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Integrating sustainability and safety in high-risk industries: A framework for balancing operational efficiency and environmental responsibility

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Abstract

The integration of sustainability and safety in high-risk industries, such as oil and gas, chemical manufacturing, and nuclear power, presents a complex but necessary challenge. These industries must balance operational efficiency with environmental responsibility while ensuring the highest safety standards for their workforce. This paper explores the interrelationship between sustainability goals and safety practices, examining best practices for achieving this balance and the role of technological innovations, such as predictive maintenance, the Internet of Things (IoT), and artificial intelligence (AI), in facilitating these efforts. Key obstacles, including financial constraints, regulatory complexity, and cultural resistance within organizations, are discussed, alongside policy and regulatory support opportunities. The paper also highlights future trends, such as the adoption of circular economy principles and renewable energy, which are likely to shape the integration of sustainability and safety moving forward. Recommendations for industry stakeholders, policymakers, and researchers emphasize the importance of adopting a holistic approach, investing in technology, and fostering collaboration across disciplines to create a more sustainable and safer operational environment.

Keywords: Sustainability; Safety; High-risk industries; Predictive maintenance; Environmental responsibility; Operational efficiency

1 Introduction

1.1 Overview of High-Risk Industries

High-risk industries, such as oil and gas, chemical manufacturing, and nuclear power generation, play a critical role in powering the global economy. These sectors are essential for producing energy, chemicals, and materials that are the backbone of various industries and consumer needs (Thompson, 2023). However, the processes involved in these industries often come with significant risks to human safety and the environment. The operations in high-risk industries involve handling hazardous materials, managing complex machinery, and operating under extreme conditions. For instance, oil rigs and refineries handle flammable and toxic substances, while nuclear plants deal with radioactive materials that, if improperly managed, can lead to catastrophic consequences (Alnabhani & Khan, 2019).

The unique challenges faced by high-risk industries make prioritizing safety practices designed to protect workers, surrounding communities, and the environment essential. Safety measures often include rigorous protocols, protective equipment, emergency response systems, and constant monitoring of operational processes (Derdowski & Mathisen, 2023). Nonetheless, while safety has traditionally been the primary focus, there is increasing pressure for these industries also to address their environmental footprint through sustainable practices. Both regulatory requirements

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and growing public awareness of environmental issues like climate change, pollution, and resource depletion drive this. For example, oil and gas companies face increasing scrutiny regarding their greenhouse gas emissions and the environmental degradation caused by drilling and refining processes (Duttagupta, Islam, Hosseinabad, & Zaman, 2021).

1.2 Importance of Integrating Sustainability with Safety Practices

The convergence of sustainability and safety is not merely a regulatory requirement or a public relations effort—it is becoming a strategic imperative. High-risk industries are under growing pressure to operate safely and sustainably. Integrating sustainability into safety practices means more than reducing emissions or waste; it involves designing operations that ensure long-term environmental, social, and economic viability. Sustainable safety management implies that safety protocols and environmental goals should not be treated as separate, sometimes competing objectives but as complementary aims that can reinforce one another (Marotta & Madnick, 2021). For instance, reducing the use of toxic chemicals in industrial processes lowers the risk of accidents and worker exposure to hazardous substances and decreases environmental pollution. Similarly, energy-efficient technologies, such as renewable energy integration in chemical plants or refineries, reduce carbon footprints while minimizing operational risks related to energy supply disruptions. Implementing sustainability-focused safety strategies, like circular economy practices, ensures that materials are reused, waste is minimized, and resource efficiency is prioritized, benefiting both the company's bottom line and the environment (Sharma, Mangla, Patil, & Liu, 2019).

Furthermore, integrating sustainability into safety protocols enhances regulatory compliance. Governments worldwide are tightening regulations around environmental and safety standards. By adopting integrated approaches, companies can stay ahead of regulatory changes and avoid costly fines, legal challenges, or shutdowns. Additionally, sustainability-driven safety can contribute to a company's corporate social responsibility (CSR) profile, enhancing its reputation and securing social license to operate—especially in environmentally sensitive regions where community opposition can derail projects (Noronha et al., 2022).

1.3 Objective and Scope of the Paper

This paper explores and examines strategies for integrating sustainability goals with safety practices in high-risk industries. The focus is on ensuring that these industries can operate efficiently while minimizing their environmental impact. The objective is to provide a comprehensive framework that highlights how sustainability and safety practices can be intertwined to create a synergistic effect, leading to operational efficiency, enhanced safety outcomes, and reduced environmental damage.

