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Advances in Health, Safety, and Environment System Management Models in the Oil and Gas Industry: A Systematic Review

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ABSTRACT

This systematic review critically evaluates health, safety, and environment (HSE) management system models in the oil and gas industry from 2020 to 2025, addressing the gap between economic optimization and social performance considerations that previous studies have largely overlooked. Analysis reveals four key findings: (1) methodological shift from traditional deterministic tools (failure mode and effects analysis (FMEA) 35.29%) toward hybrid intelligent models (Fuzzy Multi-Criteria Decision Making-Fuzzy (MCDM) 23.53%, Bayesian Networks 5.88%), though operational adoption remains unclear; (2) extreme geographical concentration in Iran (64.71%) limits knowledge transferability; (3) research-risk misalignment with downstream operations dominating (35.29%) while critical offshore sectors under-represented (11.76%); (4) persistent gaps in safety culture, economic analysis, regulatory effectiveness, and energy transition implications despite quantitative method dominance (47.06%). The proposed Integrated HSE Risk Management Framework connects operational contexts, hybrid assessment tools, organizational enablers, and digital technologies, offering actionable guidance for organizations seeking to modernize HSE management systems while balancing economic efficiency with social responsibility. To the best of the authors' knowledge, this review constitutes a focused synthesis of post-2020 HSE within the oil and gas sector based on Scopus-indexed literature and advances a taxonomical framework capturing the evolution of methodological approaches. The analysis further identifies critical gaps, particularly in relation to offshore operations, cross-cultural validation, the integration of AI/ML techniques, and the implications energy transition. Nevertheless, it is important to acknowledge that the final dataset compromises only 17 studies; accordingly, the findings should be interpreted with due caution regarding their broader generalizability.

1. INTRODUCTION

The oil and gas industry operates within environments characterized by inherent high-consequence risks, complex operational systems, and significant environmental impacts that necessitate robust health, safety, and environment (HSE) management frameworks [1, 2]. As global energy demands continue alongside increasing regulatory scrutiny and environmental consciousness, sophisticated HSE risk management systems have become critical not only for accident prevention but also for operational sustainability and social license to operate. While historical catastrophic incidents such as Piper Alpha (1988, 167 fatalities) and Deepwater Horizon (2010, 11 fatalities) established the foundational imperative for HSE advancement, recent events demonstrate that catastrophic risks persist despite decades of system evolution. The Pemex E-Ku-A2 platform fire in the Gulf of Mexico (August 2021, 5 fatalities, 421,000 bpd production loss) [3], Freeport LNG explosion in Texas (June 2022, major facility damage) [4], and the Keystone Pipeline rupture in Kansas (December 2022, over 500,000 gallons spilled) [5] underscore that even with advanced technologies and regulatory frameworks, HSE failures continue to threaten worker safety, environmental integrity, and operational continuity, reinforcing the imperative for continuous innovation in risk assessment methodologies [6, 7].

Traditional risk assessment approaches such as failure mode and effects analysis (FMEA) and hazard and operability study (HAZOP), while foundational to industrial safety practices, face mounting challenges in addressing the dynamic complexity of modern petroleum operations spanning upstream exploration, midstream transportation, downstream refining, and offshore environments [8-10]. Recent research demonstrates growing adoption of hybrid methodologies combining advanced computational techniques with conventional tools to enhance risk prioritization accuracy under uncertainty [11-13]. These innovations respond to industry recognition that petroleum operations involve complex socio-technical systems where human factors, organizational culture, technological capabilities, and regulatory contexts interact in ways that linear risk models inadequately capture [14, 15].

Despite extensive HSE implementation globally and proliferating research on industrial safety management, significant knowledge gaps persist regarding the effectiveness of different risk management models specifically tailored to oil and gas operational contexts. The offshore sector continues presenting unique HSE challenges due to harsh environmental conditions, remote locations, and catastrophic failure potential [1, 16]. Furthermore, the industry's digital transformation-incorporating Internet of Things (IoT) sensors, Enterprise Resource Planning (ERP) systems, and artificial intelligence applications-introduces both opportunities and complexities for HSE management that existing literature has yet to comprehensively synthesize [17, 18].

Several critical factors create urgency for systematic review of recent HSE advancements in the petroleum sector. First, no recent systematic review has synthesized HSE risk management models specifically for this industry in the post-2020 era [12, 13, 17]. Second, the COVID-19 pandemic fundamentally altered HSE practices and revealed system vulnerabilities, necessitating reassessment of risk management frameworks [19, 20]. Third, the global energy transition toward net-zero emissions introduces unprecedented HSE challenges [2, 21]. Fourth, geographical concentration of HSE research raises questions about model transferability across diverse regulatory environments [22, 23]. Finally, economic implications of HSE investments require evidence-based justification [24]. This systematic review addresses these knowledge gaps by synthesizing advances in HSE risk management models for the oil and gas industry published between 2020 and 2025, following PRISMA 2020 guidelines [25].

