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Analysing Energy Security in India through a Regional Lens: A SAP-LAP Inquiry into Uttarakhand Sustainable Energy Challenges

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ABSTRACT

Ensuring a reliable energy supply through solar energy projects is a critical component of India's energy security strategy, particularly for the state of Uttarakhand, where challenging terrain and ecological sensitivities complicate solar capacity addition goals. This paper develops an inquiry model based on the situation-actor-process (SAP) and learning-action-performance (LAP) framework to analyse the supply-side dynamics of solar energy security. The model synthesizes the situations within India's national solar energy sector and the specific solar energy landscape of Uttarakhand. The application of the SAP-LAP framework reveals that both national and Uttarakhand's solar energy sectors require significant investment and proactive, sustainable decision-making from identified actors. For Uttarakhand, this entails embracing life cycle management and costing for its solar resources to balance development with environmental conservation, thereby strengthening regional and national solar energy security. The framework provides a managerial perspective and serves as a robust decision-support tool for managing complex priorities within India's solar energy sector, particularly in environmentally significant states.

Keywords Energy security, India, life cycle costing, life cycle management, SAP-LAP, solar energy, sustainability, Uttarakhand.

1. INTRODUCTION

ENERGY security encompasses multiple dimensions, a critical one being the assurance of a reliable energy supply from diverse projects, with solar power being a central pillar [1], [2]. India faces significant energy security challenges, and solar energy is key to addressing the persistent capacity shortfall [3], [4]. This national concern is acutely felt in regions like Uttarakhand, where the difficult Himalayan terrain and environmental imperatives add layers of complexity to solar capacity addition goals. The constraints in solar energy supply are analysed by considering both current and future project execution scenarios, which are fundamentally dependent on decisions regarding sustainable investment strategies [5], [6].

India's solar energy generation is a national priority, with a policy objective of providing electricity at the lowest feasible cost to consumers [7]. Achieving this goal necessitates the effective utilization of domestic solar resources, a principle that is particularly relevant for Uttarakhand, which possesses significant potential for solar energy [8]. Justifying investments in the solar sector requires balancing this low-cost production with sustainable practices [9]. Furthermore, solar energy pricing is influenced by technology costs and efficiency, and from a broader perspective, the timely addition of new solar capacity directly impacts the economics of sustainable development for both the state and the nation [10]. Consequently, generating solar energy from upcoming projects at reasonable prices, while adhering to ecological safeguards, is a paramount factor for sustainability in the sector [11], [12].

This case study is developed to examine these dynamics within the Indian solar energy sector, with a specific focus on the unique context of Uttarakhand. It discusses a scenario including investment, project review, and making decisions about adding solar power. It shows how national goals and regional implementation work together.

The structure of this document is as follows: Section II gives the case study its backdrop by talking about the solar energy scene in India and Uttarakhand. In this section, we show how the situation-actor-process (SAP)-learning-action-performance (LAP) model may be used in this case. Section IV contains the discussion that is based on the SAP-LAP synthesis. Section V has some last thoughts.

2. CASE STUDY OVERVIEW

This case study inquiries into and evaluates the present situation of solar energy security on the supply side in India, with a specific focus on the unique challenges and opportunities present in the state of Uttarakhand. The solar power distribution and supply position is observed from the perspectives of its performance, delays, and investment-related challenges, particularly those arising from the state's mountainous terrain, ecological priorities, and solar intermittency [13], [14]. The SAP-LAP (Situation-Actor-Process Learning-Action-Performance) model of system inquiry is deemed best suited for highlighting this complex situation [15]–[17]. The specific SAP-LAP model proposed by Sushil is employed here [18], [19]. The case study presents a set of interpretive frameworks. These frameworks serve as a guide for creating SAP-LAP models, which in turn facilitate effective solar energy program planning.

3. SAP-LAP MODELS OF SOLAR ENERGY SECURITY AND SUSTAINABILITY FOR INDIA AND UTTARAKHAND

This case highlights SAP-LAP components applicable to the national and Uttarakhand solar settings. (Figure 3) The research initially evaluates the problem qualitatively and builds SAP-LAP links.(Table I) This section shows the SAP components and their modification.

