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# A Conceptual Model For Sustainable And Resilient Palm Oil Supply Chains: Integrating Digital Innovations, Circular Economy, And Policy Alignment

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# ABSTRACT

**The global palm oil industry faces mounting pressure to balance economic growth with environmental protection and social equity. This study addresses the critical need for sustainable and resilient supply chain management (SCM) strategies in response to deforestation concerns, regulatory pressures, and stakeholder demands. The purpose is to develop an integrative conceptual framework that unites sustainability imperatives, digital transformations, and multi-stakeholder engagement in palm oil SCM. Through a systematic literature review of 46 peer-reviewed articles from Scopus and Web of Science, complemented by bibliometric analysis, this research consolidates existing knowledge on SCM practices, emergent technologies, and policy instruments. Findings indicate that integrating blockchain, machine learning, and circular economy principles significantly enhances traceability, resource efficiency, and compliance with sustainability certifications such as RSPO and NDPE. However, persistent barriers including high implementation costs, limited infrastructure, and smallholder exclusion hinder large-scale adoption. The proposed framework emphasizes the interdependence of regulatory frameworks, technological enablers, circular economy strategies, and policy alignment. Critical research gaps identified include the need for longitudinal analyses of certification impacts, comparative studies beyond Southeast Asia, and deeper investigations into social sustainability. This study provides actionable guidelines for industry practitioners and policymakers to foster a more sustainable, transparent, and resilient palm oil industry**


**Keywords:** *sustainable supply chain, resilient supply chain, palm oil, circular economy, digital integration.*

# 1. INTRODUCTION

Palm oil is a cornerstone of global agribusiness, underpinning industries from food and cosmetics to biofuels (FAO, 2023; Lakshmanan & Yung, 2024). Driven by rising demand and economic incentives (Alhaji *et al*., 2024), production has expanded across Southeast Asia, Latin America, and Africa (Abideen *et al*., 2023). While this growth generates jobs and development, it also intensifies environmental and social issues such as deforestation, biodiversity loss, land disputes, and labour inequities (Murphy *et al*., 2021; Chiriacò *et al*., 2024). In response, stakeholders are calling for solutions that balance economic and sustainability goals (Meijaard & Sheil, 2019; Purnomo *et al*, 2020; Wang *et al*., 2022).

Supply chain management (SCM) is central to these efforts. Conventional SCM often neglects ecological and social consequences, exacerbating degradation and displacement (Haryati *et al*., 2022; Karmakar *et al*., 2023). Sustainable SCM, by contrast, emphasizes traceability, fair labour, and resource conservation, offering tools to reduce deforestation and improve livelihoods (Cammelli *et al*., 2022; Lestari *et al*., 2014a). However, its implementation across multi-tiered and fragmented palm oil networks, spanning smallholders to exporters, remains challenging (Degli Innocenti & Oosterveer, 2020).

Recent research has examined how sustainability principles, technological innovation, and stakeholder collaboration can reshape SCM (Dutta *et al*., 2020; Shoomal *et al*., 2024). Tools like blockchain and IoT improve sourcing transparency (Kasim *et al*., 2021; Wang *et al*., 2020), while circular economy practices promote resource reuse and waste reduction (Abdul-Hamid *et al*., 2021; García-Orozco *et al*., 2023). Yet these efforts remain partial, limited by costs, regulations, and uneven capacities (Abideen *et al*., 2023; Hidayat *et al*., 2018). Smallholders, in particular, face exclusion due to financial and infrastructural constraints (Cafer & Rikoon, 2018).

Prior reviews have provided thematic insights; for example, on certification barriers (Abideen *et al*., 2023), quality management (Ghani *et al*., 2019), and resilience during COVID-19 (Hafiz *et al*., 2021). Other studies explored frameworks like SCOR and IoT (Kurniawan, 2022; Lestari *et al*., 2014a). However, research remains fragmented across traceability, economic viability, and risk management (El Hathat *et al*., 2023; Piya, 2024), lacking a unified model that integrates sustainability, technology, and collaboration. This paper addresses that gap.

We propose an integrative framework grounded in stakeholder theory and circular economy principles, aimed at balancing efficiency, resilience, and equity (Chen & Yang, 2024). Focusing on upstream and midstream segments, the study addresses three questions: How can SCM align with sustainability? What barriers hinder technology adoption? How can stakeholders drive systemic change? By linking policy, technology, and collaboration, this research informs efforts toward achieving the UN Sustainable Development Goals in agribusiness.

We propose an integrative framework grounded in stakeholder theory and circular economy principles, aimed at balancing efficiency, resilience, and equity (Chen & Yang, 2024; El Hathat *et al*., 2023). Focusing on upstream and midstream segments, the study addresses three questions: How can SCM align with sustainability? What barriers hinder technology adoption? How can stakeholders drive systemic change? By linking policy, technology, and collaboration, this research informs efforts toward achieving the UN Sustainable Development Goals in agribusiness.

The paper proceeds as follows: Section 2 introduces the theoretical basis of sustainable SCM. Section 3 details the research design. Section 4 synthesizes findings on sustainability initiatives, technology, and stakeholder engagement. Section 5 discusses challenges and opportunities. Section 6 presents a conceptual framework, followed by conclusions and policy implications.

# 2. THEORETICAL APPROACH

SCM is a strategic framework for coordinating and optimizing the flow of goods, information, and resources across production and distribution networks (Islam *et al*., 2024). Within the agri-food sector, SCM is instrumental in tackling efficiency, sustainability, and market responsiveness, challenges that are especially pronounced in the palm oil industry (Yadav *et al*., 2022; Bhat & Jõudu, 2019). By integrating procurement, production, logistics, and customer delivery, SCM seeks to enhance operational performance while simultaneously addressing economic,

**Table 1**. Search protocol

| Protocol | Description |
|---|---|
| Database | Scopus and WoS |
| Search field | Title, keywords and abstract |
| Search string | (TITLE-ABS-KEY ("supply chain" OR "logistics management") AND TITLE-ABS-KEY ("oil industry" OR "oil production" OR "oil supply chain") AND TITLE-ABS-KEY ("improvement" OR "profitability" OR "performance" OR "sustainab*" OR "efficiency" OR "strategic planning") AND TITLE-ABS-KEY ("model*" OR "strateg*" OR "optimization") AND NOT TITLE-ABS-KEY ("petroleum" OR "crude oil")) |
| Inclusion criteria | ● Type of document: article and review<br>● Language: English<br>● Scopus research areas: Engineering, Management and Decision Sciences<br>● WoS research areas: Engineering, operations research management science, business economics |
| Exclusion criteria | ● Not aligned with SCM in oil palm industry<br>● Written in a language other than English<br>● Duplicates (same articles found in different databases) |
| Data analysis | Bibliometric and content analysis |
| Tools used | VOSviewer© for bibliometric analysis |

environmental, and social objectives (Ayyildiz, 2023; Kazancoglu *et al*., 2018).

Over the past decades, SCM theories and models have evolved to capture growing complexity and interconnectedness in global supply chains. Foundational frameworks, such as the Supply Chain Operations Reference (SCOR) model, emphasize performance metrics like reliability, responsiveness, and agility (Kusrini *et al*., 2019; Rezaei *et al*., 2023). Governance-oriented approaches highlight compliance with regulatory standards and the importance of transparency and traceability (Cemberci *et al*., 2024; Pacheco *et al*., 2020). Meanwhile, resilience-based models underscore adaptability and robustness in the face of environmental and social uncertainties, factors particularly relevant in palm oil production, where extreme weather events and socio-political pressures can significantly disrupt supply flows (Ben Abdallah *et al*., 2024; Afrasiabi *et al*.,2022).

Sustainability has emerged as a central pillar in modern SCM, driven by the imperative to balance profitability with environmental stewardship and social responsibility (Ciccullo *et al*., 2018). Green supply chain management (GSCM) frameworks promote eco-friendly practices throughout the supply chain (Singh & Trived, 2016; Gawusu *et al*., 2022). Extending this focus, the triple bottom line evaluates economic, social, and environmental impacts collectively, thus offering a more holistic yardstick of performance (Gimenez *et al*., 2019; Rashidi *et al*., 2020; Svensson *et al*., 2018). While these sustainability-driven paradigms provide a robust conceptual foundation, their scalability and real-world impact in industries like palm oil warrant further investigation (Hadiguna & Tjahjono, 2017; Macdonald *et al*., 2024).

Simultaneously, technological innovation is reshaping SCM practices. Breakthroughs in blockchain, artificial intelligence, and big data analytics have substantially improved traceability, decision-making, and resource allocation (Darbanian *et al*., 2024; Tsolakis *et al*., 2023; Epiphaniou *et al*., 2020). These advancements hold promise for overcoming persistent inefficiencies in complex sectors such as palm oil, where transparency and accountability are increasingly demanded by consumers, regulators, and civil society (Zamri *et al*., 2022; Rashid *et al*., 2021). Nonetheless, questions remain regarding the level of adoption, cost-effectiveness, and long-term sustainability of these technologies, particularly among smallholder farmers with limited capital and infrastructure (Liu & Panagiotakos, 2022; Dehghani *et al*., 2022).

In this context, the palm oil industry represents both a critical economic driver and a case study in managing extensive global supply chains marked by environmental and socioeconomic trade-offs (Teng *et al*., 2020; Sarpong *et al*., 2022). Although existing SCM models provide valuable insights into governance, risk mitigation, and operational efficiencies, the implementation of sustainability principles and emerging technologies in palm oil supply chains remains underexplored (de Oliveira *et al*., 2023; Matarneh *et al*., 2024). By grounding our analysis in these theoretical constructs, this review seeks to identify key gaps and opportunities for innovation. Through this lens, we aim to contextualize how various SCM frameworks, sustainability strategies, and digital tools could converge to foster a more responsible and robust palm oil supply chain (Jackson *et al*., 2024).

# 3. METHODOLOGY

This study employs a systematic literature review (SLR) to consolidate and evaluate research on SCM in the palm oil industry. A bibliometric review complements the SLR, offering a quantitative lens on emerging trajectories (Linnenluecke *et al*., 2019; Kraus *et al*., 2022). This combined approach ensures a comprehensive understanding of the knowledge base while identifying gaps and opportunities for future work (Snyder, 2024). Table 1 presents the structured review protocol, and Figure 1 illustrates the sequential phases of the SLR, detailed in the following subsections.