The paper will delve into various strategies that industries can adopt to integrate sustainability with safety. It will explore case studies and best practices from different sectors, particularly the oil and gas, chemical manufacturing, and nuclear power industries, where these challenges are most pronounced. Additionally, it will look at how technological innovations, such as advanced sensors, artificial intelligence (AI), and big data analytics, drive both safety and sustainability efforts. These technologies enable more precise monitoring and management of operations, allowing companies to mitigate risks in real time while reducing their environmental impact.

The scope of the paper also extends to discussing the challenges and opportunities in achieving this integration. High-risk industries face unique obstacles, such as the high upfront costs of implementing sustainable practices and the complexity of retrofitting old systems with new technologies. Moreover, organizational culture and resistance to change can pose significant hurdles. However, these challenges also present opportunities for innovation, particularly as global environmental standards evolve, and consumer expectations shift toward more responsible corporate behavior.

This exploration will be structured into several key sections. First, the paper will provide an in-depth overview of sustainability and safety within high-risk industries, discussing how these concepts are currently approached. Following this, it will focus on the specific strategies that companies can implement to align safety and sustainability goals. The third section will analyze the challenges industries face when integrating these practices and propose potential solutions. Finally, the paper will conclude with a set of recommendations for policymakers, industry leaders, and researchers, suggesting pathways for further research and implementation to ensure that high-risk industries can continue to meet both safety and sustainability demands in the future.

In sum, this paper seeks to address a critical gap in current operational frameworks in high-risk industries by providing insights into how sustainability and safety can be integrated more effectively. By doing so, the paper hopes to contribute to the broader discourse on how industries can balance operational efficiency with environmental responsibility, ensuring a more sustainable and safer future for both workers and the planet.

2 Sustainability and Safety in High-Risk Industries

2.1 Defining Sustainability in High-Risk Sectors

Sustainability in high-risk industries refers to the ability of these sectors to operate in ways that meet present needs without compromising the ability of future generations to meet their own. This concept has evolved significantly over recent years, driven by increased global awareness of industrial activities' environmental and social impacts. For high-risk sectors like oil and gas, chemical manufacturing, and nuclear power, sustainability involves minimizing negative environmental impacts, reducing resource consumption, and ensuring that long-term environmental and social risks are effectively managed (Settembre-Blundo, González-Sánchez, Medina-Salgado, & García-Muiña, 2021).

Sustainability in these industries is not limited to environmental concerns. It encompasses a broad range of issues, including the ethical treatment of workers, safe disposal of hazardous materials, efficient use of energy and resources, and the development of technologies that can mitigate the adverse effects of industrial activities (Ostad-Ali-Askari, 2022). For example, sustainability efforts in the oil and gas sector include reducing carbon emissions through carbon capture and storage technologies and transitioning toward renewable energy sources. Similarly, chemical manufacturers are increasingly adopting green chemistry principles, which aim to design products and processes that reduce or eliminate the use and generation of hazardous substances. In the nuclear power industry, sustainability efforts involve improving the efficiency of nuclear fuel cycles and enhancing the safety and security of nuclear waste management systems (Besha et al., 2020).

The importance of sustainability in high-risk industries is growing as these sectors face increasing pressure from regulators, investors, and the public to adopt more environmentally and socially responsible practices. Failure to address sustainability concerns can result in reputational damage, regulatory fines, and lost business opportunities. Therefore, sustainability is a moral and environmental imperative and a strategic business consideration for high-risk industries (Jagoda & Wojcik, 2019).

2.2 Common Safety Practices and Challenges

Safety is a fundamental priority in high-risk industries due to the inherent dangers associated with their operations. Safety practices are designed to protect workers, communities, and the environment from accidents, spills, and other potentially catastrophic events. In industries such as oil and gas, chemical manufacturing, and nuclear power, safety protocols are highly regulated and must comply with stringent industry standards and government regulations. These protocols often include hazard identification, risk assessment, emergency response planning, and continuous monitoring of operations to prevent accidents (Williams, 2019).

