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Research Article

Investigating and Overcoming the Barriers in adoption of Rooftop Solar PV Adoption with Information Systems

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ABSTRACT

The installation of rooftop solar panels is a vital aspect of smart city development, promoting the shift to affordable and clean energy. However, achieving widespread public participation in this effort faces significant challenges. This research examines the hindrances in adopting rooftop solar PV systems by residents of Patna, the capital city of Bihar, India. Understanding these barriers is crucial to encouraging public involvement and accelerating the integration of renewable energy solutions. If Patna can overcome these obstacles, it will greatly enhance sustainable urban development, reduce fossil fuel consumption, and improve energy security. Furthermore, the adoption of rooftop solar will contribute to pollution reduction and support the natural ecosystem. This research focuses on resident-driven insights, which are key to the future success of smart cities. The methodology involves identifying barriers to public participation through a questionnaire survey conducted among 200 residents of Patna. Data adequacy was established using statistical tools, and factor analysis was utilized to evaluate the identified variables, supplemented by a correlation matrix for further examination. The study highlights the necessity of collaboration among government agencies, energy providers, and the public to foster a cooperative and supportive environment. The findings reveal three primary barriers relevant to Patna that could be addressed through public participation. This research aims to drive sustainable urban transformation by tackling the challenges to public engagement in rooftop solar PV adoption. By identifying and mitigating these obstacles through information systems, the study will offer valuable insights applicable not only in Patna but also in other cities, facilitating the accelerated integration of renewable energy solutions.

Keywords: Rooftop Solar P.V., Public participation, Renewable energy, Sustainable power sources, Information System

INTRODUCTION

As the world pushes toward more sustainable and maintainable energy sources, there has been a comparing ascend in interest in introducing sunlight-based power on homes and organizations. Advancing sustainable power innovations is turning into an inexorably pivotal part of metropolitan advancement as urban areas endeavour to become better and harmless to the ecosystem. Renewable energy sources are sustainable energy sources, which will not only contribute through the energy sector to help countries become energy-secure nations but it will also help to abate global warming by preventing temperature rise [1][2]. As discussed by Singh (2020), in the current global energy scenario, renewable energy sources are gaining increasing significance. Efforts in research and development, application, and commercialization of viable renewable energy technologies are growing. A key technology in this regard is rooftop solar photovoltaic technology, which plays a vital role in addressing the growing energy demands of urban areas worldwide. [3]

1.1. Solar Scenario around the world

Two of the most common types of solar power systems are photovoltaic (PV) and concentrated solar power (CSP). Instead of using photovoltaic cells, which convert light directly into electricity, concentrated solar power (CSP) uses mirrors to concentrate sunlight into a pillar that warms a liquid in a collector. CSP assumes a little part in the solar power area, and PV is supposed to overpower it.[4] Just 512 GW of solar limit had been added overall as of the finish of 2018. The general capability of solar energy on Earth is far more prominent than this. More than 22 nations, PV as of now meets over 1% of yearly power interest. Italy (8.6%), Greece (8.3%), and Germany (8.2%) lead the globe in absolute electricity yield from photovoltaics (PV).[4]. Solar photovoltaic (PV) technology has emerged as a rapidly growing renewable energy source with significant potential to transform the global energy landscape. Studies indicate that PV could become the largest and most cost-effective energy source in the mid to long-term, with projected global capacity requirements of 27.4-42 TWp. [5]. Despite its abundant availability and declining costs, PV adoption scenarios in long-term energy models have often been conservative [6].

1.2. The Benefits of PV Rooftop Solar

The advantages of solar photovoltaics (PV) are (a) the absence of ozone-depleting material emissions, (b) quiet operation, (c) a system lifespan of around 25 years, (d) low maintenance costs, and (e) ease of installation. The primary benefits of solar electricity have been found through analysis of solar energy programmes. There would be no increase in greenhouse gases or other toxins, (b) degraded land could be restored, (c) lesser transmission lines would be needed, (d) water quality would improve, (e) energy independence would increase, (f) energy supply would be upgraded, leading to greater energy security, and (g) rural and remote areas of developing countries would be reached more quickly. A study conducted in Hong Kong found that doing so will reduce ozone-depleting substances' radiation and other harmful toxins [7].

Wind power might have ascended to noticeable quality in India first, yet solar power enjoys a few benefits. Solar energy has expanded accessibility and unwavering quality. Another review led in India found that PV enjoys many benefits, including (a) the nation gets extremely high solar radiation, with day to day occurrence going from 4 to 7 kWh/m2 and 2300 to 3200 hours of daylight each year, (b) low minor expense of age, (c) the capacity to increment energy security by expanding supply, (d) the decrease of import reliance, (e) the moderation of fuel value unpredictability, and (f) the potential job it can play in encouraging territorial monetary development. A review distributed in Tajikistan underlined the potential for neighbourhood economies and economical improvement to profit from the utilization of solar photovoltaic (PV) power in the country's far off uneven districts. There are many variables adding to solar PV's expanded prevalence in Bangladesh.[8]. Since there are no moving parts, no extra assets (such water or fuel), and insignificant support is required. Solar photovoltaics (PV) in Hong Kong are essentially determined by worries about environmental change and natural risks. Solar power is the most encouraging elective energy choice presently that anyone could hope to find. San Francisco, a city in the US, has a scope of 967-2,110 kWh/m2 in yearly solar radiation got by structures. The whole nation of Lebanon could be provided with power (around 2.3 GW), as per a review done there. All it would take is to use 12.5% of the absolute housetop surfaces of the private structures. That implies we can decommission all petroleum product power plants right away. The potential for solar power is colossal, and the energy it produces is completely maintainable. An examination from Denmark proposes that worldwide ozone harming substance discharges may be diminished by 10.2% from their 2000 levels continuously 2050. This change to environmentally friendly power will valuably affect the economy and society overall, particularly as far as expanded nearby work age and diminished medical services costs.[9]

