

A Multi-Criteria Decision Support Framework for Sustainable Transmission Line Right-of-Way Planning in India.

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Abstract: -

Expansion of high-voltage transmission networks is essential for integrating renewable energy and ensuring reliable electricity supply in emerging economies such as India. However, the acquisition and management of transmission line Right-of-Way (ROW) remain among the most critical barriers to timely project implementation due to stakeholder conflicts, environmental concerns, land-use constraints, and vegetation management challenges. Existing planning approaches in the electricity sector often treat technical optimization, stakeholder engagement, and environmental sustainability as separate processes, resulting in project delays, increased costs, and reduced social acceptance.

This paper proposes a **Multi-Criteria Decision Support Framework (MCDSF)** for sustainable transmission line Right-of-Way planning in India. Building on prior research on stakeholder engagement in electricity sector interventions, large-scale energy project participation strategies, multi-criteria decision aiding, socio-economic implications of ROW corridors, and vegetation management practices, the study integrates technical, environmental, economic, and social dimensions into a unified socio-technical planning model.

The proposed framework combines Multi-Criteria Decision Analysis (MCDA) with structured stakeholder participation to support transparent and evidence-based route selection and corridor management. The framework identifies key evaluation criteria including land acquisition complexity, environmental sensitivity, vegetation risks, community acceptance, reliability impacts, and lifecycle costs. A participatory decision process is embedded to incorporate government agencies, utilities, local communities, and environmental stakeholders into planning and prioritization.

The paper contributes by:

1. Synthesizing fragmented literature into an integrated socio-technical planning approach.
2. Providing a conceptual decision-support model tailored to India's transmission expansion context.
3. Demonstrating how stakeholder engagement and vegetation management can be embedded into technical planning.

4. Offering a foundation for future empirical and tool-based implementation.

The proposed framework aims to enhance social acceptance, reduce project delays, and support sustainable grid expansion in India's rapidly evolving energy transition.

KEYWORDS: -

Multi-Criteria Decision Analysis (MCDA);
Transmission Line Planning;
Right-of-Way (ROW);
Stakeholder Engagement;
Sustainable Energy Infrastructure;
Grid Expansion;
Vegetation Management;
Socio-Technical Systems;
Energy Governance;
India.

Introduction

The rapid expansion of electricity transmission infrastructure has become a strategic priority for India as the country accelerates renewable energy integration, regional power exchange, and electrification. Large-scale initiatives such as Green Energy Corridors and cross-regional transmission upgrades require extensive development of high-voltage transmission lines. While technological capabilities for grid expansion have advanced significantly, the planning and acquisition of transmission line Right-of-Way (ROW) remain major bottlenecks affecting project timelines, costs, and public acceptance.

Transmission ROW development is inherently complex because it intersects technical engineering requirements with environmental systems, land-use dynamics, and socio-economic realities. Transmission corridors often pass through agricultural land, forests, and peri-urban settlements, creating conflicts related to land acquisition, compensation, vegetation clearance, ecological protection, and perceived health and safety risks. These challenges frequently lead to stakeholder opposition, legal disputes, and project delays.

Traditional transmission planning approaches in many developing countries, including India, remain largely techno-economic and engineering-driven. Route selection is typically optimized based on electrical performance and cost considerations, while social, environmental, and governance dimensions are addressed later in the project lifecycle. This fragmented approach has contributed to growing resistance to infrastructure projects and increased implementation risks.

Recent literature emphasizes the need for integrated planning approaches that incorporate stakeholder engagement, environmental sustainability, and participatory decision-making alongside technical optimization. Multi-Criteria Decision Analysis (MCDA) has emerged as a promising tool for addressing complex infrastructure decisions involving multiple, often conflicting criteria. At the same time, research on stakeholder engagement

highlights the importance of participatory processes in enhancing transparency, trust, and social acceptance of energy infrastructure projects. Vegetation management and corridor land use further add layers of operational and ecological considerations that must be integrated into planning decisions.

Despite these advances, there is a lack of an integrated decision-support framework tailored to the Indian context that combines MCDA, stakeholder engagement, and sustainable ROW management into a unified socio-technical planning approach. Addressing this gap is critical for enabling timely and socially acceptable grid expansion. This paper therefore proposes a conceptual Multi-Criteria Decision Support Framework to support sustainable transmission line ROW planning in India.

2. Research Problem

Transmission line projects in India face recurring challenges including:

- Delays in land acquisition and approvals
- Community resistance and stakeholder conflicts
- Environmental and vegetation management concerns
- Rising project costs and uncertainty
- Lack of structured participatory planning tools

Existing planning methods do not adequately integrate technical, environmental, and social dimensions into a single decision process.

3. Research Objectives

Main Objective

- To develop a conceptual Multi-Criteria Decision Support Framework for sustainable transmission line Right-of-Way planning in India.
- Specific Objectives
- To identify key technical, environmental, social, and economic criteria influencing ROW planning.
- To examine the role of stakeholder engagement in transmission infrastructure development.
- To integrate Multi-Criteria Decision Analysis (MCDA) into ROW route selection and corridor management.
- To propose a participatory socio-technical framework for sustainable transmission planning.
- To provide a conceptual foundation for future empirical implementation and decision-support tools.

