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A Study of Safety Compliances and Incident Analysis in Renewable Energy Projects

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Abstract: ***The rapid expansion of renewable energy projects such as solar, wind, and biomass in India has been pivotal to achieving sustainable development goals and reducing carbon emissions. However, amidst this growth, occupational safety and health (OSH) concerns have received insufficient attention, leading to frequent incidents and safety lapses across sectors. This study investigates safety compliance levels, incident patterns, and root causes in six operational renewable energy projects, employing a mixed-methods approach that includes surveys, interviews, site observations, and document analysis. Findings reveal significant disparities in safety practices among different technologies, with wind projects demonstrating higher adherence to standards such as ISO 45001 and OSHA guidelines, while biomass plants lag due to inadequate safety systems and training. Common issues identified include PPE non-compliance, poor incident reporting, and weak emergency preparedness. The research underscores the urgent need for strengthening safety management systems, fostering a safety culture, and aligning practices with national standards like the Indian Electricity Rules and international norms. Implementing targeted recommendations can significantly reduce workplace incidents, improve safety performance, and support India's broader energy transition objectives, ensuring that sustainable development is accompanied by responsible occupational safety practices.***

Keywords: Renewable Energy, Safety Compliance, Incident Analysis, Wind Energy, Solar Energy, Safety Management Systems, ISO 45001, OSHA Guidelines, Safety Culture, Workplace Safety, Risk Assessment, Energy Transition, Sustainable Development, Renewable Energy, emergency preparedness in renewable projects.

I. INTRODUCTION

The global shift toward renewable energy (RE) sources like solar, wind, and biomass is driven by the urgent need to combat climate change and achieve sustainable development goals.[1] India, in particular, has set ambitious targets under the National Solar Mission and Green Energy Corridors, aiming for 500 GW of non-fossil fuel capacity by 2030.[2] While the environmental and economic benefits of RE are well-recognised, the sector's rapid growth introduces significant occupational safety challenges that are often overlooked.[3]

Despite the perceived "green" image of renewable energy, incidents such as falls from height, electrical shocks, and equipment failures continue to occur, compromising worker safety and project continuity.[4] Existing safety standards, both national and international, are inconsistently implemented, especially in developing regions and decentralised projects.[5] This research aims to fill this gap by systematically examining safety compliance, incident patterns, and root causes across diverse RE projects in India, providing actionable recommendations for stakeholders.[6]

II. BACKGROUND AND LITERATURE REVIEW

The expansion of renewable energy technologies has been accompanied by unique safety challenges.[7] Wind turbines involve working at heights with rotating machinery, solar projects require working with live electrical circuits, and biomass plants pose fire and chemical hazards.[8] Prior studies have emphasized the importance of safety management systems, training, and incident analysis in industrial sectors, but literature specific to the renewable sector remains limited.[9]

Research by Iqbal et al. (2010), Sharma (2021), and recent industry reports have identified safety lapses related to PPE non-compliance, inadequate training, and poor incident reporting.[10] Moreover, technological innovations such as drone inspections and IoT-based monitoring are emerging solutions, but their integration into safety protocols is still nascent. Notably, most existing studies focus on technical performance rather than safety culture and systemic gaps in the operational environment.[11]

This study builds on these insights by conducting a comprehensive field investigation across multiple RE projects, emphasizing the human, organizational, and technological factors influencing safety.[12]

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III. RESEARCH METHODOLOGY

A mixed-methods approach was employed, combining quantitative surveys with qualitative interviews and field observations. Six operational RE projects in India two each from solar, wind, and biomass sectors, served as case studies. Data collection included structured questionnaires administered to 60 workers and safety personnel, semi-structured interviews with 12 key stakeholders, and direct site observations using standardized checklists.

Document analysis of safety audit reports, incident logs, and regulatory compliance records supplemented primary data. Purposive sampling ensured representation across job roles, experience levels, and employment types. Data analysis involved descriptive statistics, thematic coding, and cross-sectional comparisons to identify compliance levels, incident trends, and root causes.