Common safety practices in high-risk industries include using personal protective equipment (PPE), regular safety audits, employee training programs, and implementing safety management systems (SMS). SMS frameworks, such as the Occupational Safety and Health Administration (OSHA) guidelines, help organizations systematically manage safety risks by identifying potential hazards, assessing risks, and implementing controls to mitigate those risks. In the nuclear industry, safety practices also involve stringent protocols for handling radioactive materials, maintaining reactor containment systems, and conducting regular inspections of critical infrastructure to prevent leaks or failures (Wu & Tham, 2023).

Despite these well-established safety practices, high-risk industries face significant challenges in maintaining consistent safety standards. One of the primary challenges is the complexity of operations, which increases the likelihood of human error, equipment failure, or unexpected incidents. Additionally, the aging infrastructure in many sectors, such as the oil and gas industry, poses a growing risk to safety. Older equipment is more prone to breakdowns, which can lead to accidents, leaks, and other dangerous situations (Zhuravlyov, Khudyakova, Varkova, Aliukov, & Shmidt, 2019). Another challenge is balancing cost with safety. High-risk industries operate under significant financial pressures, and while safety is a priority, the cost of maintaining high safety standards can be prohibitive. Companies may face difficulties justifying investments in new safety technologies or infrastructure improvements, especially during economic downturns. Moreover, the globalization of operations in these sectors often leads to outsourcing production or services to countries with less stringent safety regulations, further complicating the enforcement of consistent safety standards (Glaeser & Poterba, 2020).

2.3 The Interrelationship Between Sustainability Goals and Operational Safety

There is a growing recognition that sustainability and safety are not separate objectives but are, in fact, deeply interconnected. Integrating sustainability goals with operational safety is crucial for long-term success in high-risk

industries. This interrelationship can be seen in several areas, such as risk management, resource efficiency, and technological innovation.

First, risk management serves as a bridge between sustainability and safety. Sustainable operations require minimizing the environmental risks associated with industrial activities, while safety management focuses on protecting workers and communities from accidents. Both goals share a common objective: preventing harm. For example, reducing the use of hazardous chemicals in manufacturing decreases the potential for environmental damage and enhances worker safety by limiting exposure to toxic substances. Similarly, implementing energy-efficient technologies in oil refineries can reduce greenhouse gas emissions while also lowering the risk of equipment malfunctions and fires associated with high-energy consumption.

Resource efficiency is another key area where sustainability and safety intersect. Sustainable practices that promote the efficient use of resources, such as water, energy, and raw materials, often lead to safer operations. For instance, minimizing water usage in chemical production reduces the likelihood of contamination or spillage, thereby enhancing both environmental sustainability and safety. In the nuclear industry, optimizing the fuel cycle to reduce waste contributes to sustainability and improves safety by reducing the volume of hazardous radioactive materials that must be managed and stored (Wilts & O'Brien, 2019).

Technological innovation plays a pivotal role in achieving both sustainability and safety goals. Technological advances, such as the development of predictive maintenance systems, enable companies to identify potential equipment failures before they occur, reducing operational risks and environmental impacts. Similarly, digital solutions like real-time monitoring systems can track emissions, leaks, and other environmental hazards, allowing for immediate corrective actions that protect both the environment and workers.

However, achieving the full integration of sustainability and safety in high-risk industries requires overcoming several challenges. One of the most significant obstacles is organizational culture. Many companies in these sectors still view sustainability and safety as separate functions, managed by different teams with distinct objectives and budgets. This siloed approach can lead to conflicts between environmental goals and safety priorities, especially when resources are limited. For example, a company may invest in sustainability initiatives that reduce emissions but fail to allocate sufficient funds to upgrade safety infrastructure, or vice versa (Al-Thani & Al-Ansari, 2021).

To overcome these challenges, high-risk industries need to adopt a more holistic approach to risk management that recognizes the interconnectedness of sustainability and safety. This requires fostering a corporate culture that prioritizes both goals equally and encourages cross-functional collaboration between environmental and safety teams. Additionally, companies must invest in training and capacity building to equip employees with the skills needed to implement integrated sustainability and safety practices effectively (Abd El-Mawla, Badawy, & Arafat, 2019).

