TPM Vol. 32, No. S6, 2025
ISSN: 1972-6325
https://www.tpmap.org/

Open Access

EVALUATING DUAL-IMPACT RISK MITIGATION STRATEGIES FOR ENHANCING SAFETY AND ENVIRONMENTAL SUSTAINABILITY IN HIGH-RISK INDUSTRIES

NISHANT SUBHASH PHAD
RESEARCH SCHOLAR, KENNEDY UNIVERSITY

Abstract
There is a growing expectation for high-risk industries to manage both occupational safety and environmental sustainability, yet empirical evidence on the effectiveness of such dual-impact mitigation strategies is still limited. This research, therefore, investigates the impact of integrated safety environmental approaches on risk reduction across high-risk industries using a systematic literature review, thematic analysis, and expert validation interviews. A total of 67 high-quality academic and regulatory sources were analyzed, supported by a standardized composite risk scoring system that compares pre- and post-integration outcomes. Results from this indicate that integrated risk management far surpasses the performance of conventional, silo-based approaches by driving risk reductions of up to 40–48% in each of the Oil & Gas, Chemical, and Nuclear industries under consideration. System-based and standards-driven strategies, like Safety Management Systems, real-time monitoring, and combined ISO 45001/14001 implementation, demonstrated the highest levels of safety-environmental alignment. Environmental monitoring was followed by emergency response planning, hazardous material controls, and pollution-reduction initiatives, all of which ranked among the most common practices within the industry. The critical enabling role of regulatory frameworks is also highlighted within this study, where compliance spurs additional risk reductions in excess of 50% in some industries. Overall, dual-impact strategies enhance operational safety, reduce environmental harm, and build organizational resilience. The study emphasizes that there should be integrated frameworks to support decision-making on a risk basis and for advancing sustainability in high-risk industries.
Keywords: dual-impact mitigation, post-integration, hazardous material, resilience, sustainability.

INTRODUCTION

High-risk industries such as oil and gas, chemical manufacturing, and nuclear power generation play a pivotal role in sustaining the global economy by supplying energy, chemicals, and critical materials that support industrial development and meet global consumer demands (Thompson, 2023). These sectors form the backbone of modern infrastructure, enabling economic growth, technological advancement, and societal well-being. However, the same processes that make these industries indispensable also expose them to substantial operational risks. The handling of hazardous substances, reliance on complex technological systems, and operation under extreme physical and environmental conditions significantly increase the likelihood of accidents with potentially severe consequences for human health and the environment. Oil and gas facilities routinely manage flammable and toxic materials, chemical plants process hazardous compounds, and nuclear power stations operate with radioactive substances that, if improperly controlled, can result in catastrophic outcomes (Alnabhani & Khan, 2019).

Due to these inherent risks, operational safety has historically been a primary concern within high-risk industries. Organizations have invested heavily in the development and enforcement of comprehensive safety management systems, including stringent operational protocols, advanced personal protective equipment, emergency response frameworks, and continuous monitoring of industrial processes. These measures aim to prevent accidents, protect workers and surrounding communities, and minimize operational disruptions (Derdowski & Mathisen, 2023). While such safety-focused approaches have significantly improved incident prevention and response, the operational context of high-risk industries is rapidly evolving. In addition to maintaining high safety standards, organizations now face growing pressure from regulators, investors, and the public to reduce their environmental footprint and adopt more sustainable practices.

Global concerns related to climate change, environmental pollution, biodiversity loss, and resource depletion have intensified scrutiny of industrial activities, particularly those associated with high-risk sectors. Industries such as oil

and gas are increasingly criticized for their contribution to greenhouse gas emissions and environmental degradation, while chemical and nuclear industries face heightened expectations regarding waste management and long-term environmental risk mitigation (Duttagupta et al., 2021). Consequently, sustainability has emerged as a central strategic concern alongside traditional safety objectives. In this context, sustainability extends beyond environmental protection to include social responsibility, ethical labor practices, efficient resource utilization, and the proactive management of long-term environmental and societal risks.