It was determined that a 5 MW solar PV establishment in Saudi Arabia would deflect 914 tons of CO_2 discharges every year. There would be yearly reserve funds of 7025 and 5944 tons of GHG if a 5 MW solar PV office were to supplant diesel and gaseous petrol-based energy age, separately, in Oman. As the temperature of the Earth rises, one more benefit of housetop PV turns out to be more significant. Less energy is expected for cooling structures. researchers in the US found that by introducing PV on roofs, top burden request may be diminished.[10]. This finding was upheld by extra exploration directed in Canada. In India, analysts used PC models to establish that PV systems can lessen cooling costs by as much as 90%. Involving PV applications in structures was found to diminish conventional energy use as well as the "top" power age from petroleum products like coal and oil, as per research from Greece. The service organization gets a good deal on development and support costs, as well as transmission and circulation misfortunes, while a structure produces its own power utilizing solar boards put on its rooftop. The utilization of solar photovoltaics (PV) is a harmless to the ecosystem method for providing the developing requirement for power in present day human progress[11].Benefits include (a) no contamination from ozone-damaging substance radiations or pernicious waste age like radioactive waste, (b) as this is a type of dispersed electrical age, collection of this reduces dependence and pressure on people in general or state grids, thereby removing the risk of power blackouts and over-loads generally, (c) it helps in open energy security, and (d) it gives reasonable and long-term financial improvement opportunities for a number of different parties. Experts in the United States discovered that the surplus energy produced by solar panels reduced the strain on electric grids in the middle of the year, when demand is highest and utilities are forced to buy large amounts of power at premium rates to keep up with demand.[12]. The progress to solar energy, as per a couple of specialists, is helping states extraordinarily in satisfying government orders to cut ozone harming substance emanations. Many individuals are finding work in the solar PV industry [12].

Research has demonstrated the way that introducing cool rooftops can diminish a city's every day cooling energy utilization by 13-14%, and introducing housetop solar photovoltaic boards can lessen it by another 8-11%.[13] Extra advantages from power age are not represented in the previously mentioned benefits. The outcomes showed that either material methodology could be utilized, which would valuably affect metropolitan life. Esteem is added by solar photovoltaic systems since they diminish the requirement for fossil fuels.[13]. Nearly 30% of Seoul's yearly power request might be fulfilled by broad establishment of housetop solar PV systems, as per a review led in South Korea. While rising urbanization all over the planet is delivering colossal expansion in energy utilization across the significant urban areas in general, the exploration featured the need of housetop solar PV. In China, generally 18% of the overall populace lives in the main 35 urban communities. These urban areas are responsible for 40% of the total energy consumption and carbon dioxide emissions in the United States. It can credit generally 67% of worldwide energy utilization and 71% of CO2 discharges from energy-related outflows to metropolitan regions on the off chance that we take a worldwide viewpoint [14]. Consequently, the drawn-out feasibility of significant urban communities relies upon measures like expanding the extent of power provided by roof solar PV systems. Housetop solar photovoltaic systems can supply 30% of Ontario, Canada's yearly energy interest. The mix of falling capital expenses and expanding discharges decrease objectives for the power area makes solar photovoltaic (PV) an appealing choice for the fate of power systems [14].

MATERIAL AND METHODS

The research methodology had been comprehensively explored to examine the barriers to public support for rooftop solar adoption in Patna, with both qualitative and quantitative approaches having been utilized to gain a detailed understanding of the factors shaping individuals' attitudes toward solar energy. The data collection strategy had included obtaining information from various sources such as surveys, interviews, and focus groups. Surveys had been distributed to a sample of the target population to gather quantitative data, while qualitative insights had been captured from key stakeholders through interviews and focus groups. The target population for this study had consisted of residents of Patna who had the potential to adopt rooftop solar energy systems. For data analysis, both qualitative and quantitative data had been analyzed using appropriate statistical tools and qualitative analysis techniques. Quantitative data had been analyzed using descriptive and inferential statistics, while qualitative data had been analyzed using thematic analysis to identify recurring themes and patterns in the responses. Overall, the mixed research methodology employed in this study had allowed for a comprehensive examination of the hindrances to rooftop solar adoption in Patna, and valuable insights had been provided for policymakers and stakeholders in the renewable energy sector.

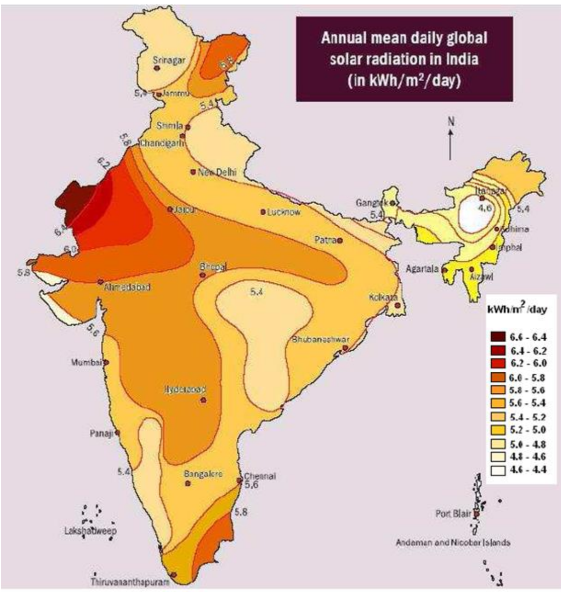
2.1 The site

Patna is the capital of Bihar located in India, desires to join the positions of the "shrewd urban areas" by taking on state of the art advances and eco-accommodating arrangements. Distinguishing the hindrances that obstruct public commitment to this drive is one of the essential difficulties in the execution of roof top solar powered chargers in Patna. Public support is crucial for the effective execution of shrewd city projects since it cultivates a feeling of pride and energizes local area contribution. By including occupants in arranging processes and empowering them to partake in supportable drives, urban areas can possibly make seriously inviting and versatile networks. However, challenges such as initial investment costs, grid integration, technical expertise, and regulatory hurdles may need to be addressed to fully realize the rooftop solar PV potential in Patna. Collaborative efforts involving government agencies, solar companies, financial institutions, and local communities can play a vital role in promoting solar energy adoption and fostering a greener future for the city. Patna, being located in the eastern part of India, experiences a subtropical climate with distinct seasons. Patna receives ample solar radiation throughout the year, due to its geographical location. Being close to the Tropic of Cancer, it experiences a higher intensity of sunlight compared to regions farther from the equator. This makes it conducive for harnessing solar energy through roof top solar photovoltaic systems in Patna. Significant Factors contributing to this roof top solar potential include following as shown in Table 1.