3 Strategies for Integrating Sustainability and Safety

3.1 Best Practices for Balancing Operational Efficiency with Environmental Responsibility

The successful integration of sustainability and safety in high-risk industries requires the implementation of best practices that balance operational efficiency with environmental responsibility. Adopting a proactive risk management approach is one of the most effective ways to achieve this balance. Proactive risk management involves anticipating potential environmental and safety risks before they occur, rather than reacting to them after they have caused harm. This approach ensures that companies can identify and mitigate risks early, allowing them to operate more efficiently while reducing their environmental impact (Settembre-Blundo et al., 2021).

A key aspect of proactive risk management is the development of comprehensive environmental and safety policies that are embedded in the company's overall business strategy. These policies should clearly define the company's commitment to sustainability and safety, outline specific goals and targets, and provide a framework for monitoring progress. By integrating sustainability and safety objectives into the core business strategy, companies can ensure that these goals are not seen as separate or competing priorities, but as mutually reinforcing components of a successful operation (Jagoda & Wojcik, 2019).

In addition to developing strong policies, companies should also prioritize continuous improvement through regular safety audits and environmental impact assessments. These assessments help identify areas where sustainability and safety practices can be enhanced, ensuring that companies remain compliant with regulations and are constantly improving their performance. For instance, conducting regular energy audits can help identify inefficiencies in energy

usage, enabling companies to implement energy-saving measures that reduce both operational costs and environmental impacts. Similarly, safety audits can help identify potential hazards and ensure that safety protocols are being followed, reducing the risk of accidents and injuries (Settembre-Blundo et al., 2021).

Employee training is another critical best practice for integrating sustainability and safety. Workers must be equipped with the knowledge and skills necessary to carry out their tasks safely and environmentally responsibly. Regular training programs on safety procedures, environmental regulations, and the use of sustainable technologies are essential for fostering a culture of sustainability and safety within the organization. By ensuring that all employees understand the importance of these goals and how to achieve them, companies can create a workforce that actively promotes safety and environmental responsibility (Bilderback, 2024).

Finally, fostering collaboration between safety and environmental teams is essential for achieving integration. These teams often operate in silos within large organizations, focusing on their own specific goals without considering how they intersect. Breaking down these silos and encouraging cross-functional collaboration can lead to more effective solutions. For example, safety teams can work with environmental teams to develop protocols for handling hazardous materials in ways that minimize both the risk of accidents and the environmental impact of disposal. Collaboration also promotes knowledge sharing, allowing teams to learn from each other's experiences and improve their respective practices (de Waal, Weaver, Day, & van der Heijden, 2019).

3.2 Examples of Successful Integration

There are numerous examples of high-risk industries successfully integrating sustainability and safety. One such example is the oil and gas sector, where companies like Shell and BP have implemented sustainability-driven safety initiatives. These companies have recognized the interdependence of safety and sustainability, particularly in offshore drilling operations, where the risk of oil spills presents a significant threat to both worker safety and the environment.

Shell, for example, has adopted a comprehensive approach to integrating sustainability and safety through its "Goal Zero" initiative, which aims to achieve zero harm to people and the environment. As part of this initiative, Shell has implemented advanced safety technologies, such as automated systems for monitoring drilling operations in real-time (Sarokin, 2022). These systems help detect potential hazards before they escalate into major incidents, reducing the likelihood of oil spills and other environmental disasters. In addition, Shell has invested heavily in renewable energy projects, such as wind and solar, to reduce its reliance on fossil fuels and lower its carbon footprint. By aligning its safety protocols with its sustainability goals, Shell has managed to operate more efficiently while minimizing its environmental impact (Korfmacher, 2019).

Another example comes from the chemical manufacturing industry. BASF, one of the largest chemical producers in the world, has successfully integrated sustainability and safety by adopting the principles of green chemistry. Green chemistry focuses on designing chemical products and processes that minimize the use of hazardous substances, reduce waste, and improve energy efficiency (Andraos & Matlack, 2022). By incorporating these principles into its safety practices, BASF has been able to reduce the environmental impact of its operations while maintaining high safety standards. The company has also implemented circular economy practices involving recycling and reusing materials to minimize waste. This reduces the company's environmental footprint and enhances safety by reducing the need for hazardous raw materials (Grosse-Sommer, Grünenwald, Paczkowski, van Gelder, & Saling, 2020).