The key components of the methodology are:

1) Research Type: Applied, field-based
2) Approach: Mixed-methods (quantitative + qualitative)
3) Sampling Technique: Purposive sampling

A. Data Sources

1) Primary Data

Structured questionnaires (n = 60 workers and safety personnel)

- Semi-structured interviews (n = 12 key stakeholders)
- Project documentation (EHS Observation Tracker, KPI trends, incident reports, legal register, Audit open Points, Risk Register)
- Field Observations

2) Secondary Data

- Literature from ISO 45001, ILO Guideline, IRENA.
- Academic dissertations from Shodhganga
- Internal safety audit reports and inspection records
- Annual incident logs maintained by site management

B. Tools for Data Analysis

- Frequency distributions and cross-tabulations
- Quantitative data from questionnaires were compiled and analysed in Microsoft Excel
- Percentage analysis to assess compliance levels
- Mean score ranking for Likert-scale responses

IV. DATA ANALYSIS AND INTERPRETATION

The collected data from safety audits, incident reports, and compliance assessments across wind, solar, and biomass energy projects were systematically analyzed to identify patterns and key factors influencing occupational safety. Quantitative data were subjected to descriptive statistics to determine the frequency and severity of safety incidents, The analysis revealed that higher adherence to safety management practices, particularly those aligned with ISO 45001 standards, significantly reduced the incidence of workplace accidents.

Furthermore, the data indicated that gaps in safety training and awareness, especially in regions with evolving regulatory frameworks like India, contributed to increased risk exposure among workers. Qualitative data from interviews and safety audits complemented these findings by highlighting organizational culture and management commitment as critical factors influencing safety outcomes.

Overall, the interpretation of these results underscores the importance of robust safety protocols, continuous training, and effective regulatory enforcement in advancing occupational safety within the renewable energy sector.

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Figure 4.12 SOP's Meeting captures the gap between formal procedures and actual practice, as well as the language and training issues highlighted.

Classification of Incidents by Type

Type of Incident	Number of Cases	Percentage (%)
Cuts and Abrasions	8	30%
Electric Shock	5	18%
Fall from Height	4	15%
Burns (Thermal/Chemical)	3	11%
Machinery-related Injury	3	11%
Fire Hazard	2	7%
Eye/Respiratory Issues	2	7%
Total	27	100%

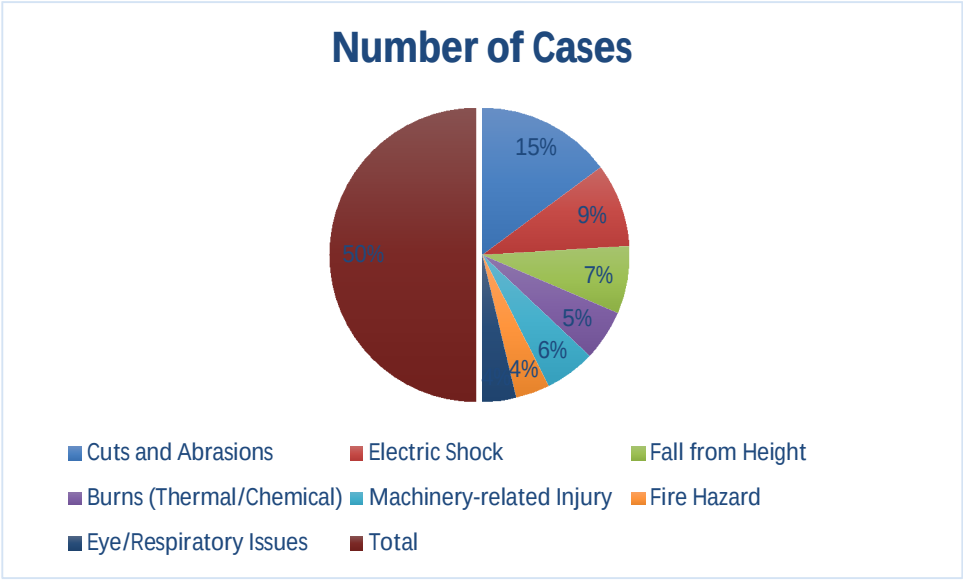


Figure 4.19: Visualize incident types by percentage

- Interpretation: The data shows that cuts and abrasions are the most common type of incidents (30%), followed by electric shocks (18%) and falls from height (15%). Burns and machinery-related injuries each account for 11%, while fire hazards and eye or respiratory issues make up 7% each. This indicates that most incidents are minor to moderate in nature but occur frequently, highlighting the need for better safety training, proper PPE use, and closer supervision at project sites.