The growing emphasis on sustainability has prompted a shift in how safety and environmental objectives are conceptualized and implemented within high-risk industries. Rather than treating sustainability and safety as separate or potentially competing priorities, organizations are increasingly recognizing their interdependent and mutually reinforcing nature. Integrating sustainability with operational safety involves designing and managing industrial processes in ways that simultaneously reduce environmental impacts and enhance workplace safety. For example, reducing the use of hazardous chemicals not only minimizes environmental contamination but also lowers the risk of worker exposure and industrial accidents. Similarly, improving energy efficiency and adopting cleaner technologies can reduce greenhouse gas emissions while decreasing the likelihood of equipment failures and fire hazards associated with high-energy consumption (Marotta & Madnick, 2021; Sharma et al., 2019).

Sustainability-driven safety practices also offer significant organizational benefits beyond risk reduction. Integrated approaches enhance regulatory compliance by enabling companies to meet increasingly stringent environmental and safety standards, thereby reducing the likelihood of fines, legal disputes, or operational shutdowns. Moreover, strong sustainability and safety performance contributes to corporate reputation and supports the maintenance of a social license to operate, particularly in environmentally sensitive or community-facing regions (Noronha et al., 2022). In high-risk industries, sustainability initiatives such as carbon capture and storage in the oil and gas sector, green chemistry in chemical manufacturing, and improved fuel cycle efficiency and waste management in nuclear power generation aim to reduce long-term environmental and societal risks while strengthening operational resilience (Besha et al., 2020; Settembre-Blundo et al., 2021).

Within this evolving operational landscape, sustainability goals and operational safety are increasingly understood as deeply interconnected priorities. Risk management serves as a unifying framework through which both objectives can be effectively addressed, as sustainability and safety share the common goal of preventing harm to people, the environment, and organizational assets. Proactive risk management strategies that identify and mitigate potential hazards early enable organizations to reduce environmental impacts while enhancing operational reliability. Furthermore, technological innovation plays a critical role in facilitating the integration of sustainability and safety. Advances such as predictive maintenance systems, real-time monitoring technologies, and data-driven decision-making tools allow organizations to detect equipment failures, emissions, and environmental hazards before they escalate, thereby protecting workers, minimizing environmental damage, and improving overall system performance (de Waal et al., 2019; Bilderback, 2024).

MATERIALS AND METHODS

This qualitative study used a systematic review of the literature, thematic content analysis, and quantitative synthesis. The systematic review served to map IRM knowledge across high-risk industries. The search strategy used domain-specific keywords and Boolean operators across Scopus, Web of Science, ScienceDirect, PubMed, and IEEE Xplore for occupational safety and environmental risk assessment studies. For industry relevance and regulatory completeness, grey literature from OSHA, EPA, IAEA, API, and IChemE was included. After screening 519 records, 67 high-quality academic and regulatory documents met the inclusion criteria. Industry type, risk factors, safety practices, environmental controls, regulatory requirements, and reported outcomes were extracted through using a structured form.

Qualitative descriptions of the risk level were coded and normalized to the scale in those studies that did not report numerical values. Compare traditional or non-integrated and integrated risk management approaches in the literature to develop pre- and post-integration risk scores. Calculate improvements by using standard percentage-change formulas. Semi-structured interviews among safety managers, environmental officers, and compliance specialists validated the synthesized findings and assessed the real-world feasibility of the IRM framework.

RESULTS AND DISCUSSION

Table 1: Comparative Risk Scores – Before & After Integration

Industry	Avg. Risk Score (Before)	Avg. Risk Score (After)	% Improvement
Oil & Gas	8.2	4.9	40.2%
Chemical Industry	7.6	4.2	44.7%
Nuclear Power	6.8	3.5	48.5%

Table 1 illustrates the results of implementing an integrated system of safety and environmental risk management for the Oil & Gas, Chemical, and Nuclear Power industries. The Oil & Gas industry lowered its average risk score from 8.2 to 4.9, a percentage improvement of 40.2%. The Chemical industry improved from an average score of 7.6 to 4.2, an average percentage reduction of 44.7%. The Nuclear Power industry reduced its average risk score from an initial value of 6.8 to 3.5, a very significant 48.5% reduction. This clearly shows the benefits of a unified approach in reducing risks within high-stakes industries.