Table 1 Potential of integration of Roof Top PV Panels in Patna

1	The city receives a high amount of solar insolation, which is crucial for the efficient generation of solar power.
2	Many residential, commercial, and industrial buildings in Patna have suitable roof spaces that can accommodate solar panels.
3	Various government schemes and incentives, such as subsidies, net metering policies, and tax benefits, encourage the adoption of rooftop solar PV systems. These initiatives make it financially viable for individuals and businesses to invest in solar energy.
4	Solar PV systems help reduce reliance on fossil fuels, lower greenhouse gas emissions, and contribute to sustainable development.

As per the existing land use map residential area comprise of 49.56 sqkm which is 47.55% of the total urban area, Patna receive more than 5.25 Kwh/sqm/day as shown in Figure 1. Patna Area had a population of 23.90 lakhs as per the 2001 Census while the PMC had a population of17 lakh (2011 Census). A stated in PATNA MASTER PLAN-2031 the growth of population in the PUA has increased rapidly in 1991-2001.Thus, using the 1991-2001 decadal growth rate as an indicator, the population of the PUA is expected to be 22.50 lakhs in the year 2011 and 28.01 lakhs in the year 2021.[15]



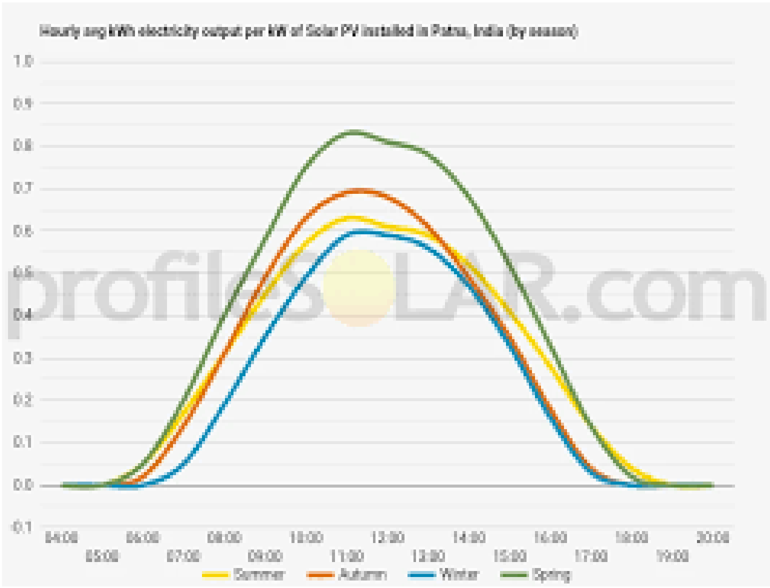


Figure 1: Annual average Global insolation map of India showing the isohels and solar hotspots, Source; Energy Alternatives India

Figure 2: Solar PV Analysis of Patna, India (source: https://profilesolar.com)

Energy Scenario in Patna

The energy circumstance in Patna mirrors that of other Indian urban areas. There are still worries about power supply because of power outages, despite the fact that there is developing help for utilizing sustainable power sources like sun oriented. The city should figure out how to accommodate the energy needs of its extending populace while likewise further developing energy proficiency citywide. A more manageable energy future is in sight, because of current endeavours to foster waste-to-energy innovation and increment energy saving mindfulness. Neighbourhood specialists and modern sources ought to be counselled for the most cutting-edge data about Patna's energy situation [1]. Bihar is considered as one of the fastest growing states in India. The rapid economic growth and infrastructural development in the state needs to be supported by a proportionate growth in electricity generation. The current installed power capacity in Bihar stands at 2984.79 MW (Mar 2016), with coal contributing to almost 92% of the installed power capacity. With its large population and rapidly growing economy, Bihar needs access to clean, cheap and reliable sources of energy. A report on energy development resolutions by the Government of Bihar (2017) outlines that the state government has set a target to provide 24-hour electricity connections to all rural and urban households by 2018-19. Achieving this ambitious goal will necessitate a comprehensive transformation of the power sector in Bihar, including harnessing the state's substantial renewable energy potential [2].

To study Patna residents' knowledge of, and sentiments towards, sun powered chargers for homes, a survey will be circulated. To additionally comprehend the obstacles according to numerous viewpoints, we will direct inside and out meetings and centre gatherings with key partners such civil specialists, energy specialists, and local area individuals. The aftereffects of this study are expected to give light on the essential factors that have eased back the boundless utilization of sun powered chargers on Patna's roofs. These outcomes can assist city organizers and authorities with contriving compelling designs to eliminate obstructions to public help for sustainable power. Patna will actually want to cut fossil fuel byproducts, increment energy security, and help to the city's reasonable turn of events on the off chance that these snags can be survived.[2]

The implications of this study extend beyond Patna, serving as a model for other cities facing similar challenges in promoting rooftop solar panels and encouraging citizen participation in sustainable urban development. This research contributes to the existing body of knowledge by providing empirical evidence and actionable strategies to enhance public engagement in smart city initiatives. It also emphasizes the crucial role of collaboration between government agencies, energy providers, and the public in achieving sustainable and smart urban growth, highlighting the central importance of residents in this process.

2.2 Research Design

The review plan had incorporated stages, including information gathering, analysis, and interpretation. Research goals had been focused on while a strategy had been developed. The objective of this research had been to identify the factors driving the popularity of residential solar PV systems in India, with a hybrid approach that had combined qualitative and quantitative methods being employed. The objective of this exploration had been to identify the variables contributing to the increasing popularity of solar PV systems installed on residential buildings. Through a combination of literature review and on-site interviews with current and potential users, a total of 39 factors had been identified. These factors had highlighted the primary barriers to adopting solar PV systems through public participation. To isolate the most significant factors driving the rapid rise in rooftop solar PV's popularity, quantitative data had been collected using interviews and questionnaires focused on these identified factors. Statistical tools had then been employed for further analysis. A scale had been developed to evaluate the significance of each variable, followed by factor analysis to determine which factors had been considered most critical. The adequacy of the data was demonstrated through statistical analysis, evidenced by a Kaiser-Meyer-Olkin (KMO) score of 0.93, which indicated excellent sampling efficiency. The Sampling Efficiency (SE) of each of the 39 identified factors was evaluated using the KMO scale, confirming that the data were sufficient for further analysis. To explore the relationships and patterns among these variables, factor analysis was conducted on the results obtained from the questionnaire. This method effectively reduced the complexity of the dataset, allowing for the identification of a smaller set of underlying factors that influenced the adoption of solar PV systems. The application of factor analysis not only streamlined the data but also enhanced the understanding of the dynamics at play among the identified barriers to public participation.