A. The SAP Parameters

The supply-side aspects of solar energy security are critical. For Uttarakhand, this means not only meeting rising electricity demand with solar power but doing so in a way that minimizes project delays and justifies investment in a manner that is sustainable and ecologically sound [20]. In this context, explanations from various scholars attribute time delays and investment costs in renewable projects to non useful information about technical and environmental constraints, a challenge acutely felt in Himalayan solar project execution due to factors like land slope, forest cover, and weather patterns [11], [21]. For each SAP and LAP component, important questions are asked to start a qualitative investigation. Based on this questioning, the scenario, the actors involved, and the processes that need to be taken are all listed below.

1) Situation: National and Uttarakhand Solar Context

Globally, "solar energy security" has emerged as a paramount concern with the expansion of solar capacity to meet demand [1], [2]. For India and Uttarakhand, external parameters affecting solar project execution include policy matters (e.g., solar parks, subsidies), new solar technologies, module supplier involvement, regional development, and infrastructure financing [7], [22]. Internal parameters comprise solar resource availability (e.g., insolation levels, land), causes of delays (e.g., environmental clearances, land acquisition in hilly areas), price variabilities of modules, tariffs, and project competencies for solar [13], [23].

The situational context (S) is defined by a synthesis of four critical factors: the deployment of utility-scale, rooftop, and off-grid solar applications in Uttarakhand (S1); the application of project evaluation techniques to analyse socio-environmental impacts within ecologically sensitive zones (S2); prevalent inaccuracies in expenditure assessment, aggravated by logistical complexities such as inaccessible terrain and adverse weather (S3); and supply-chain limitations, including the variability of solar resources and the challenges of installing equipment in remote, mountainous regions (S4). These factors are treated as an integrated whole.[26]

TABLE I
SAP COMPONENTS AND ISSUES FOR THE SOLAR ENERGY CONTEXT

Stage	Issues	Using SAP-LAP framework
(a): SAP Components		
Situation		
	How have we reached the present condition?	Significant role and contribution of solar in developing the nation's renewable economy
	What is the present position?	Technological challenges and competitiveness for solar resource utilization (e.g., efficiency, storage)
	What is expected to happen?	National solar missions focus heavily on utility-scale and rooftop solar
		Land availability issues for solar parks in mountainous regions
		Sector's concern for environmental degradation from large solar farms
		Grid stability challenges due to solar intermittency
		The emphasis must transition from the financial optimization of decentralized solar deployment to the implementation of sustainable operational frameworks and strategic governance for effective resource utilization.
Actor		
	What are the concerns of the ministries, R&D and technical institutions engaged?	Ministry of New and Renewable Energy, GoI: making enough efforts to convert market for solar energy to required level of demand fulfilment.
		SECI (Solar Energy Corporation of India): responsible for solar project development and bidding
	What roles and capabilities are exhibited?	Uttarakhand Renewable Energy Development Agency (UREDA): promoting and implementing state solar projects
	In what domain is freedom of choice available?	CERC/UERC (as power sector regulators): responsible for meeting challenges of project delays, setting solar tariffs, and research
		NITI Aayog: apex body responsible for monitoring of budget estimates, approvals and management of solar projects' execution
Process		

Stage	Issues	Using SAP-LAP framework
	What is the current state of affairs?	Accelerating solar capacity additions to meet energy demands
	What factors must be taken into account?	Synthesizing solar module supply chain and technology options
	What are the defining constraints or boundaries?	Justification of new solar projects based on financial feasibility and grid integration
	What elements are within our control to modify?	Close eye keeping on projects for solar capacity addition
	What additional resources or actions are needed?	Keeping eye on of solar project delays
		Land acquisition interlinked with societal issues [12]
		Environmental clearance for solar projects
		Promoting solar rooftop schemes
		Requirement for training and development (T&D) to fulfil skilled manpower voids for solar O&M
		Enhancing grid storage to manage solar intermittency
		Need for strategic assessment of solar potential
		Integrating sustainability in solar project development
(b): LAP Components (Synthesis)		
Learning		
	What are the key issues related to the situation?	National deficit is major challenge to minimize in energy through solar
	What are the key issues related to the actors?	Reforms in management of solar technology options and energy costs
	What are the key issues related to the process?	Applications of sustainable practices and need to create institutional mechanisms for solar
		Prioritization of solar projects for scaling supply
		More focus on solar R&D infrastructure (e.g., storage, high-altitude performance)
		Conducting research through LCM in solar projects/technology options [4]
		Revisiting investment in the solar sector, especially for decentralized projects [10]

