Journal of Information Systems Engineering and Management
2025, 10(53s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Identification of Barriers for Solar Power Park installation in Northern Himalayan States: A study of Uttarakhand

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ARTICLE INFO

Received: 24 Dec 2024

Revised: 12 Feb 2025

Accepted: 26 Feb 2025

ABSTRACT

India is currently facing significant energy demands, and it is becoming increasingly challenging to meet these needs through conventional power sources. The rapid population growth is intensifying this demand, making it harder to fulfil. To enhance energy security, limit carbon emissions, and drive economic growth, the implementation of progressive policies and systems that stimulate the use of renewable and clean energy is crucial. With its excellent population and geographic factors, India possesses enormous potential for solar energy growth. This study focuses on installation of solar power park in Uttarakhand, one of the Northern Himalayan state of India. The study contributes to the literature by identifying barriers to solar adoption in the state. However, research on solar energy implementation in various regions remains limited. This paper examines solar power usage in Uttarakhand by identifying key barriers. The study uses Interpretative Structural Modelling (ISM) to explore the relationships between these barriers, while MICMAC analysis is employed to validate the model. Key barrier such as inadequate government policies issues rank high in the ISM structure, while inadequate government policies are identified as the most influential barrier at the base of the structure. The following research gives insight to overcome these barriers by utilizing solar power in electricity generating facilities.

Keywords: Solar Power Park, Barriers, Uttarakhand, ISM, MICMAC

1. INTRODUCTION

The energy deficit in Uttarakhand arises from a confluence of topographical, infrastructural, and financial obstacles. Although abundant in hydropower potential, the state's hilly topography complicates energy transmission and distribution, resulting in electricity shortages in remote areas. Moreover, seasonal fluctuations in river flows impact hydroelectric power, resulting in supply discrepancies. The restricted availability of alternate energy sources and significant reliance on imports from neighbouring states intensify the issue. Uttarakhand is striving to diversify its energy portfolio by including solar and wind power, despite existing financial and policy-related barriers.. Uttarakhand state of India is mostly spanning southern perimeter of Himalayas. Electrification in villages of Uttarakhand is significantly behind the target set by union power ministry as only 4 villages have been granted power supply under Deendayal Upadhyaya Gram Jyoti Yojana and 75 villages had to be reached in 2016-2017.although there are 9,126 unelectrified villages are yet to be electrified as on 31 July 2016,still 20% of villages falls under the electrification as on 2024. (McKenna & Main, 2015) This study intends to analyse the potential of solar energy to relieve these limitations while simultaneously investigating the barriers and potential benefits intertwined within its integration.

The ensuing sections will provide a comprehensive overview of solar power's potential in Uttarakhand, elucidating on the economic, technical, and infrastructure barriers that currently impede solar power installation and solar power generation. (Nandal et al., 2019)Further, it will discuss opportunities for maximizing solar energy solutions through financial closure, solar power subsidies, and solar power incentives. (Dalapati et al., 2023)Insights into effective policy recommendations and government policies aimed at promoting solar energy technology and solar power

e-ISSN: 2468-4376
https://www.jisem-journal.com/

development will be offered. The study, which includes case study analyses from various Indian states, suggests that solar energy systems in Uttarakhand have the ability to not only fulfil but surpass future energy demand sustainably. This approach can be fulfilled via concerted efforts in research, investment, and policy development. (Shiradkar et al., 2022)

1.1 Overview of Solar Power Potential in Uttarakhand

Uttarakhand, a state blessed with a ample amount of natural resources, displays considerable potential for solar power generation. This potential is primarily due to the state's geographic as well as environmental conditions, which offer a ideal situation for holding solar insolation. (Mishra et al., 2020) According to the Global Solar Atlas of 2023, Uttarakhand receives a broad variety of solar radiations, varying from 1.9 to 5.9 kWh/m^2/day throughout different locations The data categorizes these radiations into eight unique ranges, with the majority of the state, comprising districts like Udham Singh Nagar, Haridwar, and Dehradun, receiving solar radiations between 4.4 to 4.9 kWh/m^2/day, which constitutes roughly 61.16% of the region (Sustainable energy in Himalayas: A case study on solar power development in Uttarakhand, Accessed 2024).

In terms of installed capacity, Uttarakhand has a total of 5359.44 MW, with a large 74.18% derived from hydropower (Castillo et al., 2016). However, solar power is emerging as a substantial contribution, accounting for 575.53 MW or 10.74% of the total capacity. This transition towards solar is in alignment with the government's objective to reach a sustainable and clean energy capacity of 2000 MW by 2028 (Sustainable energy in Himalayas: A case study on solar power development in Uttarakhand, Accessed 2024).

The state's solar energy future is further supported by its good meteorological circumstances. With around 280 days of sunshine each year, Uttarakhand has an outstanding solar incident energy range from 4 to 7 kWh/m^2 per day (Information System, 2020).This ample sunshine, along with appropriate ambient temperatures, makes it an ideal location for both solar power generation as well as thermal power generation .Despite the state's focus on hydropower, the potential for solar energy cannot be disregarded. Experts say that with better planning and resolution of implementation difficulties, Uttarakhand might greatly enhance its solar power output (Solar power could emerge as a dependable energy alternative for Uttarakhand, 2021).Currently, the state also displays potential growth in the rooftop solar industry, which not only decreases electricity prices but also contributes to the grid. As of October 2021, Uttarakhand had achieved a total installed capacity of 0.262 GW in rooftop solar, aiming to reach 0.350 GW by the end of 2022 (Information System, 2020).

Moreover, a joint study by Doon University and G.B. Pant University of Agriculture and Technology in 2020 highlighted that all districts in Uttarakhand could meet over half of their electricity demand, approximately 57 percent, using rooftop solar (Information System, 2020).This indicates a substantial opportunity for expanding solar energy utilization across the state, thereby reducing dependency on conventional power sources and enhancing sustainability.

2. METHODS APPLIED FOR PRISMA APPROACH

The PRISMA framework guided a systematic review of 40 studies (13 Scopus, 27 ScienceDirect) to identify barriers, while ISM-MICMAC elucidated their interdependencies. Twelve experts (5 industry, 7 academia) validated relationships through a structured matrix, prioritizing barriers based on driving/dependency power. Unlike conventional applications, this approach highlights Uttarakhand's geographic and administrative nuances, such as land acquisition complexities in hilly terrain, ensuring context-specific validity. VOS-Viewer visualizations (Figures 1a–2b) were minimized in favor of interpretive analysis to avoid tool-centric descriptions.

2.1. Eligibility Criteria

- **Inclusion Criteria**:

Studies focusing on barriers to solar power implementation in Uttarakhand.

Articles published in peer-reviewed journals, conference papers, government reports, and credible online sources.Studies published in English.

Journal of Information Systems Engineering and Management
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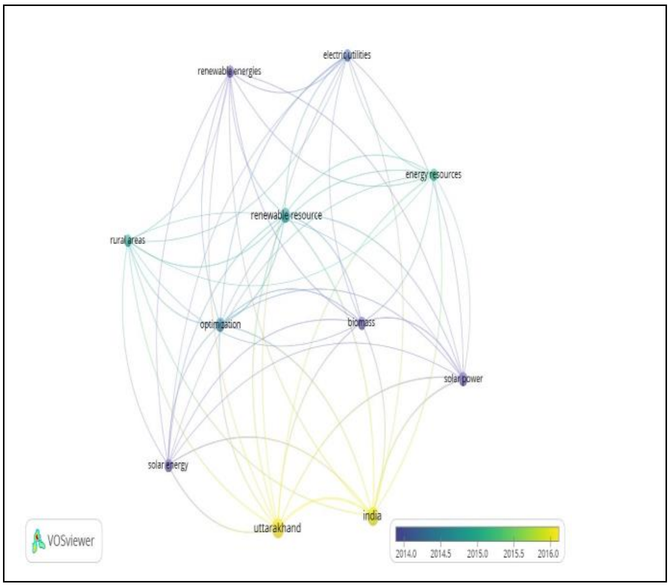
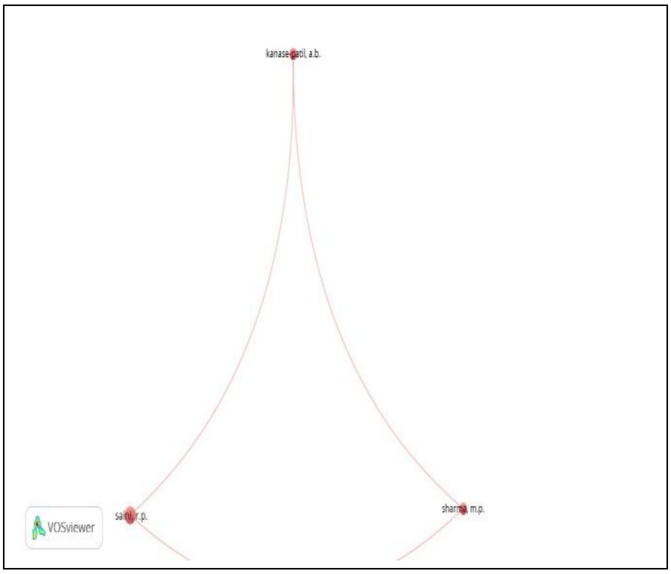
Overall 13 Documents has been identified in Scopus database having the word count and main authors given below in VOS-Viewer Output. Searching criteria KEY (Uttarakhand* AND solar AND energy*) as shown in figure 1(a) and 1(b)