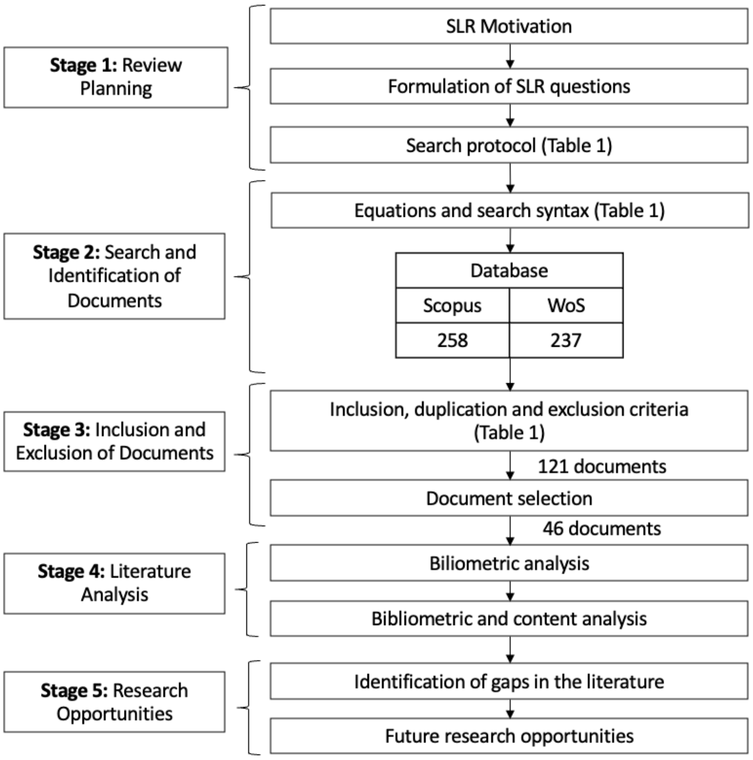


**Figure 1**. SLR Search Methodology

### *3.1 Database Selection and Search Strategy*

To ensure quality and scope, Scopus and WoS databases were selected for their extensive coverage in engineering, business, and decision sciences. In January 2025, a refined query was applied to titles, abstracts, and keywords to ensure relevance to both palm oil and SCM (Table 1).

### *3.2 Inclusion and Exclusion Criteria*

Following SLR protocols, eligible studies were peer-reviewed, written in English, and focused on SCM in agricultural or oil production contexts. Priority was given to work addressing sustainability, efficiency, or technological innovations. Studies unrelated to palm oil SCM, particularly those on petroleum or crude oil, were excluded. Duplicates and articles lacking methodological clarity were also removed.

### *3.3 Study Selection Process*

Selection followed three phases. 1) Initial Screening: The search returned 495 articles. Titles and abstracts were reviewed to exclude irrelevant and duplicate records, yielding 169 candidates. 2) Full-Text Review: Articles were assessed for relevance and methodological rigour, resulting in 46 eligible studies. 3) Final Inclusion: 35 articles from Scopus and 11 from WoS comprised the final dataset, reflecting a robust multi-database approach.

### *3.4 Data Analysis*

Bibliometric analysis using VOSviewer© identified co-authorship patterns, keyword co-occurrence, and citation networks to uncover influential topics and contributors (Linnenluecke *et al*., 2019). Each article was coded via a standardized protocol, capturing bibliographic data, research objectives, methodology, theoretical frameworks, geographic scope, sustainability focus, and digital tools. Multiple researchers conducted cross-checks to ensure coding consistency and reliability. This was complemented by qualitative synthesis.

## 4. RESULT

### *4.1 Bibliometric Analysis*

Academic publications on SCM in the palm oil industry have grown notably over the past two decades (Figure 2). Prior to 2010, research in this area remained limited, suggesting that the complexities of palm oil SCM were not yet a focus of widespread academic inquiry. A pronounced surge is evident from 2016 onward corresponding to global events such as the Paris Agreement (2015) and major companies' commitments to sustainable sourcing. Peaks observed in 2022 and 2024 align with heightened regulatory measures, particularly the European Union's deforestation-free supply chain policies, and an increasing demand for RSPO-certified palm oil.

Table 2 lists the top-cited works that have substantially influenced research on palm oil SCM. Pettit *et al*. (2013), with 723 citations, offers foundational insights into resilience-based SCM frameworks, while Trkman *et al*. (2007) contributes theoretical perspectives on supply chain integration. More recent studies, such as Ayyildiz & Taskin (2021), propose SCOR 4.0 for integrating Industry 4.0 metrics into SCM optimization, and García-Orozco *et al*. (2023) explore the deployment of blockchain for traceability

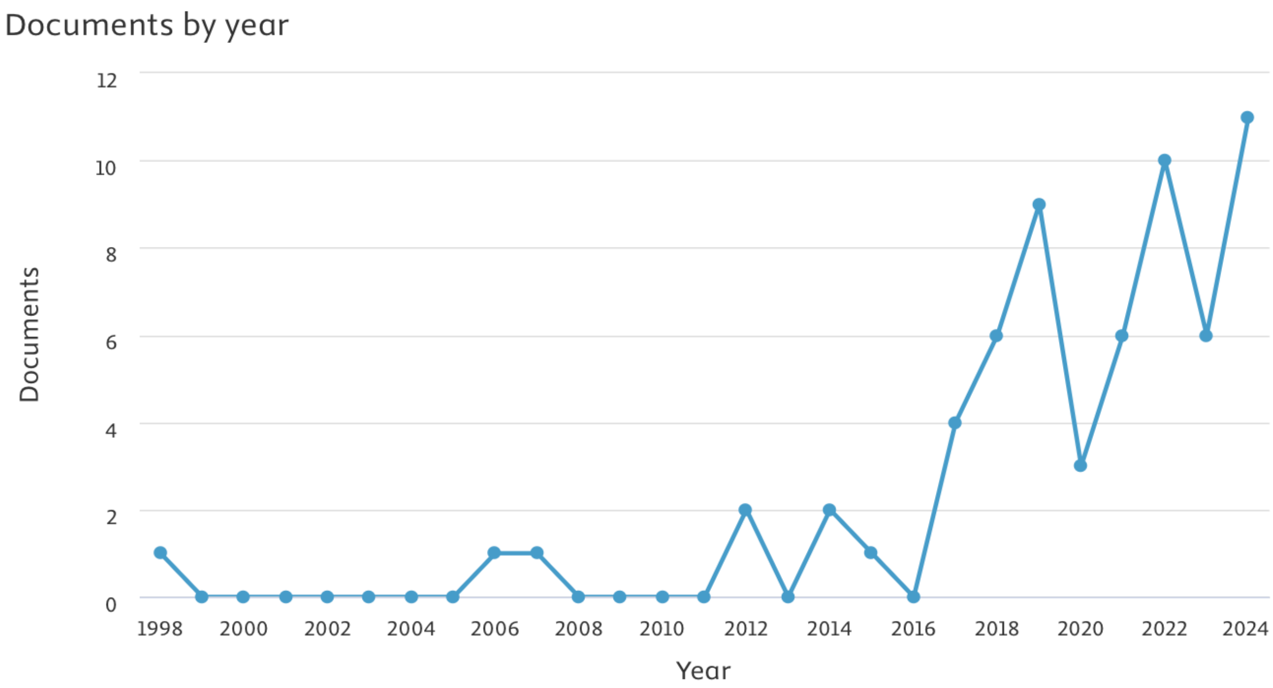


**Figure 2**. Documents by year

**Table 2.** Most cited publications and key contributions

| Document | Citations | Citations per Year |
|---|---|---|
| Pettit *et al*. (2013) | 723 | 66 |
| Trkman *et al*. (2007) | 152 | 9 |
| Ayyildiz & Taskin (2021) | 69 | 23 |
| Nikoloyuk *et al*. (2010) | 67 | 5 |
| Wang *et al*. (2018) | 59 | 10 |
| Manzini *et al*. (2014) | 55 | 6 |
| Abdulrazik *et al*. (2017) | 53 | 8 |
| Furumo *et al*. (2020) | 47 | 12 |
| Harahap *et al*. (2019) | 47 | 9 |
| Larsen *et al*. (2018) | 45 | 8 |
| Zahraee *et al*. (2022) | 27 | 14 |
| Haryati *et al*. (2022) | 25 | 13 |
| García-Orozco *et al*. (2023) | 12 | 12 |

and emissions monitoring. Environmental concerns dominate works by Furumo *et al*. (2020) and Larsen *et al*. (2018), which evaluate the effectiveness of certification schemes in mitigating deforestation. Overall, these publications demonstrate the evolution of the field from conceptual risk-management frameworks toward applied, technology-driven solutions.

### *4.2 Keywords Analysis*

A co-occurrence network of keywords (Figure 3) depicts the thematic structure of SCM research in the palm oil industry. The centrality of “supply chain management” and “supply chains” reaffirms their foundational role. Strong linkages to “sustainability,” “profitability,” “modelling,” and “risk management” signify the tension between economic performance and environmental or social considerations. “Sustainability” forms one of the largest clusters, incorporating terms like “deforestation,” “carbon footprint,” “greenhouse gases,” and “RSPO,” reflecting a robust focus on environmental impacts and responsible sourcing.

Additionally, distinct keyword clusters indicate specialized research paths. 1) Sustainability and Environmental Impact: Emphasizing carbon emissions, waste management, and certification. 2) Modelling and Optimization: Centred on simulation, discrete-event models, and advanced algorithms for operational efficiency. 3) Economic and Strategic Focus: Incorporating profitability, cost analysis, and strategic decision-making tools. 4) Governance and Certification: Highlighting institutional frameworks, policy interventions, and collaborative models. 5) Technology and Innovation: Concentrating on disruptive tools like blockchain, big data, and IoT to enhance traceability and transparency. Chronologically, purple nodes (e.g., “deforestation”) represent earlier focal points in palm oil SCM research, while green or yellow nodes (e.g., “sustainability,” “biofuels,” “simulation,” “blockchain”) reflect more recent emphasis on advanced methodologies, renewable energy, and digital solutions. The emergence of terms like “resilience” and “blockchain” underlines the growing interest in adaptive, tech-driven supply chains in the face of regulatory and environmental uncertainties.

