

## STRENGTHENING PALM OIL AGRIBUSINESS TRACEABILITY SYSTEMS TO ADDRESS VIRAL CONCERNS ON SUPPLY CHAIN TRANSPARENCY AND ENVIRONMENTAL ACCOUNTABILITY

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### ABSTRACT

The increasing global demand for sustainable palm oil has intensified concerns regarding supply chain transparency and environmental accountability, particularly in complex production systems such as Indonesia's palm oil sector. This study aims to analyze and formulate strategies for strengthening traceability systems to enhance transparency and environmental responsibility in the palm oil agribusiness supply chain. A qualitative approach was employed using a systematic literature review of academic publications, institutional reports, and policy documents. Data were analyzed through content and thematic analysis to identify key challenges, patterns, and strategic solutions related to traceability implementation. The findings reveal that major challenges include supply chain fragmentation, limited integration of smallholder farmers, weak data systems, and inadequate institutional coordination. Although initiatives such as ISPO, RSPO, and NDPE policies have improved governance, traceability remains incomplete, particularly at the plantation level. Strengthening traceability through digital technologies, improved governance frameworks, and multi-stakeholder collaboration is therefore essential. This study contributes by providing a comprehensive conceptual understanding of traceability strengthening strategies and highlighting the importance of integrating technological, institutional, and stakeholder dimensions to support more transparent and environmentally accountable palm oil supply chains.

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### INTRODUCTION

The palm oil industry is one of the most important global agribusiness sectors, playing a significant role in meeting the world's demand for vegetable oils while supporting economic growth in producing countries, particularly

in Southeast Asia (Meijaard et al., 2018; Rival & Levang, 2014). Palm oil is widely used in a variety of products including food, cosmetics, and bioenergy, leading to a continuous increase in global demand alongside population and industrial growth (Forster et al., 2017; Murphy et al., 2021). However, the expansion of oil palm plantations has often been associated with environmental issues such as deforestation, land degradation, and biodiversity loss, which have raised global concerns about the sustainability of the industry (Carlson et al., 2018; Vijay et al., 2016). These concerns have intensified calls for more transparent, sustainable, and accountable practices throughout the palm oil supply chain (Schleifer & Sun, 2018).

Within the global supply chain context, palm oil distribution involves a complex network of actors, including smallholder farmers, plantation companies, processing mills, traders, manufacturers, and retailers (Pacheco et al., 2017). Such complexity often results in limited visibility regarding the origin of raw materials and the production processes occurring along the supply chain (Hirbli, 2018). This lack of visibility can generate uncertainty regarding compliance with environmental and social standards, thereby triggering concerns among consumers and stakeholders regarding supply chain transparency and accountability. Consequently, improving transparency within supply chains has become a crucial element in building public trust in sustainable palm oil products (Kasim et al., 2021).

One approach that has increasingly been adopted to enhance transparency and accountability in supply chains is the implementation of traceability systems that allow products to be tracked from their point of origin to the final consumer (Mol & Oosterveer, 2015). Traceability systems enable the identification of production locations, processing activities, and product movements throughout the supply chain, thereby facilitating monitoring of compliance with sustainability standards (Gajderowicz et al., 2025). In the palm oil industry, such systems play a critical role in ensuring that marketed products originate from sources that do not contribute to deforestation and that comply with environmental and social regulations. Furthermore, traceability systems can help resolve disputes related to product origin while enhancing the integrity and credibility of palm oil supply chains in global markets (Caro et al., 2018).

Advances in digital technology have also created new opportunities to strengthen traceability systems in agribusiness supply chains, including through the use of blockchain technology, satellite-based monitoring systems, and digital data-sharing platforms. These technologies enable supply chain data to be recorded in a more transparent, accurate, and tamper-resistant manner, thereby improving trust among supply chain. In addition, digital integration allows real-time monitoring of production practices and supports environmental risk mitigation efforts, such as preventing deforestation in agricultural commodity supply chains. Therefore, strengthening technology-based traceability systems has the potential to become a key instrument in improving transparency and environmental accountability in the palm oil agribusiness sector.