The Interview Insights

S.no.	Interviewees Parties	Number
1	Safety Officers (one from each sector)	3
2	Project Engineers	4
3	Site Supervisors	2
4	HSE (Health, Safety, and Environment) Consultants	2
5	Maintenance Head (Wind sector)	1

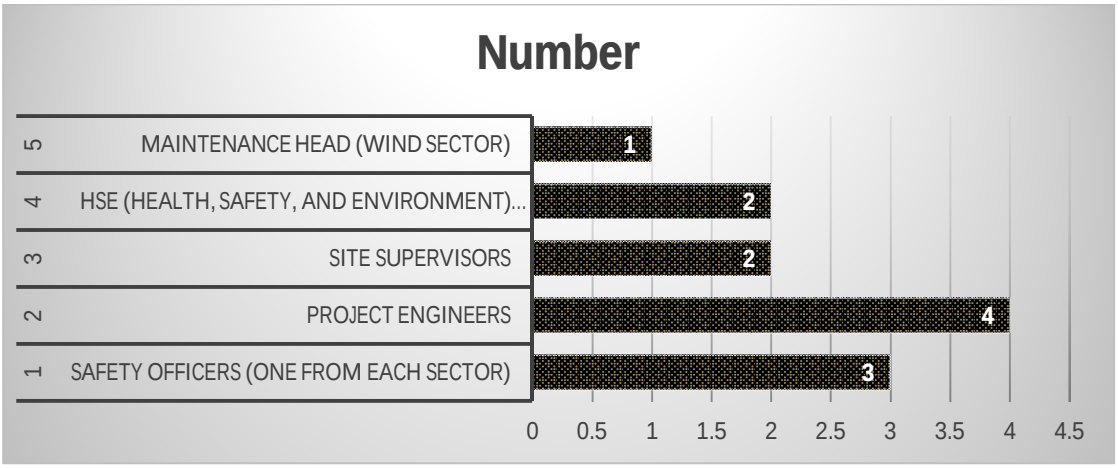


Figure 4.8: The Interview Insights graphs

- Interpretation: Most of the interviews were conducted with project engineers (4) and safety officers (3), as they play a key role in implementing safety measures on-site. A few interviews were held with site supervisors (2) and HSE consultants (2) to understand operational and compliance challenges. One interview was conducted with the maintenance head from the wind sector, giving specific insights into maintenance-related safety practices.

Root Cause Analysis of Incidents

Root Cause	Number of Incidents	Percentage
Human Error (Carelessness)	11	41%
Inadequate Training	7	26%
Equipment Failure	4	15%
SOP Non-Compliance	3	11%
Poor Housekeeping	2	7%

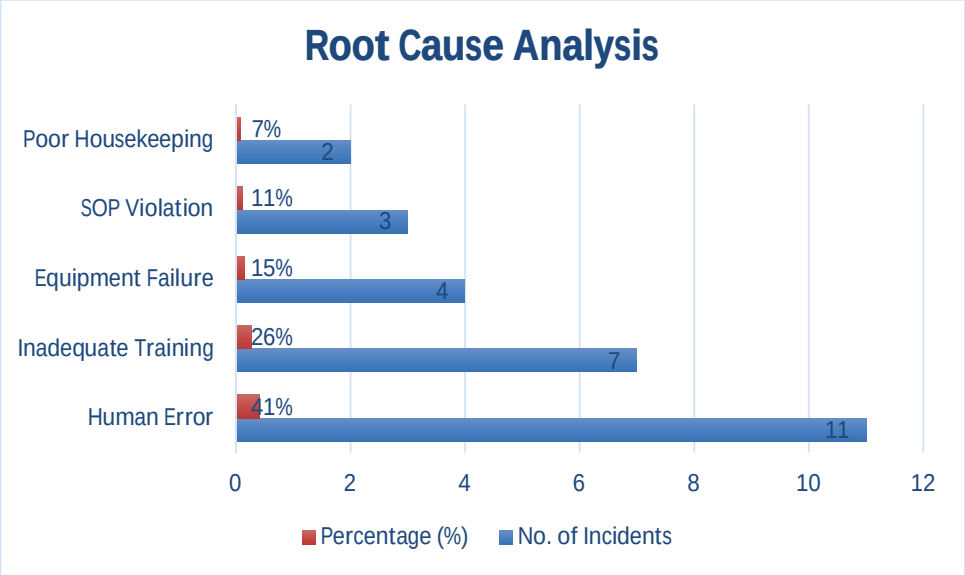


Figure 4.22: Root cause breakdown of incidents.