The nuclear power industry also provides a notable example of successful integration. The nuclear sector is one of the most heavily regulated industries in the world due to the significant safety and environmental risks associated with nuclear energy. Companies like EDF Energy have embraced sustainability as a core component of their safety strategies. EDF has implemented advanced reactor designs that are more energy-efficient and produce less nuclear waste, reducing both environmental and safety risks. The company also invests in robust safety measures, such as rigorous maintenance schedules and comprehensive emergency response plans, to ensure its operations remain safe for workers and the environment (Campbell, 2019).

3.3 Role of Technology and Innovation in Facilitating This Balance

Technology and innovation play a critical role in facilitating the integration of sustainability and safety in high-risk industries. Advances in technology have enabled companies to monitor and manage their operations more effectively, reducing both safety risks and environmental impacts. One of the most significant technological developments in recent years is the use of predictive maintenance systems. Predictive maintenance uses sensors and data analytics to monitor the condition of equipment in real-time and predict when maintenance is required. By identifying potential equipment failures before they occur, companies can prevent accidents, reduce downtime, and extend the lifespan of their

equipment (Jagoda & Wojcik, 2019). This enhances safety and promotes sustainability by reducing the need for new materials and energy to replace damaged equipment. Predictive maintenance is particularly valuable in industries such as oil and gas, where equipment failures can lead to catastrophic environmental disasters, such as oil spills (Settembre-Blundo et al., 2021).

The use of digital technologies, such as the Internet of Things (IoT) and artificial intelligence (AI), has also revolutionized the way high-risk industries approach sustainability and safety. IoT devices can monitor environmental conditions, such as air and water quality, in real-time, allowing companies to detect pollution and take corrective actions immediately. AI can be used to analyze vast amounts of data from sensors and other sources, helping companies optimize their operations for both safety and sustainability. For example, AI-powered systems can recommend energy-saving measures that reduce greenhouse gas emissions while maintaining operational efficiency (Taj & Zaman, 2022).

Furthermore, automation has significantly improved safety in high-risk industries by reducing the need for human intervention in hazardous environments. Automated systems can perform dangerous tasks, such as handling toxic chemicals or operating machinery in extreme conditions, thereby reducing the risk of accidents and injuries. At the same time, these systems can be designed to operate more efficiently, reducing energy consumption and minimizing waste (Jagatheesaperumal, Rahouti, Ahmad, Al-Fuqaha, & Guizani, 2021).

4 Challenges and Opportunities

4.1 Key Obstacles Industries Face in Implementing Both Sustainability and Safety Practices

The integration of sustainability and safety practices in high-risk industries faces several significant challenges. These industries, which include oil and gas, chemical manufacturing, and nuclear power, are under pressure to balance operational efficiency with environmental responsibility while maintaining the highest safety standards. Achieving this balance is not without its difficulties, as companies must navigate complex operational, financial, and cultural barriers. One of the most prominent obstacles is the inherent tension between short-term operational goals and long-term sustainability objectives (Duan et al., 2021). High-risk industries often prioritize short-term production targets and profitability, which can lead to the neglect of long-term investments in sustainability and safety. For instance, implementing sustainable technologies or upgrading safety infrastructure can be capital-intensive, with returns on investment realized only over extended periods. Companies, especially those operating under tight profit margins or during economic downturns, may be reluctant to allocate significant resources to these areas when immediate financial gains are not guaranteed (Nguyen, Safder, Kim, Heo, & Yoo, 2022).

Another challenge is the complexity of regulatory compliance. High-risk industries are subject to many regulations governing safety and environmental practices. Navigating these regulatory frameworks can be difficult, especially when different regions and countries have varying requirements. Inconsistent regulations across jurisdictions make it harder for multinational companies to adopt uniform sustainability and safety practices. Furthermore, frequent changes in environmental policies can create uncertainty for businesses, complicating long-term planning and investment in sustainable and safe practices (Lindøe & Baram, 2019).

Technological limitations also pose a challenge. While significant advancements in technologies have been designed to enhance sustainability and safety, these innovations are often costly to implement and maintain. Additionally, older facilities with aging infrastructure may not be compatible with newer, more sustainable technologies, making it difficult for companies to upgrade without significant investments. Adopting technologies such as predictive maintenance systems, real-time environmental monitoring, and automated safety controls requires financial resources and technical expertise that may not be readily available in all organizations (Shah et al., 2021).