The reason for the need for a literature review is mandatory, here is the list of the research questions (RQ) of this paper:

RQ1: "What geographical and sectorial patterns characterize the distribution of HSE research, and what gaps does this reveal?"

RQ2: "What methodological approaches and risk assessment tools characterize HSE management model development in the oil and gas industry from 2020 to 2025?"

RQ3: "What thematic gaps exist in current HSE management model research, particularly regarding safety culture, economic analysis, regulatory effectiveness, and digital transformation?"

RQ4: "What integrated framework can be proposed to guide future HSE risk management practice in the oil and gas sector?"

The review provides several significant contributions: to the best of the authors' knowledge, it offers one of the more focused syntheses of hybrid risk assessment methodologies within the post-2020 Scopus-indexed literature [11, 12, 13, 26], addresses critical literature gaps by mapping geographical research distribution patterns [22, 23, 27], enables evidence-based decisions by practitioners [18, 24, 28], and proposes an Integrated Oil and Gas HSE Risk Model Framework [16, 17, 29].

2. MATERIALS AND METHODS

2.1 Review protocol and guidelines

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement guidelines, which provide an evidence-based framework for transparent and complete reporting of systematic reviews [25]. The PRISMA methodology (Figure 1) ensures rigor through standardized processes for literature identification, screening, eligibility assessment, and data synthesis, thereby enhancing reproducibility and minimizing selection bias. As a systematic review of published research, this study did not involve human subjects or primary data collection. Therefore, approval from an ethics committee or institutional review board was not required.

2.2 Information sources and search strategy

Scopus was selected as the primary bibliographic database due to its comprehensive coverage of engineering, environmental science, and occupational health journals; rigorous indexing standards ensuring quality control; and broad international scope. The primary search string was: ("HSE" OR "Health Safety Environment" OR "HSE Management System") AND ("Risk Management" OR "Risk Assessment" OR "Hazard Identification") AND ("Oil and Gas" OR "Petroleum" OR "Hydrocarbon" OR "Refinery" OR "Pipeline" OR "Offshore"). The systematic search was conducted on November 8-11, 2025, restricted to journal articles published from January 2020 to December 2025 in English language.

2.3 Inclusion and exclusion criteria

The inclusion and exclusion criteria must be carefully defined to give a good review of literature, and to select only papers that are relevant to our research. Table 1 summarizes the complete inclusion and exclusion criteria.

Table 1. Summary of inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Peer-reviewed articles indexed in Scopus	Conference papers, book chapters, review articles, and grey literature
Published between January 2020 - December 2025	Studies published before January 2020
Explicitly focused on HSE management or risk assessment in oil and gas operations	Studies not specific to the oil and gas sector (e.g., construction, mining, manufacturing)
Empirical studies reporting primary data collection or secondary data analysis with an explicit, replicable methodology	Studies without a clearly described research methodology or data collection process
Conducted in oil and gas operational contexts: refineries, pipelines, offshore platforms, or upstream field operations	Studies addressing only general industrial safety without explicit oil and gas operational context
Written in English	Non-English language publications

2.4 Study selection process

The selection process followed a three-stage screening protocol. Stage 1 (n = 847): Initial database screening with automated duplicate removal; title and abstract screening against general HSE criteria. Stage 2 (n = 61): Full-text retrieval and detailed evaluation against inclusion/exclusion criteria; two independent reviewers with inter-rater reliability of Cohen's kappa $\kappa = 0.87$ (strong agreement). Stage 3 (n = 17): Oil and gas sector-specific filtering.

The combination of these criteria was anticipated to yield a relatively small final sample, as each filter independently narrows the eligible pool and their simultaneous application produces a narrow but methodologically coherent intersection. This is consistent with systematic reviews in highly specialized industrial domains, where research specificity, single-database reliance, and the prevalence of proprietary industry reporting outside academic indexing systems typically constrain the volume of eligible literature. The priority in this review is therefore methodological coherence over sample volume.

2.5 Quality assessment

Included studies underwent methodological quality appraisal using adapted AMSTAR 2 criteria, modified for primary empirical research in the oil and gas HSE domain. The framework evaluated seven dimensions: clear research objectives, appropriate study design, adequate data collection, appropriate analysis methods, clear results presentation, limitations discussion, and practical/theoretical contribution. Studies were classified as high quality (≥10/14 points), moderate quality (7-9/14), or low quality (<7/14). The 17 included studies yielded a mean quality score of 11.3/14 (SD = 1.2).

2.6 Data extraction and coding

A standardized data extraction form captured bibliometric data, study characteristics, oil and gas contextual information, HSE risk management focus, and theoretical and methodological contributions from each included study. Data were synthesized using descriptive statistics and thematic grouping to identify patterns across studies.