- Interpretation: The data shows that human error is the leading root cause of incidents, accounting for 41% of cases. Inadequate training follows with 26%, highlighting gaps in skill development and awareness. Equipment failure contributed to 15% of incidents, while SOP non-compliance and poor housekeeping accounted for 11% and 7% respectively. These findings suggest that most incidents are preventable through better training, stricter adherence to procedures, and improved workplace discipline.

Worker Participation in Training (by Sector)

S.No.	Project Type	% Workers Trained in Last Year
1	Wind	82%
2	Solar	65%
3	Biomass	54%

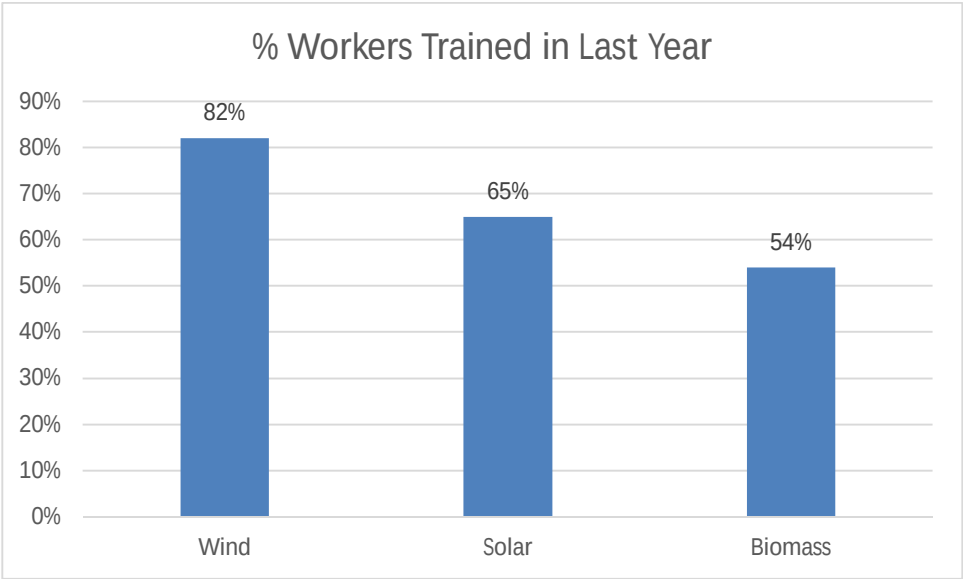


Figure 4.23: Compare training participation by sector

- Interpretation: The data shows that wind sector projects have the highest worker participation in training programs, with 82% of workers trained in the last year. The solar sector follows with 65%, while the biomass sector has the lowest participation at 54%. This indicates that training initiatives are stronger in wind projects, whereas solar and biomass projects need to improve regular training coverage.



Figure 4.26 Management Interview for the underlying causes of safety gaps and the practical realities of workplace conditions

- Interpretation: Figure 4.26 highlights insights from management interviews regarding the root causes of safety gaps at renewable energy sites. The responses indicate that human factors, inadequate training, inconsistent enforcement of SOPs, and contractor-related issues are the primary contributors to non-compliance. Managers also emphasized practical challenges such as time pressure, resource constraints, and site-specific operational complexities that hinder full adherence to safety protocols. These findings underscore the need for stronger supervision, regular training, and a culture of safety ownership across all levels of the organization.

V. RECOMMENDATIONS AND CONCLUSION

A. *Recommendations*

Based on the findings, the following key recommendations are proposed:

1) Structured Training: Implement mandatory, periodic safety training in local languages, including practical demonstrations, especially targeting contract workers.[13]
2) PPE Enforcement: Establish strict PPE policies with routine checks, supervision, and positive reinforcement.
3) Emergency Preparedness: Develop comprehensive ERPs, conduct regular drills, and ensure functional safety infrastructure.[14]
4) Incident Reporting: Standardize digital reporting tools, foster a non-punitive reporting culture, and analyze near misses for continuous improvement.[15]
5) Inclusive Safety Culture: Engage all workers, including subcontractors, in safety planning and decision-making.
6) Management Commitment: Leaders must exemplify safety priorities, allocate resources, and recognize safe practices.[16]