The sampling frame for this study consists of buildings in Patna that have installed PV systems on their rooftops. Despite receiving ample solar radiation, the adoption of rooftop solar PV has been modest in many regions, mirroring trends seen in most states across India. It is intriguing to explore why these areas have not fully embraced rooftop solar PV. Additionally, understanding who the early adopters are and what motivated them to switch to solar panels is equally compelling. This investigation also includes respondents who have the capacity to install rooftop solar PV but have not yet done so, aiding in the identification of key factors influencing adoption. This population encompasses a diverse range of individuals, including homeowners, business owners, policymakers, and community leaders. Considering Patna's large population, a sample of around 200 respondents has been selected using stratified sampling techniques. This sample size found to be adequate to reflect the diverse perspectives of the target population while ensuring statistical validity. The preferred localities selected for the study include partially government quarters, owners of newly constructed apartments, and individual residential properties situated in and around Bailey Road, Patna, as well as areas in Saguna More and new developments in Danapur. A few selected sites for the study include mixed-use establishments such as clinics with residential facilities, nursing homes, and stores that also provide residential accommodations, as the availability of PV board installations is quite rare in solely residential buildings.

Figure 3: Location of studied area (authors interpretation extracted from google map)

The sample size for this study was set at 200 individuals who have installed rooftop solar PV systems, aiming to understand the barriers to integrating rooftop PV in the studied area. The identification of the number of factors and the relevant concepts will determine the required sample size for conducting a factor analysis. According to Comrey and Lee (1992), sample sizes of 100 (fair), 200 (good), 500 (excellent), and 1000 (outstanding) are rated on a scale from 100 (poor) to 1000 (excellent). Finding the appropriateness of the data at the time of conducting the factor analysis is considered more critical than determining the sample size beforehand. To investigate potential variability among the factors due to hidden sources, the Kaiser-Meyer-Olkin (KMO) test was performed to assess data adequacy. The KMO score serves as a useful measure of sample adequacy; a score below 0.05 suggests unsuitability for factor analysis. Given the limited uptake of rooftop solar PV, the researcher confirmed that a sample size of 200 was sufficient for a robust factor analysis. Additionally, the results of Bartlett's test of sphericity further indicated the adequacy of the factors for factor analysis, supporting the validity of the sample size chosen.

A poll survey had been employed as a methodical and efficient technique for data collection. A set of predefined questions had been designed to gather specific information or opinions from a targeted group of respondents. The survey had been structured to ensure consistency in the data collection process, allowing for the analysis of responses across a broad sample. The survey had begun with a series of demographic questions designed to gather detailed information about each responder, followed by 39 questions regarding characteristics that had been determined to be significant. At the end of the survey, participants had been given the opportunity to provide input on any additional relevant topics. In the subsequent survey, after several demographic and personality questions, respondents had been asked to rate their level of understanding or disagreement with statements presented on five different measures. A span scale had been selected because it allowed for more rigorous statistical testing. In the first survey, participants had been asked to rate each question on a scale from one to seven, with one indicating the least critical and seven the most critical. A response of 1 to question 2 had indicated disagreement with statement 7 as much as other options. Pilot testing had been utilized to refine the phrasing and wording of the poll and to eliminate any ambiguity in the responses. The clarity and ease of answering the survey's questions had been verified to ensure that they had been straightforward.

RESULT

It has been observed that the city of Patna is gradually adopting alternative energy sources, shifting towards sustainable and renewable energy solutions. Insights from the pilot survey interviews revealed that individuals who have installed rooftop solar PV systems are generally more aware of alternative energy options, government schemes, and economic benefits. They are also more likely to be in contact with vendors supplying solar panels. Among the 200 samples surveyed, the majority of installations—around 70—were found in small residential apartments, while the rest were in nursing homes with residential facilities, clinics, and large independent houses as shown in Figure 4. However, it was also noted that some of these installations are poorly managed, with a few in a state of disrepair or incomplete.

Figure 4: Roof top PV Panels installed in Patna

The 39 parameters have been identified through extensive interviews and in-depth knowledge of the studied areas. These parameters provide a comprehensive overview of the barriers to installing solar PV panels in the city of Patna, which is a key element of the Smart City initiative. This analysis also highlights the challenges in encouraging public participation in the broader framework of Smart City projects, illustrating the obstacles residents face in embracing sustainable technologies. The detailed elaboration on the 39 variables identified as barriers in the installation of Solar PV for sustainable cities in Patna, as gathered through interviews are in Table 2.

Table 2: Identified Parameters in barriers in Installation of solar PV

Sl No	Parameter	Description
1	Freedom from rate hikes	Interest in avoiding future electricity rate increases by switching to solar PV.
2	Affordability of electricity tariffs	If current electricity rates are affordable, residents may delay solar PV adoption.
3	Return on investment potential	Concerns about whether solar PV provides enough return on investment.
4	Appeal of feed-in-tariffs	Attractiveness of feed-in tariffs to sell excess energy back to the grid.
5	Low installation cost	High installation costs may deter solar PV adoption.
6	Low operating costs	Perception of low maintenance and operating costs after installation.
7	Access to sufficient power	Expectation of generating enough energy for household needs.
8	Government subsidies	Awareness of subsidies, and complex procedures as a barrier.
9	Tax incentives	Lack of knowledge about tax benefits can impede solar PV adoption.
10	Reputation boost	Adoption seen as improving reputation as eco-conscious individuals.
11	Easy financing options	Difficulty in obtaining financing for upfront costs as a barrier.
12	Access to government incentives	Bureaucratic hurdles in obtaining government incentives.
13	Environmental concern	Environmental concerns drive adoption, lack of concern deters it.
14	Ease of maintenance	Misconceptions about maintenance complexity and cost.
15	Trial project feasibility	Ability to conduct small-scale trials encourages adoption.
16	Understanding of solar PV	Lack of understanding of how solar PV systems work as a barrier.
17	No additional resource needs	Solar PV systems don't require extra resources like water.
18	Cooling load reduction	Solar PV systems can reduce building cooling needs.
19	Peak load management	Understanding solar PV's role in managing peak energy loads.
20	Independence from utilities	Desire for less dependence on traditional energy suppliers.
21	Environmental benefits	Awareness of the environmental benefits drives adoption.
22	Knowledge sharing	Lack of shared knowledge or demo projects limits adoption.
23	Eco-friendly image	Desire to project an environmentally friendly image drives adoption.
24	Global trend alignment	Aligning with global renewable energy trends.
25	Future feed-in tariff clarity	Uncertainty about long-term feed-in tariffs deters adoption.