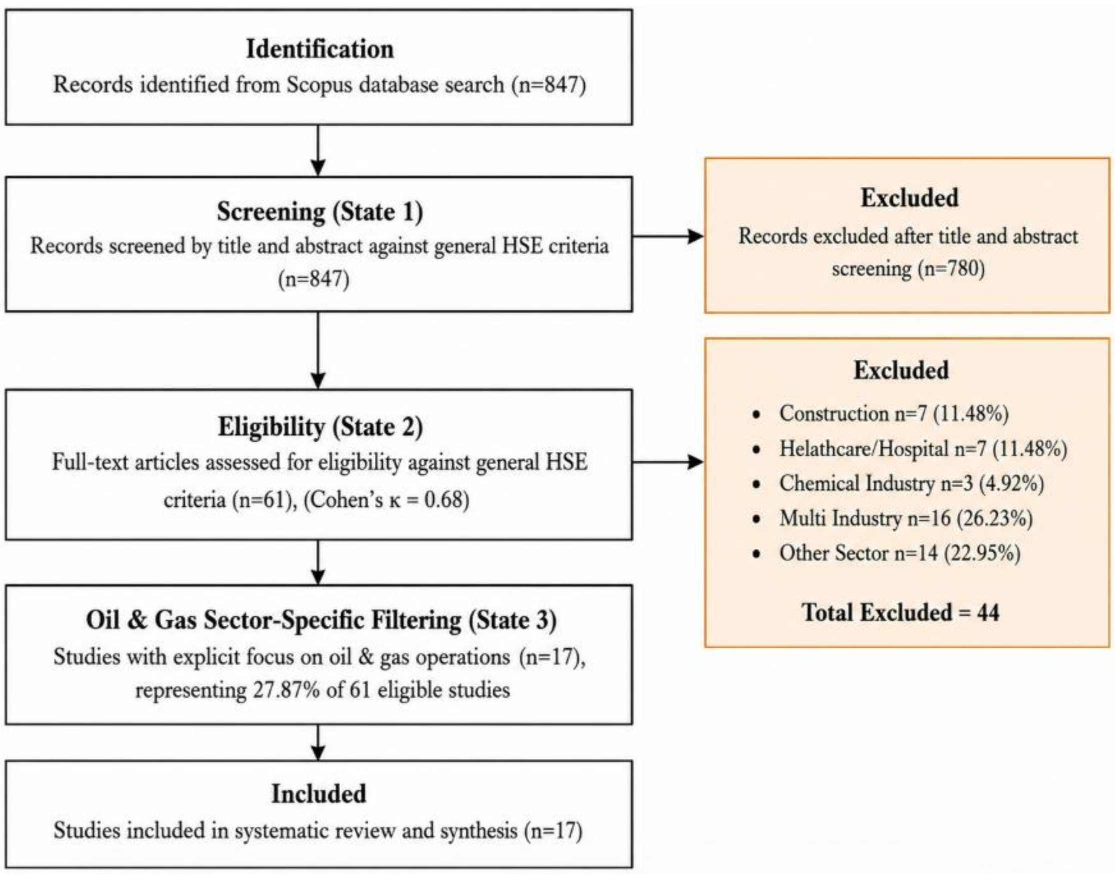

Figure 1. The PRISMA diagram

3. RESULT

The following presents detailed tables and graphs showing the findings obtained from the selected studies, in accordance with the basis and strategy mentioned earlier. This display includes information about the year of publication, the country where each study was conducted, and the methods used. In addition, a narrative analysis is provided to enable a deeper understanding of the trends and patterns identified in the included studies. This combination of tables, graphs, and narratives facilitates a clear and detailed representation of the results obtained in the research.

Furthermore, a co-occurrence analysis of keywords (Figure 2) from the studies found in the database was performed using the VOS viewer tool, which identified the most frequently used terms relevant to this research topic: HSE, HSE system, Risk Management, Oil and Gas industry.

3.1 Descriptive analysis

The final sample of 17 studies reflects the cumulative effect of multiple methodological constraints: the narrow eligibility intersection created by combining post-2020, Scopus-only, English-language, and oil and gas-specific filters; the five-year time window limiting cumulative publication volume; and the structural characteristic of this research domain whereby a substantial proportion of HSE research is conducted internally by major operators and disseminated as proprietary reports outside academic databases. This sample size should therefore be understood as a predictable and transparent outcome of the methodological design. All 17 included studies met stringent quality criteria with a mean AMSTAR 2 score of 11.3/14, ensuring findings reflect a coherent and high-quality evidence base. Given the small final sample (n = 17), all percentages reported in the following sections should be interpreted as descriptive proportions rather than statistically robust estimates. Each study accounts for approximately 5.88% of the total, and readers are advised to consider this when interpreting the distributional patterns.