B. *Conclusion*

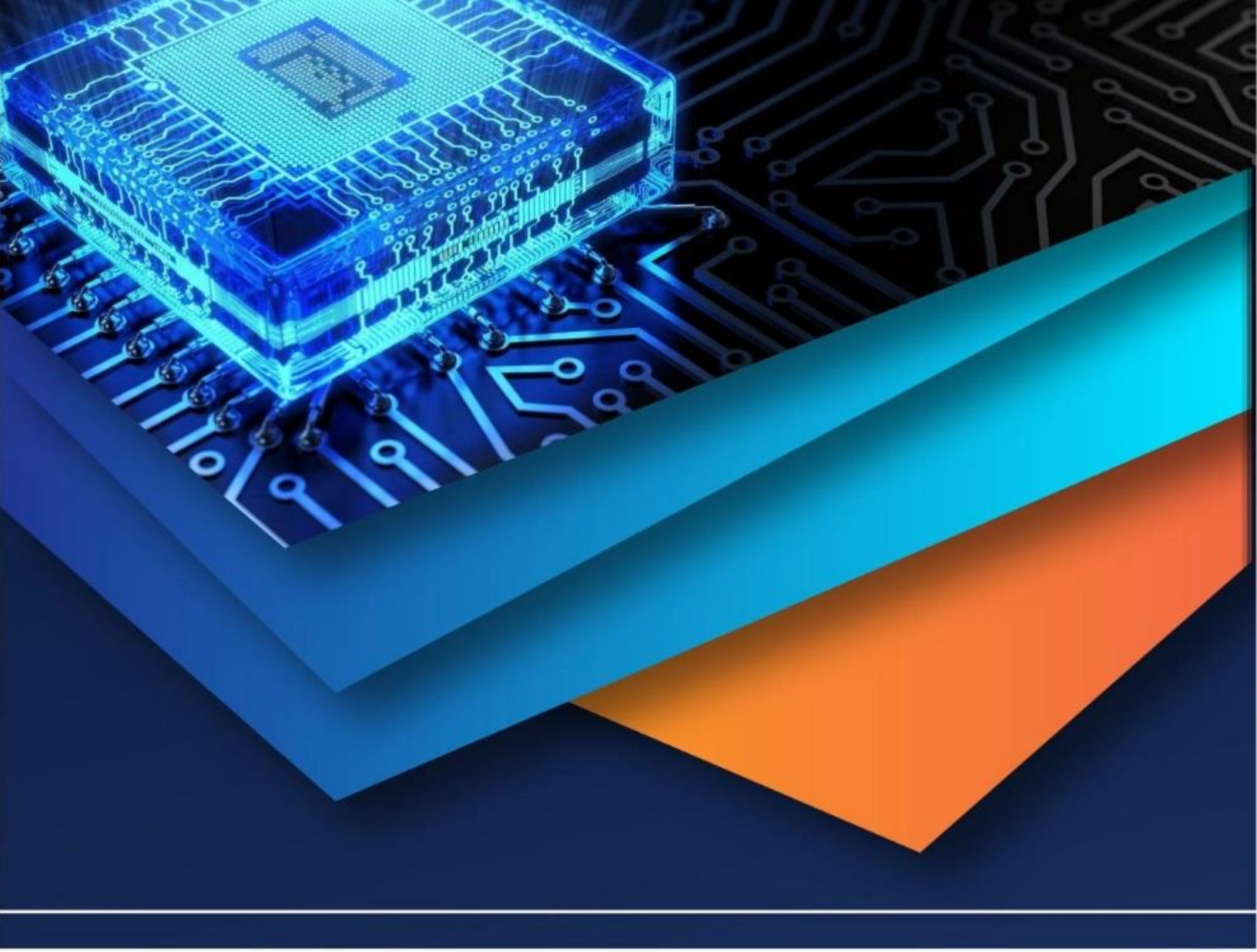
The growth of India's renewable energy sector offers promising avenues for sustainable development but is impeded by significant safety challenges.[17] This study highlights critical gaps in safety compliance, incident management, and organizational culture across solar, wind, and biomass projects.[18] Addressing these gaps requires a holistic approach involving targeted training, infrastructure upgrades, inclusive safety policies, and strong leadership commitment.

Implementing these recommendations can lead to safer workplaces, reduced incident rates, and enhanced project sustainability, aligning with national and global energy transition goals.[19] Future research should explore technological innovations and long-term safety performance to further strengthen the sector's safety framework.

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