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(IJIREV)**www.gaexcellence.com/ijirev**INTEGRATIVE LITERATURE REVIEW ON RISK
MANAGEMENT IN PALM OIL MANUFACTURING**Umol Syamsyul Rakiman^{1*}, Hanis Marhaini Masri², Aizuddin Abdul Hamid³¹Department of Business Management, Universiti Teknologi MARA, Perak umolsyamsyul@uitm.edu.my <https://orcid.org/0000-0002-2059-2918>²Department of Business Management, Universiti Teknologi MARA, Perak hanismarhaini@uitm.edu.my <https://orcid.org/0009-0000-0521-4612>³Kilang Sawit Sungai Tenegang tenegangmill@yahoo.com NA

*Corresponding Author

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Abstract:

Worker safety, process integrity, environmental performance and increasingly demanding supply-chain requirements are the risk dimension which palm oil mills operate within. Separate evaluation of these issues limits understanding of how risks interact across the mill and the wider enterprise. This integrative literature review brings those issues together then develops a conceptual framework for palm oil manufacturing. Based on Torraco's review approach, a structured search of major academic, technical and institutional sources produced 32 documents for synthesis: 28 empirical or technical studies and 4 methodological or standards references. Four themes were identified: occupational safety; process and engineering safety; environmental and climate risk; and supply chain, regulatory and reputational risk. Within the reviewed literature, occupational and environmental risks receive comparatively greater attention, while process-safety governance and enterprise-wide integration are discussed less systematically. The proposed framework organises the evidence at three connected levels: micro-level task and workstation risks, meso-level plant-wide process and environmental risks, and macro-level supply-chain, ESG and enterprise risks. Linking these levels through ISO 31000-based governance offers a practical way to connect day-to-day controls with broader organisational decisions. Such integration may strengthen resilience, operational performance, compliance, waste valorisation and longer-term sustainability in the palm oil industry.

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Keyword:

Risk Management, Palm Oil Mill, Palm Oil Manufacturing, Occupational Safety, Process Safety, POME, Environmental Risk, Supply-Chain Risk, Value Creation, Integrative Literature Review



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Introduction

Palm oil milling sits at the centre of the agro-industrial economy in Malaysia, Indonesia and several other tropical countries. In a conventional mill, fresh fruit bunches (FFB) pass through sterilisation, threshing, pressing, clarification and kernel recovery before crude palm oil (CPO) and palm kernel products are obtained (González-Delgado et al., 2021). These operations create economic value, but they also bring together occupational hazards, high-pressure equipment, environmental emissions, climate-related exposure and reputational concerns associated with deforestation and labour practices (Myzabella et al., 2019; Razak et al., 2024).

At plant level, the risk profile is equally varied. Mill workers may encounter excessive noise and heat, moving machinery, manual handling of heavy materials, slippery work areas and biological hazards. Among the reported consequences are acute injuries, musculoskeletal problems and longer-term health effects (Myzabella et al., 2019; Ruslan et al., 2017; Wondi et al., 2020). HIRARC-based studies also consistently found that loading ramps, press plants, kernel plants and boiler houses as locations where high-risk tasks tend to take place (Ngadiman et al., 2019).

Process hazards are unique in its category due to failures that can escalate quickly. Boilers, steam systems, pressure vessels and storage tanks may contribute to fires, explosions or major equipment failure. This can happen when design, operating discipline or maintenance is inadequate (Menon, 2009; Hong, 2022; González-Delgado et al., 2021). Environmental performance creates a next layer of risk. POME, boiler emissions and solid residues such as EFB and fibre require consistent control. While poorly managed POME remains an important source of water pollution and methane emissions (Hosseini & Abdul Wahid, 2015; Yacob et al., 2006; Imam et al., 2024; Pallikodathan et al., 2025).

Risk also happens beyond the mill gate. Palm oil companies and their suppliers are increasingly assessed on deforestation, land-use change, labour and human-rights practices, traceability and compliance with regulations such as the EU Deforestation Regulation (EUDR). Weak performance during assessment in these areas can affect market access, financing and corporate reputation (CDP, 2023; EBRD, 2023; Musim Mas, 2025; Preferred by Nature, 2017).