Despite the development of various sustainability initiatives, global concerns regarding supply chain transparency and environmental accountability in the palm oil industry continue to grow and spread rapidly through global information networks. These concerns not only influence consumer perceptions but also affect international trade policies and sustainability regulations that are becoming increasingly strict toward palm oil-based products. Therefore, more systematic efforts are required to strengthen palm oil agribusiness traceability systems in order to ensure supply chain transparency and enhance environmental accountability comprehensively.

Several previous studies have examined various aspects related to sustainability and transparency within palm oil supply chains. For example, (Carlson et al., 2018) demonstrated that oil palm plantation expansion has a significant relationship with land-use change and deforestation in tropical regions. Another study by (Schleifer & Sun, 2018) highlighted the role of sustainability certification schemes in improving governance within the global palm oil supply chain. Meanwhile, (Caro et al., 2018; Hirbli, 2018) emphasized the potential of digital technologies such as blockchain to enhance transparency and traceability in food supply chains. However, most existing studies focus primarily on either technical traceability mechanisms or sustainability certification systems separately. Consequently, research that specifically addresses the strengthening of palm oil agribusiness traceability systems to respond to global concerns about supply chain transparency and environmental accountability remains relatively limited.

Based on the above background, this study aims to analyze and formulate strategies for strengthening palm oil agribusiness traceability systems in order to improve supply chain transparency and environmental accountability.

This research is expected to contribute both conceptually and practically to the development of more effective traceability systems that support transparent, responsible, and sustainable palm oil agribusiness practices.

## RESEARCH METHODS

This study adopts a qualitative approach using a literature review to develop an in-depth understanding of traceability systems in the palm oil agribusiness supply chain, particularly regarding transparency and environmental accountability. This method enables the synthesis of theoretical and empirical insights to identify strategic approaches and research gaps. Literature reviews are widely used to integrate multidisciplinary perspectives in sustainability studies (Snyder, 2019; Xiao & Watson, 2019).

The study uses secondary data from peer-reviewed journals, books, conference proceedings, and reports obtained from databases such as Scopus, Web of Science, ScienceDirect, and Google Scholar. Keywords include palm oil supply chain, traceability system, supply chain transparency, and environmental accountability. Sources were selected based on relevance, credibility, and contribution to sustainability discussions (Glasbergen, 2018; Pye et al., 2012).

Data were collected through systematic literature searching and documentation. The process included identification, screening, evaluation, and classification of relevant sources based on predefined criteria to ensure comprehensive coverage of traceability and sustainability issues (Papaioannou et al., 2016; Tranfield et al., 2003).

Data were analyzed using content and thematic analysis. Content analysis identified key concepts and patterns, while thematic analysis categorized findings into major themes such as governance, certification, digital traceability, and environmental responsibility. This approach supports conceptual synthesis and identification of research gaps (Braun & Clarke, 2021; Krippendorff, 2018).

## RESULTS AND DISCUSSION

### Current Conditions of Traceability in the Palm Oil Agribusiness Supply Chain

The palm oil supply chain in Indonesia is highly complex, involving multiple actors such as smallholders, intermediaries, mills, refiners, and global manufacturers. This multi-layered structure makes full traceability difficult, particularly in the upstream segment. Smallholders contribute around 40–45% of production but are often outside formal monitoring systems, creating significant transparency gaps (Purnomo et al., 2020). Plantation ownership is dominated by private companies (52%), followed by smallholders (41%) and state-owned enterprises (7%), highlighting the importance of integrating smallholders into traceability systems.

