



ISSN 2599-3496 print
ISSN 2614-2376 online
Volume 9, Number 2, 2026

INTERNATIONAL JOURNAL of OIL PALM

By Indonesian Oil Palm Society





INTERNATIONAL JOURNAL of OIL PALM

By Indonesian Oil Palm Society

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Indonesian Oil Palm Society
International Journal of Oil Palm



Bridging the Technology Gap: Smart Farming for Sustainable Palm Oil

Dheni Anugerah Prasetya*, Shealsy Ainunna Mei Pratiwi

1

Behavioral Drivers of Students' Intention for Sustainable Palm Oil

Yasminnasywa Iskandar*, Thifal Yumna Nazihah, Abdullah Haidar

16

Integrating Indigenous Knowledge Systems into Sustainable Oil Palm Cultivation: A Pathway to Inclusive Green Growth

Thomas Sheku Marah

29

Bridging the Technology Gap: Smart Farming for Sustainable Palm Oil

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ABSTRACT

The Indonesian palm oil industry is currently facing a technological divide between smart farming practices and traditional old farming methods. While large plantation corporations have adopted Artificial Intelligence (AI), Internet of Things (IoT), and drone-based precision agriculture to improve productivity and sustainability, smallholder farmers remain constrained by limited digital access, infrastructure, and financial capacity. This imbalance not only affects production efficiency but also threatens the inclusivity of sustainable palm oil certification and global market access. This study aims to analyze the impact of the digital divide on productivity and sustainability in the palm oil sector and to identify innovative solutions that bridge technological gaps between smallholders and large-scale plantations. Using a Systematic Literature Review (SLR) approach, 25 relevant publications from 2015–2025 were reviewed and synthesized thematically. The results reveal that while smart farming can reduce input costs by up to 20% and improve yield prediction accuracy, adoption barriers such as low digital literacy, inadequate infrastructure, and high initial investment persist. Innovative models such as Smart Cooperative Systems, AI Advisory Platforms, and IoT Leasing Programs demonstrate potential to enhance inclusivity and accelerate digital transformation in palm oil plantations. However, the success of this transformation depends on multi-stakeholder collaboration involving government policy support, academic innovation, and private sector partnerships. Therefore, the shift toward Smart and Sustainable Palm Oil Plantation 4.0 must be accompanied by digital inclusion strategies to ensure that smallholders are empowered as active agents in Indonesia's sustainable palm oil transformation.

Keywords: artificial intelligence, digital agriculture; oil palm sustainability; smart farming; technology gap.

INTRODUCTION

The palm oil industry has long stood as a cornerstone of Indonesia's economy, functioning not merely as an agricultural sector but as a strategic national asset that drives exports, employment, and regional development. As of 2023, the palm oil industry contributes approximately 14.3% of Indonesia's total export value and provides employment to over 17 million people, both

directly and indirectly (BPS 2023). With an annual production exceeding 48 million tons of Crude Palm Oil (CPO), Indonesia remains the world's leading producer and exporter, surpassing Malaysia, which produces around 18.5 million tons annually (USDA 2024). Palm oil's contribution extends beyond trade: it supports the downstream industries of biofuel, oleochemical, and food processing, while simultaneously functioning as a vital element in Indonesia's green energy transition through the national B35

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biodiesel policy.

However, this industrial dominance masks persistent structural disparities that threaten long-term sustainability. While large-scale corporations have rapidly modernized operations using digital precision technologies, smallholder farmers, who collectively manage about 42% of the total plantation area (GAPKI 2023) remain reliant on conventional, labor-intensive practices often described as old farming. This uneven transformation has produced a widening technological and productivity gap that challenges Indonesia's ambitions to lead in sustainable palm oil production.

The international perception of palm oil has become increasingly contentious over the past decade. Indonesia's palm oil is frequently associated with environmental degradation, deforestation, loss of biodiversity, and human rights violations (Van Duijn 2013). These narratives, often amplified by non-governmental organizations and protectionist trade policies, have placed the industry under strict international scrutiny. The introduction of the European Union Deforestation Regulation (EUDR) in 2023 marked a new phase of global trade governance, requiring commodities such as palm oil, cocoa, and coffee to prove they are deforestation-free and traceable throughout their supply chains (Kementerian Perdagangan 2024).

This regulation carries profound implications for Indonesia's palm oil export market, as the European Union absorbs nearly 34% of Indonesia's total CPO exports (BPDP 2022). Without traceable and verifiable sustainability documentation, palm oil shipments face the risk of rejection or higher compliance costs. Consequently, the adoption of digital traceability systems leveraging satellite monitoring, blockchain, and Internet of Things (IoT) technology has become indispensable. Yet, the capacity to implement such technologies is concentrated among large corporations, while smallholders remain technologically excluded. Emergence of Smart Farming and Agriculture 4.0, In this context, Smart Farming, a core component of the Agriculture 4.0 paradigm, has emerged as a

strategic solution to bridge the gap between productivity, efficiency, and environmental responsibility. Smart farming employs Artificial Intelligence (AI), Internet of Things (IoT), drones, sensors, cloud computing, and data analytics to enhance decision-making in agricultural operations (Purwanto *et al.* 2022). Through predictive algorithms, AI systems can forecast crop yields, optimize fertilizer application, detect pest infestations early, and even automate harvesting processes.

Studies indicate that the implementation of AI and IoT in palm oil plantations can reduce fertilizer input by 18–22%, lower pesticide usage by up to 15%, and increase yield predictability and harvest scheduling efficiency (Purwanto *et al.* 2022; BPDP 2022). Similarly, precision irrigation and soil monitoring technologies have been proven to mitigate water waste and reduce methane emissions from palm oil mill effluent (POME), directly supporting Indonesia's commitment to the Net Zero Emissions 2060 roadmap. Moreover, the adoption of smart technologies has become crucial for improving carbon footprint tracking, traceability, and compliance with sustainability certifications such as RSPO (Roundtable on Sustainable Palm Oil) and ISPO (Indonesian Sustainable Palm Oil). Digital data enables transparent, verifiable reporting to international buyers and regulators an essential step in countering the negative global campaigns that portray palm oil as unsustainable.