4. Research Questions

Secondary Research Questions

1. What are the critical criteria influencing sustainable ROW planning in transmission projects?

2. How can stakeholder engagement be systematically integrated into transmission planning processes?
3. How can MCDA methods support transparent and balanced decision-making in route selection?
4. How can vegetation management and environmental considerations be embedded into early planning stages?
5. What conceptual framework can guide participatory and sustainable grid expansion in India?

5. Literature Review

Transmission line Right-of-Way (ROW) planning sits at the intersection of engineering design, environmental sustainability, land governance, and stakeholder engagement. The literature relevant to this research spans four major themes: stakeholder engagement in electricity infrastructure, participatory planning in large-scale energy projects, multi-criteria decision analysis (MCDA) in energy planning, socio-economic dimensions of transmission corridors, and vegetation management in ROW corridors.

5.1 Stakeholders and Governance in the Electricity Sector

Electricity infrastructure development is widely recognized as a multi-stakeholder process involving governments, utilities, regulators, local communities, and environmental actors. A comprehensive review of stakeholder interventions in the electricity sector highlights how fragmented governance and weak coordination often delay infrastructure projects and reduce their effectiveness. The study emphasizes that stakeholder mapping and early engagement are essential for addressing conflicts, building trust, and improving project outcomes.

The review further notes that electricity sector reforms in developing countries frequently struggle due to insufficient integration of social and institutional factors into technical planning. Stakeholder participation is therefore increasingly viewed as a key component of sustainable energy governance, particularly in contexts where land acquisition and public acceptance are major challenges.

These findings are highly relevant to India, where transmission projects often face opposition related to land rights, compensation, and environmental concerns.

5.2 Stakeholder Engagement in Large-Scale Energy Projects

Large-scale energy infrastructure projects commonly experience delays due to public resistance and inadequate community engagement. Research on engagement strategies demonstrates that participatory planning can significantly improve project acceptance, reduce conflict, and enhance transparency.

The literature identifies several key engagement strategies:

- Early stakeholder involvement in decision-making
- Stakeholders mapping
- Transparent communication and information sharing
- Inclusion of local knowledge in planning
- Collaborative problem solving and negotiation
- Importantly, the study concludes that stakeholder engagement must move beyond consultation toward co-creation of solutions, especially in projects affecting land use and local livelihoods.
- For transmission ROW planning, this implies that communities should be involved not only during route finalization in village level but also during route selection and corridor management.

5.3 MCDA Methods Used in Infrastructure and ROW Studies

5.3.1 Analytic Hierarchy Process (AHP)

AHP is widely used in infrastructure planning because it converts subjective judgments into numerical priorities.

Applications in ROW:

- Route selection
- Stakeholder prioritization
- Compensation framework design
- Conflict risk assessment

AHP allows inclusion of qualitative criteria such as:

- Trust level
- Community resistance probability
- Cultural sensitivity

5.3.2 Analytic Network Process (ANP)

ANP extends AHP by considering interdependencies between criteria.

In ROW:

- Compensation influences trust
- Trust influences cooperation
- Cooperation reduces delays
- Reduced delays reduce cost

This interrelationship makes ANP highly relevant.

5.3.3 TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)

TOPSIS ranks alternatives based on distance from ideal and worst scenarios.

Used for:

- Route corridor selection
- Stakeholder engagement strategies
- Compensation model comparison

5.3.4 PROMETHEE and ELECTRE

These outranking methods are useful when:

- Criteria conflict strongly
- Stakeholder opinions vary widely
- Decision transparency is critical

They are particularly suited for **social acceptance analysis**

5.4 Role of Recognition and Non-Monetary Incentives

5.4.1 Shift from Compensation to Relationship Management

Emerging literature emphasizes **non-financial value creation** in ROW projects:

Examples include:

- Public recognition
- Community development programs
- Cultural sensitivity initiatives
- Symbolic gestures and appreciation

These actions influence **perceived fairness**, which research identifies as a major determinant of acceptance.

5.4.2 Behavioural Economics Perspective

Stakeholder responses are influenced by:

- Respect and dignity
- Social identity
- Emotional connection
- Recognition of contribution

The Khavda IV-C initiative demonstrates how symbolic recognition:

- Enhances trust
- Builds partnership
- Strengthens project legitimacy

In MCDA terms, such initiatives improve scores under criteria like:

- Trust index
- Stakeholder satisfaction
- Cooperation probability
- Social acceptance score

5.5 Symbolic Ownership and Participatory Recognition in ROW Projects

5.5.1 Emergence of Symbolic Ownership in Infrastructure Development

Recent infrastructure governance literature highlights a transition from land acquisition land partnership. Projects increasingly seek to create a sense of symbolic ownership among landowners.

- Symbolic ownership refers to:
- Emotional association with infrastructure
- Recognition of stakeholder contribution
- Inclusion in the project identity
- Pride in nation-building participation
- The “हरित ऊर्जा स्तंभ” initiative reflects this shift by transforming a transmission tower from a physical asset into a social symbol.