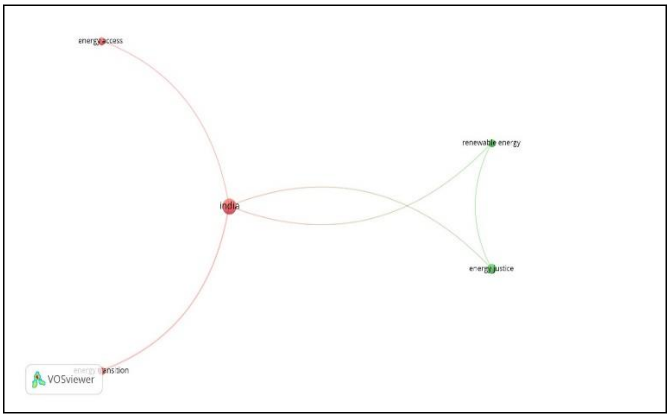


Figure(1)a VOS-Viewer Overlay Visualization

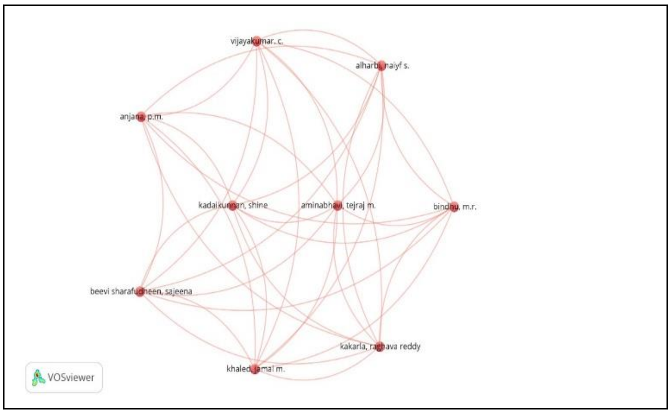


Figure(1)b Main Authors VOS-Viewer Network Visualization

Overall 27 Documents has been identified in ScienceDirect database having the word count and main authors given below in VOS-Viewer Output. Searching criteria KEY (Uttarakhand* AND solar AND energy*) but some research articles relates to India. as shown in figure 2(a) and 2 (b)



Figure(2)a VOS-Viewer Network Visualization



Figure(2)b Main Authors VOS-Viewer Network Visualization

- **Exclusion Criteria**:

Studies not focused on India, Northern Himalayan States of India and Uttarakhand.

Articles not accessible in full text.

Non-English studies.

2.2. Information Sources

- Databases: PubMed, Scopus, Web of Science, Google Scholar, and other relevant databases.

- Grey literature: Government reports, NGO reports, and industry publications.

2.3. Search Strategy

- Develop a comprehensive search strategy using keywords and Boolean operators.

Example: ("Solar power" OR "solar energy") AND ("barriers" OR "challenges") AND ("Uttarakhand").few literature found on the selected criteria so barriers and challenges has been taken from national and global level.

2.4. Study Selection

- Use a PRISMA flow diagram to illustrate the selection process, including the number of studies identified, screened, excluded, and included in the review as shown in figure 3.

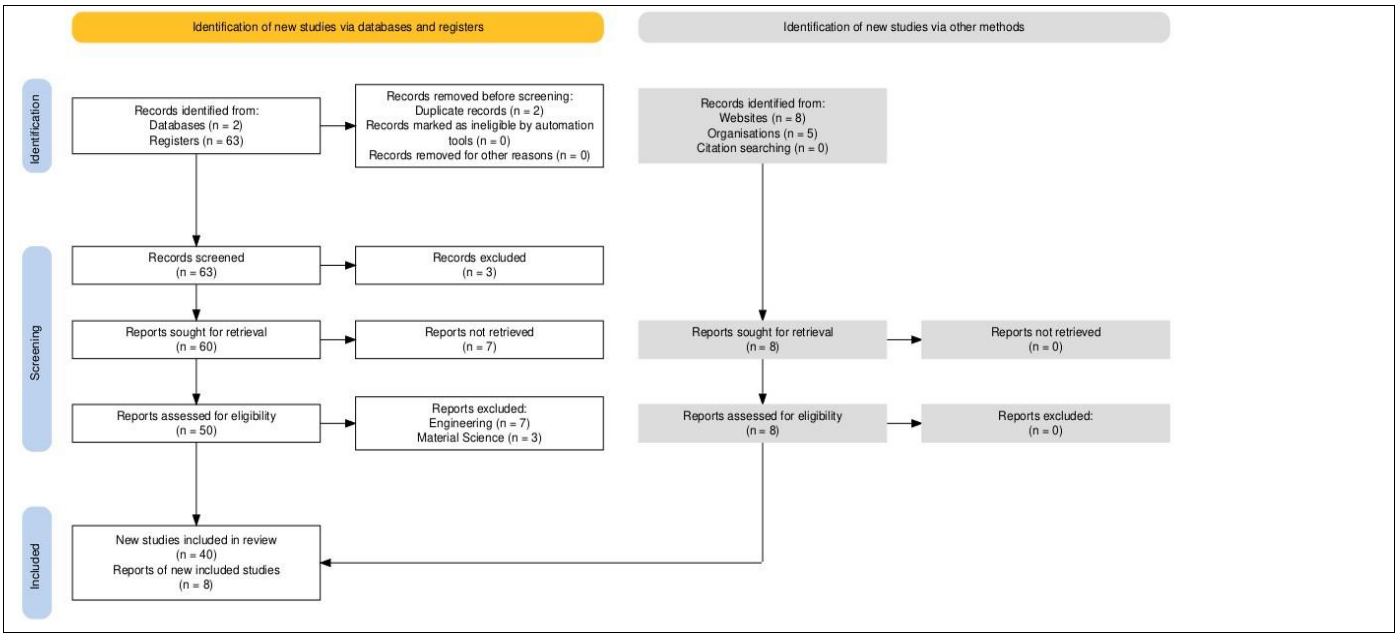


Figure 3. Prisma approach for selection of literature

2.5. Synthesis of Results

- Provide a narrative synthesis of the findings, organized by the type of barriers.
- Use thematic analysis to identify common themes and patterns across the studies.

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology can be effectively utilised to synthesise findings concerning the categorisation of barriers in the establishment of solar power parks in Uttarakhand. (Page et al., 2021) This strategy employs a systematic and transparent approach for locating, filtering, and incorporating pertinent studies, facilitating the categorisation of barriers into financial, technical, regulatory, and social challenges. The application of the PRISMA framework facilitates a methodical synthesis of barriers, ensuring thorough coverage of both published literature and grey studies, thereby elucidating the primary challenges to the establishment of solar power parks. (Page et al., 2021)

3. BARRIERS TO SPP IMPLEMENTATION

3.1 Economic Barriers

Economic barriers significantly effects the establishment of solar power parks in India, especially in areas such as Uttarakhand. A significant barrier is the substantial initial capital expenditure necessary for the establishment of solar infrastructure, encompassing site acquisition, solar panel installation, and grid integration. (Kar et al., 2016) Finance alternatives for extensive projects are frequently restricted, (Reddy & Painuly, 2004), (Karakosta et al., 2010) particularly in regions with challenging topography, as shown in Uttarakhand. Moreover, the expenses associated

Journal of Information Systems Engineering and Management
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e-ISSN: 2468-4376
https://www.jisem-journal.com/

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with the maintenance and upgradation of transmission lines to support renewable energy may impose additional financial strain. (Hirmer & Cruickshank, 2014), (Varma & Salama, 2009) Uncertainties about government subsidies, price frameworks, and payment delays from electricity distribution firms (DISCOMs) further intensify the risk for investors. The limited capability of local industries to absorb these expenses, coupled with the region's distinct topographical limits, exacerbates the financial viability of solar parks, dissuading potential investors and slowing adoption.