Technological Divide: Smart Farming vs Old Farming, despite these technological advances, Indonesia's palm oil sector remains highly polarized between modernized corporate estates and smallholder-managed plantations. According to the Indonesian Palm Oil Association (GAPKI 2023), productivity on corporate plantations can reach 6.8 tons/ha/year, while independent smallholders typically achieve only 3.5–4 tons/ha/year. This productivity disparity stems not from biological limitations but from systemic inequalities in access to technology, capital, information, and training. Smallholders often lack access to

stable electricity, internet connectivity, and affordable digital tools necessary for implementing smart farming. In addition, the average cost of a single IoT soil sensor ranges from IDR 4–7 million, while drone mapping services can exceed IDR 20 million per 100 hectares, representing a prohibitive investment for small-scale farmers (BPDP 2022). Compounded by limited financial inclusion and weak institutional support, these constraints perpetuate a cycle where technological innovation is monopolized by

large firms, leaving smallholders technologically stagnant. This “digital divide” not only restricts productivity gains but also undermines inclusive sustainability. Without digital verification and traceability, smallholders risk exclusion from certified supply chains, losing access to premium international markets (Pahan *et al.* 2011). This exclusion amplifies socio-economic inequalities and threatens the government’s vision of a people-centered, sustainable palm oil industry.

Table 1 Comparison of Productivity and Technology Adoption in Indonesia’s Palm Oil Sector (2023)

Indicator	Smallholder Plantations	Corporate Plantations	Sources
Average land ownership (ha/farmer)	2.1 ha	4,000–25,000 ha	GAPKI (2023)
Average productivity (tons CPO/ha/year)	3.5 – 4.0	6.5 – 7.2	BPDP (2022)
Use of digital monitoring (IoT sensors, drones, AI)	<10%	>75%	Purwanto <i>et al.</i> (2022)
Access to internet connectivity	41% of farmers	100% (corporate areas)	Kominfo (2023)
Certification (ISPO/RSPO) compliance	28%	89%	GAPKI (2023)
Training participation in digital literacy	12%	74%	BPDP (2022)

This table shows the structural gap between smallholder farmers and large companies, both in terms of productivity and digital capacity. This disparity is the reason why smart farming cannot be implemented evenly without a technology inclusion strategy.

Socioeconomic Implications and the Concept of Digital Justice, beyond productivity metrics, the digital divide in the palm oil sector has significant socioeconomic and ethical implications. The concentration of technological capacity in corporate hands risks creating a new form of digital colonialism, where data ownership and decision-making are dominated by technologically superior actors. The notion of digital justice therefore becomes critical, it emphasizes the equitable distribution of

technological benefits and the empowerment of smallholders as active participants in digital transformation rather than passive recipients (Srinivasan 2021).

The shift toward smart farming necessitates inclusive digital policies, targeted financial instruments, and capacity-building programs that enable smallholders to access, understand, and utilize digital tools effectively. Programs such as Smart Cooperative Systems and Digital Extension Platforms, supported by the Badan Pengelola Dana Perkebunan (BPDP), have shown promising early results. Pilot projects in Riau and Kalimantan have reported yield increases of 15–20% after smallholders received training and digital monitoring tools, suggesting that inclusive innovation can narrow the technological gap when

adequately supported by institutional frameworks (BPDP 2022). However, the transition toward smart farming cannot rely solely on technological provision. It requires a holistic transformation encompassing financial mechanisms, infrastructure development, regulatory support, and cultural adaptation. Without coordinated efforts, digital tools risk reinforcing existing inequalities rather than resolving them.

Table 2 Barriers to Smart Farming Adoption among Smallholders (Survey Result 2022)

Barrier Type	Percentage of Respondents
High technology cost	34%
Low digital literacy	28%
Lack of internet access	21%
Absence of training/incentives	11%
Others	6%

Cost and literacy factors are major obstacles. This confirms that digital transformation requires not only technology, but also incentive policies and systemic education. Institutional and Policy Challenges, from a policy perspective, Indonesia's digitalization in agriculture is guided by the Making Indonesia 4.0 roadmap and the National Digital Transformation Strategy 2021–2024. Yet, these frameworks remain largely industry-centered, with insufficient focus on agricultural inclusion and digital literacy in rural areas (Kementerian Kominfo 2023). Current government initiatives such as Petani Go Digital and Sistem Informasi Perkebunan Kelapa Sawit Berkelanjutan (SIPKS) are valuable, but their implementation remains fragmented and underfunded. Furthermore, there is an absence of a national regulatory framework for digital agriculture that defines data governance, privacy protection, and interoperability standards among stakeholders. This regulatory vacuum raises concerns about the ownership of agricultural

data, particularly when private technology companies handle sensitive plantation information. A multi-stakeholder governance model is therefore essential. Collaboration between government agencies, academic institutions, industry players, and civil society can facilitate equitable technology dissemination, foster research and innovation, and ensure that smart farming evolves as a tool for empowerment rather than exclusion.

Research Gaps and Problem Formulation, despite numerous case studies and policy initiatives, comprehensive academic analyses on how digital transformation can inclusively reshape Indonesia's palm oil sector remain limited. Existing literature primarily focuses on technological feasibility and environmental outcomes, leaving social and governance dimensions underexplored. The integration of smart farming with digital justice and inclusive sustainability frameworks is still in its infancy.

Based on this background, the present study formulates two central research questions:

1. How does the digital technology adoption gap between smallholder farmers and large corporations affect productivity and sustainability in Indonesia's palm oil industry?
2. What innovative solutions can bridge the technological divide and foster inclusive, sustainable transformation in the palm oil sector?

Objectives and Contribution

The objectives of this study are threefold:

- (1) To analyze the nature and extent of the technological divide in Indonesia's palm oil sector;
- (2) To evaluate its impact on productivity, economic inclusion, and environmental sustainability; and
- (3) To propose innovative and policy-relevant strategies that can enable Smart and Sustainable Palm Oil Plantation 4.0 through inclusive digital transformation.

Methodologically, the study employs a Systematic Literature Review (SLR) of 25

scholarly and institutional publications (2015–2025) that discuss smart farming, AI, IoT, and sustainability in the context of palm oil. This approach allows for a comprehensive synthesis of empirical evidence and theoretical insights, generating a conceptual framework that links technological innovation, digital inclusion, and sustainability outcomes.

The significance of this research lies in its dual contribution. Academically, it enriches the discourse on agricultural digitalization by contextualizing smart farming within Indonesia's unique socio-political economy. Practically, it provides an evidence-based foundation for policy-makers and industry leaders to design inclusive innovation policies, ensuring that smallholders are not left behind in the digital revolution. Ultimately, Indonesia's aspiration to maintain global leadership in palm oil production depends not only on productivity gains but on equitable digital transformation. Bridging the divide between smart and old farming is not merely a technological challenge but a moral and developmental imperative an effort to ensure that sustainability, in its truest sense, is shared across all levels of society.