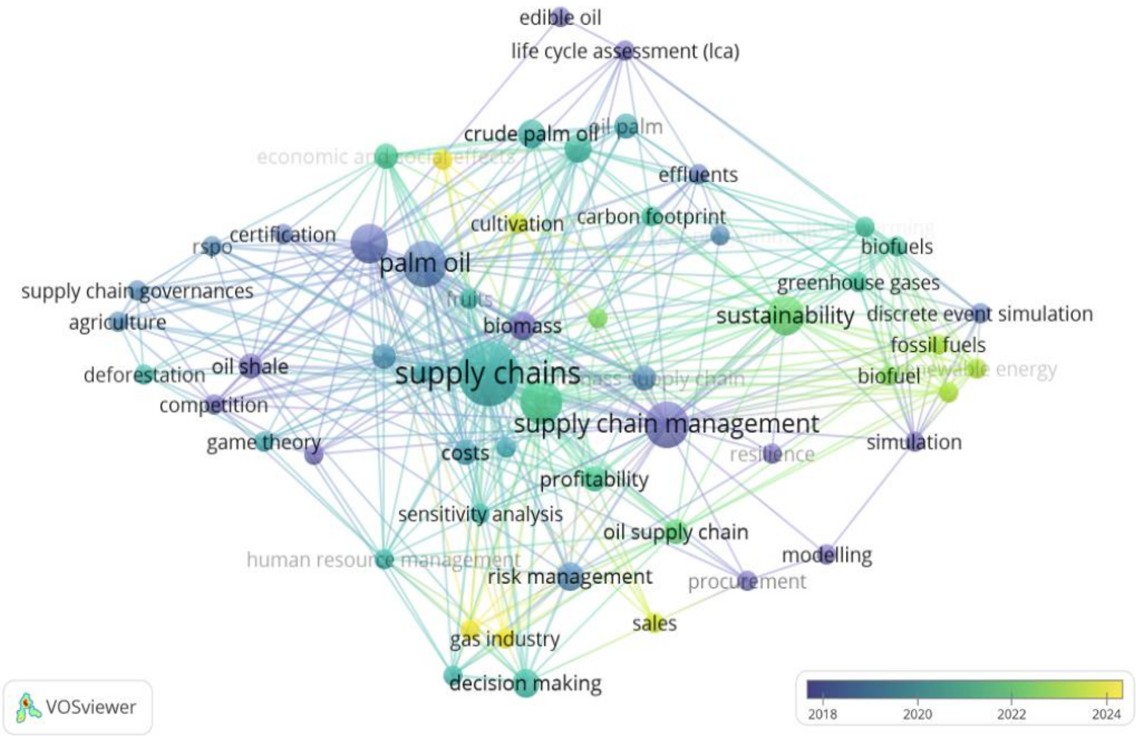


**Figure 3.** Keywords co-occurrence network

### *4.3 Geographical Context Analysis*

Indonesia and Malaysia stand out as primary contributors to palm oil SCM research, mirroring their global production leadership. Studies in this region (e.g., El Hathat *et al*., 2023; Harahap *et al*., 2019) underscore sustainability issues such as deforestation, carbon emissions, and labour conditions, while highlighting the influence of policy frameworks like RSPO and ISPO. Despite growing emphasis on certification, smallholder inclusion remains limited, reflecting persistent barriers in capacity-building and market access. Latin America explored on smallholder dynamics and biofuel expansion. Investigations in Colombia (Furumo *et al*., 2020) and Brazil (Vásquez *et al*., 2019) emphasize smallholder participation and biofuel development.

Research from Iran and Kuwait (e.g., Babaveisi *et al*., 2023; Erfani & AlEdan, 2024) largely addresses oil and gas supply chains, offering parallels with palm oil in terms of resource dependency, logistics bottlenecks, and regulatory constraints. The emphasis here lies in resilience, which may yield transferable insights for palm oil sector stability. Additionally, there is a global perspectives and emerging regions. Some studies adopt a broader lens, assessing macro trends in sustainability and risk management (Piya, 2024; Min, 2023). Nevertheless, Africa and China remain underrepresented despite their expanding roles in palm oil production and trade. Africa, for instance, faces unique land-tenure and governance challenges, while China's growing demand significantly shapes global market dynamics.

### *4.4 Categorisation of Research Themes*

Table 3 classifies the literature into broad thematic categories and subcategories. Studies predominantly investigate deforestation, labour conditions, and certification schemes as central themes (Nikoloyuk *et al*., 2010; Larsen *et al*., 2018). The integration of blockchain for traceability (El Hathat *et al*., 2023) reflects a growing demand for transparent and ethical sourcing. However, complex certification requirements often marginalize smallholders, indicating a critical need for more inclusive supply chain models. Research on renewable energy (Leong *et al*., 2019; Wang *et al*., 2024) and biomass utilization (Abdulrazik *et al*., 2017; Harahap *et al*., 2019) showcases the potential for circular economies within palm oil supply chains. Waste-to-energy systems and biofuel production exemplify an industry shift toward low-carbon operations, suggesting overlapping strategies for both energy and agricultural supply chains. There is a supply chain segmentation. Upstream studies focus on raw material procurement, land-use policy, and resource optimization (Harahap *et al*., 2019). Midstream studies emphasis is on processing, refining, and traceability, especially in milling operations (Chong Tan & Ndubisi, 2014; Gallemore & Jespersen, 2019). Downstream research addresses distribution, market access, and consumer preferences, including price volatility and ethical sourcing (Gassler & Spiller, 2018).

### *4.5 SCM Models in The Palm Oil Industry*

The palm oil industry operates within highly complex and interdependent supply chains, necessitating innovative management approaches to achieve efficiency, resilience, and sustainability (Macdonald *et al*., 2024; Williams *et al*., 2021). To address these challenges, SCM models in this sector can be broadly classified into three categories: 1) Optimisation Models, which focus on maximizing efficiency, profitability, and overall performance; 2) Resilience Models, aimed at strengthening supply chains against disruptions and improving adaptive capacities; and 3) Sustainability Models, designed to incorporate environmental, social, and governance (ESG) dimensions into SCM practices. Table 4 highlights representative models, their core purposes, and relevant case studies

**Table 3.** Thematic categorisation of research in palm oil SCM

| Category | Subcategory | Description | Source |
|---|---|---|---|
| Sustainability and Environmental Impact | Biomass Utilisation and Emission Reduction | Evaluation of biomass residue utilisation to enhance sustainability and reduce emissions | Abdulrazik *et al*. (2017); Harahap *et al*. (2019); El Hathat *et al*. (2023); How *et al*. (2018); Sadeghi & Haapala (2019) |
| | Sustainability Certifications | Analysis of the impact of certifications like RSPO and IFOAM on socio-environmental practices | Furumo *et al*. (2020); Nikoloyuk *et al*. (2010) |
| | Life Cycle Assessments | Life cycle assessments to measure environmental impact in agricultural and energy systems | Mankong *et al*. (2024); Vásquez *et al*. (2019) |
| Technological Integration and Optimisation | Industry 4.0 and Digital Transformation | Expansion of the SCOR model with Industry 4.0 metrics to improve performance | Ayyildiz & Taskin (2021) |
| | Optimisation Models | Development of robust models for network optimisation and inventory management | Dehghan *et al*. (2018); Babaveisi *et al*. (2023); Jafarzadeh *et al*. (2019) |
| | Simulation and System Dynamics (SD) | Use of modelling and SD to improve productivity and efficiency | Kim *et al*. (2023); Handaya *et al*. (2022); Suryani *et al*. (2018) |
| Governance and Collaborative Frameworks | Collaborative Governance Models | Analysis of collaborative models to tackle sustainability challenges | Larsen *et al*. (2018); Nikoloyuk *et al*. (2010) |
| | Policy Implications | Assessment of regulatory policies promoting sustainable SCM | Mareeh *et al*. (2023); Heryani *et al*. (2022) |
| Resilience and Risk Management | Pandemic-Driven Resilience | Impacts of COVID-19 on SCM and resilience strategies | Zahraee *et al*. (2022); Piya (2024) |
| | Risk Management | Tools and frameworks for risk management in volatile supply chains | Pettit *et al*. (2013); Utari *et al*. (2022); Jenkins & Wright (1998) |
| Economic Optimisation and Value Chain Analysis | Economic Potential of Biomass | Evaluation of biomass profitability in supply chains | Abdulrazik *et al*. (2017); Sadeghi & Haapala (2019) |
| | Value Chain Optimisation | Optimisation of added value in the palm oil supply chain | Hidayati & Hasibuan (2019); How *et al*. (2018); Lestari *et al*. (2014b) |
| Social Dimensions and Stakeholder Engagement | Social Performance Metrics | Assessment of social performance in the palm oil industry | Haryati *et al*. (2022) |
| | Stakeholder Collaboration | Credibility of corporate commitments in collaboration with stakeholders | Grabs (2023) |
| Renewable Energy and Biomass Integration | Bioenergy Supply Chains | Integrated bioenergy systems to optimise SCM | Leong *et al*. (2019); Wang *et al*. (2024); Manzini *et al*. (2014) |
| | Renewable Energy Systems | Multi-criteria methodologies applied to renewable energy technology development | García-Orozco *et al*. (2023) |
| Consumer Behaviour and Market Dynamics | Consumer Preferences | Consumer preferences for transparency versus cost in palm oil markets | Gassler & Spiller (2018) |
| | Market Conditions | Disruptions and competitive dynamics in global markets | Tang *et al*. (2017); Karmakar *et al*. (2023) |
| Regional and Sectoral Focus | Asia and Southeast Asia | Geographic context in Malaysia, Indonesia, and other Southeast Asian regions | Harahap *et al*. (2019); Handaya *et al*. (2022); Tang *et al*. (2017) |
| | Sector-Specific Applications | Case studies in industries such as oil and gas and food supply chains | Piya (2024); Erfani & AlEdan (2024); Wang *et al*. (2018); Min (2023); Primadasa & Christata (2023) |

**Table 4.** SCM Models Applied in the Palm Oil Industry

| Category | Model | Purpose | Application Examples |
|---|---|---|---|
| Optimisation Models | SCOR | Provides a framework for process improvement and benchmarking | SCOR 4.0 integrated with Industry 4.0 metrics in oil & gas SCM (Erfani & AlEdan, 2024) |
| | MILP | Offers mathematical optimization for energy systems & resource allocation | BeWhere model used for energy SCM (Wang et al., 2018) |
| Resilience Models | Economic Models | Maximizes profits while accounting for processing routes & costs | Optimization of EFB (Empty Fruit Bunch) supply chain in Malaysia (Abdulrazik et al., 2017) |
| | System Dynamics | Simulates supply chain behaviour under different policies & scenarios | Replantation policy evaluation in Indonesia (Lestari et al., 2014b; Suryani et al., 2018) |
| | Supply Chain Resilience Framework | Identifies vulnerabilities & capabilities for disruption management | SCRAM™ tool used in palm oil SCM (Mankong et al., 2024) |
| Sustainability Models | MCDM | Evaluates multiple sustainability criteria for informed decision-making | Prioritization of key sustainability drivers in renewable energy (Pettit et al., 2013) |
| | LCA | Analyses environmental impacts across entire product lifecycles | Well-to-wake biofuel evaluation from palm oil (Harahap et al., 2019) |
| | Blockchain | Enhances traceability & accountability | GHG emission tracking in the palm oil industry (El Hathat et al., 2023) |