3.2 Technical Barriers

Technical barriers to solar power park installation in India, particularly in state of Uttarakhand, are considerable and multilevel. The principal challenge arises from the intermittent nature of solar energy, (Agarwal & Kansal, 2017) as power generation is heavily reliant on sunshine, which can fluctuate considerably due to the state's undulating topography and changing weather conditions. (Uttarakhand solar self-employment: Challenges remain, accessed 2024)This requires complex energy storage solutions and grid control technologies, which are pricey and still evolving in India. Furthermore, Uttarakhand hilly topography affects the installation of solar infrastructure, requiring specialized equipment and building procedures that are more expensive and difficult to deploy than in flat locations. (Kabir et al., 2018) The limited availability of suitable land for large-scale solar parks in this topography further exacerbates the issue. the primary obstacle to solar energy getting a significant proportion of the energy market in the future is the lack of consumer understanding and awareness of solar power. (Nandal et al., 2019) Few individuals obtain training on this technology, and there are limited solar training educational institutions. The spread of solar power is further delayed by a dearth of competent technical staff and issues inside training institutes.(Sustainable power solutions: A solar energy case study,Nov,2021). Transmission infrastructure is another key challenge, as remote regions sometimes lack proper grid connectivity, necessitating expensive and lengthy transmission lines to link solar power generation to the main grid. Additionally, a dearth of qualified labours conversant with the latest solar technology, including photovoltaic (PV) systems and modern inverters, causes challenges for the efficient operation and maintenance of solar parks in this region. Together, these technical constraints prevent the large-scale implementation and adoption of solar electricity in Uttarakhand.

3.3 Infrastructure Barriers

The development of solar power parks in Uttarakhand confronts significant infrastructure challenges, mostly due to the state's tough geology and inadequate grid infrastructures. The mountainous topography hinders the shipment and installation of solar equipment, as many rural places lack sufficient road networks or access to heavy equipment. (Kumar & Majid, 2020) lack of market infrastructure and distribution network is another challenge for solar power technology is experiencing in the competitive industry. Lack of infrastructure has been identified as a hindrance. Land Acquisition is the most crucial factor for infrastructure development (Mohan, 2017).The people in hilly terrain of Uttarakhand are facing the challenges of restricted access to energy, limited road access, and transportation services. (Mathiyazhagan et al., 2013) (Kar et al., 2016) Setting up additional training institutes for solar PV technologies in rural areas significantly increases green energy adoption. It will boost the skill of rural youngsters and increase employment. The skilled worker and professionals are not intended to arrive and work in remote and local regions till they are lured for more advantages and incentives. The lack of political commitment in Uttarakhand has hindered the installation of solar power parks, with inequitable governmental assistance and prolonged implementation of renewable energy schemes. Frequent changes in government objectives and poor allocation of funds for solar projects generate uncertainty for investors and developers. Additionally, little political will to streamline regulatory processes and give clear incentives for solar power further limits large-scale deployment.

3.4 Policy & Regulation

Policy and regulatory barriers in Uttarakhand create substantial challenges to the development of solar power infrastructure. One of the primary challenges is the lack of a unified and long-term renewable energy policy matched to the state's particular geographic and climatic constraints. (Khare et al., 2013) While national policies stimulate solar adoption, their implementation at the state level is often delayed, fragmented, and uneven. Complex regulatory procedures, including lengthy approval processes for land purchase, environmental approvals, and grid connectivity, further delay the establishment of solar power parks. (Challenges in land acquisition for solar projects, 2022)

Additionally, the absence of clear and stable incentives, such as tax benefits or subsidies for solar power developer companies, generates uncertainty for investors. Tariff policies are also a concern, as variable rates and delays in payments from power distribution firms (DISCOMs) impair the financial feasibility of solar installations. Moreover, Uttarakhand regulatory framework lacks adequate focus on grid modernization, making it difficult to integrate renewable energy efficiently. These policy and regulatory constraints jointly hamper the large-scale growth of solar energy in the region.

3.5 Summary of Evidence:

Dimension s. n.	Dimensions of barriers to adopt renewable/sustainable energy technologies	Barrier s. n.	Barriers to adopt renewable/sustainable energy technologies
1	Financial & Economical (FE)	1.1	High initial capital cost (Reddy & Painuly, 2004), (Karakosta et al., 2010) (FE1)
		1.2	Insufficient financing systems (Kar et al., 2016) (FE2)
		1.3	Transmission & distribution losses (Varma & Salama, 2009) (FE3)
		1.4	Technology Inefficiency (Thapar et al., 2018) (FE4)
		1.5	Absence of subsidies (Kar et al., 2016) (FE5)
2	Market Factor (MF)	2.1	Insufficient customer knowledge on technology (Ansari et al., 2013) (MF1)
		2.2.	Inadequate market size (Das et al., 2020a) (MF2)
		2.3	Incapable of satisfying the electricity power demand independently (Das et al., 2020b) (MF3)
		2.4	Insufficient financial means (Manju & Sagar, 2017) (MF4)
3	Information & Awareness (IA)	3.1	Need for backup or storage device (Werulkar & Kulkarni, 2015) (IA1)
		3.2	Unavailability of solar radiation data (Mohanty et al., 2017) (IA2)
		3.3	Lack of IT enablement (Kapoor et al., 2014) (IA3)
4	Technical Factor (TF)	4.1	Lack of awareness of technology (Nandal et al., 2019) (TF1)
		4.2	Less efficiency (Kapoor et al., 2014) (TF2)
		4.3	Inadequate efforts on research & development work (Nandal et al., 2019) (TF3)

Journal of Information Systems Engineering and Management
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e-ISSN: 2468-4376
https://www.jisem-journal.com/
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Dimension s. n.	Dimensions of barriers to adopt renewable/sustainable energy technologies	Barrier s. n.	Barriers to adopt renewable/sustainable energy technologies
		4.4	Lack of trained people & training institutes (Kapoor et al., 2014) (TF4)
		4.5	Lack of local infrastructure (Nandal et al., 2019) (TF5)
5	Geographical Issues (GE)	5.1	Geographic conditions (Nandal et al., 2019) (GE1)
		5.2	Land Acquisition Issue (Mohan, 2017) (GE2)
6	Government Issues (GI)	6.1	Lack of political commitment (Luthra et al., 2015) (GI1)
		6.2	Inadequate government policies (Luthra et al., 2015) (GI2)
		6.3	Lack of transportation & Installation (Kar et al., 2016) (GI3)

Table 1. Barriers in Implementation of SPP in Uttarakhand.

Following Table (1) shows the selected barriers which hinders the solar power park installation in Uttarakhand, the barriers has been identified from the literature review by applying PRISMA approach in selection of articles.