MATERIALS AND METHODS

This study applies a Systematic Literature Review (SLR) method to synthesize empirical evidence, theoretical perspectives, and policy analyses related to the application of digital technology in Indonesia's palm oil sector. The SLR method was chosen to ensure analytical depth and to integrate findings from multiple disciplines, agriculture, economics, and information technology providing a holistic understanding of the digital transformation process. This approach aligns with the IJOP's emphasis on scientific synthesis and evidence-based policy contributions. The SLR framework in this study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, consisting of four key stages: (1) identification of relevant studies, (2) screening and eligibility evaluation, (3) data

extraction and synthesis, and (4) thematic analysis. Data were collected from both primary and secondary academic databases, including Scopus, ScienceDirect, Google Scholar, and institutional repositories of relevant agencies such as BPDP (Badan Pengelola Dana Perkebunan Kelapa Sawit), GAPKI (Gabungan Pengusaha Kelapa Sawit Indonesia), FAO (Food and Agriculture Organization), and World Bank. A total of 112 publications were initially identified, consisting of peer-reviewed journal articles, conference papers, official reports, and policy documents. After a series of screening processes, 25 publications met the inclusion criteria and were selected for detailed analysis. The time frame of literature coverage spans from 2015 to 2025, capturing the evolution of digital transformation in palm oil particularly the emergence of smart farming, AI-based agricultural management, and sustainability certification integration.

To analyze and synthesize the selected literature, this study employed a thematic coding and synthesis approach. Following the guidelines of Braun and Clarke (2021), each document was systematically coded to identify recurring themes, such as "technological inequality," "digital inclusion," and "policy adaptation." The coding process was performed manually and verified through NVivo-assisted cross-checking to ensure reliability and thematic coherence. Codes were then clustered into higher-order categories that represent structural and institutional dimensions of smart farming adoption. Through iterative synthesis, patterns of convergence and divergence across studies were identified, enabling a conceptual framework that links digital transformation with social inclusion and sustainability outcomes. Data analysis was conducted using manual synthesis supported by thematic coding through NVivo 14 software, allowing the identification of dominant patterns, co-occurring concepts, and evidence gaps across the reviewed studies. This method enhanced analytical transparency and ensured replicability in

identifying key determinants of digital transformation in the palm oil industry. The thematic coding process revealed five dominant themes across the literature: (1) digital infrastructure inequality, (2) cost barriers and financial exclusion, (3) governance fragmentation, (4) socio-economic inequality in digital adoption, and (5) policy innovation toward inclusion. These themes form the analytical backbone of the discussion, allowing the synthesis of empirical findings with theoretical frameworks of digital justice and inclusive innovation

RESULTS AND DISCUSSION

The Digital Divide in Smart Farming Practices in the Palm Oil Sector

The empirical findings of this study reveal a significant digital divide between corporate palm oil estates and smallholder-managed plantations in Indonesia. This gap

manifests not only in the level of technological adoption but also in infrastructure access, financial capacity, digital literacy, and institutional support. The divide underscores the dual reality of Indonesia's palm oil industry: while major corporations have rapidly advanced toward Smart Plantation 4.0, smallholders remain largely dependent on conventional, labor-intensive methods often referred to as old farming. Data synthesized from GAPKI (2023), BPDP (2022), and several peer-reviewed studies (Purwanto *et al.* 2022; Setiawan *et al.* 2021) show that only 8–12% of smallholder plantations in Indonesia have adopted at least one form of smart farming technology such as IoT-based monitoring, drone mapping, or AI-driven yield prediction systems. In contrast, over 75% of corporate plantations operate using integrated digital systems that connect field sensors, satellite imagery, and management software for precision agriculture.

Table 3 Comparative Adoption of Smart Farming Technologies in Palm Oil Plantations

Technology	Corporate Plantations (%) adoption)	Smallholder Plantations (%) adoption)	Source
IoT soil & humidity sensors	78%	9%	Purwanto <i>et al.</i> (2022); GAPKI (2023)
Drone surveillance & mapping	72%	6%	BPDP (2022)
AI-based yield prediction	61%	<5%	FAO (2023)
Digital traceability & certification	89%	28%	GAPKI (2023); Kominfo (2023)
Data management via cloud/ERP systems	75%	4%	Setiawan <i>et al.</i> (2021)

These data demonstrate that smart technologies have been predominantly concentrated in large-scale operations, reflecting both capital intensity and technological path dependence. Corporations such as Astra Agro Lestari and Sinar Mas have invested heavily in Integrated Plantation Management Systems (IPMS), combining remote sensing, IoT, and AI for real-time decision-making (Astra Agro Lestari Sustainability Report 2023).

Meanwhile, smallholders in provinces like Riau, Jambi, and Central Kalimantan operate under limited access to infrastructure and information networks. This unequal technological landscape represents not merely a difference in production tools but a structural asymmetry in innovation capacity. Smart farming in Indonesia has thus evolved as a corporate-driven phenomenon, raising concerns about inclusivity and sustainability equity across

the supply chain. Structural and Contextual Causes of the Digital Divide, the persistence of this technological gap can be attributed to three interrelated factors: (1) digital infrastructure inequality, (2) high capital and operational costs, and (3) limited digital literacy and institutional support.

a. Digital Infrastructure Inequality

Rural digital infrastructure remains a major constraint to smart farming adoption. According to the Ministry of Communication and Information (Kominfo 2023), only 61% of rural plantation regions in Sumatra and Kalimantan have stable 4G coverage. The absence of reliable connectivity hinders the installation and operation of IoT devices, real-time data transmission, and cloud-based management systems. Furthermore, electricity instability in remote areas restricts the use of sensor-based monitoring tools that require constant power supply.

In contrast, large corporate estates often operate in industrial clusters equipped with private communication networks and centralized data servers, enabling seamless automation. This infrastructural disparity results in spatial inequality, where the same technology yields different levels of effectiveness depending on geographic and network accessibility.

b. High Investment Costs and Financial Barriers

Smart farming technologies are capital-intensive. A single IoT soil sensor costs approximately IDR 4–7 million, while drone-based aerial mapping services may reach IDR 20–30 million per 100 hectares (BPDP 2022). For smallholders with average land ownership of only 2.1 hectares (GAPKI 2023), such investments are economically unfeasible without external subsidies or cooperative models.