Even though there is increasing number of works on those specific topics, the evidence is still fragmented. Occupational safety, process safety, environmental management and supply-chain sustainability are commonly in the same literature, despite of the fact that mill managers and corporate risk officers must manage them together. The lack of a more integrated synthesis makes it harder to translate ISO 31000, MSPO/RSPO and wider ESG expectations into a synchronised risk architecture for palm oil manufacturing (ISO, 2009; ISO, 2018; Razak et al., 2024).

This review tries to combine that fragment together. It directs the available evidence across occupational, process, environmental and supply-chain risk; compares the assessment tools and control approaches used in those domains; and then brings the findings together in a multi-level framework by referring to ISO 31000. The review also identifies areas where the evidence remains scarce and where possible improvement could better support safer and more sustainable mill operations.

Literature Review

Risk Management And ISO 31000 Principles

ISO 31000 defines risk management as coordinated activities for directing and controlling an organisation with regard to risk (ISO, 2009; ISO, 2018). Its emphasis is not limited to risk assessment. The standard also stresses integration with governance, a structured and comprehensive process, adaptation to organisational context, participation of relevant stakeholders, responsiveness to change and continual improvement. In practice, the cycle includes identification, analysis and evaluation, treatment, monitoring and review, together with communication and consultation (ISO, 2018; PECB, 2025).

For industrial organisations, this broad risk-management logic intersects with more specialised systems, including occupational safety and health requirements, ISO 45001, process safety management (PSM), ISO 14001 and sector schemes such as RSPO and MSPO. Palm oil mills require these systems to work together because their operations combine wet processing, high-temperature and high-pressure systems, biomass-based energy production and close links with upstream suppliers and downstream markets.

Palm Oil Manufacturing Processes And Risk Profile

A typical palm oil mill receives FFB from estates and smallholders and then subjects the crop to high-pressure steam sterilisation, threshing, mesocarp pressing, oil clarification and kernel recovery. At the same time, the mill must manage biomass and effluent streams generated throughout the process (Menon, 2009; Hong, 2022; González-Delgado et al., 2021).

Key risk nodes include:

FFB reception and loading ramp

Vehicle-pedestrian interaction, falling bunches and ergonomic strain from manual handling are recurring concerns (Ngadiman et al., 2019; Ruslan et al., 2017).

Sterilisation and press stations

Workers may be exposed to steam, hot condensate, moving press machinery and high-pressure pipelines, with the potential for scalding or explosion (Menon, 2009; Hong, 2022).

Boiler and power plant

Fibre- and shell-fired boilers combine pressure, superheated steam, combustible fuel and combustion emissions, making equipment integrity and operating control particularly important (González-Delgado et al., 2021; Moreno-Sader et al., 2020).

Clarification and effluent systems

Inadequate POME treatment can lead to water pollution and methane emissions, creating both compliance and reputational consequences (Hosseini & Abdul Wahid, 2015; Imam et al., 2024). Because these hazards occur at different points in the production chain, risk management should cover all related workstation or department. It has to cover all task, station, plant and supply-chain levels, drawing on both qualitative judgement and quantitative evidence.

Methodology: Integrative Literature Review

Review Design And Scope

Torraco's (2005, 2016) integrative literature review approach is adopted because the research question covers several bodies of knowledge rather than a single defined field. Evidence was drawn from occupational safety, process engineering, environmental management and supply-chain/ESG research. Peer-reviewed work was considered alongside relevant technical and institutional material where those sources contributed operational detail or supported the development of the conceptual framework.

Search And Selection

The search was carried out in English between October and December 2025. Major academic databases, industry sources and relevant institutional publications were examined across four domains: occupational safety; process and engineering safety; environmental and climate risk; and supply chain, regulatory and reputational risk. A document was retained when it dealt directly with risk in palm oil manufacturing and contained enough empirical, technical or conceptual detail to inform the synthesis. Studies focused only on upstream agronomy, broad commodity-level ESG discussions with no operational relevance, opinion pieces without transparent methods and sources with insufficient detail were excluded.