5.5.2 Emotional Value in Infrastructure Projects

Infrastructure is traditionally evaluated using:

- Cost–benefit analysis
- Risk assessment
- Engineering feasibility
- However, modern research stresses emotional value creation as a decision criterion.
- Emotional value includes:
- Pride
- Recognition
- Social respect
- Contribution to national development
- Participation in sustainability goals

The appreciation board initiative activates these emotional drivers.

5.6 Research Gap

The reviewed literature clearly demonstrates progress in several individual areas:

- Stakeholder engagement in electricity sector governance
- Participatory planning in large-scale energy projects
- MCDA for complex energy decisions
- Socio-economic impacts of ROW corridors
- Vegetation management in transmission infrastructure
- However, these domains remain largely fragmented. No integrated framework currently combines:
- MCDA-based route selection
- Structured stakeholder participation
- Socio-economic and land-use considerations

- Vegetation and environmental management
- A context-specific focus on India

Existing literature focuses heavily on:

- Route optimization
- Compensation modelling
- Conflict resolution

However, limited research exists on:

Integrating **symbolic recognition and relationship-building initiatives** into MCDA frameworks.

This gap motivates the development of a Multi-Criteria Decision Support Framework for Sustainable Transmission Line ROW Planning, which is proposed in the following sections.

6. Discussion and Implications

The proposed Multi-Criteria Decision Support Framework (MCDSF) responds directly to the fragmented nature of current transmission Right-of-Way (ROW) planning practices. The literature review demonstrates that technical optimization, stakeholder engagement, vegetation management, and socio-economic considerations are typically addressed independently rather than as an integrated planning process.

6.1 Integration of Technical and Social Planning

The reviewed studies collectively highlight that infrastructure planning failures often stem from governance and stakeholder misalignment rather than purely technical limitations. Electricity sector research shows that stakeholder coordination and institutional collaboration are essential for effective infrastructure development.

By embedding stakeholder engagement into early planning stages, the proposed framework shifts ROW planning from a reactive process to a proactive, participatory model. This has strong implications for India, where land acquisition and community resistance remain major project risks.

6.2 Role of Participatory Decision-Making

Engagement strategies in large-scale energy projects emphasize that early and meaningful participation improves trust and project legitimacy.

The framework operationalizes this concept by integrating stakeholder participation directly into MCDA-based route evaluation.

This approach may lead to:

- Reduced project delays and litigation
- Improved transparency and accountability
- Increased community acceptance
- Better alignment between infrastructure and local development goals

6.3 Advancing MCDA Applications in Transmission Planning

MCDA literature confirms its suitability for complex energy decisions involving multiple criteria and stakeholders. However, its application in transmission ROW planning remains limited.

The proposed framework contributes by extending MCDA from a technical evaluation tool into a **socio-technical planning instrument**. This represents a significant methodological advancement.

6.4 Reframing ROW Corridors as Socio-Economic Spaces

The literature on ROW as an economical shelter highlights that transmission corridors influence livelihoods and land use. This insight challenges the traditional view of ROW as merely a technical clearance zone.

The framework therefore promotes a shift toward:

- Multi-use corridor planning
- Inclusive land-use strategies
- Compensation and livelihood integration

6.5 Sustainability and Vegetation Management

Vegetation management research stresses that corridor sustainability must be integrated into planning rather than treated as maintenance.

The framework incorporates vegetation risk and ecological sensitivity as early decision criteria, aligning transmission planning with environmental sustainability goals.

7. Key Findings

This conceptual study produces several important findings:

1. **ROW planning is a socio-technical challenge**, not purely an engineering task.
2. **Stakeholder engagement must occur during route selection**, not only during land acquisition.
3. **MCDA provides an effective structure** for integrating technical, environmental, and social criteria.
4. **Transmission corridors create socio-economic impacts** that should be incorporated into planning decisions.
5. **Vegetation management should be integrated into early planning**, improving reliability and sustainability.
6. There is a **clear need for an India-specific integrated planning framework**, which this paper proposes.

8. Policy and Practical Implications

For Government and Regulators

- Support participatory planning policies for transmission projects
- Develop guidelines for multi-criteria corridor selection
- Encourage integrated environmental and social assessment

For Transmission Utilities

- Adopt MCDA tools for route selection
- Engage stakeholders early in project development
- Integrate vegetation and land-use planning into feasibility studies

For Researchers

- Provides a foundation for empirical validation
- Opens opportunities for GIS-based decision support tools
- Supports development of participatory planning models

9. Limitations of the Study

As a conceptual research paper, this study has several limitations:

1. No empirical validation

The framework is theoretical and requires testing through case studies.

2. Limited geographic focus

Although tailored for India, regional variations within the country are not analyzed.

3. Data and implementation challenges

Practical application will require detailed datasets, stakeholder mapping, and tool development.

4. Method selection not tested

Specific MCDA techniques (AHP, PROMETHEE, ELECTRE) are not compared empirically.

These limitations create opportunities for future research and real-world applications.

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