Table 2: Commonly Used Risk Mitigation Strategies in High-Risk Industries

Mitigation Strategy	Frequency in Studies (n=45)	Percentage (%)
Safety Management Systems (SMS)	38	84.4%
Environmental Monitoring and Control	35	77.8%
Emergency Response Planning	32	71.1%
Hazardous Material Handling Procedures	29	64.4%
Waste Reduction and Pollution Prevention	27	60.0%
Employee Training and Safety Drills	25	55.6%

Table 2 presents the safety and environmental risk mitigation strategies adopted by high-risk industries such as oil and gas, chemical manufacturing, and nuclear power plants. The most identified strategy isSMS, which is a proactive management approach towards safety risks, adopted in 84.4% of the research. This is followed by 77.8% of the studies adopting environmental monitoring and control strategies to manage emissions, waste, and other pollutants. Emergency response planning was cited by 71.1% of studies to ensure that responses to accidents are effectively handled to protect health and the environment. Handling hazardous materials was mentioned by 64.4% of studies, underlining safe storage and disposal. Furthermore, 60.0% of the studies focused on the implementation of cleaner technologies that reduce waste and prevent pollution. Lastly, 55.6% emphasized the training of staff through regular safety drills, preparing employees for emergency conditions and compliance with the safety legislations.

Table 3: Integration of Safety and Environmental Goals in Mitigation Strategies

Strategy Type	Safety Focus (%)	Environmental Focus (%)	Integrated (%)
SMS Implementation	90	60	66.7
Real-Time Monitoring Systems	75	80	71.1
Incident Reporting and Feedback Loops	85	50	60.0
ISO 14001 + ISO 45001 Compliance	70	85	80.0

Table 3 presents the integration of safety and environmental objectives in selected risk-reduction practices by high-risk industries. SMS tends to focus primarily on safety improvement (90% of studies) but also covers environmental concerns (60%). Indeed, 66.7% of studies combined both objectives in SMS. Real-Time Monitoring Systems showed a similar balance, with 75% focusing on safety and 80% on environmental issues, which resulted in an integration rate of 71.1%. Incident Reporting and Feedback Loops are mostly directed at safety improvement (85%), but only 50% deal with environmental an aspect, which yields an integration rate of 60.0%. In contrast, ISO 14001 + ISO 45001 Compliance shows strong integration of 80.0%, with 70% of studies focusing on safety and 85% on environmental objectives, which underlines that ISO standards are effective in integrating safety and environmental management.

Table 4: Major International Regulatory Frameworks in High-Risk Industries

Regulation/Standard	Governing Body	Applicable Sector	Focus Area
OSHA (29 CFR 1910)	U.S. Occupational Safety	Industrial Safety	Worker safety, hazard control
REACH	European Chemicals Agency	Chemical	Chemical safety, health, environment
ISO 45001	ISO	All	“Occupational health and safety”
ISO 14001	ISO	All	“Environmental management systems”
Seveso III Directive	European Union	Chemical	Major accident prevention

API RP 75	American Petroleum Institute	Oil & Gas	Safety and Environmental Management Systems (SEMS)

Table 4 presents some of the major international regulations relating to high-risk industries, including applicable industries, governing bodies, and key objectives that aim to enhance standards for safety, health, and the environment. Specifically, OSHA's 29 CFR 1910 standard addresses the safety of industries in terms of ensuring the safety of workers. The REACH regulation by the European Chemicals Agency focuses on chemical safety through risk assessments and hazard communications. ISO 45001 is the international standard for occupational health and safety management, while ISO 14001 deals with environmental management in industries. Seveso III Directive was laid down by the European Union to prevent industrial accidents in the chemical industry. API RP 75 deals with safety and environmental management for oil and gas industries.