Table 1 shows the material retained after screening and removal of duplicates. The figures should therefore be read as the set of documents used in the conceptual synthesis, not as the total number of search results returned by each database.

Table 1. Included documents per search string (post-screening)

Search String Code	Focus Area	Example Databases / Sources	Number of Included Documents*
S1	Occupational / HIRARC risk in palm oil mills	Scopus, Web of Science, ScienceDirect, Google Scholar	9
S2	Process safety and engineering hazards in CPO processes	ScienceDirect, Scopus, IEEE Xplore, MPOB technical notes	7
S3	Environmental / POME and emissions-related risk	ScienceDirect, MDPI, industry reports	6
S4	Supply-chain, ESG and sustainability risk	CDP, EBRD, NGO and corporate reports, Scopus	6

*Does not include four additional methodological and standards documents (e.g., Torraco's integrative review articles and ISO 31000), which were added via backward citation and expert-guided searching.

After screening, 32 documents were taken forward. Of these, 28 were empirical or technical sources distributed across the four risk domains, while 4 were methodological or standards references identified through backward citation and expert-guided searching.

Screening And Synthesis

Screening was undertaken in two stages: titles and abstracts were reviewed first, followed by full-text assessment of potentially relevant documents. For each retained source, information was extracted on study setting, risk domain, method, principal findings, controls and implications for risk management. The material was then compared iteratively to identify recurring patterns, links between domains and gaps in the evidence, consistent with the integrative approach described by Torraco (2005, 2016).

Findings

Descriptive Overview Of The Literature

Across the 32 documents included:

- Researches that were published after 2015 are considered in this review, with more attention is given in recent years directed to sustainability, safety and ESG pressures in the palm oil sector (Myzabella et al., 2019; González-Delgado et al., 2021; Razak et al., 2024).

- Researchers that cover evidence from Malaysia, Indonesia and Colombia, all of which are geographically relevant in palm oil producing contexts (Myzabella et al., 2019; Moreno-Sader et al., 2020; Preferred by Nature, 2017).
- It included field measurements of noise, injuries and POME characteristics; structured methods such as HIRARC, HIRA and risk matrices; environmental and life-cycle tools including TRACI; and organisation-level sustainability frameworks used by institutions such as CDP and EBRD.

Table 2 describes the 28 empirical and technical sources across the four domains of risk.

Table 2. Distribution of empirical/technical documents by risk domain

Risk Domain	Typical Methods / Tools	Number of Documents (n = 28)	Representative Sources (Examples)
Occupational health and safety	HIRARC, noise measurement, injury statistics	9	Myzabella et al. (2019); Ruslan et al. (2017); Ngadiman et al. (2019); Wondi et al. (2020); Sulong et al. (2020)
Process safety and engineering hazards	HIRA, inherent safety indices, case studies	7	Menon (2009); Hong (2022); González-Delgado et al. (2021); Moreno-Sader et al. (2020)
Environmental / POME and emissions	POME characterisation, life cycle assessment (LCA), mitigation models	6	Hosseini and Abdul Wahid (2015); Imam et al. (2024); Pallikodathan et al. (2025)
Supply-chain / sustainability risk	ESG risk frameworks, investor guidance, sustainability assessment tools	6	CDP (2023); EBRD (2023); Preferred by Nature (2017); Musim Mas (2025); Razak et al. (2024)

Explanation

The distribution of studies is scattered. Attention is given more to occupational and environmental risks, partly because both are supported by established regulatory requirements and familiar assessment approaches such as HIRARC and environmental impact assessment. Process safety and supply-chain risk are less paid attention, and the available evidence relies more heavily on case studies and conceptual work than on multi-site analysis (Hong, 2022; CDP, 2023). This uneven supports the case for a more connected approach to worker safety, process integrity, environmental performance and enterprise-level ESG risk.

Theme 1: Occupational Safety

Main Occupational Hazards And Health Outcomes

Myzabella et al. (2019) found that workers in the palm oil sector, including mill personnel, is exposed to physical, ergonomic, chemical, biological and psychosocial hazards. The research finds effect such as musculoskeletal disorders and noise-induced hearing loss to infectious disease. Studies done in mills explain this situation further by locating recurrent hazards at the loading ramp, press plant, kernel plant and boiler house (Ruslan et al., 2017; Ngadiman et al., 2019; Wondi et al., 2020).