**Table 5**. Sustainability approaches in the palm oil supply chain

| Authors | Sustainability Approach |
|---|---|
| Mankong *et al.*, 2024 | Integrated strategies such as reducing diesel use, optimising pesticide applications, and using pig manure to mitigate human and ecotoxicity impacts. |
| Suryani *et al.*, 2018 | System dynamics modelling to improve productivity and efficiency, reduce deforestation, and address policy-related challenges. |
| Vásquez *et al.*, 2019 | Renewable hydrogen production through biomass gasification, reducing greenhouse gas emissions by 66.2%. |
| El Hathat *et al.*, 2023 | Blockchain technology for real-time GHG monitoring, predictive modelling, and satellite imagery for emissions tracking. |
| Furumo *et al.*, 2020 | Adoption of RSPO and IFOAM certification schemes to ensure compliance with environmental standards. |
| Haryati *et al.*, 2022 | Focus on labour standards, social benefits, and compliance with human rights regulations. |
| Wang *et al.*, 2018 | Sustainability in supplier selection using criteria such as carbon footprint, environmental planning, and material usage. |
| How *et al.*, 2018 | Debottlenecking with sustainability indices addressing economic, environmental, and social dimensions. |
| Piya, 2024 | Use of fuzzy methods to calculate sustainability indices and identify key drivers like risk management, regulations, and health and safety. |

# 5. INTEGRATION OF SUSTAINABILITY APPROACHES INTO SCM MODELS

## *5.1 Sustainability Approaches in the Palm Oil Supply Chain*

The literature highlights a variety of sustainability approaches in palm oil SCM, including green supply chain initiatives, certification schemes, and digital innovations (Table 5). Technological tools such as blockchain and system dynamics modelling are increasingly used for traceability and impact assessment, while certifications like RSPO and IFOAM remain vital for ensuring environmental compliance and market credibility.

## *5.2 Sustainability Approaches in the Palm Oil Supply Chain*

Evaluating sustainability in palm oil SCM requires multidimensional indicators across environmental, economic, and social domains. Table 6 presents a shift from isolated metrics to integrated assessment frameworks like LCA and sustainability indices. However, the lack of standardized global indicators hampers cross-regional comparability. Blockchain tools enable real-time GHG tracking and regulatory compliance (El Hathat *et al*., 2023), enhancing transparency. Renewable hydrogen via biomass (Vásquez *et al*., 2019) represents a viable emissions-reduction strategy, reinforcing biofuel potential. Financial viability, measured by NPV and OPEX, remains crucial for adoption, especially given high upfront costs and limited readiness among SMEs (How *et al*., 2018). This underscores the role of public-private partnerships and financial incentives. On the social side, compliance with human rights, safe working conditions, and equitable pay are increasingly central (Haryati *et al*., 2022). However, smallholders often face barriers to certification, such as prohibitive costs and administrative burdens. More inclusive schemes and stakeholder training are vital for advancing social sustainability. Holistic tools like fuzzy multi-criteria methods (Piya, 2024) and LCA (Vásquez *et al*., 2019) offer robust, data-driven sustainability assessments. To scale their use, harmonized indicators, sector-wide cooperation, and enabling policies are needed.

**Table 6**.Sustainability metrics in the palm oil supply chain

| Dimension | Metric/Indicator | Example Source |
|---|---|---|
| Environmental | GHG emissions (PAS 2050), energy efficiency (LCEE), fossil energy ratio (FER), and carbon footprint. | Vásquez *et al.*, 2019; El Hathat *et al.*, 2023 |
| Economic | Net Present Value (NPV), benefit-cost ratio (BCR), cost of logistics, and operating expenditures (OPEX). | How *et al.*, 2018 |
| Social | Workplace safety, job creation, and compliance with human rights standards. | Haryati *et al.*, 2022 |
| Integrated Metrics | Sustainability index, positive-ideal solution (PIS), and negative-ideal solution (NIS). | Piya, 2024 |
| Lifecycle Analysis | Metrics for water footprint (WF), emissions of pollutants (PM, NOx, SOx), and resource utilisation. | Vásquez *et al.*, 2019; How *et al.*, 2018 |

**Table 7.** Barriers to implementing sustainable SCM strategies

| Type of Barrier | Description | Example Source |
|---|---|---|
| Economic Constraints | High initial costs for adopting sustainable practices, limited funding for technology upgrades. | Vásquez *et al.* (2019); Mareeh *et al.* (2023) |
| Technological Limitations | Lack of advanced infrastructure, reliance on outdated technologies, and challenges in digital transformation. | Wang *et al.* (2024); How *et al.* (2018) |
| Operational Inefficiencies | Suboptimal utilisation of resources such as EFB and liquid waste, limited scope of analysis. | Hidayati & Hasibuan (2019) |
| Policy and Regulatory Gaps | Inconsistent or insufficient regulations to support sustainable practices; high export taxes. | Larsen *et al.* (2018); Suryani *et al.* (2018) |
| Sociocultural Resistance | Resistance from stakeholders, such as farmers and vendors, to shift to sustainable practices. | Mareeh *et al.* (2023); Chen & Yang (2024) |
| Environmental Challenges | Monoculture practices leading to poor soil health and higher pest levels; vulnerability to climate impacts. | El Hathat *et al.* (2023) |
| Labour and Workforce Issues | Dependence on foreign labour and inadequate mechanisation in high-demand periods. | Zahraee *et al.* (2022); Haryati *et al.* (2022) |

**Table 8**. Strategies to mitigate SCM barriers

| Barrier | Proposed Strategy | Example Source |
|---|---|---|
| Economic Constraints | Subsidies or incentives for adopting renewable technologies; collaboration with financial institutions. | Vásquez *et al.* (2019) |
| Technological Limitations | Investment in modernising infrastructure; fostering public-private partnerships for technology development. | El Hathat *et al.* (2023); Wang *et al.* (2024) |
| Operational Inefficiencies | Comprehensive value chain analysis; optimising resource utilisation through advanced planning systems. | Hidayati & Hasibuan (2019) |
| Policy and Regulatory Gaps | Harmonised international standards; government-led initiatives to support sustainable practices. | Suryani *et al.* (2018); Larsen *et al.* (2018) |
| Sociocultural Resistance | Educational campaigns for stakeholders; engagement with local communities to foster acceptance. | Mareeh *et al.* (2023); Chen & Yang (2024) |
| Environmental Challenges | Promoting crop diversification; integrating sustainable agricultural practices to restore soil health. | El Hathat *et al.* (2023) |

# 6. CHALLENGES AND BARRIERS IN IMPLEMENTING SUSTAINABLE SCM MODELS

Despite increased awareness and technological progress, multiple barriers hinder the widespread adoption and scalability of sustainable supply chain management (SCM) in the palm oil sector. Table 7 categorizes the key challenges identified in the reviewed literature

Economic barriers, notably the high costs of renewable energy systems and blockchain infrastructure, often discourage small and mid-sized producers from pursuing sustainability (Vásquez *et al.*, 2019). Technological constraints, including limited access to digital tools and infrastructure, further complicate implementation (How *et al.*, 2018). Inefficiencies in resource utilization—such as underused biomass or waste—add cost and environmental burdens (Hidayati & Hasibuan, 2019)..

From a regulatory standpoint, fragmented and inconsistent policies, including burdensome export taxes, reduce the attractiveness of sustainable markets (Suryani *et al.*, 2018). Socially, certification schemes can seem inaccessible to smallholders due to high costs, complex procedures, and limited short-term benefits (Mareeh *et al.*, 2023). Environmental degradation from monocropping intensifies soil depletion and emission levels (El Hathat *et al.*, 2023), while low mechanisation and labour dependency impair responsiveness during harvest peaks (Haryati *et al.*, 2022).

Addressing these multifaceted barriers calls for coordinated action across technological, economic, and policy domains. Table 8 summarizes mitigation strategies recommended by the literature. Financial incentives and risk-sharing mechanisms can lower entry barriers for smaller producers (Vásquez *et al.*, 2019). Infrastructure upgrades are essential for enabling digital adoption, including IoT and blockchain (El Hathat *et al.*, 2023). Equally important is policy harmonization at national and international levels, which can provide regulatory clarity and enhance market confidence (Larsen *et al.*, 2018; Rehman *et al.*, 2025).

**Table 9**. Process innovations in SCM

| Authors | Technology/Innovation | Application |
|---|---|---|
| Babaveisi *et al*., 2023 | Heuristic and genetic algorithms | Optimising spare parts supply chains by addressing uncertainty and integrating inventory decisions. |
| El Hathat *et al*., 2023 | Blockchain, machine learning, satellite imagery | Enhancing traceability, real-time GHG monitoring, and emissions analysis in palm oil supply chains. |
| How *et al*., 2018 | P-graph framework, AHP | Identifying bottlenecks in biomass supply chains and prioritising sustainability dimensions for optimisation. |
| Suryani *et al*., 2018 | System dynamics modelling | Understanding systemic behaviours and improving supply chain productivity and efficiency in the palm oil sector. |
| Wang *et al*., 2024 | Energy conversion optimisation | Improving the operational efficiency of coal-based energy supply chains. |
| Manzini *et al*., 2014 | Closed-loop monitoring systems | Evaluating logistics and environmental impacts on food quality during transportation. |
| Vásquez *et al*., 2019 | Biomass gasification, water electrolysis | Renewable hydrogen production for aviation biofuels, reducing GHG emissions and improving lifecycle efficiency. |
| Chen & Yang, 2024 | Edible coatings | Extending the shelf life of perishable goods to reduce waste and improve replenishment capabilities. |
| Kim *et al*., 2023 | Advanced bioconversion technologies | Reducing GHG emissions and water consumption in ethanol production. |
| Hidayati & Hasibuan, 2019 | Technological upgrades in processing, transportation, and communication | Enhancing value chain efficiency and reducing resource waste in CPO supply chains. |
| Mareeh *et al*., 2023 | Sustainable replanting techniques | Eliminating burning practices and adopting efficient transportation methods to reduce emissions. |
| Ayyildiz & Taskin, 2021 | Digital mapping and machine learning | Integrating Industry 4.0 tools for data analysis and predictive insights in supply chains. |

# 7. TECHNOLOGICAL AND INNOVATIVE CONTRIBUTIONS TO SCM

The integration of advanced technologies and innovative approaches has significantly enhanced the efficiency, transparency, and sustainability of SCM in the palm oil industry.