26	Extended investment horizon	Long payback periods may discourage adoption.
27	Equipment compatibility	Concerns about compatibility with existing electrical systems.
28	Building suitability	Buildings may not be suitable (roof space/angle) for installation.
29	Ease of operation	Fear of difficulty in operating solar PV systems.
30	Sufficient rooftop space	Lack of sufficient rooftop space for solar PV panels.
31	Availability of service providers	Limited access to reliable service providers in the area.
32	Building position suitability	Some buildings may lack optimal sunlight exposure for solar PV.
33	Utility provider dealings	Difficulty in dealing with utility companies (e.g., net metering).
34	Monitoring complexity	Complicated electricity monitoring systems can deter adoption.
35	Unclear benefits	Unclear benefits of solar PV may prevent investment.
36	Lack of demonstrations	Lack of opportunities to see solar PV systems in action.
37	Health hazard concerns	Concerns over potential health risks deter adoption.
38	Availability of quality systems	Limited access to high-quality solar PV systems locally.
39	Cultural alignment	If solar PV adoption conflicts with local cultural values.

Statistical Analysis

The statistical analysis of the identified parameters begins with the correlation matrix, which helps uncover relationships between the 39 variables collected from survey data. This matrix serves as a foundation to understand how different factors influencing solar PV installation are interrelated, revealing clusters or common themes among them. Following this, an adequacy test was performed using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity to determine if the sample size was sufficient for deeper analysis. The KMO score indicated that the data was well-suited for factor analysis, ensuring the robustness of the sample collection process.

Subsequently, factor analysis was conducted to distill the 39 parameters into a smaller set of core factors. This statistical method helped in identifying the most significant barriers to solar PV adoption by reducing the complexity of the data and pinpointing the key obstacles that need to be addressed. By understanding these core factors, it becomes easier to formulate strategies for increasing public participation in the installation of rooftop solar PV systems in Patna, thereby supporting the city's smart city initiatives and sustainable energy goals.

Factor Analysis for Consumers: Basic achievement factors for roof solar photovoltaics in India. Factor examination is utilized by researchers to reduce the information contained in countless factors into a more modest arrangement of additional significant factors. Inside and out research has uncovered that there are 39 variables that might impact the spread of roof solar PV. A poll was created to determine the weight each such variable played in the last reception choice on a scale from 1 (least essential) to 7 (generally significant). A factor analysis with "r" was performed on these responses.

Adequacy data testing: Many factors that were determined the health of the component investigation, and it was found that the model is a good fit. A score of 0.93 was obtained on the Kaiser-Meyer-Olkin (KMO) test. The interpretation of the KMO score is as follows: a score of 0.9 and above is considered superb; 0.8 to 0.89 is great; 0.7 to 0.79 is good; 0.5 to 0.69 is mediocre; and a score below 0.5 is deemed unacceptable (18). The KMO test demonstrates the extent to which observed test variation can be attributed to rational causes, with closer values suggesting that factor analysis may be more useful for the data.

In this analysis, a Chi-Square value of 5741.4 was shown by the results of Bartlett's Sphericity Test, along with 741 degrees of freedom and a p-value of less than 2.2e-16, confirming the suitability of factor analysis. The hypothesis of the identity matrix for the correlation matrix was tested by Bartlett's test of sphericity, which was confirmed. It was checked whether the variables are sufficiently correlated for factor analysis by this method. It is suggested by the small p-values that the variables are indeed related, supporting the use of factor analysis for this dataset.

Table 3 The Sampling Efficiency (SE) of each independent variable

Sl no	Variable	ASA
1	Freedom from rate hikes	0.82
2	Affordability of electricity tariffs	0.91
3	Return on investment potential	0.93
4	Appeal of feed-in-tariffs	0.93
5	Low installation cost	0.91
6	Low operating costs	0.90
7	Access to sufficient power	0.80
8	Government subsidies	0.91
9	Tax incentives	0.95
10	Reputation boost	0.90
11	Easy financing options	0.92
12	Access to government incentives	0.91
13	Environmental concern	0.70
14	Ease of maintenance	0.90
15	Trial project feasibility	0.87
16	Understanding of solar PV	0.94
17	No additional resource needs	0.74
18	Cooling load reduction	0.70
19	Peak load management	0.83
20	Independence from utilities	0.80
21	Environmental benefits	0.68
22	Knowledge sharing	0.93
23	Eco-friendly image	0.92
24	Global trend alignment	0.95
25	Future feed-in tariff clarity	0.95
26	Extended investment horizon	0.80
27	Equipment compatibility	0.87
28	Building suitability	0.90
29	Ease of operation	0.94
30	Sufficient rooftop space	0.71
31	Availability of service providers	0.94
32	Building position suitability	0.94
33	Utility provider dealings	0.93
34	Monitoring complexity	0.94
35	Unclear benefits	0.96
36	Lack of demonstrations	0.95
37	Health hazard concerns	0.93
38	Availability of quality systems	0.94
39	Cultural alignment	0.96

This establishes the fact that the variables are suitable for factor analysis, as their individual measures of data adequacy are all greater than 0.7, indicating strong correlations and the appropriateness of further analysis.

Factor Extraction: The factor extraction procedure is employed to simplify complex qualitative data through statistical analysis. A critical step in factor analysis is the determination of the optimal number of factors to represent the available variables. The Eigenvalue analysis method was applied using the 'r' data analysis program to select the ideal number of factors for analysis. Five criteria were proposed by the Eigenvalue analysis approach. Additionally, scree plots were generated to further validate the optimal factor count. The scree plot is utilized to identify statistically significant factors, variables, or components. It displays the significant variables among the identified parameters.