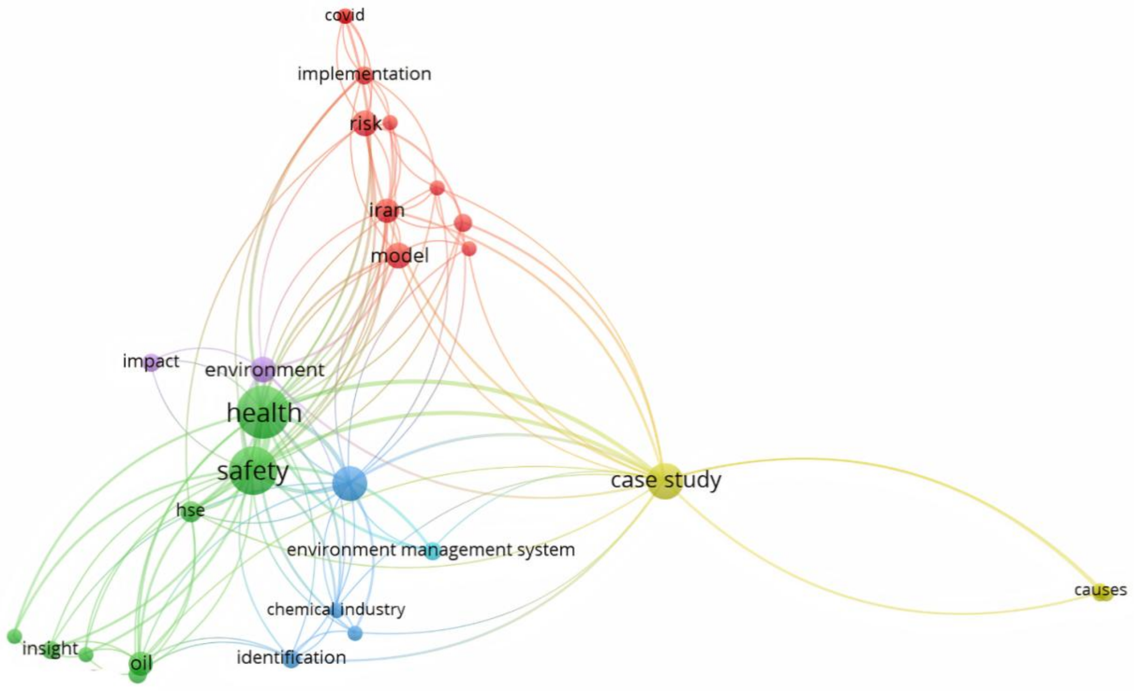

Figure 2. Keyword co-occurrence map

3.1.1 Publication trends

Temporal distribution of the 17 oil and gas HSE studies shows non-linear publication patterns (Figure 3). The temporal distribution demonstrates a peak in 2023 (35.29%, n = 6). The year 2020 showed 17.65% (n = 3), decreasing to its lowest in 2021 (5.88%, n = 1), then increasing in 2022 (11.76%, n = 2), peaking in 2023, followed by a decline in 2024 (11.76%, n = 2), and rebounding in 2025 to 17.65% (n = 3), suggesting sustained research momentum with post-COVID-19 recovery as a driver.

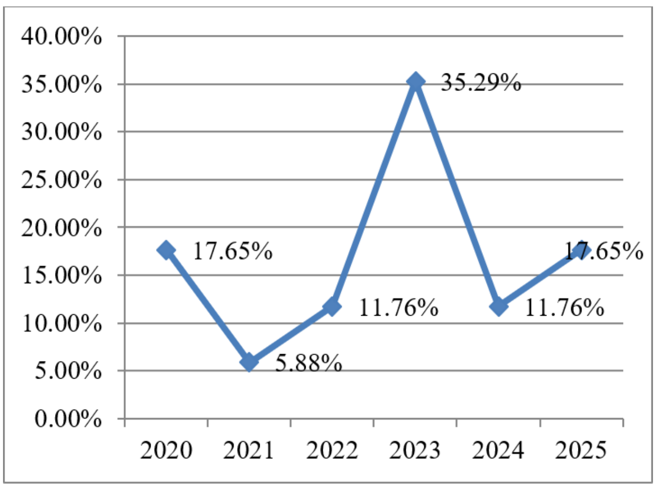

Figure 3. Annual publication distribution

3.1.2 Geographical distribution

Research origins show pronounced geographical concentration (Figure 4).

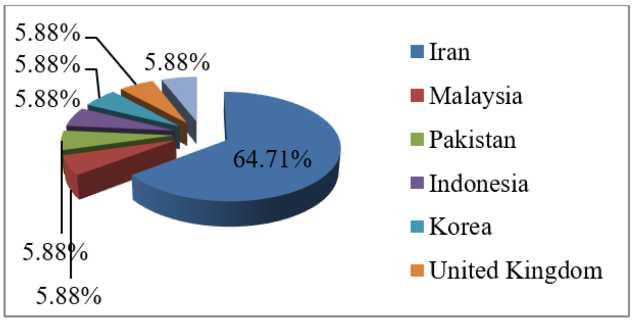

Figure 4. Geographical distribution of studies

Iran dominates with 64.71% (n = 11) of all oil and gas HSE studies, raising important questions about generalizability and cross-cultural validity. Several factors may explain this concentration. First, Iran holds the world's fourth-largest proven oil reserves and operates major facilities such as South Pars Gas Complex, creating strong domestic research incentives and access to industrial data. Second, Iranian academic institutions have established active HSE research programs supported by national funding priorities. Third, database bias is likely: Scopus indexes a higher proportion of Iranian HSE journals relative to similarly active research communities in Arabic-speaking countries or Sub-Saharan Africa. Fourth, proprietary research conducted by major Western and Gulf operators (e.g., Saudi Aramco, ExxonMobil, Equinor) rarely enters peer-reviewed academic literature. Fifth, linguistic barriers may systematically exclude non-