- **Process-Oriented Technological Advancements**. Process innovations focus on streamlining operations, logistics, and decision-making to boost overall supply chain performance. These advancements help mitigate operational risks, enhance traceability, and raise efficiency. Table 9 summarizes the key process-related technologies in use. Among these, blockchain (El Hathat *et al*., 2023) is particularly transformative, enabling real-time traceability, emission tracking, and tighter regulatory compliance. Meanwhile, heuristic and genetic algorithms (Babaveisi *et al.,* 2023) streamline inventory management and spare parts logistics in multi-tier supply chains.
- **Product-Focused Technological Advancements.** Product innovations primarily target waste reduction, improved processing techniques, and value-added transformations. Table 9 highlights key product-oriented technologies aimed at sustainability and market competitiveness. Biomass gasification (Vásquez *et al*., 2019) notably reduces reliance on fossil fuels, while edible coatings (Chen & Yang, 2024) prolong product lifespan, thereby curbing food waste. Industry 4.0 applications (Ayyildiz & Taskin, 2021), encompassing machine learning and digital mapping, further bolster strategic decision-making in palm oil SCM.

# 8. PROPOSED CONCEPTUAL MODEL FOR SUSTAINABLE PALM OIL SCM

Given the multifaceted challenges facing palm oil supply chains, ranging from environmental, social, and economic pressures to technological barriers and policy complexities, an integrated conceptual framework is essential. Drawing on the Triple Bottom Line (TBL) concept (Elkington, 1997), supply chain resilience theory (Pettit *et al*., 2013), and innovation diffusion models (Rogers, 2003), the proposed model aims to: capture the interdependencies among supply chain actors and their operational contexts; identify key enablers and barriers that influence sustainable SCM implementation; integrate multiple dimensions of sustainability within a unified framework; and establish feedback mechanisms that promote continuous improvement and adaptive learning. Figure 4 presents the proposed conceptual framework, which is structured around five interconnected components that collectively shape the sustainability and resilience of palm oil supply chains. The external driver's component encompasses three critical dimensions that influence supply chain operations. Regulatory frameworks include international standards, certification schemes, and compliance requirements that establish the operational boundaries for the industry. Market dynamics reflect evolving consumer demands, sustainability premiums, and quality requirements that shape competitive strategies. Environmental context captures climate variability, resource constraints, and conservation imperatives that pose both challenges and opportunities for the sector.

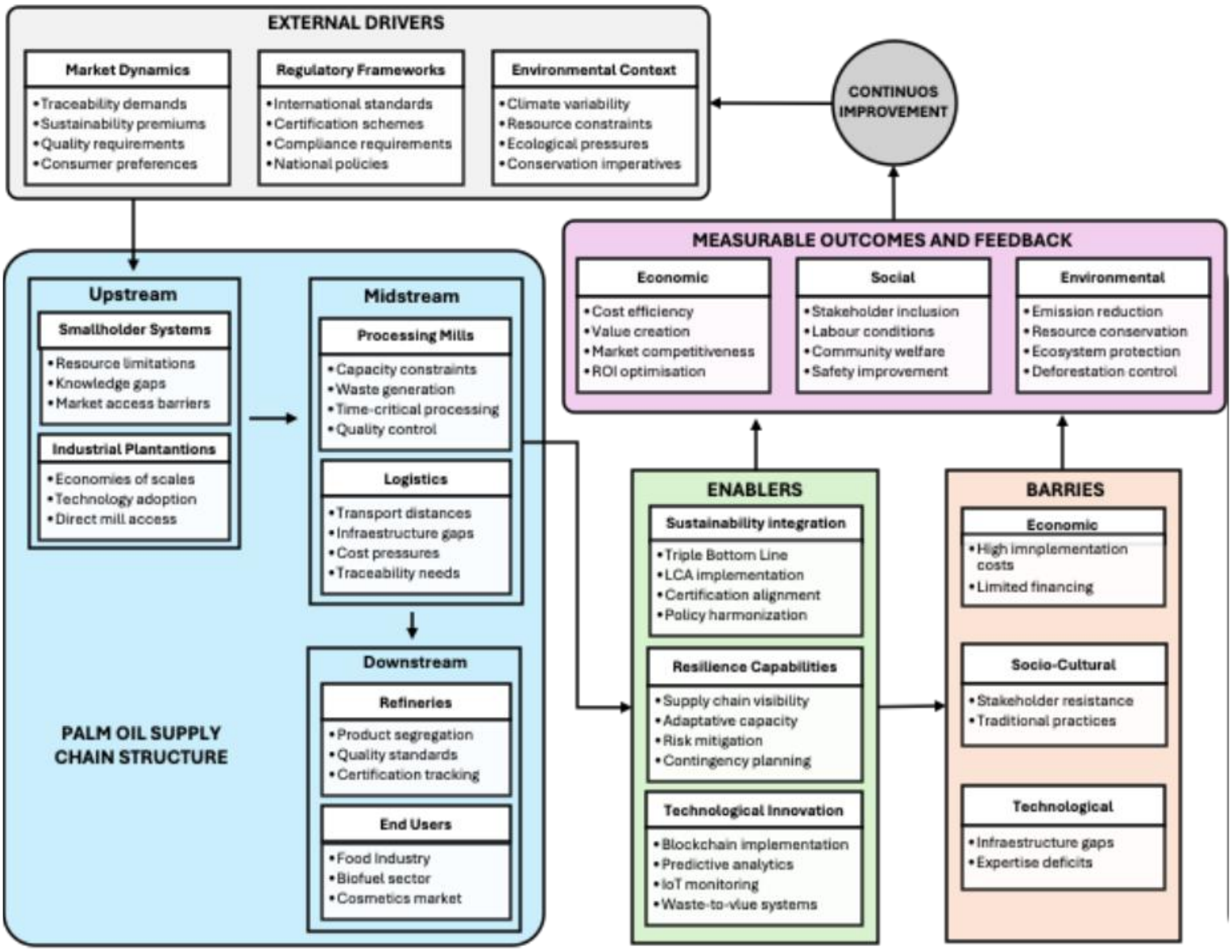

**Figure 4**. Conceptual framework for sustainable palm oil supply chain management

The palm oil supply chain structure represents the operational core of the framework, organized across three main segments. The upstream segment comprises smallholder systems and industrial plantations, each facing distinct challenges related to resource access, knowledge capabilities, and market integration. The midstream segment encompasses processing mills and logistics operations, where time-critical processes, capacity constraints, and efficiency optimization intersect. The downstream segment includes refineries and end users across various industries, where product differentiation, quality standards, and market segmentation drive value creation

Enablers represent the mechanisms that facilitate sustainable transformation. Technological enablers include digital innovations for traceability, process optimization tools, data analytics capabilities, and automation systems that enhance operational efficiency. Managerial enablers comprise resilience capabilities, sustainability integration strategies, collaborative governance models, and continuous improvement processes that strengthen adaptive capacity.

Barriers identify the key constraints that impede sustainable SCM implementation. Economic barriers include high implementation costs, limited financing options, and uncertain return on investment. Socio-cultural barriers encompass stakeholder resistance, traditional practice persistence, knowledge gaps, and trust deficits. Technological barriers involve infrastructure limitations, expertise shortages, system integration challenges, and standardization gaps.

The framework culminates in measurable outcomes and feedback mechanisms. Performance indicators across environmental, economic, and social dimensions provide objective measures of progress. The continuous improvement loop enables system learning, policy cdcdrefinement, innovation diffusion, and adaptive responses to emerging challenges. This iterative process ensures that the framework remains dynamic and responsive to changing conditions.

The proposed framework offers several theoretical and practical contributions. It integrates multiple theoretical perspectives within a unified model, providing a holistic view of sustainable palm oil SCM. The framework explicitly acknowledges the multi-level nature of supply chain challenges, from individual actors to systemic issues. By incorporating feedback mechanisms, it recognizes SCM as a dynamic, evolving system rather than a static structure. Finally, the framework balances comprehensiveness with parsimony, offering sufficient detail for practical application while maintaining conceptual clarity for theoretical development.

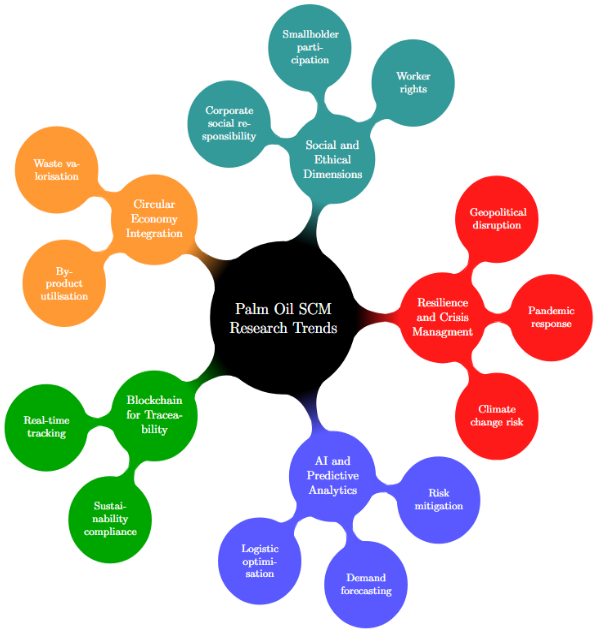


**Figure 5**. Emerging research trends in palm oil SCM

# 9. EMERGING TRENDS AND RESEARCH GAPS IN PALM OIL SCM

Despite progress in sustainability, resilience, and digital integration, key gaps continue to limit the long-term effectiveness of SCM models in the palm oil industry. This section identifies these shortcomings, highlights emerging trends, and outlines future research priorities.

## *9.1 Identified Research Gaps*

One critical gap is the scarcity of longitudinal studies examining the lasting effects of sustainability certifications and digitalization efforts (Furumo *et al*., 2020; El Hathat *et al*., 2023). Most research emphasises short-term improvements, leaving unclear whether such interventions sustainably reduce deforestation or enhance smallholder livelihoods.

Another persistent issue is the regional imbalance in research. While Indonesia and Malaysia dominate scholarly focus, Latin America and Africa remain underrepresented despite their expanding roles in palm oil production (Harahap *et al*., 2019; Vásquez *et al*., 2019). These regions possess distinct governance, infrastructure, and regulatory conditions, necessitating comparative studies to adapt sustainability strategies accordingly.

Social sustainability also remains insufficiently explored. While environmental and economic aspects are well-covered, issues like labour conditions, fair wages, and smallholder inclusion receive limited attention (Haryati *et al*., 2022; Chen & Yang, 2024). This is particularly problematic in an industry reliant on migrant labour and small-scale producers, who face barriers in accessing certifications and financial support.