Stage	Issues	Using SAP-LAP framework
		Effective, project-management-oriented techniques for solar [21]
Action		
	What should to be done to improve the situation?	Promotion of solar sector via academia connections to tackle uncertainties and dangers
	What can be done to improve the actors?	Investment in solar technology to boost energy flexibility and minimize energy poverty
	What ought to be done to improve processes?	Manpower training for solar skills development
		Integrating all actors to operate in harmony for an acceleration of solar performance
Performance		
	What will be its impact on the situation?	GDP may increase due to solar industry development and reduced diesel imports [9]
	How will the actors be affected?	Given diversity, impact of improvement in the solar sector will be less, but progressive in the long term
	How will the performance of the processes be affected?	Solar infrastructure will increase and lead to enhanced energy access and GDP
		Economic impact on country's growth will be enhanced [3]

2) Actor

Key actors are classified based on their role in national and state-level solar capacity addition [7], [25]:

(1) Internal actors:

(A1) Ministry of New and Renewable Energy (MNRE), Government of India (GoI);

(A2) Solar Energy Corporation of India (SECI), GoI;

(A3) The technical wing responsible for implementing solar energy efficiency action plans and manpower training;

(A4) Uttarakhand Renewable Energy Development Agency (UREDA), responsible for promoting and implementing solar energy projects in the state.

(2) External actors:

(A5) Solar contractors and vendors, particularly those specializing in hilly terrain and off-grid technologies;

(A6) Power sector regulators (Central Electricity Regulatory Commission, Uttarakhand Electricity Regulatory Commission);

(A7) The National Institute for Transforming India (NITI Aayog), GoI; and

(A8) Local communities and environmental groups in Uttarakhand, crucial for social licensing of solar projects [12].

3) Process

The evaluation of solar energy project procedures is crucial since judgments must deal with a broad variety of technological and environmental factors. Processes are complicated and dynamic [15], [19]. The standard method for solar project implementation is broken into multiple stages, which sometimes creates considerable delays in topographically problematic places like Uttarakhand [11].(Figure 1)

Project evaluations based on Life Cycle Costing (LCC) are important when considering cost components like Operations and Maintenance (O&M) for remote solar projects [4].(Figure 2) LCC provides a better project cost evaluation than traditional approaches.

Various internal and external processes involved in solar capacity addition are:

(1) Internal processes:

(P1): Arrangements for solar deployment, emphasizing decentralized and rooftop options [24];

(P2): Cost management using Life Cycle Management (LCM) and LCC approaches for solar [4];

(P3): Human resource management, developing local expertise for solar installation and O&M;

(P4): Minimizing delays in solar project execution through better stakeholder engagement and planning [12].

(2) External processes:

(P5): Examining decision-making frameworks to enhance the efficient use of decentralized solar solutions.

(P6): Investigating solar technology management and strategic partnerships tailored for hilly regions (e.g., bifacial panels, microgrids).

(P7): Assessing risk management strategies to address weather-related and geological challenges in solar farms.

(P8): Analysing the influence of other sectors, such as tourism and forestry, on the selection of solar project sites.

B. Learning

Based on the synthesis of SAP components, the following points are found as learning points for the Uttarakhand solar context:

(L1*): Supply shortages can be overcome by promoting decentralized solar energy projects suitable for hilly terrain and remote communities [24];

(L2*): Applying sustainable approaches to solar tariff regulation through LCM and LCC can simplify processes and support long-term sustainability [4], [10].

(L3*): Properly organized land acquisition and forest clearance procedures for solar farms are essential to reduce disputes and uncertainty [12].

(L4*): More attention is required for solar solutions like rooftop PV, decentralized small-scale systems, and solar-based microgrids [8], [24].

(L5*): Encouraging community-driven solar energy projects is important for achieving sustainability.