4. RESEARCH APPROACH

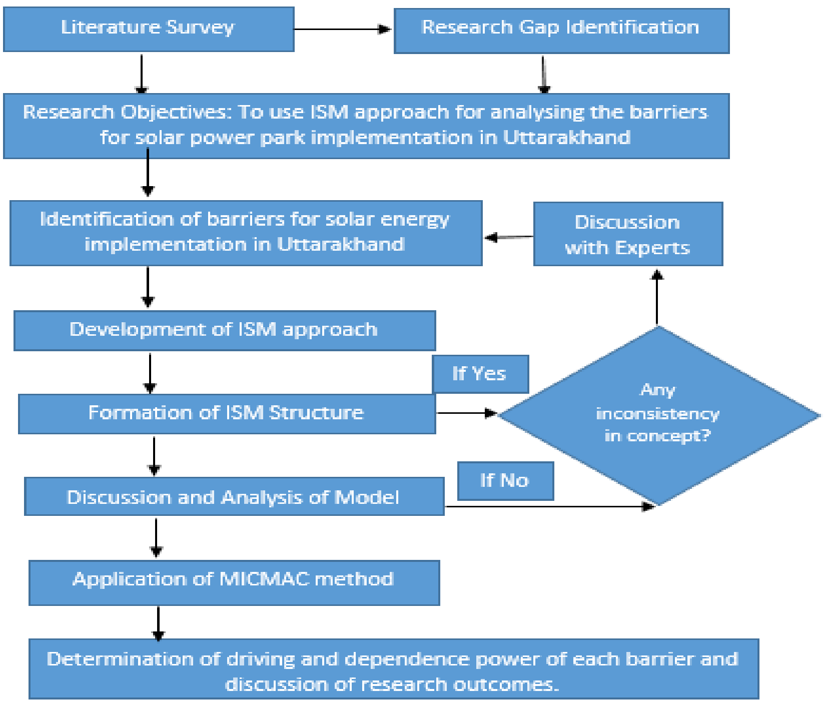

Figure (4) ISM Implication Process

The Interpretive Structural Modeling (ISM) approach can be effectively employed to identify and address challenges in the development of solar power parks in Uttarakhand. ISM aids in recognising, organising, and comprehending the interrelationships among numerous barriers. By constructing a hierarchical framework of various barriers, ISM

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helps policymakers and stakeholders to prioritize the most significant ones, enabling more efficient ways to overcome them. (Nandal et al., 2019) In Uttarakhand, this strategy is particularly useful in overcoming the region's specific topographical and environmental challenges in solar power park development. There is absence of research and specialists perspective on solar power park implementation inside Uttarakhand, this study focuses on the barrier's identification and implementation of solar power park in Uttarakhand (Luthra et al., 2014).Initially, 18 experts from the solar energy sectors and academic persons were contacted via phone and direct visits to explain the research's purpose. The experts were selected based on the researcher's mutual agreement, and personal connections. 12 out of the 18 experts agreed to participate, which was deemed a satisfactory sample size for this research (Luthra et al., 2011), (Sindhu et al., 2016), (Azevedo et al., 2019).Although the study is based on a relatively small sample size (12 experts), it provides a foundation for further research that can be expanded to a larger population. In the final selection of experts, 5 from the solar industry, and 7 from academia, all with over 12 years of experience in their fields. A brainstorming session followed, involving a questionnaire-based survey to assess the relationships between the barriers using a matrix. This was the initial step in developing the ISM modelling framework. (Mathiyazhagan et al., 2013)The ISM approach, combined with MICMAC analysis, was then applied to evaluate the interactions between the identified determinants and determine the relative importance of these determinants for implementing solar energy in context to Uttarakhand.

4.1 (ISM) Approach

The sequence of phases calculated in the mentioned method of the ISM technique is depicted in Fig. 8. Initially, various barriers to adopting in the solar power park installation in Uttarakhand are identified. In the 2nd phase, a Structured Self-Interaction Matrix (SSIM) is developed through the comparison and analysis of the selected determinants. Followed by 3rd phase, an initial reachability matrix is constructed by replacing symbols with binary values. The final reachability matrix is then obtained by applying transitivity theory, which states that if L is related to M and M is related to N, then L and N are also related. In the fourth phase, level separation is performed using the reachability matrix. Following that, a graphical model is created. Finally, the ISM structure is developed.

4.2 Developing the (SSIM) Structural Self-Interaction Matrix

Expert opinions from both industry and academia, along with a literature review, are employed to identify appropriate associations among the components relevant to the adoption of solar power in the installation of solar power parks in Uttarakhand. The expert panel performed comparisons of determinant assessments to establish these relationships. The subsequent codes are employed to construct the SSIM for identifying the relationship between two determinants, 'i' and 'j':

• V: The role of determinant 'i' in facilitating the attainment of determinant 'j'.

• A: When determinant 'j' facilitates the attainment of determinant 'i'.

• X: When determinants 'i' and 'j' mutually facilitate each other's achievement.

• O: In the absence of a relationship between determinants 'i' and 'j'.

Figure 5 illustrates the developed SSIM, which is grounded in the identified relationships among the determinants. Determinant FE1 affects determinant MF2, resulting in code 'A' in cell (1, 7). Determinant FE3 influences determinant FE4, leading to code 'V' in cell (3, 4). Determinants MF1 and TF1 mutually influence each other, thus code 'X' is in cell (7, 13). There is no relationship between determinants FE2 and FE3, so code 'O' is placed in cell (2, 3). This process is followed for all cells.

4.3 Formation of the Reachability Matrix (RM)

The reachability matrix is generated by substituting the SSIM codes (V, A, X, O) with binary values ('1' and '0') according to particular rules, resulting in the initial reachability matrix. The following principles are implemented, as indicated in Figure 6:

• For 'V' in SSIM, place '1' in cell (i, j) and '0' in cell (j, i).

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2025, 10(53s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/
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• For 'A', place '0' in cell (i, j) and '1' in cell (j, i).

• For 'X', place '1' in both cells (i, j) and (j, i).

• For 'O', place '0' in both cells (i, j) and (j, i).

Figure 7 illustrates the final reachability matrix (FRM), obtained from the initial matrix through the use of transitivity theory (dependent on action and Participant), as discussed in chapter 4.1. The entries specified with an asterisk (*) signify transitivity. The dependency and driving power are subsequently investigated.

4.4. Level Partitioning (LP) of the Final Reachability Matrix (FRM)

Level partitioning is performed to determine the hierarchy of the determinants under consideration. The reachability and antecedent sets are derived from the final reachability matrix. The reachability set consists of the determinant itself and other determinants with a value of 1 in that determinant's row. Similarly, the antecedent set includes the determinant itself and other determinants with a value of 1 in that determinant's column. The intersection of these two sets is used for all determinants to determine their levels.

The determinants that appear in both the reachability and intersection sets are placed at the highest level in the ISM structure. In this case, determinants FE1 are assigned to level "1," as shown in Figure 7. These top-level determinants do not contribute to achieving any other determinants in the structure, so they are removed from the next iteration. The process is then repeated to determine the levels of the remaining determinants. This iterative approach continues until all the determinants are assigned levels, with the final level distribution summarized in Table 2.

The article discuss about the barriers to solar power adoption in Uttarakhand to highlight numerous important issues. The primary barriers are lack of government subsidies (FE5), inadequate market size (MF2), lack of solar radiation data (IA2), low public knowledge of solar technology (TF1), lower system efficiency (TF2), a lack of qualified professionals and training programs (TF4), and weak political will (GI1). These elements taken together hasten the state change to solar energy. However the need for backup storage systems (IA1) and transmission and distribution losses (FE3) were seen as relatively small obstacles indicating these problems may be better under control in the present setting. The results underline the importance of focused policy interventions to handle high priority issues.

4.5. ISM Model (Digraph)

The above mentioned levels help in developing the graphical structure, finally defining the final ISM framework, as shown in Figure. 9.The topmost level barriers is Absence of subsidies (FE5), Inadequate market size (MF2), Unavailability of Solar radiation Data (IA2), Lack of awareness of technology (TF1), Less efficiency (TF2), Lack of trained people & training institutes (TF4) and Lack of political commitment (GI1).These barrier is highly dependent and do not influence other barriers in the system. At the lowest level of the ISM hierarchy, barriers such as the Transmission & distribution losses (FE3) and Need for backup or storage device (IA1),emerge as the most influential, as they significantly drive other barriers while being independent themselves. No barrier shows autonomous characteristics. The barriers positioned between the top levels includes low efficiency with linkage High initial capital cost (FE1), Insufficient financing systems (FE2),Technology Inefficiency (FE4),Insufficient customer knowledge on technology (MF1),Incapable of satisfying the electricity power demand independently (MF3),Insufficient financial means (MF4),Lack of IT enablement (IA3),Inadequate efforts on research & development work (TF3),Lack of local infrastructure (TF5),Land Acquisition Issue (GE2), Geographic condition (GE1), Lack of transportation & Installation (GI3) and inadequate government policy (GI2) .