Additionally, although digital technologies such as blockchain, AI, and IoT are widely acknowledged as enablers of traceability and efficiency, practical implementation challenges are seldom addressed (Ayyildiz & Taskin, 2021; El Hathat *et al*., 2023). High costs, limited infrastructure, and lack of technical expertise restrict adoption among smallholders and SMEs, widening the gap between innovation and applicability.

Lastly, research on circular economy models in palm oil SCM is fragmented (How *et al*., 2018; Wang *et al*., 2024). Interest is growing in valorising waste streams like empty fruit bunches (EFB) and palm oil mill effluent (POME), but most studies focus on isolated applications rather than integrated supply chain-wide strategies. A more systemic approach is needed to assess economic viability, scalability, and regulatory implications.

## *9.2 Emerging Research Trends in Palm Oil SCM*

As shown in Figure 5, palm oil SCM is increasingly shaped by regulatory scrutiny, the proliferation of Industry 4.0 tools, and the growing role of stakeholder collaboration.

## *9.3 Priority Areas for Future Research*

Closing the identified gaps will require interdisciplinary efforts across academia, industry, and policy. First, future studies should prioritise longitudinal analyses to evaluate the real-world impacts of certifications on deforestation, carbon emissions, and smallholder income. Second, the roles of AI and automation in predictive analytics, demand forecasting, and risk management deserve further empirical validation. Third, more inclusive approaches are essential to integrate smallholders and SMEs into sustainable SCM practices, including financial incentives, supportive policy frameworks, and capacity-building initiatives.

Fourth, circular economy strategies should be explored more comprehensively to evaluate how palm oil by-products can be transformed into high-value, low-carbon alternatives. Finally, expanding regional studies to encompass Latin America and Africa would yield a deeper understanding of how diverse governance and supply chain conditions influence sustainable transitions. Bridging these knowledge gaps will help construct more globally adaptable SCM strategies that align efficiency, inclusivity, and sustainability in the palm oil sector.

# 10.CONCLUSION

This study underscores the urgency of transforming SCM within the palm oil industry to meet rising demands for sustainability, efficiency, and resilience. By synthesizing both theoretical models and real-world applications, the findings demonstrate that emerging technologies can substantially boost traceability and transparency, thereby aligning palm oil production with global sustainability standards. Nevertheless, persistent obstacles remain, particularly around high initial costs, limited infrastructure, and insufficient training for smallholders. These challenges necessitate stronger collaboration between governments, businesses, and local communities, supported by enabling policies that foster inclusive adoption of sustainable practices.

Looking ahead, future research should delve into longitudinal studies that measure the long-term impacts of sustainability certifications on deforestation and smallholder livelihoods, as most existing work emphasizes short-term outcomes. Another pressing need is to develop policies and financial instruments that integrate smallholders more effectively into sustainable supply chains, reducing the barriers they face in certification processes. Moreover, deeper exploration of artificial intelligence and blockchain applications would clarify how such innovations can address current gaps in traceability and operational efficiency. Lastly, adopting circular economy approaches emerges as a key strategy to mitigate environmental harm while creating new revenue streams. In conclusion, although notable strides are being made, Achieving fully responsible palm oil SCM demands a long-term vision, coordinated efforts, and continuous research, alongside strong policy alignment to facilitate the adoption of sustainable and digital solutions. By bridging these knowledge gaps, stakeholders can move the industry closer to a more sustainable and resilient future.

# REFERENCES

Abdul-Hamid, A. Q., Ali, M. H., Tseng, M. L., Lan, S., & Kumar, M. (2020). Impeding challenges on industry 4.0 in circular economy: Palm oil industry in Malaysia. *Computers & Operations Research*, 123, 105052.

Abdul-Hamid, A. Q., Ali, M. H., Osman, L. H., & Tseng, M. L. (2021). The drivers of industry 4.0 in a circular economy: The palm oil industry in Malaysia. *Journal of Cleaner Production*, 324, 129216.

Abdulrazik, A., Elsholkami, M., Elkamel, A., & Simon, L. (2017). Multi-products productions from Malaysian oil palm empty fruit bunch (EFB): Analyzing economic potentials from the optimal biomass supply chain. *Journal of Cleaner Production*, 168,pp. 131–148. https://doi.org/10.1016/j.jclepro.2017.08.088

Abideen, A. Z., Sundram, V. P. K., & Sorooshian, S. (2023). Scope for Sustainable Development of Small Holder Farmers in the Palm Oil Supply Chain—A Systematic Literature Review and Thematic Scientific Mapping. Logistics, 7(1). https://doi.org/10.3390/logistics7010006

Abubakar, A., & Ishak, M. Y. (2024). Exploring the intersection of digitalization and sustainability in oil palm production: challenges, opportunities, and future research agenda. *Environmental Science and Pollution Research*, 31(38), pp. 50036-50055.

Afrasiabi, A., Tavana, M., & Di Caprio, D. (2022). An extended hybrid fuzzy multi-criteria decision model for sustainable and resilient supplier selection. *Environmental Science and Pollution Research*, 29(25), pp. 37291-37314.

Alhaji, A. M., Almeida, E. S., Carneiro, C. R., da Silva, C. A. S., Monteiro, S., & Coimbra, J. S. D. R. (2024). Palm Oil (Elaeis guineensis): A Journey through Sustainability, Processing, and Utilization. *Foods*, 13(17), 2814.

Ayyildiz, E. (2023). Interval valued intuitionistic fuzzy analytic hierarchy process-based green supply chain resilience evaluation methodology in post COVID-19 era. *Environmental Science and Pollution Research*, 30(15),pp. 42476-42494.

Ayyildiz, E., & Taskin Gumus, A. (2021). Interval-valued Pythagorean fuzzy AHP method-based supply chain performance evaluation by a new extension of SCOR model: SCOR 4.0. *Complex and Intelligent Systems*, 7(1),pp. 559–576. https://doi.org/10.1007/s40747-020-00221-9

Babaveisi, V., Teimoury, E., & Gholamian, M. R. (2023). A planning model for repairable spare part supply chain considering stochastic demand and backorder: an empirical investigation. *Decision Science Letters*, 12(2), pp. 239–254. https://doi.org/10.5267/j.dsl.2023.2.001

Ben Abdallah, C., El-Amraoui, A., Delmotte, F., & Frikha, A. (2024). A Hybrid Approach for Sustainable and Resilient Farmer Selection in Food Industry: Tunisian Case Study. Sustainability, 16(5), 1889.

Cafer, A. M., & Rikoon, J. S. (2018). Adoption of new technologies by smallholder farmers: the contributions of extension, research institutes, cooperatives, and access to cash for improving tef production in Ethiopia. *Agriculture and human values*, 35, pp. 685-699.

Cammelli, F., Levy, S. A., Grabs, J., Valentim, J. F., & Garrett, R. D. (2022). Effectiveness-equity tradeoffs in enforcing exclusionary supply chain policies: Lessons from the Amazonian cattle sector. *Journal of Cleaner Production*, 332, 130031.

Cemberci, M., Cicek Vural, S., & Celik, C., & Canbaz, E. (2024). The Role of Supply Chain Transparency in the Relation between Supply Chain Analytics Capabilities and Firm Performance. *Operations and Supply Chain Management: An International Journal*, 17(2), pp. 253-263.

Chen, L.-M., & Yang, S.-J. S. (2024). Designing an Optimal Two-Bin Strategy for Selling Perishable Produce to Responsible and Mainstream Buyers. *IEEE Transactions on Engineering Management*, 71, pp. 2089–2102. https://doi.org/10.1109/TEM.2022.3148405

Chiriacò, M. V., Galli, N., Santini, M., & Rulli, M. C. (2024). Deforestation and greenhouse gas emissions could arise when replacing palm oil with other vegetable oils. *Science of the Total Environment*, 914, 169486.

Chong Tan, Y., & Oly Ndubisi, N. (2014). Evaluating supply chain relationship Quality, Organisational resources, technological innovation and enterprise performance in the Palm oil processing sector in Asia. *Journal of Business and Industrial Marketing*, 29(6), pp. 487–498. https://doi.org/10.1108/JBIM-07-2013-0147

Ciccullo, F., Pero, M., Caridi, M., Gosling, J., & Purvis, L. (2018). Integrating the environmental and social sustainability pillars into the lean and agile supply chain management paradigms: A literature review and future research directions. *Journal of cleaner production*, pp. 172, 2336-2350.

Darbanian, F., Brandtner, P., & Falatouri, T., & Nasseri, M. (2024). Data Analytics in Supply Chain Management: A State-of-the-Art Literature Review. *Operations and Supply Chain Management: An International Journal*, 17(1), pp. 1-31.

de Oliveira, R. T., Ghobakhloo, M., & Figueira, S. (2023). Industry 4.0 towards social and environmental sustainability in multinationals: Enabling circular economy, organizational social practices, and corporate purpose. *Journal of Cleaner Production*, 139712.

Degli Innocenti, E., & Oosterveer, P. (2020). Opportunities and bottlenecks for upstream learning within RSPO certified palm oil value chains: A comparative analysis between Indonesia and Thailand. *Journal of Rural Studies*, 78, pp. 426-437.

Dehghan, E., Amiri, M., Shafiei Nikabadi, M., & Jabbarzadeh, A. (2019). Novel robust fuzzy programming for closed-loop supply chain network design under hybrid uncertainty. *Journal of Intelligent and Fuzzy Systems*, 37(5), pp. 6457–6470. https://doi.org/10.3233/JIFS-18117

Dehghani, M., Popova, A., & Gheitanchi, S. (2022). Factors impacting digital transformations of the food industry by adoption of blockchain technology. *Journal of Business & Industrial Marketing*, 37(9), pp. 1818-1834.

Dutta, P., Choi, T. M., Somani, S., & Butala, R. (2020). Blockchain technology in supply chain operations: Applications, challenges and research opportunities. *Transportation research part e: Logistics and transportation review*, 142, 102067.

el Hathat, Z., Venkatesh, V. G., Zouadi, T., Sreedharan, V. R., Manimuthu, A., & Shi, Y. (2023). Analyzing the greenhouse gas emissions in the palm oil supply chain in the VUCA world: A blockchain initiative. *Business Strategy and the Environment*, 32(8), pp. 5563–5582. https://doi.org/10.1002/bse.3436

Epiphaniou, G., Bottarelli, M., Al-Khateeb, H., Ersotelos, N. T., Kanyaru, J., & Nahar, V. (2020). Smart distributed ledger technologies in Industry 4.0: Challenges and opportunities in supply chain management. *Cyber Defence in the Age of AI, Smart Societies and Augmented Humanity*, pp. 319-345.