English research from regions such as Russia, China, or Latin America. These structural factors, rather than Iran's unique operational conditions alone, explain the observed concentration. The remaining six countries each contribute single studies (5.88%): United Kingdom, Indonesia, South Korea, Malaysia, Pakistan, and Ukraine [1, 2, 16, 18, 22, 26, 29]. Within Iranian research, South Pars Gas Complex appears in multiple studies [9, 27, 30-32], alongside Marun Oil Field [8], North-Azadegan Oil Field [10], and various gas refineries and pipeline operations [13, 33, 34].

3.1.3 Research methodology distribution

The 17 studies employed diverse methodological approaches (Figure 5).

Quantitative methods predominate (47.06%, n = 8), with mixed methods constituting the second largest proportion (35.29%, n = 6). Qualitative methods represent a smaller proportion (17.65%, n = 3), utilizing systematic review and case study approaches.

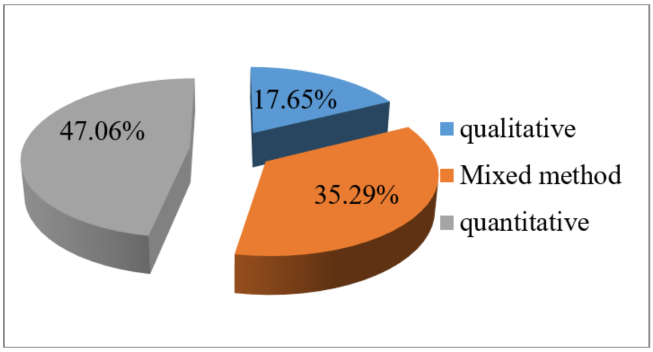

Figure 5. Methodological approaches

3.2 Operational sub-sector focus

Studies were categorized by primary operational focus within the oil and gas value chain (Table 2).

Downstream refining and gas processing operations receive the greatest research attention (35.29%), addressing refinery chemical exposure, hydrocarbon-rich sludge management, process safety, and environmental risks. Midstream pipeline operations and upstream exploration/production each constitute 23.53%. Midstream studies focus on pipeline excavation accidents, safety-conscious work environments, and sustainable safety practices. Upstream research examines workplace risk factors, field operations, economic aspects of HSE investment, and safety culture maturity. Offshore operations show modest representation (11.76%,), limited to UK Continental Shelf regulatory analysis and Korean offshore wind systems engineering. One study (5.88%) provides general hazard identification and risk assessment methods applicable across the oil and gas industry.

Table 2. Operational sub-sector distribution

Sub-Sector	Count	Study References
Downstream (Refining/Processing)	6	[8, 9, 11, 30-32]
Midstream (Pipeline/Transport)	4	[2, 13, 33, 34]
Upstream (Exploration/Production)	4	[8, 10, 24, 29]
Offshore Operations	2	[1, 16]
General/Multi-sector	1	[26]

3.3 HSE risk assessment methods and tools

Studies employed diverse analytical methods and tools (Table 3).

FMEA emerged as the most frequently employed method (35.29% of studies), applied in refinery sludge management, field operations, and hybrid model integration. To ensure consistent classification, methods in Table 3 are organized by analytical function rather than tool name alone. Specific techniques (e.g., FMEA, Fuzzy AHP) are nested under broader methodological categories (e.g., Failure Analysis, Fuzzy Multi-Criteria Decision Making), while broader approaches such as "Statistical Analysis" encompass multiple statistical tools applied for descriptive or inferential purposes. This structure distinguishes between individual techniques and overarching analytical paradigms, improving replicability of the classification.

Table 3. Risk assessment methods employed

Method Category	Specific Tools	Study Count	Representative Studies
Failure Analysis	FMEA (Failure Mode and Effects Analysis)	6	[8, 11, 30-32, 35]
Fuzzy Multi-Criteria Decision Making	Fuzzy AHP, Fuzzy TOPSIS, Fuzzy DEMATEL	4	[11, 13, 32, 35]
Probabilistic Methods	Bayesian Networks	1	[13]
Hazard Identification	Bow-Tie Analysis, Tripod Beta	2	[13, 33]
Risk Prioritization Indices	HARPI (Harmful Agents Risk Priority Index)	1	[10]
Atmospheric Modeling	AERMOD + SQRA	1	[31]
Systems Engineering	Requirements Analysis, V-Model	1	[16]
Project Management	PMBOK Risk Management Framework	1	[30]
Statistical Analysis	Regression, Correlation, Trend Analysis	2	[1, 9]
Qualitative Reviews	Comparative Method Analysis	2	[2, 26]
Economic Analysis	Cost-Benefit, ROI Evaluation	1	[24]
Maturity Assessment	Safety Culture Maturity Models	1	[29]