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FE1	FE2	FE3	FE4	FE5	MF1	MF2	MF3	MF4	IA1	IA2	IA3	TF1	TF2	TF3	TF4	TF5	GE1	GE2	GI1	GI2	GI3	Barrier
X	V	V	V	V	V	A	A	A	O	O	O	O	V	A	A	A	A	O	O	V	V	High initial capital cost (FE1)
	X	O	O	A	A	A	V	X	O	O	O	O	O	V	A	A	A	A	A	V	V	Insufficient financing systems (FE2)
		X	V	O	A	O	A	A	A	O	O	O	V	A	O	A	A	A	O	A	V	Transmission & distribution losses (FE3)
			X	A	A	O	A	A	O	O	O	O	A	A	A	O	A	A	O	O	A	Technology Inefficiency (FE4)
				X	V	O	A	A	O	O	O	O	A	O	A	A	A	A	A	O	A	Absence of subsidies (FE5)
					X	A	O	O	O	O	O	X	O	A	A	O	A	A	A	A	A	Insufficient customer knowledge on technology (MF1)
						X	A	V	O	O	O	O	O	A	A	A	A	A	A	A	V	Inadequate market size (MF2)
							X	V	A	O	O	O	O	A	A	A	A	A	A	A	V	Incapable of satisfying electricity demand (MF3)
								X	A	O	O	O	A	A	A	A	A	A	A	A	A	Insufficient financial means (MF4)
									X	O	O	O	O	O	O	O	A	A	A	A	A	Need for backup or storage device (IA1)
										X	O	A	A	O	A	A	A	O	O	A	A	Unavailability of solar radiation data (IA2)
											X	A	O	O	O	O	A	O	A	O	A	Lack of IT enablement (IA3)
												X	A	V	O	A	O	O	O	A	A	Lack of awareness of technology (TF1)
													X	A	A	A	A	O	O	O	A	Less efficiency (TF2)
														X	A	A	A	A	A	O	A	Inadequate R&D work (TF3)
															X	V	A	A	A	A	O	Lack of trained people (TF4)
																X	A	A	A	A	A	Lack of local infrastructure (TF5)
																	X	V	O	A	A	Geographic conditions (GE1)
																		X	A	A	A	Land Acquisition Issue (GE2)
																			X	V	V	Lack of political commitment (GI1)
																				X	A	Inadequate government policies (GI2)
																					X	Lack of transportation & installation (GI3)

Figure (5) SSIM representation of Barriers

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Driving Power
FE1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	9
FE2	0	1	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	1	1	6
FE3	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	4
FE4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
FE5	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
MF1	0	1	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	5
MF2	1	1	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	6
MF3	1	0	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	8
MF4	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	6
IA1	0	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	4
IA2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
IA3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
TF1	0	0	0	0	0	1	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	5
TF2	0	0	0	1	1	0	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	6
TF3	1	0	1	1	0	1	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	9
TF4	1	1	0	1	1	1	1	1	1	0	1	0	0	1	1	1	1	0	0	0	0	0	13
TF5	1	1	1	0	1	0	1	1	1	0	1	0	1	1	1	0	1	0	0	0	0	0	12
GE1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	18
GE2	0	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	0	1	0	0	0	13
GI1	0	1	0	0	1	1	1	1	1	1	0	1	0	0	1	1	1	0	1	1	1	1	15
GI2	0	0	1	0	0	1	1	1	1	1	1	0	1	0	0	1	1	1	1	0	1	0	13
GI3	0	0	0	1	1	1	0	0	1	1	1	1	1	1	1	0	1	1	1	0	1	1	15
Dependence Power	8	11	11	13	11	12	9	10	14	6	8	5	6	8	9	5	7	3	5	1	5	7	

Figure (6) Reachability Matrix (RM)

Barriers	FE1	FE2	FE3	FE4	FE5	MF1	MF2	MF3	MF4	IA1	IA2	IA3	TF1	TF2	TF3	TF4	TF5	GE1	GE2	GI1	GI2	GI3	Driving Power
High initial capital cost (FE1)	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	0	0	0	0	1	1	14
Insufficient financing systems (FE2)	1	1	0	1	0	1	0	0	0	1	0	0	0	1	0	0	1	0	1	1	1	1	11
Transmission & distribution losses (FE3)	1	1	1	0	1	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0	8
Technology Inefficiency (FE4)	1	1	0	1	0	0	1	0	1	1	1	1	0	1	1	0	1	1	0	1	1	0	14
Absence of subsidies (FE5)	0	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	0	1	0	0	1	15
Insufficient customer knowledge on technology (MF1)	1	0	1	1	1	1	0	0	1	0	1	0	1	0	0	1	1	0	1	0	0	1	12
Inadequate market size (MF2)	1	1	1	0	1	0	1	1	0	1	0	1	0	1	0	1	0	1	0	0	1	0	12
Incapable of satisfying electricity demand (MF3)	1	1	1	0	1	0	1	1	0	1	0	1	0	0	0	0	0	0	1	0	0	1	10
Insufficient financial means (MF4)	1	1	1	0	1	0	1	1	0	1	0	1	0	0	1	0	1	1	0	0	1	1	13
Need for backup or storage device (IA1)	1	0	1	1	0	0	0	0	1	0	0	1	0	0	0	0	0	1	1	0	0	1	8
Unavailability of solar radiation data (IA2)	1	1	1	0	0	1	0	1	1	0	1	1	0	0	0	0	0	1	0	1	0	1	11
Lack of IT enablement (IA3)	0	1	1	0	0	1	0	0	1	1	1	0	0	0	0	0	1	0	0	0	1	1	9
Lack of awareness of technology (TF1)	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	1	1	0	9
Less efficiency (TF2)	1	1	1	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0	1	0	9
Inadequate R&D work (TF3)	1	1	1	1	1	1	0	1	0	1	0	0	0	1	0	0	1	0	1	0	1	1	13
Lack of trained people (TF4)	1	1	0	1	0	1	0	0	1	0	0	1	1	1	0	0	1	1	0	1	0	1	12
Lack of local infrastructure (TF5)	1	1	1	1	0	0	1	0	1	1	1	0	1	0	0	0	1	0	1	0	1	1	13
Geographic conditions (GE1)	1	0	1	1	0	1	1	1	0	1	0	0	0	1	1	1	1	1	1	1	1	1	16
Land Acquisition Issue (GE2)	1	0	1	0	0	0	1	0	1	1	0	0	0	1	1	0	1	0	0	1	1	1	11
Lack of political commitment (GI1)	1	1	0	0	0	1	0	0	1	1	0	1	0	1	0	0	1	0	0	0	1	1	10
Inadequate government policies (GI2)	1	1	0	1	0	1	0	1	1	0	0	1	0	1	0	0	1	0	0	0	1	1	11
Lack of transportation & installation (GI3)	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0	0	0	1	16
Dependance Power	20	18	17	13	9	13	9	11	12	15	8	12	6	12	6	6	15	7	9	7	15	17	

Figure (7) Final Reachability Matrix (FRM)

Journal of Information Systems Engineering and Management
2025, 10(53s)
e-ISSN: 2468-4376
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5. MICMAC ANALYSIS FOR BARRIER CLASSIFICATION

MICMAC (Matrix of Cross Impact Multiplication Applied to a Classification) Analysis is an effective tool for categorizing and understanding barriers in solar power park installations, such as those in Uttarakhand. (Luthra et al., 2011), (Diabat & Govindan, 2011), (Kannan et al., 2009) These determinants are used to group the barriers into four categories: autonomous, dependent, independent, and linkage barriers. (Vimal et al., 2011) The primary objective of this section is to facilitate the implementation of solar power parks in Uttarakhand by evaluating the driving and dependency power of the barriers. The relationship between these powers in the context of solar energy adoption in Uttarakhand is depicted in Figure. 8. The key findings of this MICMAC analysis are as follows:

5.1 Autonomous Barriers: Barriers in this category exhibit low driving and low dependency power, meaning they have minimal interaction with or influence on the system. In this study, no barrier shows autonomous characteristics were found in the autonomous category. There is no variable in this category, as absence of all other variables indicates that all mentioned barriers are crucial and have a substantial impact on the implementation of solar parks in Uttarakhand.

5.2 Dependent Barriers: These barriers have high dependency but low driving power. Seven barrier fall into this group, Absence of subsidies (FE5), Inadequate market size (MF2), Unavailability of Solar radiation Data (IA2), Lack of awareness of technology (TF1), Less efficiency (TF2), Lack of trained people & training institutes (TF4) and Lack of political commitment (GI1).These barriers rank highest in the ISM hierarchy, as shown in Figure 8.out of which (TF4) is highly dependent.