(L6*): Solar tariff structures should be reviewed and validated with public involvement, especially to ensure affordability in remote regions.

(L7*): The solar sector should incorporate management training to address the shortage of skilled local workers for installation and maintenance.

1) Actions

The following actions are needed to minimize delays and enhance decision-making for solar security:

(A1*): Prioritizing investments in solar technologies suitable for Uttarakhand, such as rooftop solar, small-scale solar PV, and solar microgrids [8];

(A2*): Improving decision-making via LCM and LCC for a true cost assessment of solar projects, including O&M in remote locations [4];

(A3*): Robust assessment of solar project performance against environmental and social indicators;

(A4*): Planning for the development of local human resources for installation and O&M of solar projects;

(A5*): Creating strategic alliances with technology providers experienced in mountainous regions and solar applications;

(A6*): Planning optimal electricity tariffs for decentralized solar projects using LCC [10]; and

(A7*): Developing comprehensive state-specific solar energy plans that support sustainable development.

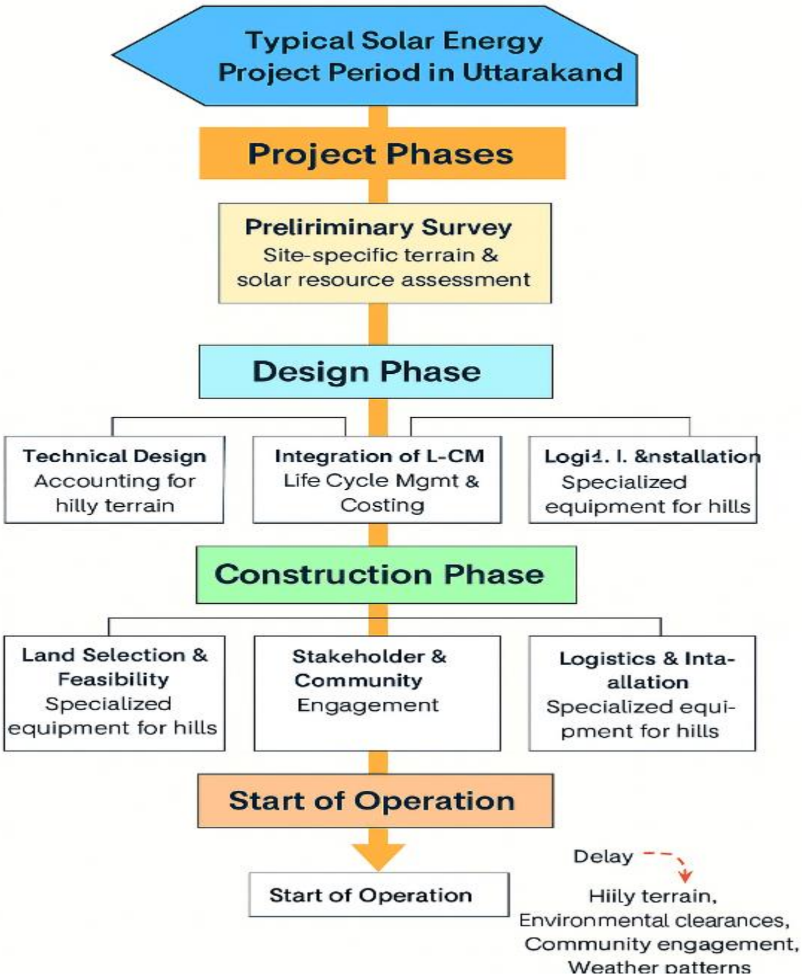

FIGURE1. **Energy Projects Execution Phases**

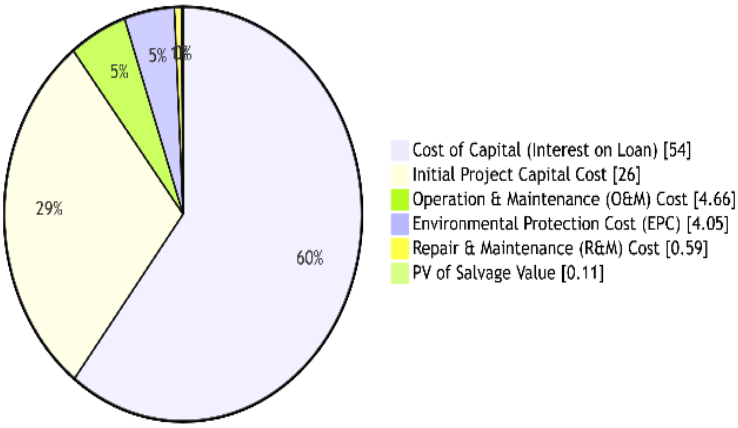

FIGURE 2. **Energy Project Execution Cost Estimation**

2) Performance

The performance areas are given below:

Solar processes require skilled local manpower to execute and operate various projects; State GDP may be increased due to the timely execution of solar projects that reduce energy costs for tourism and industry [9];LCM- and LCC-based evaluation approaches lead to better long-term economic and environmental performance for solar [4];Timely execution of decentralized solar projects leads to energy accessibility for remote communities [24]; and Challenges related to land and environment for solar farms are effectively managed through participatory approaches [12].Improving performance includes:

(P1*): Solar project schedule performance in difficult terrain;

(P2*): LCM- and LCC-based financial and environmental performance for solar;

(P3*): Performance in managing land acquisition and community engagement for solar projects; and

(P4*): Performance in environmental risk mitigation and social inclusion for solar development.

4. DISCUSSION

The Indian solar energy sector, with a specific focus on the regional context of Uttarakhand, has been assessed using the SAP-LAP model (Figure 3) of inquiry [15]–[19]. This model was implemented using a mixed-methods approach. The qualitative component involved a critical examination of the region's specific context, while the quantitative component employed analytical tools, specifically the Cross-Interaction Matrix (CIM), to map relationships between actors, processes, actions, and performance [19].

After analysing the interpretive process through the SAP-LAP framework,(Table II) it was found that the actors most critical for solar capacity addition in Uttarakhand's context are those responsible for solar energy, such as the Ministry of New and Renewable Energy (MNRE), Solar Energy Corporation of India (SECI), and the Uttarakhand Renewable Energy Development Agency (UREDA)**.** Consequently, solar energy projects particularly rooftop, small-scale PV, and microgrids should be prioritized to contribute more significantly to both the state's and the nation's energy mix [8], [24].

Analysis of the dominance matrix (Table III) revealed that the rank of actor **A2 (SECI)** was equally important to other key stakeholders, such as regulators and local communities. This parity in ranking stems from the equal importance of navigating the complex constraints environmental clearances, community engagement, and difficult terrain—that are dynamic forces in the state's solar energy sector [11], [12].

In the final LAP synthesis, a dominance matrix was formed to rank improvement actions against various performance metrics (Table V). The results indicate that designing electricity tariffs that serve consumers in remote and hilly regions for solar projects should be a high priority [10]. This involves minimizing costs where

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possible and ensuring that each cost component, including the higher operations and maintenance expenses for decentralized solar projects in difficult terrain, is transparently considered in tariff formulation. The costs associated with developing local skilled manpower for solar must also be integrated into tariff structures and assessed during decision-making.(Table IV)