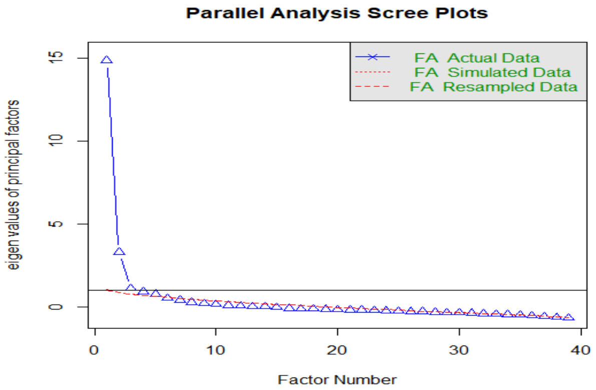


Figure 6 Scree plots of factor analysis in parallel

Scree plots displaying eigenvalues were shown, with the blue line representing the original data and the two red lines representing the reconstructed and resampled versions, respectively. The eigenvalues of genuine information were observed to first drop off emphatically, then show some straightening out. The inflection point was also identified, or when the difference between the two sets of values was likely to be at its smallest. An eigenvalue represents the portion of total variation attributable to that specific component. Scree plots representing the inflection point supported the suggestion from the parallel analysis to use five separate components.

Table 4 Factor Analysis Correlation Matrix

	Variable	MR1	MR3	MR2	MR4	MR5
1	Freedom from rate hikes	0.10	0.49	0.14	-0.04	-0.21
2	Affordability of electricity tariffs	0.14	0.47	0.11	0.24	-0.31
3	Return on investment potential	0.16	0.71	0.05	0.10	-0.11
4	Appeal of feed-in-tariffs	0.23	0.56	-0.08	0.29	-0.09
5	Low installation cost	0.19	0.65	-0.03	-0.27	0.13
6	Low operating costs	0.07	0.53	0.25	-0.16	-0.04
7	Access to sufficient power	-0.12	0.24	0.46	-0.36	0.12
8	Government subsidies	0.01	0.69	0.00	0.01	0.06
9	Tax incentives	0.17	0.71	-0.09	0.07	0.06
10	Reputation boost	-0.05	0.27	0.14	0.43	0.08
11	Easy financing options	-0.13	0.76	-0.06	0.21	0.12
12	Access to government incentives	0.03	0.63	0.09	0.02	0.28
13	Environmental concern	-0.25	-0.02	0.70	0.26	0.15
14	Ease of maintenance	0.54	0.23	0.12	-0.01	0.26
15	Trial project feasibility	0.20	0.14	0.22	0.03	0.46
16	Understanding of solar PV	0.41	0.11	0.19	0.26	0.30
17	No additional resource needs	0.06	-0.01	0.50	0.11	0.05
18	Cooling load reduction	0.08	0.03	0.62	-0.21	0.05
19	Peak load management	0.31	0.03	0.54	0.01	0.06
20	Independence from utilities	0.64	0.07	0.24	-0.20	-0.16
21	Environmental benefits	0.09	-0.16	0.66	0.23	0.01
22	Knowledge sharing	0.26	0.15	0.16	0.07	0.57
23	Eco-friendly image	0.15	0.19	0.02	0.70	0.01
24	Global trend alignment	0.23	0.13	-0.06	0.62	0.12
25	Future feed-in tariff clarity	0.38	0.41	-0.02	0.25	0.10
26	Extended investment horizon	0.22	0.42	0.12	-0.02	-0.06
27	Equipment compatibility	0.56	0.11	0.23	-0.04	-0.22
28	Building suitability	0.89	-0.01	0.10	-0.01	-0.11
29	Ease of operation	0.74	-0.02	0.06	0.15	0.01

30	Sufficient rooftop space	0.39	-0.03	0.24	-0.19	-0.03
31	Availability of service providers	0.51	0.27	-0.02	0.08	-0.02
32	Building position suitability	0.64	0.01	0.12	0.04	0.17
33	Utility provider dealings	0.65	0.08	-0.09	0.06	0.25
34	Monitoring complexity	0.58	0.17	-0.22	0.24	0.17
35	Unclear benefits	0.62	0.20	-0.13	0.19	0.11
36	Lack of demonstrations	0.45	0.33	0.15	0.23	0.10
37	Health hazard concerns	0.47	0.16	0.19	-0.04	0.24
38	Availability of quality systems	0.61	0.27	-0.06	0.04	0.17
39	Cultural alignment	0.22	0.19	-0.09	0.46	0.19

Scree plots displaying eigenvalues were created, with the blue line representing the original data and the two red lines representing the reconstructed and resampled versions, respectively. The inflection point, or the point at which the difference between the two sets of values is likely to be at its smallest, was also identified. The articulation location represented by the scree plots supported the recommendation from the eigenvalue analysis to utilize five distinct components. The loadings of every variable onto each of the five components are shown in this matrix. Loadings greater than 0.4 were considered, and no variables were found to be double-loaded.

Adequacy Test

The median difficulty of the items was found to be 1.2. In the case of Bartlett's test, the results were as follows: the Chi-square value was 5741.4, with 741 degrees of freedom and a p-value of 2.2e-16. The Chi-square value of 5752.11 has been found, along with an object function of 31.06. The null model had 741 degrees of freedom, while the model itself had 556 degrees of freedom and an object function of 5.97. This indicates that the root mean square residual (RMSR) for the residuals was 0.04.

The value of 0.076 for the RMSEA Index is considered commendable when compared to alternative measures. The RMSEA is classified as excellent when it is below 0.05, good when it is between 0.05 and 0.08, poor when it is between 0.08 and 0.1, and terrible when it exceeds 0.1. After df adjustment, the residuals have a root mean square of 0.04.

Based on these 200 data points, an empirical chi-square of 447.82 was obtained, which is statistically significant at the 0.05 level. A probability of 1.9e-36 was calculated, with the number of observations recorded as 200 and the Chi-Square value determined to be 1084.78. The reliability of the factors was indicated by an Index of Root-Mean-Square Error (RMSEA) of 0.076, a 90% Confidence Interval (CI) of 0.063, and a Bayesian Information Criterion (BIC) of -1861.08. The fit was deemed satisfactory as the off-diagonal values were equal to 0.99. Additionally, Tucker Lewis' index suggested that the factoring reliability was above average at 0.856.