Erfani, T., & AlEdan, A. (2024). Sustainable management of produced water supply chain system: the validation of model-independent parameters for Kuwait oil company case study. *International Journal of Sustainable Engineering*, 17(1), pp. 1–9. https://doi.org/10.1080/19397038.2024.2324006

FAO. (2023). The State of Food and Agriculture 2023 – Revealing the true cost of food to transform agrifood systems. Rome. https://doi.org/10.4060/cc7724en

Furumo, P. R., Rueda, X., Rodríguez, J. S., & Parés Ramos, I. K. (2020). Field evidence for positive certification outcomes on oil palm smallholder management practices in Colombia. *Journal of Cleaner Production*, 245. https://doi.org/10.1016/j.jclepro.2019.118891

Gallemore, C., & Jespersen, K. (2019). Offsetting, insetting, or both? current trends in sustainable palm oil certification. *Sustainability (Switzerland)*, 11(19). https://doi.org/10.3390/su11195393

García-Orozco, S., Vargas-Gutiérrez, G., Ordóñez-Sánchez, S., & Silva, R. (2023). Using Multi-Criteria Decision Making in Quality Function Deployment for Offshore Renewable Energies. *Energies*, 16(18). https://doi.org/10.3390/en16186533

Gassler, B., & Spiller, A. (2018). Is it all in the MIX? Consumer preferences for segregated and mass balance certified sustainable palm oil. *Journal of Cleaner Production*, 195, pp. 21–31. https://doi.org/10.1016/j.jclepro.2018.05.039

Gawusu, S., Zhang, X., Jamatutu, S. A., Ahmed, A., Amadu, A. A., & Djam Miensah, E. (2022). The dynamics of green supply chain management within the framework of renewable energy. *International Journal of Energy Research*, 46(2), pp. 684-711.

Ghani, M. F. S. A., Zahid-Muhamad, M., Aziz, M. F. A., & Syahlan, S. (2019). Systematic Literature Review on Evaluation of Quality Management Practices in Palm Oil Supply Chain: The Case of Upstream. *IOP Conference Series: Earth and Environmental Science*, 327(1). https://doi.org/10.1088/1755-1315/327/1/012001

Gimenez, C., Sierra, V., & Rodon, J. (2012). Sustainable operations: Their impact on the triple bottom line. *International journal of production economics*, 140(1), 149-159.

Govindan, K., Kannan, D., Jørgensen, T. B., & Nielsen, T. S. (2022). Supply Chain 4.0 performance measurement: A systematic literature review, framework development, and empirical evidence. Transportation Research Part E: Logistics and Transportation Review, 164, 102725.

Grabs, J. (2023). A theory of credible cross-temporal corporate commitments as goal-based private sustainability governance. *Business Strategy and the Environment*, 32(8), pp. 5146–5160. https://doi.org/10.1002/bse.3423

Hadiguna, R. A., & Tjahjono, B. (2017). A framework for managing sustainable palm oil supply chain operations: a case of Indonesia. Production Planning and Control, 28(13), 1093–1106. https://doi.org/10.1080/09537287.2017.1335900

Hafiz, N., Azmi, K. M., Nimfa, D. T., Latiff, A. S. A., & Wahab, S. A. (2021). COVID-19 and Its Implications to the Assessment of Sustainable Palm Oil Supply Chain Management: An Indonesian Perspective. *Frontiers in Sustainability*, 2. https://doi.org/10.3389/frsus.2021.738985

Handaya, Susanto, H., Indrawan, D., & Marimin. (2022). A Soft System Dynamic Approach for Designing Palm Kernel Shell Supply Chain. *Operations and Supply Chain Management*, 15(1), pp. 148–163. https://doi.org/10.31387/oscm0480337

Harahap, F., Leduc, S., Mesfun, S., Khatiwada, D., Kraxner, F., & Silveira, S. (2019). Opportunities to optimize the palm oil supply chain in Sumatra, Indonesia. *Energies*, 12(3). https://doi.org/10.3390/en12030420

Haryati, Z., Subramaniam, V., Noor, Z. Z., Hashim, Z., Loh, S. K., & Aziz, A. A. (2022). Social life cycle assessment of crude palm oil production in Malaysia. *Sustainable Production and Consumption,* 29, pp. 90–99. https://doi.org/10.1016/j.spc.2021.10.002

Heryani, H., Legowo, A. C., Yanti, N. R., Marimin, Raharja, S., Machfud, Djatna, T., Martini, S., Baidawi, T., & Afrianto, I. (2022). Institutional Development in the Supply Chain System of Oil Palm Agroindustry in South Kalimantan. International *Journal of Technology*, 13(3), pp. 643–654. https://doi.org/10.14716/ijtech.v13i3.4754

Hidayat, N. K., Offermans, A., & Glasbergen, P. (2018). Sustainable palm oil as a public responsibility? On the governance capacity of Indonesian Standard for Sustainable Palm Oil (ISPO). *Agriculture and human values*, 35, pp. 223-242.

Hidayati, J., & Hasibuan, S. (2019). Value chain analysis and value added enhancement of Indonesia Crude Palm Oil supply chain. *International Journal on Advanced Science, Engineering and Information Technology*, 9(2), pp. 397–404. https://doi.org/10.18517/ijaseit.9.2.7708

How, B. S., Yeoh, T. T., Tan, T. K., Chong, K. H., Ganga, D., & Lam, H. L. (2018). Debottlenecking of sustainability performance for integrated biomass supply chain: P-graph approach. *Journal of Cleaner Production*, 193, pp. 720–733. https://doi.org/10.1016/j.jclepro.2018.04.240

Islam, R., Ansari, M. E., Dewan, M. A., Sultana, S., & Rivin, M. A. H. (2024). Supply Chain Management Analysis and Design for a Variety of Economic Scenarios, Including Data and System Administration. *Journal of Software Engineering and Applications*, 17(10), pp. 770-785.

Ivanov, D., & Dolgui, A. (2021). A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0. *Production Planning & Control*, 32(9), pp. 775-788.

Jackson, A., Spiegler, V. L., & Kotiadis, K. (2024). Exploring the potential of blockchain-enabled lean automation in supply chain management: a systematic literature review, classification taxonomy, and future research agenda. *Production Planning & Control*, 35(9), pp. 866-885.

Jafarzadeh Ghoushchi, S., Khazaeili, M., Amini, A., & Osgooei, E. (2019). Multi-criteria sustainable supplier selection using piecewise linear value function and fuzzy best-worst method. *Journal of Intelligent and Fuzzy Systems*, 37(2), pp. 2309–2325. https://doi.org/10.3233/JIFS-182609

Jenkins, G. P., & Wright, D. S. (1998). Managing Inflexible Supply Chains. *The International Journal of Logistics Management*, 9(2), pp. 83–90. https://doi.org/10.1108/09574099810805852

Karmakar, R., Mazumder, S. K., Hossain, M. B., Illes, C. B., & Garai, A. (2023). Sustainable Green Economy for a Supply Chain with Remanufacturing by Both the Supplier and Manufacturer in a Varying Market. *Logistics*, 7(3). https://doi.org/10.3390/logistics7030037

Kasim, E., Stöhr, J., & Herzig, C. (2021). Promoting sustainable palm oil in supply chain strategy: a food business case study. *Qualitative Research in Organizations and Management: An International Journal*, 16(3–4), pp. 550–571. https://doi.org/10.1108/QROM-03-2020-1907

Kazancoglu, Y., Kazancoglu, I., & Sagnak, M. (2018). A new holistic conceptual framework for green supply chain management performance assessment based on circular economy. *Journal of cleaner production*, 195, pp. 1282-1299.

Kim, S., Choi, Y., & Kim, S. (2023). Simulation Modeling in Supply Chain Management Research of Ethanol: A Review. *Energies*, 16(21). https://doi.org/10.3390/en16217429

Kraus, S., Breier, M., Lim, W. M., Dabić, M., Kumar, S., Kanbach, D., ... & Ferreira, J. J. (2022). Literature reviews as independent studies: guidelines for academic practice. *Review of Managerial Science*, 16(8), pp. 2577-2595.

Kurniawan, I. (2022). Sustainable Supply Chain Framework Design in Indonesian Palm Oil Industry with IoT Integration. *ACM International Conference Proceeding Series.* https://doi.org/10.1145/3557738.3557868

Kusrini, E., Caneca, V. I., Helia, V. N., & Miranda, S. (2019, December). Supply Chain Performance Measurement Using Supply Chain Operation Reference (SCOR) 12.0 Model: A Case Study in AA Leather SME in Indonesia. *In IOP Conference Series: Materials Science and Engineering* (Vol. 697, No. 1, p. 012023). IOP Publishing.

Lakshmanan, S., & Yung, Y. L. (2024). Circular and Sustainable Practices of a Palm Oil Processing Complex. In Palm Oil Industry: Plantation and Process Towards Circular Economy (pp. 31-57). Singapore: Springer Nature Singapore.

Larsen, R. K., Osbeck, M., Dawkins, E., Tuhkanen, H., Nguyen, H., Nugroho, A., Gardner, T. A., Zulfahm, & Wolvekamp, P. (2018). Hybrid governance in agricultural commodity chains: Insights from implementation of 'No Deforestation, No Peat, No Exploitation' (NDPE) policies in the oil palm industry. *Journal of Cleaner Production*, 183, pp. 544–554. https://doi.org/10.1016/j.jclepro.2018.02.125

Leong, H., Leong, H., Foo, D. C. Y., Ng, L. Y., & Andiappan, V. (2019). Hybrid approach for carbon-constrained planning of bioenergy supply chain network. *Sustainable Production and Consumption*, 18, pp. 250–267. https://doi.org/10.1016/j.spc.2019.02.011

Lestari, F., Ismail, K., Hamid, A. A., Supriyanto, E., Hisbunnazar, & Sutupo, W. (2014a). Measuring supply chain using SCOR model in palm oil downstream industry: A review. Lecture Notes in Engineering and Computer Science, 2, 967–972.

Lestari, F., Ismail, K., Hamid, A. B. A., & Sutupo, W. (2014b). Measuring the value-added of oil palm products with integrating SCOR model and discrete event simulation. *Research Journal of Applied Sciences, Engineering and Technology*, 8(10), pp. 1244–1249. https://doi.org/10.19026/rjaset.8.1090

Linnenluecke, M. K., Marrone, M., & Singh, A. K. (2020). Conducting systematic literature reviews and bibliometric analyses. *Australian Journal of Management*, 45(2), pp. 175-194.

Liu, F., & Panagiotakos, D. (2022). Real-world data: a brief review of the methods, applications, challenges and opportunities. *BMC Medical Research Methodology*, 22(1), 287.