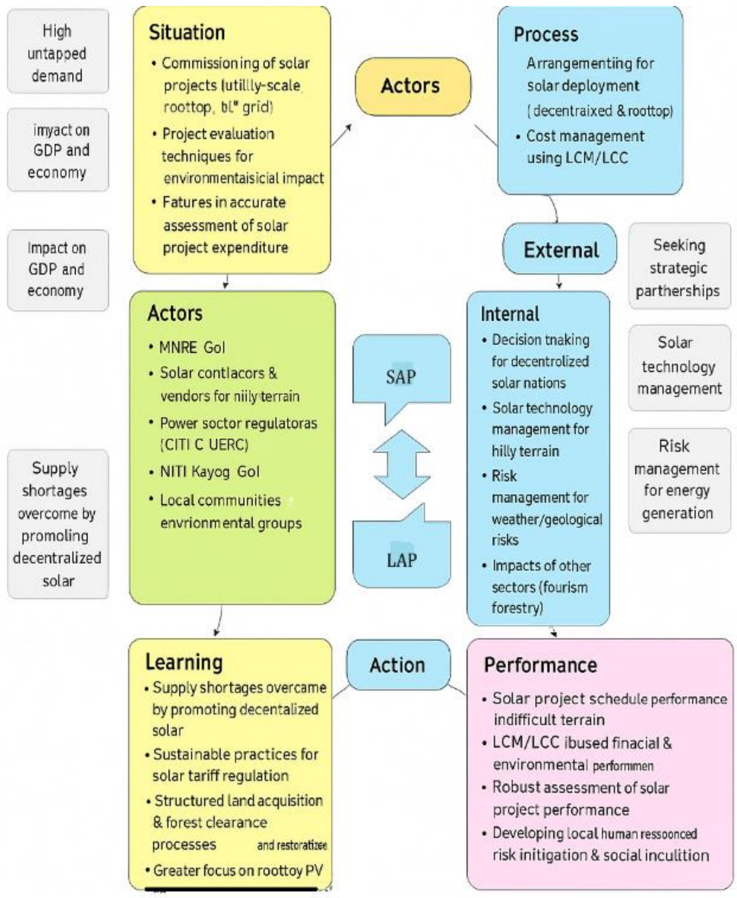

FIGURE3. **SAP-LAP Framework for Energy Security**

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As indicated by the analysis, high-priority actions include assessing priority-based decisions for investments in region-specific solar technologies**,** and applying Life Cycle Management (LCM) based applications to evaluate the financial, environmental, and social impacts of solar projects on Uttarakhand's other critical sectors, such as tourism and forestry [4]. Furthermore, actions for the development of skilled local solar manpower and creating strategic alliances with technology providers experienced in mountainous regions were found to be of paramount importance for the state's sustainable solar energy security.

TABLE II
INTERPRETIVE BINARY REPRESENTATION (ACTORS OVER PROCESS) FOR UTTARAKHAND SOLAR CONTEXT

Actor (A) / Process (P)	P1 (Promoting Solar: Rooftop, Microgrids)	P2 (Project Cost Mgmt: LCM/LCC for solar)	P3 (Human Resource Mgmt: Local solar skills development)	P4 (Minimizing delays: Env. & community engagement)	P5 (Effective utilization of decentralized solar)	P6 (Risk Mgmt: Weather & terrain)	P7 (Support for strategic alliances for solar in hills)	P8 (Support for Sustainable State GDP)
A1: MNRE, GoI	H (1)	H (1)	M (1)	H (1)	H (1)	M (1)	H (1)	H (1)
A2: SECI, GoI	VH (1)	VH (1)	H (1)	H (1)	VH (1)	H (1)	VH (1)	H (1)
A3: UREDA	VH (1)	VH (1)	VH (1)	VH (1)	VH (1)	VH (1)	VH (1)	VH (1)
A4: Regulatory Bodies (CERC, UERC)	H (1)	VH (1)	L (0)	M (1)	H (1)	M (1)	L (0)	M (1)
A5: Solar Contractors & Vendors	M (1)	VH (1)	VH (1)	VH (1)	H (1)	VH (1)	H (1)	L (0)
A6: Local Communities & Groups	M (1)	L (0)	L (0)	VH (1)	H (1)	H (1)	M (1)	M (1)
A7: NITI Aayog, GoI	VH (1)	H (1)	H (1)	M (1)	VH (1)	H (1)	H (1)	VH (1)

Scale: Very High (VH)=5, High (H)=4, Medium (M)=3, Low (L)=2, Very Low (VL)=1. *Binary Conversion:* VL/L = 0 (Low Influence), M/H/VH = 1 (High Influence).