Approximate Distribution of Oil Palm Plantation Ownership in Indonesia

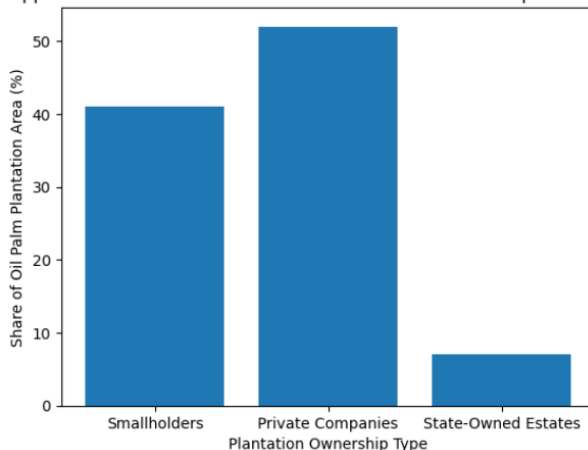


Figure 1. Distribution of Oil Palm Plantation Ownership in Indonesia

A key challenge lies in the fragmented trading network, where smallholders sell fresh fruit bunches (FFB) to intermediaries who mix products from multiple sources. This aggregation obscures product origins and weakens verification of legal and sustainable practices (Pacheco et al., 2017). In regions such as Riau, many smallholders lack formal land titles, and mills often process mixed certified and non-certified FFB, further undermining traceability and certification credibility (Purnomo et al., 2020).

Traceability is also critical in addressing environmental concerns, particularly deforestation linked to oil palm expansion. Weak traceability systems limit the ability to verify whether production originates from legal or deforested land (Austin et al., 2017). Similarly, the 2015 forest and peatland fires exposed the inability to identify responsible actors due to poor supply chain monitoring (Tacconi, 2016).

Efforts to improve traceability include certification schemes such as ISPO and RSPO, which require supply chain documentation. However, their effectiveness is limited by smallholders' constraints in resources, knowledge, and institutional support. Increasing global pressure, especially from the European Union, further emphasizes the need for traceability to ensure deforestation-free supply chains and maintain market access (Garrett et al., 2019).

Overall, traceability in Indonesia's palm oil sector remains uneven, particularly in smallholder-dominated upstream segments. Challenges such as fragmented supply chains, weak governance, and limited technological adoption hinder effectiveness. Strengthening traceability requires digital innovation, improved governance, and stronger stakeholder collaboration to enhance transparency and environmental accountability.

### The Role of Traceability in Enhancing Supply Chain Transparency

Traceability systems are essential for improving transparency in the palm oil supply chain by enabling the tracking of product origin, movement, and processing from plantations to consumers. These systems allow stakeholders to verify whether production complies with sustainability and environmental standards, reducing uncertainty regarding social and environmental impacts (Ahmed & MacCarthy, 2023). However, traceability remains uneven, with high coverage at the mill level (around 95%) but significantly lower at the plantation level (around 60%), reflecting difficulties in identifying the origin of fresh fruit bunches (FFB) due to mixing from multiple sources.

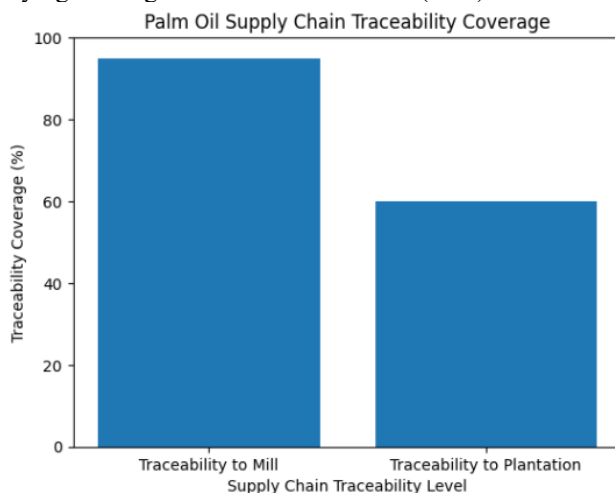


Figure 2. Palm Oil Traceability Coverage

The complexity of Indonesia's supply chain increases the risk of information asymmetry, as mills receive FFB from smallholders, companies, and intermediaries, limiting transparency (Pacheco et al., 2017). This challenge is evident in regions such as Central and West Kalimantan, where companies adopting NDPE commitments still struggle to verify deforestation-free supply chains due to incomplete traceability systems (Garrett et al., 2019).

