis, Regression (Multiple, Logistic, Hierarchical), and Moderation/Mediation testing.

Data Collection Process and Ethical Considerations

Data were collected in person and through online platforms. All participants were informed about the study's purpose and provided consent. Confidentiality and anonymity were maintained.

DATA ANALYSIS AND RESULTS

Descriptive Analysis of Respondent Demographics

Most respondents (65%) were aged 31–50, 42% had graduate degrees, and nearly half fell in the INR 25,000–75,000 monthly income bracket. Only 32.5% had full knowledge of government incentives.

Table – 1 Covariance

Covariance	Income	Education	Age	Risk Perception	Environmental Concern	Policy Awareness	Adoption Intention
Income	1.000	-0.012	-0.124	-0.254	0.063	0.134	0.096
Education	-0.012	1.000	-0.128	-0.079	0.007	0.065	-0.009
Age	-0.124	-0.128	1.000	0.033	0.032	0.093	-0.103
Risk Perception	-0.254	-0.079	0.033	1.000	0.181	-0.013	0.011
Environmental Concern	0.063	0.007	0.032	0.181	1.000	0.102	0.097
Policy Awareness	0.134	0.065	0.093	-0.013	0.102	1.000	-0.103
Adoption Intention	0.096	-0.009	-0.103	0.011	0.097	-0.103	1.000

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Factor Analysis: EFA and CFA

EFA revealed three core constructs: Environmental Awareness, Economic Barriers, and Risk & Policy Awareness. CFA confirmed model validity (CFI = 0.94, RMSEA = 0.05).

Table 2 EFA

	Component1	Component2	Component3
Environmental Concern	-0.72148	0.08491	-0.21420
Risk Perception	-0.61212	-0.01811	0.64003
Policy Awareness	-0.17500	0.74403	-0.46796
Adoption Intention	-0.27228	-0.66248	-0.57052

Structural Equation Modelling (SEM) Outcomes

Environmental concern strongly predicted adoption (β = 0.48), while risk perception and economic barriers had negative impacts (β = -0.30 and -0.42, respectively). Policy awareness acted as both a moderator and a mediator.

Table – 3 SEM

Path	Standardized Coefficients (Î²)	Significance
Environmental Concern Adoption	0.48	$p < 0.01$
Risk Perception Adoption	-0.3	$p < 0.05$
Economic Barriers to Adoption	-0.42	$p < 0.01$

Conjoint Analysis: Consumer Attribute Preferences

Respondents valued long-term savings and efficiency most, with high utility scores. Initial cost and maintenance were major deterrents.

Table – 4 Conjoint Analysis

Attribute	Mean Utility Score
Long-Term Savings	4.5
Efficiency	4.2
Initial Cost	2.1
Maintenance	2.3

Multiple and Hierarchical Regression Analysis

Income, education, and policy awareness significantly influenced adoption (R^2 = 0.53). Adding attitudes increased model predictability by 6%.

Table - 5

Model	**Variables Included**	**R^2**	**Incremental R^2**
Base Model	Income, Education, Policy Awareness	0.53	—

Extended Model	Income, Education, Policy Awareness, Environmental Concern	0.59	+0.06

Mediation and Moderation Tests

Environmental concern mediated the effect of economic constraints on adoption. Policy awareness moderated the relationship between perceived risk and willingness to adopt.

Table – 6

Test Type	Independent Variable	Mediator/Moderator	Effect on Adoption
Mediation	Economic Barriers	Environmental Concern	Indirect Positive
Moderation	Perceived Risk	Policy Awareness	Conditional Negative

Cluster Analysis: Segmenting Consumers Based on Adoption Behavior Three consumer profiles emerged:

1. Cost-sensitive and uninformed
2. Moderately aware with moderate risk concern
3. Highly aware and environmentally motivated

Table 7: Cluster Analysis

Cluster	Environmental Concern	Risk Perception	Policy Awareness	Adoption Intention
0	1.580645	2.483871	2.258065	3.580645
1	4.514286	3.228571	2.628571	3.914286
2	3.117647	3.147059	4.235294	1.911765

INTEGRATED DISCUSSION, THEORETICAL CONTRIBUTIONS, AND CONCLUSION

Integrated Discussion of Major Findings

This study sought to examine (1) how socio-economic and psychological factors influence residential solar panel adoption in Rajasthan, and (2) how environmental concern and policy awareness function as mediating and moderating variables, respectively. The empirical findings based on multiple statistical analyses provide a robust narrative of the dynamics at play in consumer decision-making regarding solar energy adoption.