Table 5: Comparative Risk Scores – Pre vs Post Regulatory Compliance

Industry	Pre-Compliance Risk Score	Post-Compliance Risk Score	% Risk Reduction
Oil & Gas	8.5	4.1	51.7%
Chemical	7.8	3.9	50.0%
Nuclear	6.9	3.2	53.6%

Table 5 shows the comparative risk scores of different industries before and after regulatory compliance measures. The significant reduction in the risk score shows that these measures are effective. The risk score of the oil and gas industry dropped from 8.5 to 4.1, a 51.7% reduction. The chemical industry risk score dropped from 7.8 to 3.9, a 50% reduction, while in the nuclear industry, the risk score dropped from 6.9 to 3.2, which indicates a 53.6% reduction.

CONCLUSION

This paper discusses integrated risk management for safety and environmental sustainability in such high-risk industries as oil and gas, chemicals, and nuclear power. While safety systems are relatively advanced, environmental frameworks are less so, which results in limited integration. The literature indicates good improvement on safety matters but insufficient proactive approaches to the environment. Gaps that were identified include a lack of longitudinal studies and the need for increased, appropriate representation of sectors such as mining. Such integrated frameworks do reduce risk scores, although it faces barriers like silos, misaligned policies, and weak collaboration. Among the recommended strategies in this regard are unified frameworks, new technologies, training for personnel, and closer stakeholder relationships to support effective and sustainable risk management.

REFERENCES

1. Thompson, S. (2023). Strategic analysis of the renewable electricity transition: power to the world without carbon emissions?. Energies, 16(17), 6183.
2. Alnabhani, K., & Khan, F. (2019). Nuclear radioactive materials in the oil and gas industry. Elsevier.
3. Derdowski, L. A., & Mathisen, G. E. (2023). Psychosocial factors and safety in high-risk industries: A systematic literature review. Safety science, 157, 105948.
4. Duttagupta, A., Islam, M., Hosseinabad, E. R., & Zaman, M. U. (2021). Corporate social responsibility and sustainability: a perspective from the oil and gas industry. Journal of Nature, Science & Technology, 2, 22-29.
5. Marotta, A., & Madnick, S. (2021). Convergence and divergence of regulatory compliance and cybersecurity. Issues in Information Systems, 22(1).
6. Sharma, Y. K., Mangla, S. K., Patil, P. P., & Liu, S. (2019). When challenges impede the process: For circular economy-driven sustainability practices in food supply chain. Management Decision, 57(4), 995-1017.
7. Noronha, E., Jain, P., Puri, D., Misra, A., Shah, P., Patel, M., . . . Bhargava, P. (2022). Social Compact: Co-creating socially responsible businesses the Indian way. Vikalpa, 47(2), 119-190.
8. Besha, A. T., Liu, Y., Bekele, D. N., Dong, Z., Naidu, R., & Gebremariam, G. N. (2020). Sustainability and environmental ethics for the application of engineered nanoparticles. Environmental Science & Policy, 103, 85-98.
9. Settembre-Blundo, D., González-Sánchez, R., Medina-Salgado, S., & García-Muiña, F. E. (2021). Flexibility and resilience in corporate decision making: a new sustainability-based risk management system in uncertain times. Global Journal of Flexible Systems Management, 22(Suppl 2), 107-132.
10. Jagoda, K., & Wojcik, P. (2019). Implementation of risk management and corporate sustainability in the Canadian oil and gas industry: An evolutionary perspective. Accounting Research Journal, 32(3), 381-398.
11. Bilderback, S. (2024). Integrating training for organizational sustainability: the application of Sustainable Development Goals globally. European Journal of Training and Development, 48(7/8), 730-748.

12. De Waal, A., Weaver, M., Day, T., & Van der Heijden, B. (2019). Silo-busting: Overcoming the greatest threat to organizational performance. Sustainability, 11(23), 6860.