Table 3. Selected Studies On Occupational Risk In Palm Oil Mills

Study	Country context	Method(s)	Key hazards / risks identified	Key recommendations for risk management
Myzabella et al. (2019)	Global (systematic rev.)	Systematic review of 20+ studies	Heat stress, heavy loads, sharp tools, pesticides, vector-borne diseases	Comprehensive OSH programmes, training, PPE, surveillance
Ruslan et al. (2017)	Malaysia (mill workers)	Cross-sectional injury survey	High non-fatal injury rates in press plant; noise and heat as leading hazards	Engineering noise control, improved guarding, job rotation
Ngadiman et al. (2019)	Malaysia (mill)	HIRARC + ergonomic assessment	33 activities analysed; high risk in lifting FFB, changing SuperCracker rollers	Redesign of tasks, mechanical aids, enhanced lockout/tagout, training
Wondi et al. (2020)	Malaysia (mill)	Noise monitoring, questionnaire	Noise levels above permissible limits in press and turbine areas	Enclosed cabins, hearing protection programme, maintenance of equipment
Sulong et al. (2020)	Malaysia (oil palm labourers)	Questionnaire, factor analysis	Weak supervisory enforcement linked to under-reporting of safety issues	Strengthening supervisory enforcement and safety culture
Ahmad et al. (2020)	Malaysia (palm oil mill employees)	Questionnaire survey	OSH awareness was associated with behavioural and workplace factors in palm oil mill operations	Strengthen safety awareness programmes, employee behaviour, and organisational OSH practices

Study	Country context	Method(s)	Key hazards / risks identified	Key recommendations for risk management
Ahmad Naim et al. (2022)	Malaysia (palm oil mill)	HIRARC, OSHMS checklist, emergency exercises, employee survey	High-risk activities included welding and conveyor maintenance; emergency preparedness knowledge was moderate	Improve emergency preparedness systems, exercises, employee knowledge, and response capability

Sources: Myzabella et al. (2019); Ruslan et al. (2017); Ngadiman et al. (2019); Wondi et al. (2020); Sulong et al. (2020); Ahmad et al. (2020); Ahmad Naim et al. (2022).

Explanation

Taken together, the occupational studies point to several recurring observations.

- First, many high-risk jobs are routine rather than unusual. Manual handling of FFB, replacement of heavy machine components and work around conveyors or presses repeatedly appear among the tasks requiring tighter control (Ngadiman et al., 2019).
- Second, chronic exposure matters as much as acute injury. Noise above occupational limits has been reported in press and turbine areas (Wondi et al., 2020), while sustained heat exposure may contribute to fatigue and reduced concentration (Myzabella et al., 2019).
- Third, the quality of supervision shapes the effectiveness of technical controls. Sulong et al. (2020) link weak supervisory enforcement with poorer safety reporting, indicating that engineering measures alone are unlikely to produce a strong safety system.
- HIRARC remains useful because it gives mills a common structure for identifying hazards and prioritising controls. Its limitation is that the assessment is largely qualitative and can depend heavily on expert judgement. The reviewed literature therefore supports combining HIRARC with ergonomic assessment, measured exposure data and stronger incident-reporting practices (Ngadiman et al., 2019; Myzabella et al., 2019).

Overall, occupational risk is one of the better represented areas in the literature. Even so, several studies describe implementation as reactive or compliance-oriented, with limited evidence that occupational risk information is consistently connected to enterprise-level risk governance.

Theme 2: Process And Engineering Safety

Hazards Associated With Process Equipment

Menon (2009), in the MPOB Palm Oil Engineering Bulletin, describes a broad range of hazards found in mill processing, including boiler explosions, press failures, steam leaks and fires

associated with oil spills or biomass handling. A useful point in that discussion is that many incidents are traceable to weaknesses in design, operation or maintenance rather than to genuinely unpredictable events.