By contrast, large corporations benefit from economies of scale, they can amortize technological costs across thousands of hectares, reducing per-unit cost by up to 60%. This financial asymmetry perpetuates a situation in which technological innovation becomes a privilege rather than a public good. Although several government

programs such as Peremajaan Sawit Rakyat (PSR) and Smart Cooperative Initiative aim to bridge this gap, their scope remains limited, covering less than 10% of total smallholder areas nationwide (BPDP 2022).

a. c. Low Digital Literacy and Limited Institutional Support

Even when digital tools are available, the level of digital literacy among smallholders is often inadequate for effective utilization. Studies by Wulandari *et al.* (2022) and Syahputra *et al.* (2023) reveal that only 27% of smallholder farmers can operate mobile-based monitoring applications, and less than 15% fully understand the data generated by sensors. The lack of consistent extension services and training exacerbates this gap. Moreover, institutional arrangements such as cooperatives, farmers' unions, and local governments often lack the capacity to facilitate digital integration. The absence of standardized digital governance, combined with fragmented policy frameworks, prevents systemic scaling of smart farming solutions.

Implications on Productivity and Efficiency, the consequences of this digital divide are evident in productivity performance and resource efficiency. On average, smallholder plantations yield 3.5–4.0 tons of CPO per hectare per year, while corporate plantations reach 6.5–7.2 tons/ha/year (BPDP 2022). This nearly twofold productivity difference cannot be fully explained by soil quality or plantation age alone but correlates strongly with technological intensity. Smart farming technologies enable precision agriculture, optimizing fertilizer and pesticide use based on real-time soil and weather data. Purwanto *et al.* (2022) demonstrated that IoT-based monitoring reduced fertilizer wastage by 22%, pesticide usage by 15%, and water consumption by 18% in corporate-managed test plots. The cumulative effect of these efficiencies translates into significant economic gains and reduced environmental impact.

Smallholders, in contrast, rely on visual observation and traditional knowledge to make cultivation decisions. Such methods, though culturally ingrained, are vulnerable to human error, leading to over-fertilization, pest outbreaks, and yield fluctuations. Without digital support systems, they cannot access predictive analytics or early warning systems that inform adaptive management strategies. This disparity reflects a dual-speed agricultural transformation, where corporate efficiency advances under digital capitalism while smallholders stagnate under analog constraints. The productivity gap not only affects individual livelihoods but also undermines Indonesia's national efficiency in global markets, as aggregate yield and sustainability performance remain below potential.

Broader Economic and Environmental Consequences, the digital divide extends beyond productivity metrics, influencing economic inclusion, environmental governance, and supply chain integrity. Economically, the exclusion of smallholders from digital systems risks marginalizing them in value chains that increasingly demand traceable, sustainable, and certified production. Under the European Union Deforestation Regulation (EUDR), exporters must provide geolocation-based traceability for all palm oil sources. Smallholders without digital traceability tools face the risk of being excluded from export markets, as their produce cannot be verified through satellite-linked systems (Kementerian Perdagangan 2024).

Environmentally, the absence of precision monitoring among smallholders contributes to inefficiencies in land and resource use. Satellite analyses show that smallholder areas are associated with higher deforestation rates per hectare, largely due to unoptimized replanting practices and limited access to sustainability training (FAO 2023). Conversely, smart farming systems using AI and remote sensing allow corporations to monitor deforestation boundaries, carbon emissions, and biodiversity indicators in real time, aligning with global sustainability standards such as RSPO and ISPO. These

dynamics reinforce a technological paradox: while smart farming enhances sustainability for corporations, its inaccessibility to smallholders exacerbates inequality and environmental vulnerability. In this sense, digitalization in palm oil production risks becoming a double-edged sword a tool for innovation and compliance on one hand, and a mechanism for exclusion on the other.

Toward Digital Inclusion: Emerging Policy and Institutional Responses, Recent policy initiatives have begun to recognize the urgency of addressing this divide. The National Digital Transformation Roadmap 2021–2024 emphasizes rural connectivity and agricultural digitalization as national priorities (Kominfo 2023).

Furthermore, BPDP has launched pilot programs integrating smallholders with AI-assisted mobile applications (e-Tani Sawit) for monitoring fertilizer usage and pest detection. Early evaluations in Riau and West Kalimantan indicate a 15–20% yield increase among participating farmers within the first two years of implementation (BPDP 2022). Nevertheless, these initiatives remain fragmented and insufficiently scaled. To transform digitalization into an inclusive movement, policy interventions must extend beyond technological provision. They must establish financial incentives, cooperative data platforms, and capacity-building mechanisms that empower smallholders as active participants in digital transformation.

Summary of Findings, the findings from this subchapter affirm that the digital divide in Indonesia's palm oil industry is multidimensional rooted in infrastructure disparities, economic inequities, and institutional fragmentation. While smart farming technologies have demonstrated measurable improvements in productivity and sustainability, their benefits remain unevenly distributed. Addressing this divide requires a paradigm shift: from technology-centric innovation toward human-centered digital inclusion. The future of sustainable palm oil depends not merely on advanced algorithms or AI systems but on the equitable access of farmers to those technologies. Bridging this gap is not only an economic necessity but also a moral and

developmental imperative aligned with Indonesia's vision of sustainable palm oil plantation 4.0 and the UN Sustainable Development Goals (SDG8, SDG9, SDG12).

Socio-Economic Implications of the Smart Farming Transition

The transition toward Smart and Sustainable Palm Oil Plantation 4.0 has far-reaching socio-economic implications for Indonesia's rural landscape. While technological innovation promises efficiency, productivity, and sustainability, it simultaneously raises critical questions regarding equity, inclusion, and social justice. The empirical literature suggests that the digital transformation of the palm oil sector is not a neutral process it redistributes economic power, alters labor dynamics, and reshapes rural livelihoods.

Economic Polarization and Inequality in the Value Chain, smart farming has introduced a new economic stratification in Indonesia's palm oil industry. Large corporations equipped with advanced digital infrastructure, AI-based management systems, and data analytics have achieved significant productivity gains and cost efficiencies. BPDP (2022) estimates that digitalized plantations experience operational cost reductions of 18–25% due to optimized input management and predictive maintenance. In contrast, smallholder-managed plantations continue to operate with low economies of scale and high production volatility, leading to unstable income patterns.

A comparative financial model from GAPKI (2023) indicates that corporate plantations, after adopting AI and IoT systems, achieved a net profit margin of 28%, while smallholders remained at 8–10%. This disparity is not only a reflection of differing production efficiency but also of unequal access to market intelligence, digital finance, and certification systems. Smart farming has also facilitated vertical integration within corporate supply chains, allowing companies to manage production, logistics, and export operations through centralized digital platforms. While this

enhances competitiveness in global markets, it marginalizes smallholders who cannot afford or access such platforms. In effect, technological progress consolidates market power among corporations, potentially reducing the bargaining position of smallholders in contract farming or nucleus-plasma arrangements.