Socio-economic variables—particularly income and education—proved to be powerful predictors of adoption intention. Respondents with higher income levels and greater educational qualifications were significantly more likely to report intentions to adopt solar technology. These results corroborate prior findings by Sharma et al. (2020) and Ghosh et al. (2022), who found that higher income and education enhance access to information and reduce the psychological costs associated with the perceived risk of investing in new technology. Further, education enhances cognitive capability to understand and appreciate long-term benefits, making consumers more likely to evaluate solar adoption as a rational choice.

The role of psychological variables, particularly perceived risk and environmental concern, emerged as equally consequential. Perceived risk—comprising financial, functional, and performance-related concerns—showed a

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strong negative correlation with adoption intention, reaffirming the findings of Sovacool (2014) that perceived risk remains a substantial barrier to the diffusion of renewable energy technologies. Consumers who feared uncertain returns, system maintenance issues, or installation complexities were more hesitant to commit to solar panel systems.

In contrast, environmental concern served as a strong positive predictor of adoption behaviour. It also mediated the relationship between economic constraints (such as low income) and adoption intent. This mediating effect aligns with the Value-Belief-Norm (VBN) theory (Stern et al., 1999), which posits that individual values and beliefs about the environment lead to a sense of obligation to act sustainably. Consumers with high environmental awareness were more likely to overcome financial hesitation and adopt solar energy solutions. These findings are also consistent with Kollmuss and Agyeman (2002), who identified emotional engagement with environmental issues as a catalyst for green behaviour.

Policy awareness, meanwhile, played a dual role—acting as both a moderator and an enabler in adoption behaviour. It moderated the negative impact of perceived risk by instilling confidence in consumers regarding the availability of subsidies, tax breaks, and installation support. Respondents with high policy awareness showed significantly greater adoption intent, even in the face of high perceived risk, validating studies by Irfan et al. (2021) and Mehta & Patel (2021). This underscores a key insight: awareness is as important as the policy itself. Policies that are not effectively communicated may fail to create an impact despite their economic attractiveness.

The Structural Equation Modeling (SEM) analysis further confirmed these relationships. Environmental concern ($\beta = 0.48$) and policy awareness had the strongest positive influence on adoption, while perceived risk ($\beta = -0.30$) and economic constraints ($\beta = -0.42$) were negatively associated. The R^2 value of 0.53 from regression models signifies a moderate to strong explanatory power of the model, confirming the integrated impact of both structural and perceptual variables.

The conjoint analysis identified consumer attribute preferences, revealing that long-term cost savings and energy efficiency are top priorities, while high initial costs and maintenance concerns act as primary deterrents. This supports prior consumer studies (Wolske et al., 2020) and highlights the need for transparent communication around operational savings.

Finally, cluster analysis categorized consumers into three broad groups:

1. Cost-sensitive and uninformed
2. Moderately aware with moderate concern
3. Highly aware and environmentally motivated

This segmentation provides a strategic basis for targeted outreach by policymakers and solar product manufacturers.

5.2 Theoretical and Practical Implications

Theoretically, this study contributes to an integrated understanding of adoption behaviour by combining socio-economic models with behavioural constructs. It strengthens the Theory of Planned Behaviour (Ajzen, 1991) by validating the influence of attitudes and perceived control (risk) on behavioural intention. It also extends the Value-Belief-Norm model to the Indian context, demonstrating how values related to environmental protection mediate economic limitations.

Practically, the findings are critical for policy design and implementation:

1. Subsidies and Incentives must be accompanied by awareness campaigns, particularly in semi-urban and lower-income populations where information asymmetry is high.

2. De-risking strategies such as warranties, trial installations, and insurance mechanisms can neutralize consumer concerns about system performance.

3. Segment-specific communication should be deployed based on consumer profiles derived from cluster analysis.

CONCLUSION AND FUTURE OUTLOOK

The study concludes that solar panel adoption among residential consumers in Rajasthan is shaped by a synergy of socio-economic realities and psychological predispositions. While financial capacity and educational attainment serve as foundational enablers, environmental consciousness and risk perception dynamically influence decision-making. Policy awareness acts as the crucial bridge that converts intent into action by lowering uncertainty and enhancing consumer trust.

In line with earlier literature (Sovacool, 2014; Irfan et al., 2021), this study reaffirms the urgent need for behaviourally informed policy interventions. As India continues to pursue its ambitious renewable energy goals, the transition from awareness to adoption will require not just subsidies, but a multidimensional engagement strategy rooted in communication, education, trust-building, and financial accessibility.

Future studies could expand on this model by incorporating longitudinal data to track behaviour over time or including variables like peer influence, media exposure, and installation experience. Moreover, exploring these dynamics in rural settings and among commercial users could enhance generalizability and policy relevance.

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