Later case-based and quantitative studies reach similar conclusions from different methods. González-Delgado et al. (2021), using an inherent-safety index for crude palm oil production in Colombia, identify boilers and dryers as comparatively unsafe units and emphasise equipment reliability and process configuration. Moreno-Sader et al. (2020) combine HIRA with environmental impact assessment in a North Colombian mill and show how fire and explosion hazards can be examined alongside environmental performance.

Hong (2022) shifts the emphasis from equipment to organisational practice by examining process-safety leadership and culture in Malaysian palm oil milling. The paper argues that process safety can be overshadowed by production and compliance priorities, and uses boiler incidents, steam explosions and near-misses to illustrate why stronger learning and leadership systems are needed.

Table 4. Key Contributions On Process Safety Risk In Palm Oil Manufacturing

Study Source	Risk Focus	Methods / Tools	Key Findings Relevant to Risk Management
Menon (2009)	Mill-level process hazards	Engineering analysis, case review	Identified boiler and pressure-vessel hazards, steam leak risks, and fire hazards. The study highlighted that many incidents originated from design deficiencies, inadequate maintenance, and operational failures.
Hong (2022)	Process safety culture	Case studies, conceptual review	Found weaknesses in process safety leadership and organizational learning from incidents. Emphasized the importance of the 3C principle (Competency, Commitment, and Culture) and the development of mature process safety cultures.
González-Delgado et al. (2021)	Inherent safety of CPO process	Inherent Safety Index (ISI), sustainability metrics	Determined that boilers and dryers represented the least inherently safe units within crude palm oil processing systems. Recommended safer equipment design and configuration to reduce operational risks.
Moreno-Sader et al. (2020)	Environmental and hazard assessment	TRACI methodology, HIRA	Identified significant fire and explosion hazards within palm oil processing operations and demonstrated the value of integrating environmental performance

Study Source	Risk Focus	Methods / Tools	Key Findings Relevant to Risk Management
			assessment with safety risk evaluation.
Hosseini & Abdul Wahid (2015)	Pollutants from palm oil production	Emission characterization and environmental assessment	Reported that many palm oil mills struggle to comply with environmental standards. Air emissions and pollution issues were strongly associated with inadequate process control and waste management practices.
UTMonBox Process Safety Module	Training for palm oil process plants	Process Safety Management (PSM) framework	Highlighted the importance of process design, safe operating procedures, accident case studies, competency development, and compliance with legal and regulatory requirements for effective risk management.

Sources: Menon (2009); Hong (2022); González-Delgado et al. (2021); Moreno-Sader et al. (2020); Hosseini & Abdul Wahid (2015); UTMonBox, 2021.

Explanation

Compared with occupational safety and environmental management, the process-safety literature is smaller. Even so, the available studies show a fairly consistent set of concerns.

- Boilers and dryers repeatedly emerge as important risk nodes because they combine pressure, high temperature and combustible material (González-Delgado et al., 2021).
- The evidence also suggests that serious incidents rarely have a single cause. Menon (2009) and Hong (2022) point to interacting weaknesses in design, maintenance, training and hazard analysis, while Ahmad Naim et al. (2022) similarly highlight preparedness and competency issues in maintenance and emergency response.
- A further development is the attempt to examine safety and environmental performance together. Moreno-Sader et al. (2020), for example, combine HIRA with TRACI-based environmental assessment, illustrating how process and environmental risks can be considered within the same analytical exercise.

What remains less visible in the published mill literature is routine use of more advanced PSM tools such as formal management of change, quantitative risk assessment (QRA) and bow-tie analysis. The absence of strong evidence on these practices suggests an area for further empirical study rather than proof that they are universally absent from industry.

Theme 3: Environmental And Climate Risk***POME And Emissions As Major Environmental Risks***

POME is consistently identified as one of the principal environmental concerns associated with palm oil milling because of its high biochemical oxygen demand (BOD), chemical oxygen demand (COD) and methane-generating potential when treated anaerobically (Hosseini & Abdul Wahid, 2015; Yacob et al., 2006). In operational terms, inadequate treatment can create both regulatory exposure and a direct environmental burden.