Impacts on Employment and Labor Structure, the introduction of automation, sensors, and AI-driven analytics is reshaping the labor market in palm oil plantations. While smart technologies reduce the need for manual observation and repetitive tasks, they also generate demand for digitally skilled workers such as data analysts, drone operators, and IoT technicians. According to a study by the Ministry of Manpower (Kemnaker 2023), approximately 18% of traditional plantation jobs such as manual monitoring, fertilization, and record-keeping are projected to be replaced by automation by 2030. However, at the same time, new employment categories are emerging in the field of digital agricultural management.

Yet, this labor transformation is asymmetric. Corporate plantations benefit from access to formal training and internal upskilling programs, whereas smallholders and local workers often lack the technical competencies required to transition into digital roles. This leads to a skill gap and potential social displacement within rural communities. Without inclusive training mechanisms, automation could inadvertently exacerbate rural unemployment and poverty contradicting the developmental goals of inclusive growth and social sustainability. Wulandari *et al.* (2022) found that 73% of smallholder farmers expressed concern about the potential "replacement effect" of drones and sensors on manual labor, fearing reduced work opportunities for local workers. However, these fears can be mitigated if smart farming is introduced through community-based cooperative models, where technology complements rather than replaces human labor.

Income Stability, Productivity, and Welfare Effects, despite the risks, several

pilot programs show that inclusive smart farming initiatives can enhance income stability and welfare among smallholders when designed equitably. In the BDP Smart Cooperative Pilot Project (2022–2023) in Riau and West Kalimantan, smallholders equipped with mobile-based data systems and drone monitoring achieved a 15–20% increase in yield and a 12% reduction in input costs within two growing seasons. Moreover, income volatility decreased due to improved harvest predictability and pest management. These results affirm the positive welfare potential of digital inclusion when accompanied by appropriate institutional support.

However, a broader nationwide evaluation by FAO (2023) emphasizes that such gains remain geographically limited. The majority of rural farmers especially those in Papua, Maluku, and remote Kalimantan still lack access to both hardware and software components of digital agriculture. Consequently, the digital economy within the palm oil sector risks reproducing the same spatial inequalities that characterize Indonesia's general economic development: coastal versus inland, western versus eastern regions. In this context, digitalization should be seen not only as a technical transformation but as an opportunity to restructure socio-economic relationships ensuring that technology serves as a bridge rather than a barrier between corporate and smallholder economies.

The Question of Digital Justice and Empowerment, from a governance and ethical perspective, the concept of digital justice becomes central to evaluating the socio-economic impacts of smart farming. As Srinivasan (2021) argues, digital transformation can reinforce inequality if data ownership, access, and benefits are monopolized by a limited group of actors. This phenomenon is increasingly visible in Indonesia's palm oil industry, where corporations control the majority of data infrastructure, traceability platforms, and cloud-based management systems. Smallholders, by contrast, often become data providers without ownership rights, as

their plantation data are uploaded into corporate or government systems without clear benefit-sharing mechanisms. This asymmetry raises fundamental questions about data sovereignty who owns, controls, and profits from agricultural data generated through digital technologies.

To ensure digital justice, smallholders must be integrated as co-owners and co-users of technological systems, not passive beneficiaries. Cooperative data governance models, supported by the state and local institutions, could help redistribute digital value more equitably. This approach aligns with the principles of Sustainable Development Goal 10 (Reduced Inequality) and the Indonesian government's One Data Policy (Satu Data Indonesia), which seeks to democratize access to digital information across sectors.

Community Empowerment and Local Innovation, an often-overlooked dimension of the smart farming transition is its potential to empower local innovation ecosystems. When smallholders and communities are actively involved in technology design and adaptation, smart farming can strengthen local resilience and autonomy. For example, in North Sumatra, the Petani Go Digital initiative launched by Kominfo (2023) enabled farmer groups to develop open-source monitoring applications using locally available data. Within two years, participating cooperatives reduced fertilizer costs by 19% and increased collective bargaining power by selling directly through e-commerce platforms connected to mill operators. Such cases demonstrate that the success of digital transformation is not solely dependent on high-end technology, but on institutional flexibility, social participation, and adaptive learning. Empowerment occurs when farmers shift from being technology users to becoming technology co-creators. This participatory approach builds social capital and enhances the sustainability of innovation.

Policy Implications, the socio-economic implications discussed above highlight the need for a comprehensive policy framework that integrates digital transformation with social inclusion

objectives. Key policy priorities should include; Digital financial inclusion, providing subsidized credit and fintech access for smallholders to invest in technology; Capacity-building programs, developing community-based digital literacy and data governance training; Public-private partnerships (PPP), fostering collaboration between corporations, government agencies, and cooperatives to share data, infrastructure, and innovation benefits; Incentive mechanisms, offering fiscal or certification rewards for companies that integrate smallholders into digital supply chains; Gender and youth mainstreaming, ensuring targeted digital inclusion for women and young rural workers.

These measures align with Indonesia's Digital Economy Framework Agreement (DEFA) under ASEAN cooperation and reinforce the country's commitment to an inclusive, data-driven agricultural transformation.

Strategic Innovation in Bridging the Technology Gap and Driving Sustainable Palm Oil Transformation

Strategic Innovation in Bridging the Technology Gap and Driving Sustainable Palm Oil Transformation. The transformation towards smart farming systems in the palm oil sector requires not only the adoption of advanced technology, but also strategic innovation that comprehensively integrates social, economic and environmental dimensions. In Indonesia, the technological gap between old farming, which still relies on manual methods based on experience, and smart farming based on data and automation, has widened the productivity gap. According to a report by the Palm Oil Plantation Fund Management Agency (BPDP 2023), land efficiency in plantations with digital systems reaches 26.7 tonnes of fresh fruit bunches (FFB) per hectare per year, while in conventional systems it is only around 18.9 tonnes. This gap not only illustrates the difference in crop yields, but also reflects the gap in access to information resources, infrastructure, and technological capital among smallholders. Therefore, strategic

innovation must be directed not only at the application of technology, but also at the creation of a digital ecosystem that is inclusive and adaptive to the social realities of Indonesian palm oil farmers. The transformation of the palm oil sector in Indonesia requires an approach that not only adopts the latest technology but also adapts it to the local capacity of farmers. One key strategy is the application of appropriate technology that serves as a bridge between old farming and smart farming systems. The application of this technology enables increased productivity without sacrificing the accessibility and operational capabilities of smallholders. Simple sensor-based technologies, such as Wireless Sensor Network (WSN) systems to monitor soil moisture, microclimate conditions, and soil nutrients, have been proven to improve water and fertiliser use efficiency in palm oil plantations. This model can be operated at low cost using microcontrollers such as Arduino or ESP32 connected to Android devices via cellular networks. This integration minimises the need for expensive IoT infrastructure, while maintaining the effectiveness of farmers' real-time data-based decision-making.