5.3 Linkage Barriers: Barriers in this category have both high driving and high dependency power, meaning they influence other barriers and are also affected by them. In this study, High initial capital cost (FE1), Insufficient financing systems (FE2),Technology Inefficiency (FE4),Insufficient customer knowledge on technology (MF1),Incapable of satisfying the electricity power demand independently (MF3),Insufficient financial means (MF4),Lack of IT enablement (IA3),Inadequate efforts on research & development work (TF3),Lack of local infrastructure (TF5),Land Acquisition Issue (GE2), Geographic condition (GE1), Lack of transportation & Installation (GI3) and inadequate government policy (GI2) are considered linkage barriers. These play a crucial role in improving the establishment of solar power projects in Uttarakhand. These barriers are located at the third level of the ISM hierarchy, as shown in Fig. 9.

5.4 Independent Barriers: These barriers have high driving power but low dependency power, meaning they have a significant influence on the system but are less affected by other determinants. One barriers fall into this category, Transmission & distribution losses (FE3) and Need for backup or storage device (IA1).These barriers are key determinants and exist in this quadrant.

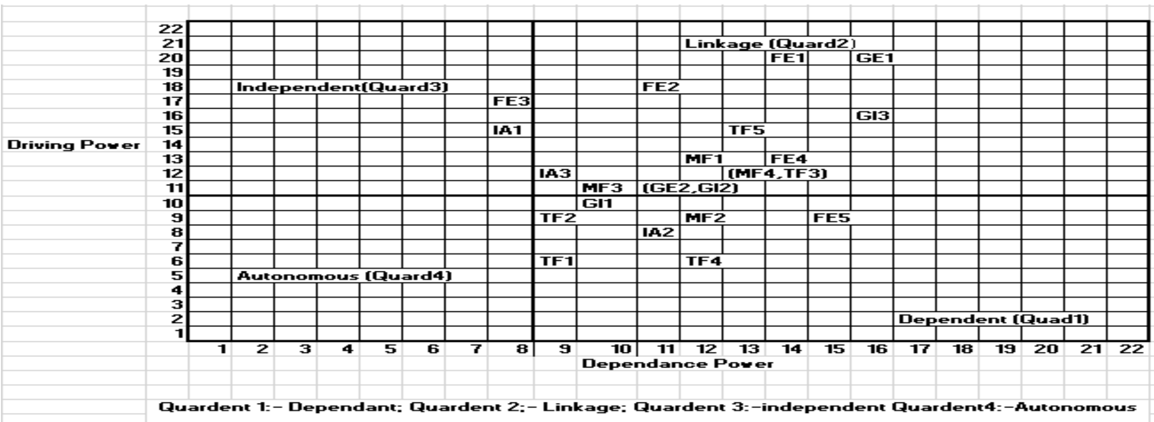

Figure (8) MICMAC Analysis of Barriers

Journal of Information Systems Engineering and Management
2025, 10(53s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

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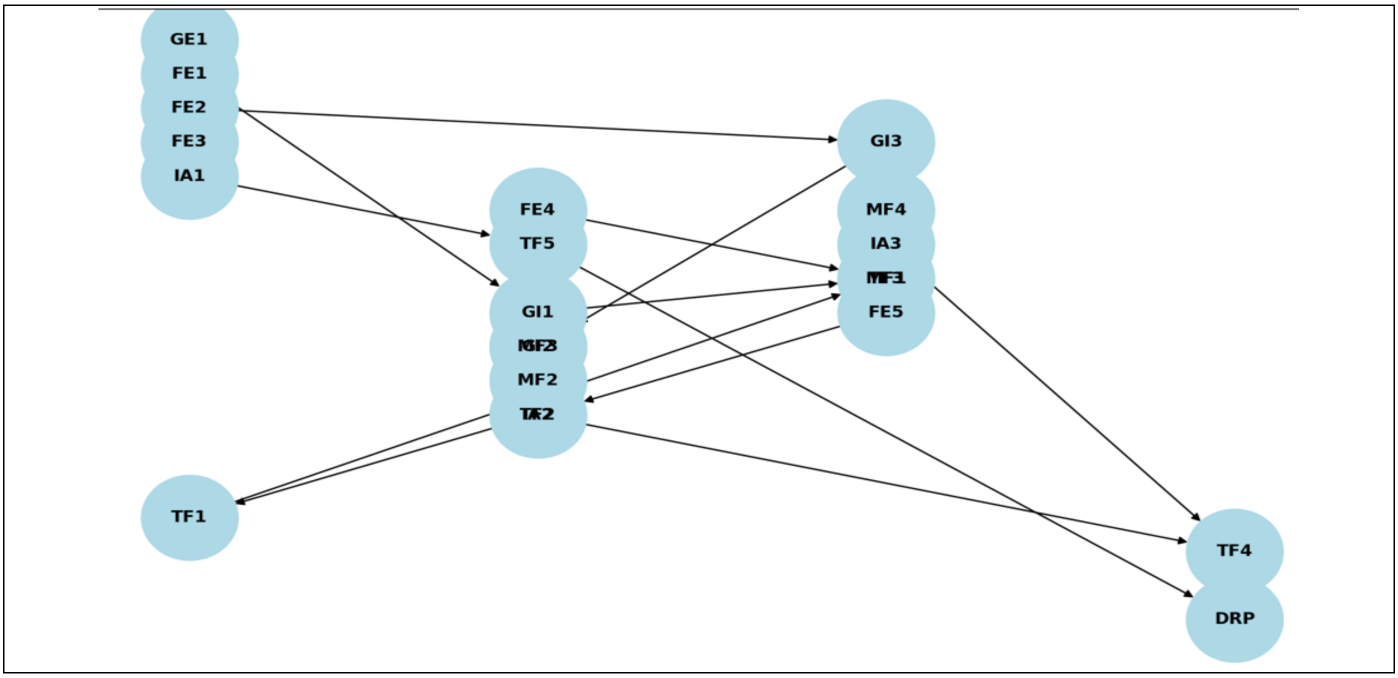

Figure (9) Diagraph of Barriers

6. Analysis of Results

Electricity is an essential component for the economic advancement of every nation, and the evolution of the power industry is intricately linked to national development. Policymakers regard renewable energy as the principal strategy for mitigating carbon emissions by decreasing dependence on fossil fuel-based power generation. (Green et al., 2016) In India, solar energy is anticipated to significantly contribute to fulfilling overall energy demands via renewable sources (Government of India [GoI], Ministry of New Renewable Energy, 2015), (Ministry of New and Renewable Energy, 2015). Nonetheless, several impediments obstruct the extensive implementation of solar energy for national advancement. Policymakers encounter many obstacles in recognising and mitigating these impediments to the proper integration of solar energy into the power industry. (Green et al., 2016) This study delineates the hurdles and examines their interrelationships through the ISM approach, establishing a hierarchy of obstacles to assist policymakers in the implementation of solar power within India's energy sector as shown in figure (10). The MICMAC study, which assesses the driving and dependence power of the obstacles, has been employed to validate this model.

S. No.	Level No.	Barriers
1	1st	• High initial capital cost (FE1)
2	2nd	• Technology Inefficiency (FE4) • Need for backup or storage device (IA1) • Lack of awareness of technology (TF1)
3	3rd	• Geographic conditions (GE1) • Insufficient customer knowledge on technology (MF1) • Land Acquisition Issue (GE2) • Inadequate market size (MF2) • Insufficient financing systems (FE2)

Journal of Information Systems Engineering and Management
2025, 10(53s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

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4	4th	• Transmission & distribution losses (FE3) • Incapable of satisfying the electricity power demand independently (MF3) • Unavailability of solar radiation data (IA2)
5	5th	• Inadequate efforts on research & development work (TF3) • Lack of trained people & training institutes (TF4) • Insufficient financial means (MF4)
6	6th	• Lack of awareness of technology (TF1) • Lack of political commitment (GI1) • Lack of local infrastructure (TF5) • Lack of IT enablement (IA3) • Lack of transportation & Installation (GI3)
7	7th	• Less efficiency (TF2) • Inadequate government policies (GI2)

Table 2 Barriers levels for propagation the solar power plants in Uttarakhand.