More recent studies broaden the discussion by treating mill residues as possible resources rather than only as wastes. Imam et al. (2024) review recovery pathways for POME, including biogas, nutrient recovery and other value-added outputs, while Pallikodathan et al. (2025) examine treatment-system selection from both emissions and cost perspectives. This shifts the management question from simple disposal toward a balance between compliance, carbon reduction, operational reliability and investment return.

The transition also creates new governance issues. Transport & Environment (2025), for example, raises concerns about fraud, mislabelling and traceability in POME-derived biofuel markets. Such concerns show that a waste stream can become a regulatory or reputational risk even when it has potential economic value.

Table 5. Environmental Risk And Mitigation Measures Related To POME

Study / source	Environmental risk focus	Methods / tools	Key mitigation / risk management insights
Hosseini & Abdul Wahid (2015)	POME and air pollutants from mills	Emission characterisation, review	Many mills exceed environmental standards; emphasises need for stricter control
Imam et al. (2024)	Resource recovery from POME	Technology review	Digesters, membrane systems, and value-added products can offset treatment costs
Pallikodathan et al. (2025)	CO ₂ emissions from POME treatment	Strategic planning model	Optimal selection of treatment systems can minimise emissions and costs
Transport & Environment (2025)	POME-based biofuels and fraud risk	Policy analysis, trade data	Traceability gaps pose regulatory and reputational risks
ISCC (2024) guidance	POME oil and waste/residue classification	Certification guidance	POME oil considered zero GHG at mill gate; emphasises robust GHG accounting

Study / source	Environmental risk focus	Methods / tools	Key mitigation / risk management insights
Wilmar (2026)	GHG reduction from methane capture	Corporate reporting	Methane capture at mills drastically reduces emissions

Sources: Hosseini & Abdul Wahid (2015); Yacob et al. (2006); Cheah et al. (2023); Imam et al. (2024); Pallikodathan et al. (2025); Transport & Environment (2025); ISCC (2024); Wilmar (2026).

Explanation

The environmental literature therefore shows a gradual widening of scope. Earlier concerns centred heavily on compliance indicators such as BOD, whereas newer work also considers greenhouse-gas performance, resource recovery and circular-economy value.

- POME remains central to this discussion because poorly controlled effluent can affect water quality and generate substantial methane emissions.
- Biogas capture and other recovery technologies may convert part of that liability into an operational or commercial opportunity, but they also require sound design, financing, maintenance and regulatory control (Imam et al., 2024; Pallikodathan et al., 2025).
- Certification guidance such as ISCC (2024) adds another dimension by placing more emphasis on classification, verification and greenhouse-gas accounting for waste and residue streams from palm oil mills.

For mill management, the practical implication is that environmental control should be embedded in routine operating and investment decisions rather than treated as a stand-alone compliance project. Options for waste valorisation need to be judged alongside their technical, financial and regulatory risks.

Theme 4: Supply Chain, Regulatory And Reputational Risk

Supply-Chain And Investor Risk Frameworks

Supply-chain and sustainability studies examine how practices at plantations and mills are translated into wider ESG exposure for companies, financiers and buyers. CDP (2023) highlights deforestation, climate and traceability concerns from an investor perspective, illustrating how operational weaknesses at supplier level can affect portfolio and corporate risk. The EBRD (2023) takes a due-diligence perspective and recommends supply-chain mapping, origin-specific risk assessment and stronger engagement with suppliers in higher-risk areas.

These practices are relevant to mills because sourcing and operating records increasingly form part of buyer and lender assessments.

Corporate frameworks provide a more operational example. Musim Mas (2025), for instance, combines satellite monitoring, supplier risk scoring and engagement to manage deforestation risk across its supply base.

Razak et al. (2024) report that Malaysian companies are paying greater attention to sustainability risk management, but formal governance and integration with corporate strategy remain uneven. This finding is important for mills because plant-level data often feed the wider sustainability and risk reporting system.