The results of Demirel and Gürkan's research show that the implementation of smart agriculture solutions in the palm oil sector increases productivity by up to 18% with a 12% reduction in production waste. This proves that innovation does not have to be high technology, but rather the optimisation of technology that is targeted and appropriate to the socio-economic context. The application of the precision agriculture concept, adapted to local capacities, also enables supply chain efficiency. Through the integration of simple data systems, farmers can monitor land conditions, estimate crop yields, and adjust fertilisation strategies according to actual needs. Thus, the digital divide can be bridged without creating new inequalities between small farmers and large corporations. Institutionally, the technology bridging approach also requires the active role of local governments, research institutions, and universities. Collaboration

in applied research and technology transfer is fundamental. Research from the Food and Fertilizer Technology Centre for the Asian and Pacific Region (FFTC) emphasises the importance of developing community-based digital business technology to accelerate the transformation of Indonesian agriculture, including the palm oil sector. This approach positions farmers not only as users of technology, but also as key actors in the innovation ecosystem. The successful adoption of appropriate technology depends on the ability to integrate technical and social aspects. Technology designed in a participatory manner, involving farmers from the design stage, will have a higher level of sustainability than top-down adoption models. Thus, appropriate innovation serves not only as a bridge to digitalisation, but also as a means of economic and social empowerment for palm oil farmers in Indonesia.

Social Empowerment and Digital Institutions as the Foundation for Sustainable Palm Oil Transformation

The success of digital transformation in the palm oil sector does not solely depend on technological capabilities, but also on the social and institutional strength that supports its adoption. Digital literacy, collective participation, and data governance are the main pillars in building a sustainable smart farming ecosystem. In this case, the establishment of farmer institutions based on digital platforms, such as digital smart cooperatives, is a strategic step to strengthen the bargaining position of farmers in the supply chain. Digital institutions enable decentralised management of harvest data, market information, and access to green financing.

Through the blockchain ledger system, palm oil transactions can be recorded transparently and securely, thereby supporting sustainable palm oil certification and open data-based carbon trading. This approach is in line with the digital agriculture model implemented in Southeast Asia,

which emphasises farmer involvement in the entire value chain process. In addition to institutionalisation, social empowerment through community-based training and technical assistance is key to increasing farmers' trust and readiness to adopt technology. Research on Wireless Sensor Network Servers for Smart Agriculture Optimisation emphasises the importance of farmers' basic digital literacy so that WSN systems can be optimally utilised without complete dependence on external technicians. Thus, technological literacy is not merely the ability to use tools, but also to understand the underlying data logic. The government and universities play a role as facilitators in expanding the reach of this digital transformation.

Programmes such as Smart Village for Palm Oil, which integrates rural internet infrastructure development, geospatial information systems, and agricultural technology education, are concrete examples of sustainability-based policies. Synergy between the government, the private sector, and academic institutions in a public-private-academic partnership model can create social innovation while strengthening rural economic resilience. Digital transformation in palm oil agriculture must always be oriented towards environmental sustainability. The implementation of air sensor-based monitoring systems and satellite data can help minimise land expansion that damages ecosystems.

The study Smart Sensors and Smart Data for Precision Agriculture emphasises the importance of integrating environmental big data with local farmers' wisdom to maintain the ecological balance of modern agriculture. Thus, social empowerment and digital institutions serve as the main foundation for sustainable palm oil transformation. When the technological, social and environmental dimensions are connected in an adaptive system, Indonesia has a great opportunity to become a pioneer of equitable and environmentally friendly digital agriculture in the tropics.

Table 4 Model of Strategic Innovation for Sustainable Palm Oil Transformation Source: Processed from FFTC-ASPAC (2022), Demirel & Gürdil (2025)

Innovation Aspects	Old Farming	Smart Farming	Bridge Innovation	Impact on Sustainability
Production Technology	Manual and conventional	IoT, AI, and automatic sensors	Simple sensors, local applications	Production efficiency increased by 25–40%
Information Access	Limited to middlemen	Real-time data platform	Community-based Android application	Increased price and market transparency
Institutional	Individual and informal	Data-based digital cooperatives	Digital partnerships between farmers and companies	Improving farmers' bargaining position
Economy	Low and volatile margins	Stable and data-driven	Micro green financing schemes	Significant improvement in farmers' welfare
Environment	Intensive land exploitation	Environment-based data monitoring	Local ecosystem-based adaptive systems	Emissions reduction and land conservation

CONCLUSION

The findings of this study underscore that Indonesia's transition toward Smart and Sustainable Palm Oil Plantation 4.0 presents both opportunities and challenges. Digital technologies such as artificial intelligence (AI), the Internet of Things (IoT), and blockchain have demonstrated their potential to enhance productivity, efficiency, and sustainability in palm oil management. However, the benefits of these innovations remain unevenly distributed along the value chain, with smallholders often excluded due to digital infrastructure gaps, cost barriers, and limited literacy. This digital divide risks reinforcing socio-economic disparities if left unaddressed.

Bridging these gaps requires more than mere technological investment; it calls for systemic inclusion policies, cooperative data governance, and targeted capacity-building measures. The integration of smallholders into digital ecosystems must be treated as a national priority rather than a peripheral component of corporate modernization. To operationalize inclusive digital transformation, Indonesia needs clear and actionable policy commitments. These

include integrating BPDP digital inclusion programs into the 2025–2030 Palm Oil Roadmap to ensure equitable access to IoT tools, literacy training, and traceability systems; establishing a *National Digital Agriculture Inclusion Fund (NDAIF)* to subsidize digital devices and data systems for smallholders through public private partnerships and carbon credit revenues; enforcing interoperability standards and data sovereignty protections in the forthcoming Peraturan Pemerintah on Smart Agriculture Governance to prevent data monopolization; expanding rural digital infrastructure under the Kominfo BPDP collaboration to achieve full 4G/5G coverage in plantation regions by 2030; and institutionalizing digital cooperatives as intermediaries that enable shared access to technology, financing, and market intelligence for farmer groups. To operationalize inclusive transformation, this paper proposes a three-tier implementation strategy:

1. **Technology Accessibility Program:** Introduce IoT Leasing Schemes and Smart Cooperative Platforms funded by BPDP and regional governments. These initiatives can lower the entry barrier for

smallholders and create shared data systems at the cooperative level.