Table 5 Critical analysis Synopsis

	MR1	MR3	MR2	MR4	MR5
SS Loadings	7.06	6.10	3.51	3.54	1.85
Proportion Variance	0.19	0.17	0.10	0.10	0.06
Cumulative Variance	0.19	0.36	0.46	0.56	0.62
Proportion Explained	0.33	0.29	0.17	0.17	0.09
Cumulative Proportion	0.33	0.62	0.79	0.96	1.00

The Known Contributors for the identified parameters

Using factor analysis, five crucial elements have been identified that influence the decision to install solar panels on rooftops Table 6. The **first element**, **Complexity**, addresses the perceived difficulty in understanding and implementing solar panel systems. This factor plays a crucial role in adoption rates, as potential users may be hesitant due to technical challenges related to installation and operation. Key factors influencing complexity include the ease of maintenance, simplicity in understanding rooftop solar PV, and compatibility with existing equipment and buildings. Additional considerations include the availability of adequate rooftop space, easy access to PV service providers, and user-friendly systems for monitoring energy generation. Clear benefits, lack of health risks, and accessible demonstrations also help reduce perceived complexity, promoting adoption. The **second element**, **Financial Attractiveness**, highlights the financial benefits of installing solar panels. Key factors include freedom from potential power tariff increases, current high electricity tariffs, and the high return on investment. The availability of an attractive feed-in tariff, low installation and operating costs, and government subsidies all make the initial investment more appealing. Attractive tax incentives and easy access to financing further reduce financial barriers. The clarity over long-term feed-in tariffs and longer investment horizons also enhances the financial viability, making solar energy an appealing and cost-effective option for many homeowners. The **third factor**, Three Pros for Nature, underscores the significant **environmental benefits** of solar energy. It emphasizes how solar power contributes to sustainability by reducing carbon emissions and promoting eco-friendly practices. Key aspects include the availability of unlimited electricity, heightened environmental awareness, and the efficient use of resources as solar energy doesn't require additional resources like water. Furthermore, solar panels help reduce a building's cooling load by keeping the roof cool, ultimately benefiting the environment. Solar systems also aid in improved peak load control, showcasing their ability to contribute positively to both the environment and energy efficiency. The **4th factor**, **Social Image**, highlights how the installation of rooftop solar PV systems can enhance a homeowner's social image. It contributes to creating an "Environmental Concern Image," aligning with global sustainability trends. The aesthetics of solar panel installation also play a crucial role, as homeowners may be concerned about how the appearance of the panels affects their property's visual appeal. This factor emphasizes the importance of aligning solar adoption with personal and societal values, promoting both environmental responsibility and social status. The **5th factor**, identified as **Trialability**, plays a crucial role in the adoption of rooftop solar PV systems. Trialability refers to the ease with which individuals can experiment with or test the technology before fully committing to it. The ability to start small-scale experimental projects allows potential adopters to assess the practicality, effectiveness, and benefits of rooftop solar PV in a low-risk environment. This hands-on experience helps mitigate uncertainty and builds confidence in the technology. Additionally, **information sharing** serves as a key enabler in this process. When users share their experiences and insights, it not only helps others to understand the installation process but also provides practical guidance on overcoming common challenges. Lastly, **the ability to be trained** highlights the importance of education and skill-building opportunities for users. Ensuring that individuals are properly trained in the operation and maintenance of solar systems is vital for fostering successful adoption and long-term sustainability. Knowledge and training empower individuals to manage and troubleshoot solar installations effectively, contributing to the widespread acceptance and growth of rooftop solar PV adoption.

Table 6: Factors for identified Variables

Sl No	Sl No of identified variables (table 4)	Variable	Factor Name	Factor Loading
1	14	Ease of maintenance	1.Complexity	0.54
2	16	Understanding of solar PV		0.41
3	20	Independence from utilities		0.62
4	27	Equipment compatibility		0.56
5	28	Building suitability		0.87
6	29	Ease of operation		0.72
7	30	Sufficient rooftop space		0.37
8	31	Availability of service providers		0.51
9	32	Building position suitability		0.64
10	33	Utility provider dealings		0.63
11	34	Monitoring complexity		0.56
12	35	Unclear benefits		0.62
13	36	Lack of demonstrations		0.43
14	37	Health hazard concerns		0.45
15	38	Availability of quality systems		0.59
16	1	Freedom from rate hikes	2. Financial	.47
17	2	Affordability of electricity tariffs		0.45

18	3	Return on investment potential	Attractiveness	0.71
19	4	Appeal of feed-in-tariffs		0.58
20	5	Low installation cost		0.63
21	6	Low operating costs		0.55
22	8	Government subsidies		0.67
23	9	Tax incentives		0.71
24	11	Easy financing options		0.76
25	12	Access to government incentives		0.63
26	25	Future feed-in tariff clarity		0.41
27	26	Extended investment horizon		0.42
28	7	Access to sufficient power	**3.Environmental Benefits**	0.48
29	13	Environmental concern		0.70
30	17	No additional resource needs		0.50
31	18	Cooling load reduction		0.62
32	19	Peak load management		0.54
33	21	Environmental benefits		0.66
34	10	Reputation boost	**4. Social Image**	0.43
35	22	Knowledge sharing		0.70
36	23	Eco-friendly image		0.62
37	24	Global trend alignment		0.46
38	15	Trial project feasibility	**5.Trialability**	0.46
39	39	Cultural alignment		0.55

CONCLUSION

To identify the barriers in adopting solar PV in the context of Patna, Rogers's diffusion theory provides a valuable framework (19). This theory outlines several factors that affect the adoption process of innovations, including solar energy systems. Based on the analysis, five key factors influencing the adoption of solar PV in Patna can be concluded: Relative Advantage, Compatibility, Complexity, Trialability, and Observability.

Relative Advantage refers to the perceived benefits of solar PV over traditional energy sources. If individuals believe that solar energy offers significant advantages, such as cost savings and environmental benefits, they are more likely to adopt it. Compatibility considers how well solar PV systems align with existing values, experiences, and needs of the community in Patna. If solar technology is seen as compatible with the local context and lifestyles, adoption rates may increase. Complexity addresses the perceived difficulty associated with understanding and using solar PV systems. If the technology is viewed as complex or challenging to implement, potential adopters may be discouraged from making the switch. Trialability refers to the opportunity for individuals to experiment with solar PV systems before fully committing to them. If potential users can test the technology in a limited capacity, they may feel more confident in their decision to adopt it. Observability involves the visibility of solar PV systems and their benefits to others in the community. When individuals can see the positive outcomes experienced by early adopters, such as reduced energy bills and increased sustainability, it can encourage wider acceptance of the technology. By examining these five factors, it becomes clear that they play a crucial role in influencing the adoption of solar PV in Patna, highlighting the barriers that need to be addressed to enhance the uptake of renewable energy solutions in the region.