To address these issues, companies like Wilmar International and Golden Agri-Resources have implemented digital traceability systems using GIS and satellite monitoring to map supply chains and detect environmental risks. These technologies improve transparency by linking production to specific geographic locations (Garrett et al., 2019; Purnomo et al., 2020). Additionally, certification schemes such as RSPO and ISPO support traceability through chain-of-custody systems, although their effectiveness is limited by smallholder constraints.

Technological innovations, including blockchain and remote sensing, further strengthen traceability by enabling real-time monitoring and data sharing, reducing information manipulation (Ahmed & MacCarthy, 2023). Increasing global regulations, such as the European Union’s deforestation-free requirements, also drive the need for robust traceability systems to maintain market access.

Overall, traceability plays a strategic role in enhancing transparency, but its effectiveness depends on smallholder integration, technological adoption, and stronger governance frameworks to ensure accountable and sustainable palm oil production.

### Environmental Accountability in Palm Oil Production

Environmental accountability is a critical issue in the global palm oil industry, particularly in Indonesia. It refers to the responsibility of stakeholders to ensure that production activities do not cause environmental harm and can be transparently monitored and verified. Rapid oil palm expansion has been linked to deforestation, biodiversity loss, peatland degradation, and greenhouse gas emissions, especially in Sumatra, Kalimantan, and Papua. Studies confirm that agricultural expansion, including oil palm, is a major driver of forest loss in Indonesia (Austin et al., 2017; Carlson et al., 2018).

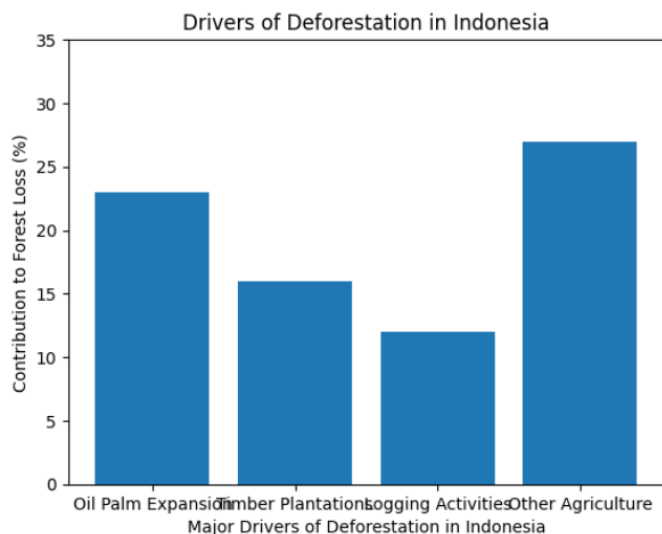


Figure 3. Drivers of Deforestation in Indonesia

Deforestation remains a central concern, with oil palm expansion contributing significantly to land-use change. Between 2000 and 2010, a substantial portion of new plantations replaced forested areas, releasing carbon emissions and threatening ecosystem stability (Carlson et al., 2018). The 2015 forest and peatland fires further highlighted weak environmental accountability, as limited traceability made it difficult to identify responsible actors (Tacconi, 2016).

In regions such as Riau, plantation expansion on peatlands has intensified environmental risks, as peatland conversion contributes significantly to carbon emissions and fire vulnerability (Miettinen et al., 2012). These challenges emphasize the need for stronger accountability mechanisms.

To address these issues, governance initiatives such as ISPO and RSPO certification require compliance with environmental standards, including forest protection and sustainable land management (Glasbergen, 2018). Traceability systems further strengthen accountability by linking products to their geographic origin, supported by technologies such as satellite monitoring and GIS, which improve the verification of sustainability claims.