2. Capacity-Building and Digital Literacy: Establish regional Digital Agriculture Training Centers in collaboration with universities and local governments, focusing on basic data interpretation, mobile application usage, and maintenance of low-cost sensors.
3. Policy and Governance Framework: Develop an integrated Digital Agriculture Regulation under the Ministry of Agriculture, addressing data governance, financing incentives, and interoperability standards among public and private platforms. This aligns with the National Digital Transformation Roadmap (2021–2024) and supports the Net Zero Emissions 2060 target.

By embedding these policy directions into Indonesia's agricultural digitalization agenda, the nation can transform Smart Farming into a platform for shared prosperity and sustainability rather than a new form of exclusion. Ultimately, digital transformation in the palm oil sector must not only aim to increase productivity but also advance digital justice, ensuring that smallholders become equal beneficiaries and co-creators of innovation within Indonesia's green and inclusive economic future.

REFERENCES

- Abdillah M, Maksum M, Alkaf I, Arifin I, Salim MA, Al-Haqqoni H. 2025. The role of Sharia economic law in advancing MSME digitalization for SDGs in Indonesia: a systematic literature review (SLR). *Profetika: J Stud Islam*. 26(1):1–16. DOI: 10.23917/profetika.v26i01.7527.
- Ardiansyah D, Huda ASM, Darusman, Pratama RG, Putra AP. 2019. Wireless Sensor Network Server for Smart Agriculture Optimization. *IOP Conf Ser: Mater Sci Eng*. 621(1):012001. DOI: 10.1088/1757-899X/621/1/012001.
- Astra Agro Lestari. 2023. Sustainability Report 2023: Integrated Plantation Management Systems. Jakarta (ID): PT Astra Agro Lestari Tbk.
- Badan Pengelola Dana Perkebunan Kelapa Sawit (BPDP). 2022. Annual Report: Program Kemitraan dan Produktivitas Perkebunan Sawit. Jakarta (ID): BPDP.
- Badan Pusat Statistik (BPS). 2023. Statistik Kelapa Sawit Indonesia 2023. Jakarta (ID): BPS.
- BPDP. 2023. Laporan Tahunan Perkebunan Sawit Indonesia. Jakarta: Kementerian Keuangan RI. Available from: <https://www.bpdp.or.id/annual-report-BPDP-tahun-2023>. Telah diakses di 14 Oktober 2025.
- Braun V, Clarke V. 2021. Thematic Analysis: A Practical Guide. London: Sage Publishing. ISBN: 978-1-4739-5323-9
- Demirel B, Gürdil GAK. 2025. Smart agriculture solutions to optimize oil palm farming. *Eur J Sci Technol*. 8(1):119–126. DOI: 10.55257/ethabd.1703723.
- Food and Agriculture Organization (FAO). 2023. Digitalization in Southeast Asian Agriculture: Case Studies on Palm Oil and Cocoa. Rome (IT): FAO. Telah diakses di 14 Oktober 2025.
- GAPKI – Gabungan Pengusaha Kelapa Sawit Indonesia. 2023. Outlook Industri Sawit Indonesia 2023-2024. Jakarta (ID): GAPKI.
- Kementerian Ketenagakerjaan (Kemnaker). 2023. Labour Market Transformation in Agricultural 4.0. Jakarta (ID): Kemnaker RI. Telah diakses di 14 Oktober 2025.
- Kementerian Komunikasi dan Informatika (Kominfo). 2023. Strategi Nasional Transformasi Digital Sektor Pertanian 2021-2024. Jakarta (ID): Kominfo RI.
- Kementerian Perdagangan. 2024. Laporan Perdagangan Komoditas Strategis 2024. Jakarta (ID): Kemendag RI.
- Pahan I, Gumbira-Sa'id E, Tambunan M. 2011. The future of palm oil industrial cluster of Riau region Indonesia. *Eur J Soc Sci*. 24(3):421-431.
- Purwanto H, Syahputra I, Wulandari R. 2022. Integrating IoT and AI for Smart

- Palm Oil Plantation: A Case Study in Sumatera. *J Agric Technol Innov.* 14(2):45-57.
- Setiawan D, Rahmawati N, Puspita A. 2021. Assessing the readiness of smart farming adoption among smallholder farmers in Indonesia. *J Sustain Agric Technol.* 11(3):90-104.
- Srinivasan J. 2021. *Digital Justice: Technology and Inequality in Agricultural Systems.* Oxford (UK): Oxford University Press.
- Sudaryanto T, Wahida, Purba HJ, Rafani I, Andoko E. 2022. Promoting smart farming-based digital business technology in the context of agricultural transformation in Indonesia. *J Agric Policy Innov Stud.* 2022 Jul 22.
- USDA – U.S. Department of Agriculture, Foreign Agricultural Service. 2024. *Oilseeds: World Markets and Trade.* Washington, DC (US): USDA.
- Van Duijn G. 2013. Traceability of the palm oil supply chain. *Lipid Technol.* 25(1):15-18. DOI: 10.1002/lite.201300251.
- Wulandari S, Syahputra I, Nugroho A. 2022. Digital literacy and technological inclusion among oil palm smallholders in Indonesia. *Asian J Rural Dev.* 14(1):31-44.

Behavioral Drivers of Students' Intention for Sustainable Palm Oil

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ABSTRACT

While sustainable palm oil is central to Indonesia's climate agenda, behavioral engagement among youth remains underexplored. This study applies the Theory of Planned Behavior (TPB) to identify psychological drivers of students' intentions to promote sustainable palm oil practices within their home regions. We surveyed 150 university students originating from Riau, Jambi, and West Kalimantan via an online questionnaire and analyzed the data using Structural Equation Modeling with SmartPLS. The extended TPB model integrates sustainability knowledge and prosocial motivation as antecedents of attitude, while retaining attitude, subjective norm, and perceived behavioral control (PBC) as predictors of intention. Results indicate that knowledge and prosocial motivation significantly strengthen positive attitudes toward sustainable practices. In turn, attitude, subjective norm, and PBC strongly predict behavioral intention. Intention also mediates the relationship between these psychological factors and students' planned sustainability actions. The model explains 93.6% of the variance in behavioral intention ($R^2=0.936$), suggesting substantial explanatory power for youth engagement in resource-based communities. Theoretically, this research enriches TPB by incorporating prosocial motivation into sustainability behavior, clarifying how value laden drivers shape attitude formation and subsequent intention. Practically, findings offer actionable guidance for universities, local cooperatives, and policymakers to design youth-oriented interventions that build knowledge, leverage social influence, and reduce perceived barriers to action through curriculum modules, peer-led campaigns, and community partnerships. By positioning students as locally embedded catalysts, these interventions can translate intention into concrete advocacy and education activities that support responsible, certified palm oil. Overall, the study highlights how empowering students as sustainability multipliers can accelerate grassroots transitions consistent with Indonesia's climate and development goals, while providing a scalable behavioral framework for similar resource-dependent regions.