Table 6. Selected Literature On Palm Oil Supply-Chain And Sustainability Risk Management

Source	Scope	Risk focus	Key implications for palm oil manufacturing and mills
CDP (2023)	Global investors, companies	Deforestation, climate, traceability, governance	Mill practices affect investor risk; calls for disclosure of mill-level risk controls
EBRD (2023)	Financial institutions	Supply-chain ESG risk	Recommends risk assessment and prioritisation across palm supply chains
Preferred by Nature (2017a,b)	Peninsular Malaysia & Sarawak	Legal, environmental, social risk	Provides country- and region-level risk profiles that mills must consider in sourcing
Musim Mas (2025)	Corporate supply-chain framework	Deforestation risk, supplier engagement	Demonstrates risk management framework integrating monitoring and engagement
GRAS (2022)	Digital platform	Automated sustainability risk assessment	Enables rapid spatial risk screening for mills and buyers
Razak et al. (2024)	Malaysian listed companies	Sustainability risk management practices	Many firms still at early stages of structured sustainability risk management

Sources: CDP, 2023; EBRD, 2023; Preferred by Nature, 2017a, 2017b; Musim Mas, 2025; GRAS, 2022; Razak et al., 2024.

Explanation

Viewed from the mill, these supply-chain and ESG frameworks lead to three practical implications.

- First, mill performance can affect supply-chain risk assessments. Environmental non-compliance, weak OSH performance or poor process-safety control may become supplier-level issues with consequences for commercial relationships and market access.
- Second, traceability depends on reliable operating data. Regulators, buyers and financiers increasingly expect evidence on sourcing, POME management, greenhouse-gas emissions and safety performance rather than broad sustainability statements alone.

- Third, risk management is becoming more system-based. International buyers and investors increasingly expect company-level governance that can connect mill controls with ISO 31000 principles, sustainability commitments and supply-chain due diligence.

Integrative Framework: Multi-Level Risk Management in Palm Oil Manufacturing

Bringing the four themes together reveals a pattern that is easy to miss when each risk domain is viewed separately. Day-to-day task hazards, plant-wide process and environmental risks, and enterprise or supply-chain risks operate at different scales, but they are not independent. The framework proposed here therefore organises risk into three connected levels: micro, meso and macro.

1. Micro level – Task and workstation risk

- Tools: HIRARC, ergonomic assessment, and measured noise or other exposure data.
- Focus: control of specific hazards during activities such as FFB unloading, press operation, kernel handling and boiler operation.
- Outcomes: fewer injuries and harmful exposures, stronger compliance and more reliable task-level control.

2. Meso level – Plant-wide process and environmental risk

- Tools: PSM, HIRA, inherent-safety indices, POME treatment planning, environmental-impact assessment and GHG accounting.
- Focus: safe and reliable operation of plant systems such as boilers, press lines and effluent treatment, while reducing environmental impacts and assessing opportunities for waste valorisation.
- Outcomes: fewer major incidents, stronger environmental performance, lower GHG emissions and better use of recoverable by-products or residues.

3. Macro level – Supply-chain, ESG, and enterprise risk

- Tools: ISO 31000-based enterprise risk management, supply-chain risk mapping, ESG assessment, spatial-risk platforms such as GRAS and investor-oriented frameworks such as CDP and EBRD.
- Focus: linking mill performance with corporate commitments, certification requirements and stakeholder expectations, including deforestation-free and lower-carbon supply chains.
- Outcomes: stronger evidence for market-access decisions, investor and buyer assurance, and corporate risk governance.

The framework encourages mills and companies to:

- At governance level, ISO 31000 can provide the common structure through which micro- and meso-level assessments are brought into enterprise risk registers, ownership arrangements and review processes (ISO, 2018; PECB, 2025).

- This also requires stronger alignment among OSH, process-safety and environmental programmes and the requirements of MSPO/RSPO and corporate sustainability commitments. Treating these systems as separate compliance exercises weakens the possibility of identifying cross-cutting risks.

Digital tools may strengthen this integration where they improve the timeliness or quality of evidence. Examples include automated risk assessment, remote sensing and real-time monitoring, provided that data quality, interpretation and accountability remain clearly defined.

Discussion

Cross-Cutting Issues In Risk Management For Palm Oil Manufacturing

Three cross-cutting issues are particularly visible when the four risk domains are considered together.