However, challenges remain, particularly in integrating smallholders who often lack resources and capacity to comply with sustainability requirements. Overall, improving environmental accountability requires stronger traceability systems, better governance, technological innovation, and inclusive stakeholder collaboration to ensure sustainable palm oil production.

### Strategies for Strengthening Palm Oil Traceability Systems

Traceability systems enable companies to track the origin of palm oil throughout the supply chain, ensuring that raw materials comply with sustainability standards and are not linked to deforestation (Gardner et al., 2019). These systems are crucial due to the complexity of the palm oil supply chain, which involves multiple actors such as smallholders, traders, mills, and global companies.

Operationally, traceability involves mapping suppliers, collecting plantation data using GIS and satellite imagery, and verifying whether production areas overlap with forests, peatlands, or protected zones. Suppliers violating NDPE (No Deforestation, No Peat, No Exploitation) policies may face suspension or termination (Furumo & Lambin, 2020). Traceability also strengthens transparency and supports certification schemes like RSPO, which require documentation and verification of production sources (Cattau et al., 2016).

Improved transparency allows companies to identify environmental risks and take corrective actions, thereby contributing to deforestation reduction. A key example is Wilmar International, which implemented NDPE policies in 2013 and achieved nearly 100% traceability to mill by 2019 (Furumo & Lambin, 2020). Through satellite monitoring, the company can detect deforestation risks and suspend non-compliant suppliers, demonstrating how traceability enhances environmental accountability.

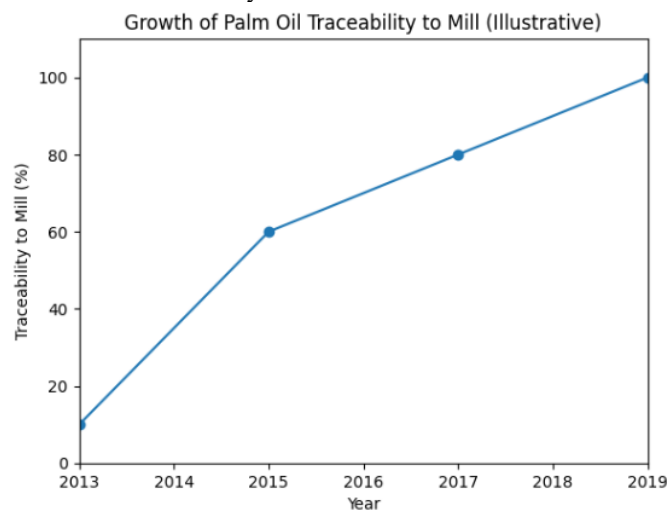


Figure 4. Increase in Traceability to Mill in the Palm Oil Supply Chain

Overall, strengthening traceability systems—through digital technologies, strict supplier policies, and certification mechanisms—can improve transparency, reduce deforestation, and encourage sustainable practices across the palm oil supply chain.

## CONCLUSION

This study highlights that traceability systems play a crucial role in enhancing supply chain transparency and environmental accountability in the palm oil sector. However, their effectiveness is constrained by complex supply chain structures, limited technological adoption, weak data integration, and insufficient institutional coordination, particularly involving smallholder farmers. While initiatives such as ISPO, RSPO, and NDPE policies support sustainability governance, their success depends on the ability to trace products to the plantation level. Therefore, strengthening traceability through digital technologies, improved governance, and stakeholder collaboration is essential.

Practically, governments and industry actors should integrate smallholders into traceability systems through capacity building, training, and access to digital tools. Companies should also expand the use of GIS, satellite monitoring, and digital platforms to improve tracking accuracy, supported by stronger multi-stakeholder collaboration.

Future research should focus on empirical and quantitative studies, particularly on smallholder-based supply chains, to evaluate the effectiveness of technologies such as blockchain and satellite monitoring, as well as to explore policies and incentives that encourage broader participation in traceability systems.

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