Cultural resistance within organizations is another key obstacle. In many high-risk industries, a deeply ingrained culture views sustainability and safety as separate or secondary to core business operations. Breaking down these cultural barriers requires a fundamental shift in how companies view sustainability and safety. Employees at all levels, from management to front-line workers, must be engaged in the process of integrating these practices into everyday operations. Without this cultural shift, efforts to integrate sustainability and safety may be met with resistance, reducing their effectiveness (Xu, 2024).

4.2 Opportunities for Policy and Regulatory Support

Despite the challenges, there are numerous opportunities for policy and regulatory support to drive the integration of sustainability and safety in high-risk industries. Governments and regulatory bodies play a critical role in shaping the

operational landscape for these sectors, and well-designed policies can encourage companies to adopt more sustainable and safer practices. One key opportunity lies in the development of incentive-based policies. Governments can provide financial incentives to companies that invest in sustainable technologies or enhance their safety protocols, such as tax credits, grants, or subsidies. For example, tax breaks for companies that adopt renewable energy sources or implement carbon capture and storage systems can encourage more businesses to integrate sustainability into their operations. Similarly, grants for research and development in safety technologies can spur innovation and help industries develop safer production and resource management methods (Nayak & Jespersen, 2022).

Regulatory frameworks can also promote the integration of sustainability and safety by setting clear and consistent standards for industries to follow. For instance, policies that mandate the use of environmentally friendly materials or limit emissions can push companies toward more sustainable practices. Safety regulations that require regular audits and inspections can ensure that companies maintain high safety standards while integrating sustainability goals. Harmonizing these regulations across different regions and industries can reduce the complexity of compliance for multinational companies, making it easier for them to adopt uniform practices (Cagno, Neri, Howard, Brenna, & Trianni, 2019).

Another opportunity for policy support is the promotion of public-private partnerships (PPPs). These partnerships can facilitate collaboration between governments, industry leaders, and research institutions to develop innovative solutions for integrating sustainability and safety. By pooling resources and sharing knowledge, PPPs can accelerate the development of new technologies and practices that enhance both safety and environmental responsibility (Wang & Ma, 2021). Governments can also support industry-led initiatives by providing funding for pilot projects that test and demonstrate the effectiveness of integrated sustainability and safety practices in real-world settings (Kang, Mulaphong, Hwang, & Chang, 2019).

Education and training programs supported by government policies can also play a vital role in fostering a culture of sustainability and safety within industries. Governments can work with educational institutions and industry associations to develop certification programs and training curricula that focus on sustainability and safety integration. These programs can help build a skilled workforce that understands the importance of these issues and is equipped to implement best practices in their daily operations. Additionally, governments can require companies to invest in employee training as part of their regulatory compliance, ensuring that workers at all levels are engaged in the process of integrating sustainability and safety (Adebayo, Ikevuje, Kwakye, & Emuobosa, 2024).

4.3 Future Trends and Developments in Sustainability and Safety Integration

The future of sustainability and safety integration in high-risk industries is likely to be shaped by several emerging trends and technological advancements. One of the most promising trends is the increasing use of digitalization and automation to enhance both safety and environmental performance. Technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics are revolutionizing the way companies monitor and manage their operations. These technologies enable real-time monitoring of safety conditions and environmental impacts, allowing companies to detect potential hazards and inefficiencies before they escalate into larger problems (Adebayo, Ikevuje, Kwakye, & Esiri, 2024b; Olajiga, Olu-lawal, Usman, & Ninduwezuor-Ehiobu, 2024).

For instance, AI-powered predictive analytics can help companies anticipate equipment failures and prevent accidents by identifying patterns in operational data. IoT devices can continuously monitor emissions, water usage, and other environmental factors, providing companies with the information they need to optimize resource use and reduce their environmental footprint. These digital tools can also improve worker safety by automating dangerous tasks and providing real-time data on workplace conditions, enabling faster responses to emergencies (Adebayo, Ikevuje, Kwakye, & Esiri, 2024a; Aderamo, Olisakwe, Adebayo, & Esiri, 2024a, 2024b).

Another emerging trend is the growing emphasis on circular economy principles in high-risk industries. The circular economy promotes the idea of designing products and processes that minimize waste and maximize resource efficiency by reusing materials and recycling products at the end of their life cycle. Adopting circular economy practices in industries such as chemical manufacturing and oil and gas can significantly reduce environmental impact while enhancing safety. For example, recycling hazardous materials can reduce the need for the extraction of new raw materials, which often involves dangerous and environmentally damaging processes (Samira, Weldegeorgise, Osundare, Ekpobimi, & Kandekere, 2024).