TABLE III
DOMINATING INTERACTION MATRIX AND RANKING REPRESENTATION (ACTORS OVER PROCESS) FOR UTTARAKHAND SOLAR CONTEXT

Actor	A1	A2	A3	A4	A5	A6	A7	Count of dominating (D)	Net Dominance (D-B)	Actor Rank
A1: MNRE, GoI	--	P1	P1	--	P1	P5	--	4	-4	V
A2: SECI, GoI	P3	--	--	--	P1	P5	P3	4	-2	IV (a)

Actor	A1	A2	A3	A4	A5	A6	A7	Count of dominating (D)	Net Dominance (D-B)	Actor Rank
A3: UREDA	P2	P2	--	--	P1	--	P2, P3	5	1	II
A4: Regulatory Bodies	P2, P3, P6	P1, P2	P1	--	P1	P5	P2, P3	10	10	I
A5: Contractors & Vendors	P2, P3	P2	--	--	--	--	--	3	-2	IV (b)
A6: Local Communities	--	--	P1	--	P1	--	--	2	-2	IV (c)
A7: NITI Aayog, GoI	P3	P1	P1	--	P1	P5	--	5	0	III
Count of dominated (B)	8	6	4	0	5	4	5	**Total interactions: 33**		

Explanation of Uttarakhand Solar Context:

A4 (Regulatory Bodies) achieves the highest rank (I). This underscores the critical role of regulators (CERC, UERC) in Uttarakhand for approving tariffs for solar projects in difficult terrain, enforcing environmental compliance, and managing the complex interplay between national solar policy and local sustainability, giving them dominance over many processes.

A3 (UREDA) holds a high rank (II), reflecting its pivotal role as the primary state-level agency for on-the-ground execution of solar projects, policy implementation, and bridging the gap between central ministries and local actors.

A7 (NITI Aayog) ranks III, due to its influence in policy framing, budget allocation, and long-term strategic planning for sustainable solar development in hill states.

The tie for Rank IV between A2 (SECI), A5 (Contractors), and A6 (Local Communities) is significant. It highlights a core Uttarakhand challenge: national solar goals (A2) and project execution (A5) are equally dominated by the influence and consent of Local Communities (A6). This reflects the absolute necessity of community engagement for solar project success in the sensitive Himalayan ecology [12].

TABLE IV
INTERPRETIVE MATRIX - ACTIONS OVER PERFORMANCE FOR UTTARAKHAND SOLAR CONTEXT

Actions (A) / *Performance (P*)	***P1 (Solar Project Schedule Performance in difficult terrain)****	***P2* (LCM & LCC-based Economic & Environmental Performance for Solar)****	***P3 (Land Acquisition & Community Engagement Performance for Solar)****	***P4 (Environmental & Social Capitalization Performance for Solar)****
A1*: Prioritizing investment in region-specific solar	H (1)	VH (1)	M (1)	VH (1)

Actions (A*) / Performance (P***)**	***P1 (Solar Project Schedule Performance in difficult terrain)****	****P2* (LCM & LCC-based Economic & Environmental Performance for Solar)****	***P3 (Land Acquisition & Community Engagement Performance for Solar)****	***P4 (Environmental & Social Capitalization Performance for Solar)****
A2*: Adopting LCM/LCC practices for solar project evaluation	VH (1)	VH (1)	H (1)	M (1)
A3*: Monitoring causes of delays (env./community for solar)	H (1)	L (0)	VH (1)	H (1)
A4*: Planning for local solar HR development and incentivizing skills	VL (0)	L (0)	VL (0)	VL (0)
A5*: Creating strategic alliances with solar tech providers for hilly regions	L (0)	M (1)	L (0)	M (1)
A6*: Planning electricity tariffs for decentralized solar projects using LCC	VL (0)	VH (1)	VL (0)	VH (1)
A7*: Promoting management education & R&D for Himalayan solar challenges	M (1)	VH (1)	M (1)	H (1)

Scale: Very High (VH)=5, High (H)=4, Medium (M)=3, Low (L)=2, Very Low (VL)=1. *Binary Conversion:* VL/L = 0 (Low Influence), M/H/VH = 1 (High Influence).

Contextual Notes for Uttarakhand Solar Context:

A1*: Directly influences sustainable performance (P2, *P4*) by focusing on Uttarakhand's solar potential.

A3*: Has the highest influence on P3*, reflecting that in Uttarakhand, managing community and environmental concerns for solar projects is the most critical action for avoiding delays [12].

A4*: Shows low influence because while important, local solar skill development is a long-term enabler rather than a direct driver of immediate project performance.

A6*:Highly influences economic and environmental performance (P2, *P4*) as correct solar tariff setting is crucial for the viability of smaller, decentralized projects in remote hilly areas [10].