Macdonald, K., Diprose, R., & Pugley, D. D. (2024). Scaling-up sustainable commodity governance through jurisdictional initiatives: Political pathways to sector transformation in the Indonesian palm oil sector? World Development, 176, 106504.

Mankong, P., Fantke, P., Ghose, A., Soheilifard, F., Oginah, S. A., Phenrat, T., ... & Prapaspongsa, T. (2024). Assessing life cycle impacts from toxic substance emissions in major crop production systems in Thailand. *Sustainable Production and Consumption*, 46, pp. 717-732.

Manzini, R., Accorsi, R., Ayyad, Z., Bendini, A., Bortolini, M., Gamberi, M., Valli, E., & Toschi, T. G. (2014). Sustainability and quality in the food supply chain. A case study of shipment of edible oils. *British Food Journal*, 116(12), pp. 2069–2090. https://doi.org/10.1108/BFJ-11-2013-0338

Mareeh, H. Y. S., Prabakusuma, A. S., Hussain, M. D., Patwary, A. K., Dedahujaev, A., & Aleryani, R. A. (2023). Sustainability and profitability of Malaysia crude palm oil supply chain management: system dynamics modelling approach. *Nankai Business Review International*, 14(4), pp. 698–719. https://doi.org/10.1108/NBRI-01-2022-0003

Matarneh, S., Piprani, A. Z., Ellahi, R. M., Nguyen, D. N., Le, T. M., & Nazir, S. (2024). Industry 4.0 technologies and circular economy synergies: Enhancing corporate sustainability through sustainable supply chain integration and flexibility. *Environmental Technology & Innovation*, 35, 103723.

Meijaard, E., & Sheil, D. (2019). *The moral minefield of ethical oil palm and sustainable development.* Frontiers in Forests and Global Change, 2, 22.

Min, H. (2023). Exploring the Commercialization of Smart Rural Energy in Times of Energy Supply Chain Disruptions. *Energies*, 16(14). https://doi.org/10.3390/en16145364

Murphy, D. J., Goggin, K., & Paterson, R. R. M. (2021). Oil palm in the 2020s and beyond: challenges and solutions. *CABI agriculture and bioscience*, 2, 1-22.

Nikoloyuk, J., Burns, T. R., & de Man, R. (2010). The promise and limitations of partnered governance: The case of sustainable palm oil. *Corporate Governance*, 10(1), pp. 59–72. https://doi.org/10.1108/14720701011021111

Pacheco, P., Schoneveld, G., Dermawan, A., Komarudin, H., & Djama, M. (2020). Governing sustainable palm oil supply: Disconnects, complementarities, and antagonisms between state regulations and private standards. *Regulation & Governance*, 14(3), pp. 568-598.

Pettit, T. J., Croxton, K. L., & Fiksel, J. (2013). Ensuring supply chain resilience: Development and implementation of an assessment tool. *Journal of Business Logistics*, 34(1), pp. 46–76. https://doi.org/10.1111/jbl.12009

Piya, S. (2024). Analysis of Supply Chain Sustainability Drivers in the Oil and Gas Industry under Covid-19 Pandemic. *Journal of Systems Science and Systems Engineering*, 33(2), pp. 131–161. https://doi.org/10.1007/s11518-024-5597-9

Primadasa, R., & Christata, B. R. (2023). Interrelationship Performance Indicators Model of Agile Supply Chain Management in Palm Oil Industry. *Jurnal Optimasi Sistem Industri*, 22(1), pp. 1–8. https://doi.org/10.25077/josi.v22.n1.p1-8.2023

Purnomo, H., Okarda, B., Dermawan, A., Ilham, Q. P., Pacheco, P., Nurfatriani, F., & Suhendang, E. (2020). Reconciling oil palm economic development and environmental conservation in Indonesia: A value chain dynamic approach. Forest Policy and Economics, 111, 102089.

Rashid, M., Bari, B. S., Yusup, Y., Kamaruddin, M. A., & Khan, N. (2021). A comprehensive review of crop yield prediction using machine learning approaches with special emphasis on palm oil yield prediction. IEEE access, 9, 63406-63439.

Rashidi, K., Noorizadeh, A., Kannan, D., & Cullinane, K. (2020). Applying the triple bottom line in sustainable supplier selection: A meta-review of the state-of-the-art. *Journal of Cleaner Production*, 269, 122001.

Rehman, S., Mahmood, R., & Abidi, N., & Wan Yusoff, W. (2025). Integrating Smart Supply Chain with Green Practices to Enhance Sustainable Supply Chain Performance. *Operations and Supply Chain Management: An International Journal*, 18(1), pp. 1-18.

Rezaei, M., Salmasnia, A., & Maleki, M. R. (2023). An integrated model for continuous and simultaneous performance improvement: A SCOR-based supply chain decision alignment. *International Journal of Industrial Engineering*, 34(3), pp. 1-18.

Sadeghi, J., & Haapala, K. R. (2019). Optimizing a sustainable logistics problem in a renewable energy network using a genetic algorithm. *OPSEARCH*, 56(1), pp. 73–90. https://doi.org/10.1007/s12597-019-00356-5

Sarpong, F., Dery, E. K., Danso, I., & Oduro-Yeboah, C. (2022). The socio-economic impact of mitigating the challenges at the artisanal palm oil mills in Ghana. *World Food Policy*, 8(2), pp. 225-236.

Sheng, S. W., & Wicha, S. (2024). Blockchain-based Traceability for Teak Identity: A Transformational Approach. *Journal of Mobile Multimedia*, pp. 267-306.

Shoomal, A., Jahanbakht, M., Componation, P. J., & Ozay, D. (2024). Enhancing supply chain resilience and efficiency through internet of things integration: Challenges and opportunities. Internet of Things, 101324.

Singh, A., & Trivedi, A. (2016). Sustainable green supply chain management: trends and current practices. Competitiveness Review, 26(3), 265-288.

Snyder, H. (2024). Designing the literature review for a strong contribution. *Journal of Decision Systems*, 33(4), pp. 551-558.

Suryani, E., Hendrawan, R. A., Muhandhis, I., & Dewi, L. P. (2018). Dynamic simulation model of crude palm oil supply chain to determine fulfillment ratio and manufacturing efficiency of cooking oil industry. *Journal of Engineering and Applied Sciences,* 13(Specialissue9), pp. 6954–6960. https://doi.org/10.3923/jeasci.2018.6954.6960

Svensson, G., Ferro, C., Høgevold, N., Padin, C., Varela, J. C. S., & Sarstedt, M. (2018). Framing the triple bottom line approach: Direct and mediation effects between economic, social and environmental elements. *Journal of cleaner production*, 197, pp. 972-991.

Tang, J. P., Lam, H. L., Abdul Aziz, M. K., & Morad, N. A. (2017). Palm biomass strategic resource managment – A competitive game analysis. *Energy*, 118, pp. 456–463. https://doi.org/10.1016/j.energy.2016.07.163

Teng, S., Khong, K. W., & Ha, N. C. (2020). Palm oil and its environmental impacts: A big data analytics study. *Journal of Cleaner Production*, 274, 122901.

Tey, Y. S., Brindal, M., Darham, S., Sidique, S. F. A., & Djama, M. (2020). Early mover advantage in Roundtable on Sustainable Palm Oil certification: A panel evidence of plantation companies. *Journal of Cleaner Production*, 252, 119775.

.

Trkman, P., Štemberger, M. I., Jaklič, J., & Groznik, A. (2007). Process approach to supply chain integration. *Supply Chain Management,* 12(2), pp. 116–128. https://doi.org/10.1108/13598540710737307

Tsolakis, N., Schumacher, R., Dora, M., & Kumar, M. (2023). Artificial intelligence and blockchain implementation in supply chains: a pathway to sustainability and data monetisation? Annals of Operations Research, 327(1), 157-210.

Utari, R. S., Buchdadi, A. D., & Warokka, A. (2022). The Impact of Supply Chain Management and Risk Management on a State Oil and Gas Industry with Competitive Advantage as Mediating Variable. Quality - Access to Success, 23(189), 253–259. https://doi.org/10.47750/QAS/23.189.29

Vásquez, M. C., Martínez, A., Castillo, E. F., & Silva, E. E. (2019). Holistic approach for sustainability enhancing of hydrotreated aviation biofuels, through life cycle assessment: A Brazilian case study. *Journal of Cleaner Production*, 237. https://doi.org/10.1016/j.jclepro.2019.117796

Wang, C.-N., Nguyen, V. T., Thai, H. T. N., Tran, N. N., & Tran, T. L. A. (2018). Sustainable supplier selection process in edible oil production by a hybrid fuzzy analytical hierarchy process and green data envelopment analysis for the SMEs food processing industry. Mathematics, 6(12). https://doi.org/10.3390/math6120302

Wang, M., Wu, Y., & Chen, B., & Evans, M. (2020). Blockchain and Supply Chain Management: A New Paradigm for Supply Chain Integration and Collaboration. *Operations and Supply Chain Management: An International Journal*, 14(1), pp. 111-122.

Wang, R., Lee, K. E., Mokhtar, M., & Goh, T. L. (2022). The challenges of palm oil sustainable consumption and production in China: An institutional theory perspective. Sustainability, 14(8), 4856.

Wang, S., Li, B., Zhao, X., Hu, Q., & Liu, D. (2024). Assessing fossil energy supply security in China using ecological network analysis from a supply chain perspective. Energy, 288. https://doi.org/10.1016/j.energy.2023.129772

Williams, A., Whiteman, G., & Kennedy, S. (2021). Cross-scale systemic resilience: Implications for organization studies. Business & Society, 60(1), 95-124.

Yadav, V. S., Singh, A. R., Gunasekaran, A., Raut, R. D., & Narkhede, B. E. (2022). A systematic literature review of the agro-food supply chain: Challenges, network design, and performance measurement perspectives. *Sustainable Production and Consumption*, 29, pp. 685-704.

Zahraee, S. M., Shiwakoti, N., & Stasinopoulos, P. (2022). Agricultural biomass supply chain resilience: COVID-19 outbreak vs. sustainability compliance, technological change, uncertainties, and policies. *Cleaner Logistics and Supply Chain*, 4. https://doi.org/10.1016/j.clscn.2022.100049

Zamri, M. F., Milano, J., Shamsuddin, A. H., Roslan, M. E., Salleh, S. F., Rahman, A. A., ... & Mahlia, T. I. (2022). An overview of palm oil biomass for power generation sector decarbonization in Malaysia: Progress, challenges, and prospects. Wiley Interdisciplinary Reviews: Energy and Environment, 11(4), e437.

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