The shift toward renewable energy is also likely to play a significant role in the future of sustainability and safety integration. High-risk industries, particularly those involved in fossil fuel extraction and energy production, are

increasingly being pushed to transition toward cleaner energy sources. The adoption of renewable energy technologies, such as wind, solar, and hydrogen, not only reduces carbon emissions but also decreases the safety risks associated with fossil fuel extraction and processing. As renewable energy technologies become more cost-effective and accessible, high-risk industries will have more opportunities to align their operations with sustainability and safety goals (Aderamo, Olisakwe, Adebayo, & Esiri; Ekpobimi, Kandekere, & Fasanmade, 2024; Hamdan, Al-Salaymeh, AlHamad, Ikemba, & Ewim, 2023).

5 Conclusion

The integration of sustainability and safety in high-risk industries, such as oil and gas, chemical manufacturing, and nuclear power, is a critical yet complex challenge. Significant operational risks characterize these industries, and the potential environmental impacts are substantial, necessitating a balanced approach that prioritizes both environmental responsibility and worker safety. In reviewing key strategies, we have identified best practices such as proactive risk management, continuous improvement through audits, and fostering collaboration between environmental and safety teams. Examples from industry leaders like Shell, BASF, and EDF demonstrate the potential for success when sustainability and safety are treated as interrelated goals.

Technological innovations, including predictive maintenance systems, automation, and the application of the Internet of Things (IoT) and artificial intelligence (AI), have emerged as powerful tools for facilitating this balance. These technologies enable companies to monitor operations in real-time, optimize resource use, and prevent accidents, creating a more efficient and safer operational environment. Moreover, policy support through incentives, regulatory frameworks, and public-private partnerships has been shown to enhance the adoption of integrated sustainability and safety practices. Although there are notable challenges, such as financial constraints, technological limitations, and cultural resistance within organizations, the growing emphasis on digitalization, circular economy principles, and renewable energy presents opportunities for future improvements.

5.1 Recommendations

Recommendations for Industry Stakeholders

The key recommendation for industry stakeholders, particularly companies in high-risk sectors, is to adopt a holistic approach to sustainability and safety. Rather than treating these two objectives as separate priorities, companies should integrate them into a unified operational strategy. This can be achieved by embedding sustainability and safety goals into corporate policies and business plans. Companies should invest in modern technologies such as AI, IoT, and predictive maintenance systems to enhance both safety and environmental performance. Furthermore, continuous employee training on sustainable practices and safety protocols is essential in building a culture that values long-term environmental and safety outcomes alongside short-term operational goals.

Collaboration across departments within organizations is also crucial. Environmental and safety teams must work together to develop comprehensive strategies for managing hazardous materials, reducing emissions, and preventing accidents. Cross-functional collaboration fosters innovation and ensures that sustainability and safety are not viewed in isolation but as mutually reinforcing priorities.

Recommendations for Policymakers

Policymakers play a critical role in encouraging the integration of sustainability and safety in high-risk industries. Governments should implement incentive-based policies, such as tax breaks and grants, to encourage companies to invest in sustainable technologies and safety enhancements. Clear and consistent regulatory frameworks are needed to ensure that companies can easily navigate environmental and safety requirements. Policymakers should also focus on harmonizing regulations across regions and industries, simplifying compliance for multinational organizations.

In addition, fostering public-private partnerships can facilitate knowledge sharing and resource pooling, accelerating innovation in sustainability and safety. Governments can further support these efforts by promoting education and training programs that equip workers with the skills to implement sustainable and safe practices effectively.

Recommendations for Researchers

For researchers, the key recommendation is to continue exploring innovative technologies and methodologies that can enhance sustainability and safety in high-risk industries. More studies are needed to assess the long-term impact of integrating digital tools like AI and IoT on both operational efficiency and environmental responsibility. Researchers

should also focus on developing frameworks that can help industries transition to circular economy models, reducing waste and enhancing resource efficiency.

Moreover, interdisciplinary research that bridges the gap between environmental science, engineering, and safety management can provide new insights into how these sectors can collaborate to develop holistic solutions. Researchers should also contribute to the policy conversation by providing evidence-based recommendations to policymakers, ensuring that regulations support the latest advancements in sustainability and safety integration.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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