TABLE V
DOMINATING INTERACTION RANKING REPRESENTATION (ACTIONS OVER PERFORMANCE) FOR UTTARAKHAND SOLAR CONTEXT

Action	A1*	A2*	A3*	A4*	A5*	A6*	A7*	Count of dominating (D)	Net Dominance (D-B)	Action Rank
A1*: Prioritizing investment	--	P4*	P4*	--	P2, *P4*	--	--	4	1	II (a)
A2*: Adopting LCM/LCC	P1, *P3*	--	P1*	--	P2*	--	P1, *P3*	6	1	II (b)
A3*: Monitoring delays	P3*	P3, *P4*	--	--	--	--	--	3	0	III (a)
A4*: Planning for local HR	--	--	--	--	--	--	--	0	0	III (b)
A5*: Creating alliances	--	--	--	--	--	--	--	0	-7	IV
A6*: Planning tariffs using LCC	--	P4*	P4*	--	P2, *P4*	--	--	4	4	I
A7*: Promoting R&D for Solar	--	P4*	--	--	P2, *P4*	--	--	3	1	II (c)
Count of being dominated (B)	3	5	3	0	7	0	2	**Total interactions: 20**		

Explanation of Uttarakhand Solar Context:

A6 (Planning tariffs using LCC for solar) achieves the highest rank (I). This action is paramount for Uttarakhand as it directly determines the financial viability and sustainability of small-scale, decentralized solar projects in remote and difficult terrain, making it a dominant factor over economic and environmental performance [10].

A1, A2, A7 (Solar investment, LCM practices, Solar R&D) share Rank II. This reflects that strategic investment in solar, rigorous life-cycle cost analysis, and context-specific research are all equally critical and interconnected actions for achieving sustainable solar performance in the state [4], [8].

A3 & A4 (Monitoring delays & Solar HR development) share Rank III. While monitoring community and environmental issues (A3*) is crucial, its impact is balanced by the long-term, foundational need to develop local solar skills (A4*). Both are essential enablers but are dominated by more direct strategic and financial actions.

A5 (Strategic alliances for solar tech) ranks lowest (IV). Although valuable for accessing specialized technology, this action is dominated by others because alliances are a means to an end; their success is dependent on the priorities set by the higher-ranked actions (e.g., investment choices, tariff models).

5. CONCLUDING REMARKS

This case study has demonstrated the application of the SAP-LAP framework to analyse solar energy security, with a specific focus on the interplay between India's national solar objectives and the unique context of Uttarakhand [15]–[19]. The situational analysis incorporated critical issues pertinent to solar project execution in the Himalayan region [11], [12]. Both qualitative and quantitative SAP-LAP models were employed, guided by system-inquiry-based questioning [20].

A synthesis of the Situation-Actor-Process (SAP) and Learning-Action-Performance (LAP) components was conducted, drawing from the complexities of the national solar sector and Uttarakhand's distinct challenges. The LAP synthesis integrated qualitative and quantitative assessments to address solar energy security aspects. The proposed model tackles investment issues related to solar energy supply, identifying time and cost overruns as critical barriers [11], [21]. For Uttarakhand, Life Cycle Costing (LCC)-based sustainable practices were found to be essential for managing the economic burdens of solar projects, particularly for harnessing solar resources in its difficult terrain [4].

The development of the SAP-LAP synthesis reveals that this framework is highly effective for resolving complex issues within the Indian solar energy sector,(Table IV) especially in diagnosing the root causes of delays, which are often exacerbated in regions like Uttarakhand by environmental and community engagement processes [12]. Based on the interpretive inquiry and matrix development, decentralized solar energy sources were identified as significant areas for bolstering both state and national solar energy security policies [24].

The application of the SAP-LAP framework offers distinct advantages for the solar sector over traditional methods like SWOT or PEST analyses. While traditional models focus on internal and external environments, the flexible SAP-LAP model accounts for the impact of dynamic, inter-organizational systems, which is crucial for managing the multi-level governance between national solar agencies and state-level agencies like UREDA [15], [19]. In addition to SAP-LAP, additional interpretative approaches such as ISM, fuzzy ISM, and TISM may also be utilized for further research of Uttarakhand's solar energy landscape [19], [20].

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