- The first is the difference between compliance and resilience. Much of the published evidence focuses on meeting legal, certification or procedural requirements. A more resilient approach would also consider how the mill responds to abnormal conditions, equipment failure, supply disruption and changing environmental or market expectations, using scenario analysis, leading indicators and learning from near-misses.
- The second issue is uneven data quality. Injury records, near-miss information, process incident databases and real-time environmental data are not consistently reported across studies. HIRARC assessments can also rely heavily on expert judgement when measured exposure or incident data are limited. This constrains comparison between mills and makes trend analysis more difficult.
- The third issue is organisational fragmentation. OSH, process safety, environmental management and supply-chain sustainability are often assigned to different functions with their own indicators and reporting routines. Without a mechanism for joint review, one risk may be transferred or amplified elsewhere in the system rather than genuinely reduced.

Implications For Mill Managers And Corporate Risk Officers

For mill managers and corporate risk officers, the framework can be translated into a small number of management priorities.

1. A formal mill-level risk register should cover occupational, process, environmental and supply-chain risks in one governance structure, with named owners, documented controls and indicators that can be reviewed over time.
2. Process-safety capability also deserves more explicit attention. Structured techniques such as HAZOP, bow-tie analysis and, where the risk justifies it, LOPA can strengthen the assessment of boilers, sterilisation systems and storage facilities when supported by competent personnel and disciplined follow-up.
3. POME and emissions management should be evaluated as an operating and investment decision rather than only as an environmental obligation. Anaerobic digesters, covered lagoons and other options can be compared using expected emissions reduction,

technical reliability and financial feasibility (Pallikodathan et al., 2025; Imam et al., 2024).

4. Supply-chain risk information should likewise be connected with mill performance. Guidance from CDP, EBRD and Preferred by Nature shows how operational controls and sourcing information can influence buyer, lender and corporate risk assessments (CDP, 2023; EBRD, 2023; Preferred by Nature, 2017).
5. Finally, reporting systems should support learning rather than simply documentation. Encouraging near-miss reporting, cross-functional review and follow-up on corrective actions can help embed safety and sustainability in routine decision-making (Sulong et al., 2020; Hong, 2022).

Limitations and Future Research

Several limitations should be considered when interpreting this review.

- Only English-language literature and accessible grey literature were included, so relevant local-language material from major producing countries may have been missed.
- The number of documents reported for each search string represents the evidence used in the synthesis rather than a complete census of every publication relevant to that topic.
- Supply-chain and ESG requirements are also changing quickly, particularly around regulations such as the EUDR. Some institutional frameworks discussed here may therefore evolve faster than the peer-reviewed literature.

These limitations point to several useful directions for future work.

- Multi-site quantitative studies could examine process-safety leading indicators, near-miss patterns and incident learning across palm oil mills rather than relying mainly on isolated case evidence.
- A second priority is integrated risk analytics that connect occupational, process, environmental and financial indicators at mill and corporate levels.
- There is also scope to test digital and GIS-based monitoring approaches for operational and supply-chain risks, including POME pond conditions, boiler performance and sourcing risk.
- Comparative studies of risk-management maturity across mills or corporate groups could help distinguish practices that are site-specific from those that are transferable at scale.
- Further work is also needed on waste valorisation, particularly frameworks that compare the technical, environmental and commercial value created from mill residues against the new risks introduced by those recovery pathways.

Conclusion

Risk in palm oil manufacturing is multi-dimensional. Occupational hazards, process and engineering failures, environmental and climate pressures, and supply-chain, regulatory and reputational issues are usually studied as separate topics, yet mill operations bring them together in practice. The literature reviewed here suggests that occupational and environmental risk management are more visible in the evidence base, while process-safety governance and enterprise-wide integration receive less systematic treatment.

Using Torraco's integrative review method and ISO 31000 as the organising logic, this study proposes a three-level framework linking micro-level task and workstation risks, meso-level process and environmental risks, and macro-level supply-chain, ESG and enterprise risks. The value of the framework lies in these connections: controls at one level should inform decisions at the others. For palm oil manufacturers, stronger integration can support safer operations, more reliable compliance, better use of risk information and more deliberate evaluation of waste valorisation and long-term sustainability opportunities.

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