Table 7: Barriers in Rooftop solar PV in Patna(author)

Relative advantage	Compatibility	Complexity	Trialability	Observability
Freedom from rate hikes	• Independence from utilities	• Ease of maintenance	• Trial project feasibility	• Sufficient rooftop space
Affordability of electricity tariffs	• Equipment compatibility	• Understanding of solar PV		• Availability of service providers
Return on investment potential	• Building suitability	• Ease of operation		• Knowledge sharing
Appeal of feed-in-tariffs	• Building position suitability	• Monitoring complexity		
Low installation cost, Low operating costs	• Utility provider dealings	• Health hazard concerns		
Government subsidies, Tax incentives, Easy financing options	• Knowledge sharing	• Lack of demonstrations		
Access to government incentives	• Cultural alignment	• Unclear benefits		
Future feed-in tariff clarity		• Availability of quality systems		
Extended investment horizon				
Access to sufficient power				
Environmental concern				
Cooling load reduction				
Peak load management				
Environmental benefits				
Reputation boost, Eco-friendly image				
Global trend alignment				

In the context of identifying barriers to the utilization of solar PV in Patna, three of Rogers's five factors—Relative Advantage, Complexity, and Trialability—can be particularly justified as significant challenges.

Relative Advantage: The perceived benefits of adopting solar PV technology compared to conventional energy sources play a crucial role in its adoption. In Patna, if potential users do not recognize substantial advantages, such as cost savings on electricity bills, environmental benefits, or energy independence, they may be less inclined to invest in solar systems. This lack of awareness or understanding regarding the relative advantages of solar energy can hinder its widespread acceptance.

Complexity: The complexity of solar PV systems can pose a barrier to their utilization in Patna. If potential users perceive the technology as complicated, difficult to install, or challenging to maintain, they may be deterred from adopting it. This perception can stem from a lack of technical knowledge, fear of the unknown, or concerns about navigating the installation process. Simplifying the technology and providing clear, accessible information could help alleviate these concerns.

Trialability: The ability to experiment with solar PV systems on a smaller scale before making a full commitment is another critical factor influencing adoption. In Patna, if potential users do not have opportunities to trial solar technology, they may feel hesitant to invest in a system without firsthand experience of its benefits and functionality. Programs that allow for pilot installations or community solar initiatives could enhance trialability, enabling users to gain confidence in the technology before fully committing.

Factors of Adoption: Identifying the barriers to adopting solar PV in Patna is essential for future planning and public participation in sustainable city policies. These barriers can inform proposals for similar initiatives in other regions. Based on Rogers' diffusion of innovations theory, factor analysis identified five key motivators for adopting rooftop solar PV in India: complexity, investor appeal, environmental benefits, peer acceptance, and trialability. The study found that complexity, relative advantage, and trialability are crucial in Patna's adoption model. Unlike many new technologies, rooftop solar PV can coexist with grid power, which may explain the lack of focus on compatibility and observability. Key adoption drivers in Patna are complexity and financial attractiveness. The uptake of rooftop solar PV could increase if obstacles related to installation and maintenance are reduced. While government schemes have made financial incentives available, their impact has been mixed. To improve the economic appeal of solar PV, new, more accessible schemes should be introduced. Addressing these barriers through effective policy frameworks is vital for encouraging solar PV adoption in Patna and promoting public participation in smart city initiatives.

Application of Information Systems to overcome the Bariers: To mitigate the barriers of Relative Advantage, Complexity, and Trialability in the adoption of rooftop solar PV in India, several specific digital media and web systems are currently prevalent in the country. These systems play a crucial role in promoting awareness, simplifying the adoption process, and allowing for trialability of solar PV technology.

For Relative Advantage, digital campaigns and awareness platforms such as the Solar Energy Corporation of India (SECI) and the Ministry of New and Renewable Energy (MNRE) provide detailed comparisons of solar PV costs, savings, and environmental benefits. These platforms present clear data on how solar energy outperforms traditional energy sources, including case studies, success stories, and financial savings calculators. Additionally, solar rooftop calculator apps like Tata Power Solar and Sunking enable users to estimate the cost savings and environmental benefits of adopting solar PV systems based on their energy consumption patterns and geographical location. These tools help potential adopters understand the relative advantages of switching to solar energy, making the decision more appealing and informed.

The complexity as barrier could be addressed with digital platforms in India. Digital platforms like MYSUN and Solarize India simplify rooftop solar PV adoption by offering end-to-end solutions, including site assessments, installation, and maintenance. They provide online consultations, interactive guides, and access to certified installers for smooth integration. Additionally, platforms like The "Model Solar Village" initiative, part of the PM-Surya Ghar: Muft Bijli Yojana, has been establish one solar-powered village per district in India, promoting solar energy adoption and energy self-reliance for village communities. It offers educational content, tutorials, FAQs, and live chat support, making it easier for users to understand and adopt solar technology without feeling overwhelmed by its complexity.

To overcome the Trialability barrier, platforms like Sustainable Solutions India and Oorjan Cleantech promote pilot projects and community solar programs. These initiatives allow users to participate in collective solar projects or install small-scale systems at reduced costs, giving them a firsthand experience of the technology and reducing the perceived risk. Additionally, tools like Solarify offer virtual simulations, enabling users to visualize how solar panels would perform on their roofs based on geographical data and energy consumption patterns. This trial-like experience allows users to experiment with different system configurations before committing to full-scale installation.

The adoption of information and digital systems can play a crucial role in removing the barriers to rooftop solar PV adoption, facilitating the successful integration of sustainable solutions. By leveraging digital platforms, potential users can access real-time data, simplified installation processes, and educational resources, addressing complexities and promoting understanding. Information systems can also provide financial tools, allowing users to assess cost savings and available subsidies, thus overcoming financial barriers. Additionally, virtual simulations and pilot projects can help users experience the technology firsthand, reducing the perceived risk and encouraging wider adoption. Ultimately, these systems enhance accessibility, support, and awareness, driving the growth of rooftop solar PV as a sustainable energy solution.

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