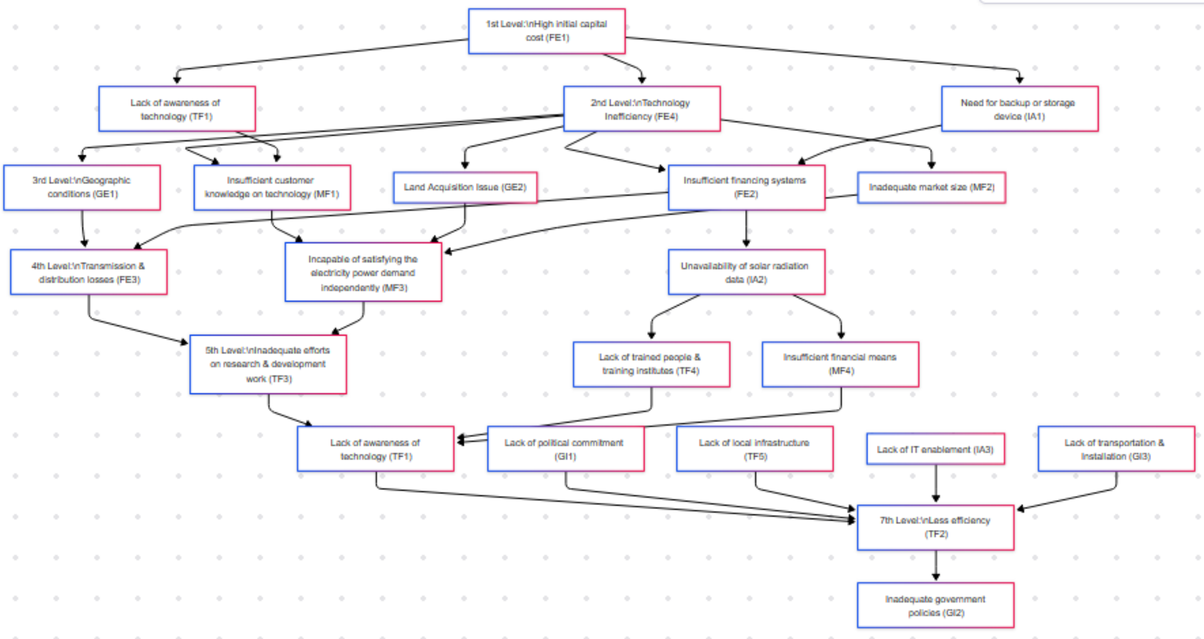

Figure10:- Final model TISM of Barrier Classification (ISM Structure)

Journal of Information Systems Engineering and Management
2025, 10(53s)
e-ISSN: 2468-4376
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Barriers	Reachability_Set	Antecedents_Set	Intersection_Set	Level
TF2	FE2 FE3 FE4 MF3 MF4 IFE1 IFE2 IFE3 TF2 TF3 TF4	FE1 FE2 FE3 FE4 MF1 MF2 MF3 MF4 IFE1 IFE2 IFE3 TF1 TF2 TF3 TF4 GE1 GI1	FE2 FE3 FE4 MF3 MF4 IFE1 IFE2 IFE3 TF2 TF3 TF4	1
GI2	FE2 FE4 FE5 MF1 MF2 MF3 MF4 IFE3 TF1 TF3 TF4 TF5 GI1 GI2	FE1 FE2 FE3 FE4 FE5 MF1 MF2 MF3 MF4 IFE1 IFE2 IFE3 TF1 TF3 TF4 TF5 GE1 GI1 GI2	FE2 FE4 FE5 MF1 MF2 MF3 MF4 IFE3 TF1 TF3 TF4 TF5 GI1 GI2	1
GI3	GI3	FE1 FE2 MF4 IFE3 TF3 TF4 TF5 GI3	GI3	1
FE2	FE2 FE3 FE4 FE5 MF1 MF2 MF3 MF4 IFE1 IFE2 IFE3 TF1 TF3 TF4 TF5 GE1 GE2 GI1	FE1 FE2 FE3 FE4 FE5 MF1 MF2 MF3 MF4 IFE1 IFE2 IFE3 TF1 TF3 TF4 TF5 GE1 GE2 GI1	FE2 FE3 FE4 FE5 MF1 MF2 MF3 MF4 IFE1 IFE2 IFE3 TF1 TF3 TF4 TF5 GE1 GE2 GI1	1
IFE2	FE2 FE4 MF1 MF4 IFE2 IFE3 TF1 TF3 TF4 GI1	FE1 FE2 FE3 FE4 MF1 MF2 MF3 MF4 IFE1 IFE2 IFE3 TF1 TF3 TF4 GE1 GE2 GI1	FE2 FE4 MF1 MF4 IFE2 IFE3 TF1 TF3 TF4 GI1	1
TF1	FE2 FE3 FE4 MF1 MF2 MF3 MF4 IFE1 IFE2 IFE3 TF1 TF3 TF4 TF5 GE1 GI1	FE1 FE2 FE3 FE4 MF1 MF2 MF3 MF4 IFE1 IFE2 IFE3 TF1 TF3 TF4 TF5 GE1 GI1	FE2 FE3 FE4 MF1 MF2 MF3 MF4 IFE1 IFE2 IFE3 TF1 TF3 TF4 TF5 GE1 GI1	1
TF5	FE2 FE4 FE5 MF3 MF4 IFE3 TF1 TF3 TF4 TF5 GE2 GI1	FE1 FE2 FE3 FE4 FE5 MF1 MF2 MF3 MF4 IFE1 IFE3 TF1 TF3 TF4 TF5 GE1 GE2 GI1	FE2 FE4 FE5 MF3 MF4 IFE3 TF1 TF3 TF4 TF5 GE2 GI1	1
GI1	FE2 FE3 FE4 FE5 MF1 MF2 MF3 MF4 IFE1 IFE2 IFE3 TF1 TF3 TF4 TF5 GE1 GI1	FE1 FE2 FE3 FE4 FE5 MF1 MF2 MF3 MF4 IFE1 IFE2 IFE3 TF1 TF3 TF4 TF5 GE1 GI1	FE2 FE3 FE4 FE5 MF1 MF2 MF3 MF4 IFE1 IFE2 IFE3 TF1 TF3 TF4 TF5 GE1 GI1	1
MF4	FE4 FE5 MF2 MF3 MF4 IFE3 TF3 TF4	FE1 FE3 FE4 FE5 MF1 MF2 MF3 MF4 IFE1 IFE3 TF3 TF4	FE4 FE5 MF2 MF3 MF4 IFE3 TF3 TF4	1
IFE3	FE4 MF1 MF4 IFE3 TF3 TF4 GE1	FE1 FE3 FE4 FE5 MF1 MF2 MF3 MF4 IFE1 IFE3 TF3 TF4 GE1	FE4 MF1 MF4 IFE3 TF3 TF4 GE1	1
TF3	FE3 FE4 MF1 MF2 MF3 MF4 IFE1 IFE3 TF3 TF4 GE1	FE1 FE3 FE4 FE5 MF1 MF2 MF3 MF4 IFE1 IFE3 TF3 TF4 GE1	FE3 FE4 MF1 MF2 MF3 MF4 IFE1 IFE3 TF3 TF4 GE1	1
TF4	FE4 MF2 MF4 IFE3 TF3 TF4	FE1 FE3 FE4 MF1 MF2 MF3 MF4 IFE1 IFE3 TF3 TF4	FE4 MF2 MF4 IFE3 TF3 TF4	1
FE3	FE3 FE4 MF1 MF3 IFE1 GE1	FE1 FE3 FE4 MF1 MF3 IFE1 GE1	FE3 FE4 MF1 MF3 IFE1 GE1	1
MF3	FE3 FE4 MF1 MF3 IFE1 GE1	FE1 FE3 FE4 FE5 MF1 MF2 MF3 IFE1 GE1	FE3 FE4 MF1 MF3 IFE1 GE1	1
IFE1	FE3 FE4 MF3 IFE1	FE1 FE3 FE4 MF1 MF2 MF3 IFE1 GE1 GE2	FE3 FE4 MF3 IFE1	1
FE5	FE5 MF2	FE1 FE5 MF2	FE5 MF2	1
MF1	FE4 MF1 GE1 GE2	FE1 FE4 MF1 GE1 GE2	FE4 MF1 GE1 GE2	1
MF2	FE5 MF2	FE1 FE5 MF2	FE5 MF2	1
GE1	FE4 MF1 GE1 GE2	FE1 FE4 MF1 GE1 GE2	FE4 MF1 GE1 GE2	1
GE2	MF1 GE1 GE2	FE1 FE4 MF1 GE1 GE2	MF1 GE1 GE2	1
FE4	FE4	FE1 FE4	FE4	1
FE1	FE1	FE1	FE1	1

Figure 11:- 1st stage of Barrier Level Iteration

7. SUGGESTIVE MEASURES FOR OVERCOMING BARRIERS

7.1 Strengthening Government Initiatives

The Government of Uttarakhand should further amplify its existing programs like the Mukhyamantri Saurya Swarojgar Yojana (MSSY) and Solar Farming initiatives, which aim to empower small farmers and unemployed youth by offering solar project opportunities. (Hairat & Ghosh, 2017)To enhance their impact, the government could expand financial support and streamline the application process for accessing subsidies. Raising awareness through targeted outreach programs will also help attract more participants, thereby increasing solar adoption.