The most analytically significant finding from Table 3 is the methodological transition away from traditional deterministic tools toward hybrid intelligent models. FMEA, while still the most frequently employed method (35.29%), is increasingly integrated with fuzzy logic extensions rather than applied in its classical form-reflecting growing recognition that crisp Risk Priority Numbers inadequately capture the epistemic uncertainty inherent in petroleum operations. Fuzzy MCDM techniques (23.53%) represent the clearest expression of this shift, with Fuzzy AHP, Fuzzy BWM, Fuzzy TOPSIS, and

Fuzzy DEMATEL all appearing as components of hybrid frameworks. Notably, however, a critical gap remains: despite substantial Industry 4.0 investments in petroleum operations, advanced data analytics, machine learning, artificial intelligence, and digital twin technologies remain conspicuously absent from the HSE risk assessment methods identified in this review.

Beyond the dominant FMEA-to-Fuzzy MCDM transition, Table 3 also documents a range of specialized techniques each appearing in only one or two studies: Bayesian Networks for pipeline accident causation modeling, Bow-Tie and Tripod Beta for barrier analysis, AERMOD combined with SQRA for respiratory exposure assessment, HARPI for workplace risk prioritization, and PMBOK frameworks integrated with FMEA for project-level risk management. Statistical analysis methods and economic cost-benefit evaluation each appeared in a small number of studies. While this diversity indicates methodological breadth, the limited replication of each approach prevents robust comparison of their relative effectiveness.

3.4 Key variables and research themes

Analysis identified recurring variables and conceptual themes (Table 4).

Table 4. Key variables in oil and gas health, safety, and environment (HSE) research

Variable Category	Specific Variables	Study Count	Representative Studies
Risk Management Effectiveness	Incident rates, near-miss frequency, risk reduction, hazard control	9	[8-11, 13, 30, 31, 33, 35]
Safety Culture	Maturity level, organizational values, behavioral patterns, management commitment	2	[29, 34]
Regulatory Compliance	Regulatory performance, inspection outcomes, violation rates, enforcement effectiveness	1	[1]
Technology Infrastructure	Monitoring systems, ERP adoption, digital tools, equipment condition	2	[16, 18]
Stakeholder Engagement	Worker participation, community relations, management-worker communication	1	[29]
Economic Factors	HSE investment, cost-benefit ratios, accident costs, ROI	1	[24]
Environmental Protection	Emissions, waste management, environmental incidents, ecological impact	4	[8, 30-32]
Human Factors	Error probability, competency, training, fatigue, workload	1	[33]
Management Systems	HSEMS maturity, system integration, audit findings, certification	2	[18, 29]

Table 4 reveals a striking imbalance in research priorities. Risk Management Effectiveness dominates (52.94%), reflecting the field's primary orientation toward technical hazard control. However, the most analytically important finding is not what is studied most, but what is studied least. Economic Factors appear in only one study (5.88%), and Human Factors similarly in only one study (5.88%)-a significant gap given that human error is widely recognized as a primary contributor to major petroleum accidents and that economic justification is increasingly required for HSE investment decisions. Safety Culture, despite its established role in organizational safety performance, appears in only two studies (11.76%). Together, these absences suggest that current HSE research in oil and gas remains predominantly tool-focused while neglecting the organizational and economic dimensions that determine whether those tools are actually adopted and sustained in practice.

3.5 Sector-specific risk themes

The quality assessment revealed that all 17 included studies demonstrated high to moderate methodological quality. Eleven studies (64.71%) achieved high quality ratings (12-14 points) and six studies (35.29%) achieved moderate quality ratings (10-11 points). All studies demonstrated clear research objectives (100%), with 88.24% employing appropriately matched study designs, and 70.59% providing explicit discussion of study limitations.

4. DISCUSSION

This systematic literature review examined 17 oil and gas-specific studies on HSE risk assessment methodologies, revealing significant advances alongside persistent limitations. The analysis demonstrates a fundamental shift toward hybrid intelligent models integrating fuzzy logic, multi-criteria decision-making, and probabilistic reasoning. Traditional FMEA's reliance on crisp Risk Priority Numbers has been progressively replaced by fuzzy set theory applications. These fuzzy approaches systematically address epistemic uncertainty inherent in petroleum operations. However, a critical gap emerges. Despite substantial Industry 4.0 investments in petroleum operations, advanced data analytics, machine learning, artificial intelligence, and digital twin technologies remain conspicuously absent from HSE risk assessment research.

The overwhelming Iranian research concentration (64.71%) demands careful interpretation regarding knowledge generalizability. Iran's position as holder of the world's fourth-largest oil reserves creates powerful research incentives. South Pars Gas Complex alone appears in multiple studies, making it the single most studied facility in this review. This concentration creates interconnected transferability challenges. The conspicuous absence of major producers-United States, Saudi Arabia, Norway, Canada-likely reflects three factors: (a) terminology differences where these industries may use alternative safety frameworks not captured by the search string; (b) proprietary research conducted internally by major operators remaining inaccessible through academic databases; and (c) linguistic barriers systematically excluding non-Anglophone research traditions. Comparative analysis between Iranian HSE models and those from, for example, Norwegian offshore or US Gulf of Mexico operations would significantly strengthen knowledge transferability and is an important direction for future research.

The distribution across operational sector reveals a systematic research accessibility bias that significantly misaligns research effort with actual risk severity. The dominance of downstream studies (35.29%) compared to the critical underrepresentation of offshores research (11.76%) is inconsistent with inherently high-risk nature of offshore operations, as evidenced by major catastrophic events such as Piper Alpha, Deepwater Horizon and P-36 sinking. The predominance of theoretical work without real-scale industrial applications indicates that HSE risk assessment methodologies remain largely at laboratory stages. The complete absence of longitudinal designs prevents understanding HSE system evolution and intervention effectiveness sustainability.

Based on systematic evidence synthesis, the recurring findings across the 17 reviewed studies consistently point to four interrelated gaps: methodological fragmentation, geographical insularity, sector misalignment, and absence of digital integration. These gaps collectively motivated the design of an Integrated HSE Risk Management Framework requiring simultaneous attention to: (1) operational context defining hazard profiles, (2) risk assessment tools spanning traditional to hybrid intelligent models, (3) organizational enablers including safety culture maturity and management commitment, (4) digital infrastructure providing real-time monitoring and predictive analytics, and (5) continuous improvement cycles ensuring systematic evolution. These five components interact sequentially and in feedback loops: the operational context (1) shapes which risk assessment tools (2) are most appropriate; tool outputs inform organizational learning (3); digital infrastructure (4) enables real-time feedback from operations back into both tool selection and organizational processes; and continuous improvement cycles (5) drive iterative refinement of all preceding components. The causal loop diagram in Figure 6 maps these interactions explicitly. Figure 6 presents a Causal Loop Diagram illustrating the dynamic feedback mechanisms among HSE investment, technological capabilities, organizational maturity, and operational outcomes.