7.2 Enhancing Private Sector Participation

Private sector players like Fenice Energy have been instrumental in providing innovative financial models and solar solutions.(https://blog.feniceenergy.com/solar-energy-case-study-sustainable-power-solutions/, Accessed ,2024)To overcome financial and technical barriers, the state can create more public-private partnership (PPP) models, offering better incentives to private entities investing in the solar sector (Uttarakhand State Solar Policy, 2023). Additionally, creating a platform for these companies to share their expertise, tools, and financial products with smaller local developers can boost solar project implementation across the state.

7.3 Facilitating International Collaborations

The formation of a Solar Research Council could play a vital role in expanding Uttarakhand solar capacity by promoting international cooperation. These agreements can assist bring in breakthrough technologies and drive down the cost of solar power installations. Furthermore, international cooperation could lead to Uttarakhand being a hub for solar manufacturing, promoting domestic manufacture of system components, and increasing local expertise in solar technology. (Purohit, 2010), (Michoud & Hafner, 2021)

7.4 Increasing Incentive Programs

To further overcome economic barriers, existing incentive programs should be expanded. While the current subsidies for solar systems are helpful, raising these incentives and extending them to larger installations could promote higher adoption. (Qadir et al., 2021) An adaptive subsidy approach that responds with shifting solar component costs would also maintain long-term project sustainability. This method can motivate homeowners and companies alike to invest in larger solar systems.

7.5 Simplification of Procedures

The administrative limitations including lengthy paperwork and complex grid-connection procedures, operate as obstacles to solar adoption. (Shahzad et al., 2023) Simplifying the process by digitizing applications for approvals, no-objection certifications, and connection to the grid will make the adoption of solar power more user-friendly. Reducing governmental layers and guaranteeing timely approvals through a streamlined, digital approach would remove considerable procedural barriers.

7.6 Improving Monitoring and Customer Service

Proactive oversight of solar projects and efficient customer service are key to creating trust among consumers. The Uttarakhand Power Corporation Limited (UPCL) should focus on modernising its technical infrastructure, training staff in solar technology, and dealing with billing mistakes. Developing an adequate customer service structure that rapidly resolves complaints and compensates consumers for surplus power generation would encourage more local residents and companies to migrate to solar electricity. (Kaiser & Barstow, 2022)

These initiatives, if implemented, could significantly reduce the economic, procedural, and technological constraints now impeding the expansion of solar power in Uttarakhand, ensuring a more sustainable solar ecosystem in the state. (Dey et al., 2022)

8. CASE STUDIES HIGHLIGHTING BEST PRACTICES

8.1 Haryana's Solar Initiatives

Despite the precise facts on Haryana's solar operations were not available in the supplied data, it is vital to notice the state's prospective involvement in India's solar economic growth. (Adekanbi et al., 2024) Haryana has been known to pursue renewable energy aggressively, and understanding its strategies could provide valuable insights for other regions, including Uttarakhand.

8.2 Tamil Nadu's Solar Expansion

Similarly, the exact details of Tamil Nadu's solar expansion efforts were not outlined in the provided excerpts. However, Tamil Nadu has historically been a leader in renewable energy in India, often setting benchmarks in solar power generation and implementation. (Supe et al., 2024) The state's approach to overcoming infrastructural and financial challenges could serve as a model for Uttarakhand, focusing on innovative solutions and robust policy frameworks to enhance solar energy capacity.

8.3 Black Star Farms: A Model of Solar Implementation

Black Star Farms in Michigan exemplifies successful solar power implementation. The farm installed a 54.08 kW solar energy system, which includes 204 Canadian Solar panels and SolarEdge inverters (Solar energy case study: Black Star Farms, accessed 2024). This project, despite initial communication concerns with the utility provider, has been operational since November 2015 without any notable problems. The installation process was intentionally organised to avoid disrupting the farm's operations, with panels positioned near a petting zoo, making them visible yet non-intrusive (Solar energy case study: Black Star Farms, accessed 2024). This careful preparation underlines the need of addressing operational procedures in solar implementations. Financially, the initiative experienced strong external sponsorship, totalling to $92,145, which helped offset the entire cost. This funding comprised contributions from a USDA REAP grant, the Michigan Farm Energy Program, and local rebates (Solar energy case study: Black Star Farms, accessed 2024). Despite changes in net metering laws altering the estimated payback period, the project highlights the potential for solar investments to create savings and even profit over time.

This case study illustrates various best practices:

1. Strategic placement of solar arrays to minimize operating disruption.
2. Leveraging external finance to decrease early investment burdens.
3. Planning for long-term operating stability and maintenance.

These insights could be instrumental for regions like Uttarakhand, where terrain and financial constraints pose significant challenges to solar power implementation. By adopting similar strategic approaches and learning from the financial planning and community engagement efforts exemplified by Black Star Farms, (McKenna & Main, 2015) Uttarakhand can enhance its solar energy capabilities and move towards a more sustainable energy future.

9. CONCLUSION

India, as one of the world's fastest-growing economies, is experiencing a significant increase in energy consumption to drive its industrial expansion, urbanization, and population growth. To continue this momentum, it requires energy that is not only inexpensive for its citizens and businesses but also reliable to assure ongoing economic operations. Simultaneously, India is committed to ecologically sustainable growth, acknowledging the necessity of addressing climate change and decreasing its environmental footprint. This combined issue leads the nation to explore clean and green energy sources, including as solar, wind, and hydropower, that cut greenhouse gas emissions, minimize pollution, and promote a sustainable future. Establishment or implementing solar energy in context to Uttarakhand is a crucial strategy to address global climate change challenges. In this context, 22 barriers hindering the implementation of solar power parks have been identified and evaluated specifically for Uttarakhand. The ISM technique has been applied to establish relationships between these barriers and to determine their dependence and driving forces. Which is conducted under Level partitioning (as shown in Figure 11), The barriers to implementing solar power plants are categorized into seven levels, and the MICMAC analysis is used to validate the model.

This research provides crucial insights for scholars, academicians, industrialists, and policymakers on how to overcome these barriers to the successful implementation of solar energy in power generation. Moreover, the encouraging prospects of enhanced government policies, community engagement, (McKenna & Main, 2015) and strategic partnerships underscore a hopeful vision for solar power in the region. The roadmap outlined for overcoming obstacles through improved incentive programs, simplified procedural frameworks, and robust monitoring mechanisms paves the way for leveraging Uttarakhand solar potential to its fullest. With a mindful approach towards environmental sustainability and economic viability, the drive towards solar power implementation in Uttarakhand exemplifies a comprehensive blueprint for energy transition, promising to illuminate the path towards a sustainable, empowered future.

10. LIMITATION OF ISM-MICMAC ANALYSIS IN BARRIER CLASSIFICATION

The ISM-MICMAC methodology, while beneficial for examining obstacles in solar power park implementation, has several limitations when utilised in a complicated location such as Uttarakhand. ISM, dependent on expert contributions, may inject subjectivity and perhaps neglect parameters locally, including geographic and environmental aspects specific to the state. The MICMAC methodology, by categorising obstacles according to their driving and dependant powers, may oversimplify interdependencies and neglect the dynamic nature of regulatory changes or advancing technical environments. Both methodologies primarily emphasise static linkages among barriers, perhaps failing to capture the rapidly evolving energy and regulatory landscape in Uttarakhand. Furthermore, these methods can be time-intensive, making them less ideal for speedy decision-making, and they may not always account for the real-world complexity where many obstacles interact in unforeseen ways, requiring more adaptable and holistic strategies.

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