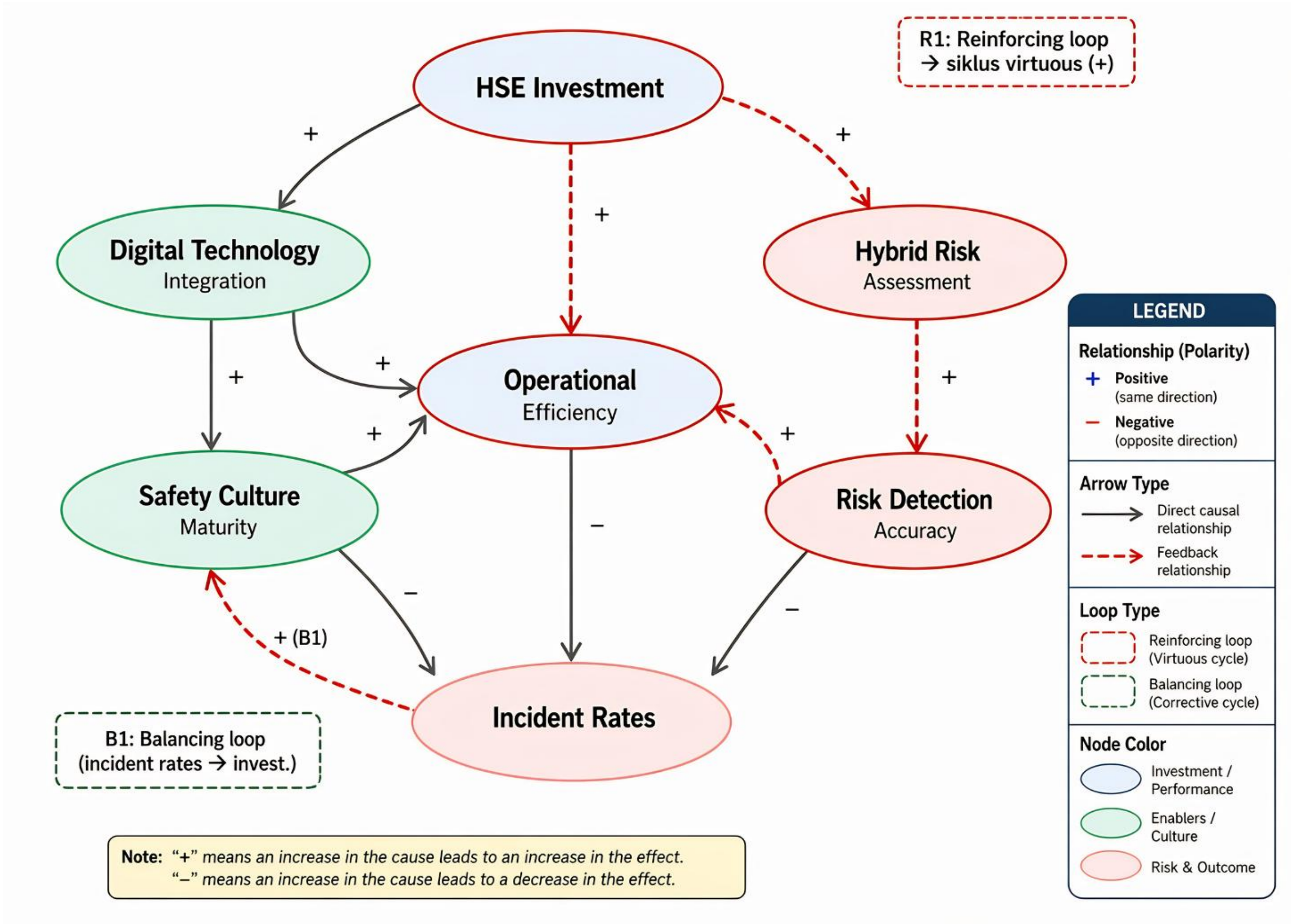

Figure 6. Causal loop diagram of integrated health, safety, and environment (HSE) management system dynamics in oil and gas operations

Figure 6 reveals the dynamic interplay through two critical feedback loops. The reinforcing loop (R1) illustrates how investment in hybrid risk assessment tools creates a virtuous cycle of improving risk detection accuracy and operational efficiency. The balancing loop (B1) demonstrates the corrective mechanism whereby incident rates drive investment that ultimately reduces future incidents. Safety Culture Maturity emerges as a key moderating factor, while HSE Investment functions as the central leverage point.

The causal relationships in the diagram were defined based on empirical evidence from the reviewed studies. The positive influence of HSE investment on both digital technology integration and hybrid risk assessment is supported by prior studies. Furthermore, the relationship between safety culture maturity and risk detection accuracy is grounded in findings from, emphasizing the role of organizational capability in improving risk management outcomes. In addition, the balancing (corrective) relationship between incident rates and

HSE investment is supported by economic and behavioural analyses, where increased incident rates trigger higher investment levels. The polarity signs (+/−) follow standard system dynamics conventions, where (+) indicates variables move in the same direction, while (−) denotes an inverse relationship.

5. CONCLUSIONS

This systematic review of 17 oil and gas HSE studies (2020-2025) reveals significant methodological advances alongside critical knowledge gaps constraining global HSE optimization. Four principal findings emerge from the evidence synthesis.

First, a paradigmatic shift is occurring from traditional deterministic tools (FMEA, HAZOP) toward hybrid intelligent models integrating fuzzy logic, multi-criteria decision-making, and probabilistic reasoning. Second, extreme geographical concentration in Iran creates knowledge transferability challenges, reflecting structural factors rather than universal industry characteristics. Third, research distribution misaligns risk severity, particularly offshore operations' critical under-representation despite generating catastrophic historical accidents. Fourth, critical thematic gaps persist in safety culture, economic analysis, regulatory effectiveness, and energy transition implications.

For future research, the following priorities are recommended: (1) Offshore Operations Research Expansion-deepwater operations, harsh environment operations, floating production systems; (2) Cross-Cultural and International Model Validation-regulatory effectiveness comparisons, cultural dimensions influencing safety behaviors; (3) Safety Culture Measurement and Development-culture assessment methodologies, development interventions; (4) Economic Analysis and Investment Optimization-cost-effectiveness analysis across interventions, risk-based budgeting frameworks; (5) Energy Transition HSE Implications-hydrogen production hazards, CO_2 capture and geological storage safety.

The proposed Integrated HSE Risk Management Framework translates into operational practice through a phased 5-to-7-year implementation approach: initial phase (Years 1–2) focusing on organizational readiness assessment; intermediate phase (Years 3–4) emphasizing digital technology integration; and maturation phase (Years 5–7) establishing continuous improvement cycles. Success metrics include measurable reductions in incident rates, improved risk prediction accuracy, enhanced regulatory compliance scores, and quantifiable ROI from HSE investments.

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STATEMENT ON THE USE OF GENERATIVE ARTIFICIAL INTELLIGENCE

The authors used generative AI tools, specifically ChatGPT (OpenAI) and Deepl, during the preparation of this manuscript for the following purposes: (1) to improve the readability and grammatical accuracy of the text, and (2) to assist with the initial organization of the literature review structure. These AI tools did not generate new scientific content, perform data analysis, or contribute to the interpretation of results. All AI-generated text has been critically reviewed, edited, and validated by the authors. The authors assume full responsibility for the content and integrity of this manuscript.

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