Keywords: Indonesia, prosocial motivation, student engagement, sustainable palm oil, theory of planned behavior

INTRODUCTION

Palm oil remains a cornerstone of Indonesia's agricultural economy, sustaining rural livelihoods, generating foreign exchange, and anchoring global supply chains. As the world's largest

producer, Indonesia depends heavily on palm oil for both economic growth and employment, particularly among millions of smallholders who manage vast plantation areas. Yet, the sector has long faced scrutiny for its association with deforestation, biodiversity loss, green-

house gas emissions, and social conflicts (Obidzinski *et al.* 2012; Heilmayr *et al.* 2020). In response, sustainability certification systems such as the Roundtable on Sustainable Palm Oil (RSPO) and the Indonesian Sustainable Palm Oil (ISPO) standard have emerged to balance environmental, economic, and social goals (Schouten and Glasbergen 2011; Hospes 2014). However, the diffusion of sustainable practices across remote rural communities remains inconsistent, reflecting gaps in awareness, accessibility, and behavioral adoption.

While most research and interventions focus on smallholders' compliance and institutional frameworks, a relatively neglected yet influential group consists of university students from palm-oil-producing regions such as Riau, Jambi, and West Kalimantan. Positioned between academic environments and rural households, students possess the potential to act as knowledge transmitters and behavioral multipliers individuals who can interpret sustainability concepts and introduce them within family and cooperative settings. Their community interactions, such as promoting good agricultural practices, organizing waste reduction initiatives, or explaining certification benefits, represent a grassroots extension of formal sustainability programs.

However, the theoretical understanding of how students form intentions to engage in such sustainability actions remains limited. Previous behavioral studies in the palm oil sector have largely concentrated on smallholders, producers, or consumers, leaving a significant theoretical gap concerning youth as emerging change agents. This study therefore responds to the need for a behavioral framework that captures students' psychological mechanisms including attitude, social norms, and perceived behavioral control in promoting sustainable palm oil within their communities. From a practical standpoint, existing sustainability

initiatives are often top-down and fail to leverage the bridging role of youth between academic institutions and local communities. Few community-based approaches explicitly integrate students into rural sustainability networks, even though they are strategically positioned to translate knowledge into family and cooperative practices. Addressing this practical gap, the present study applies the Theory of Planned Behavior (TPB) to explore how cognitive, motivational, and social factors drive students' engagement intentions. By focusing on students as locally embedded catalysts, this study offers insights into how behavioral intention can be transformed into tangible sustainability actions at the grassroots level.

The Theory of Planned Behavior (TPB) (Ajzen 1991) provides a robust framework to explain intention formation through three antecedents: attitude toward the behavior, subjective norm, and perceived behavioral control (PBC). Prior studies confirm that positive attitudes, supportive norms, and perceived capability predict sustainability-related intentions across contexts such as pro-environmental behavior (Lucarelli *et al.* 2020), renewable energy adoption (de Leeuw *et al.* 2015), and agricultural innovation (Djibo and Maman 2019). However, to enhance predictive precision in culturally and socially complex settings, scholars have proposed extending TPB with context-specific constructs (Fishbein and Ajzen 2010; Armitage and Conner 2001). Within palm-oil-producing regions, two factors stand out: sustainability knowledge, which reduces uncertainty and strengthens favorable attitudes, and prosocial motivation, which drives individuals to act for collective benefit despite limited personal gains (Grant 2007; Varni *et al.* 2024; Sundaraja *et al.* 2021). Recent research by Tabanao *et al.* (2025) further supports this integration, demonstrating that prosocial motivation and environmental knowledge jointly enhance youths' green behavioral intentions and complement each

other in fostering sustainability-oriented attitudes.

Despite growing recognition of youth participation in sustainability transitions, few studies investigate how these psychological mechanisms shape students' community engagement intentions within palm-oil contexts. Existing research predominantly examines green consumption (Nguyen *et al.* 2022), carbon-offset behavior (Li *et al.* 2025), or campus environmental participation (Hayadi and Hariguna 2025; Sun and Liu 2023; Assefa *et al.* 2025), overlooking rural-based initiatives. In collectivist societies like Indonesia, subjective norms and social expectations from families and community leaders are also likely to influence action, given the high value placed on social credibility and intergenerational trust (Molenaar *et al.* 2013). This underscores the relevance of investigating how attitudes, social pressures, and perceived control interact to predict students' sustainability intentions.

This study takes the Theory of Planned Behavior a step further. With data from 150 students in Riau, Jambi, and West Kalimantan, we examine how sustainability knowledge and prosocial motivation feed into attitudes, and how those attitudes together with norms and perceived control shape intention. We then ask a practical question: does intention show up as action? In our setting, action means very specific things circulating sustainability tips within families, helping cooperatives deliver brief trainings, and encouraging certification where feasible. We estimate the model with PLS-SEM and use the results to design youth-focused, low-cost interventions that rely on peer leadership and community-based learning rather than expensive top-down campaigns. Unlike previous TPB studies focusing on consumers or smallholders, this research uniquely positions university students from palm-oil-producing regions as bridges between academic knowledge

and rural sustainability practices. The findings contribute to understanding how youth-driven behavioral mechanisms can complement policy interventions and educational programs aimed at accelerating Indonesia's transition toward sustainable, certified palm oil.

MATERIALS AND METHODS

The study utilized a structured questionnaire to assess students' psychological and behavioral constructs related to their intention to promote sustainable palm oil practices. All items were measured using a five-point Likert scale (1 = strongly disagree to 5 = strongly agree) adapted from previously validated instruments. The initial survey contained 28 items grouped into seven latent constructs and was designed following Nurhidayati and Sukri (2025) to ensure compatibility with structural equation modeling (SEM). Data were collected online via Google Forms to reach respondents across Riau, Jambi, and West Kalimantan.

Respondents were selected using purposive sampling based on their origin from palm-oil-producing regions, ensuring contextual relevance and sufficient representation of students with family involvement in the palm oil sector. Participation was voluntary, and informed consent was obtained from all respondents before completing the questionnaire.

Descriptive analyses were conducted in IBM SPSS Statistics 26, while model estimation and hypothesis testing employed SmartPLS 4.0, which is appropriate for exploratory research and small to medium sample sizes. Prosocial motivation complements the Theory of Planned Behavior by offering a moral and empathic foundation that explains why individuals act beyond self-interest. It emphasizes intrinsic concern for others, aligning with the collective orientation typical of Southeast Asian societies (Grant 2007; Rioux and Penner 2001).

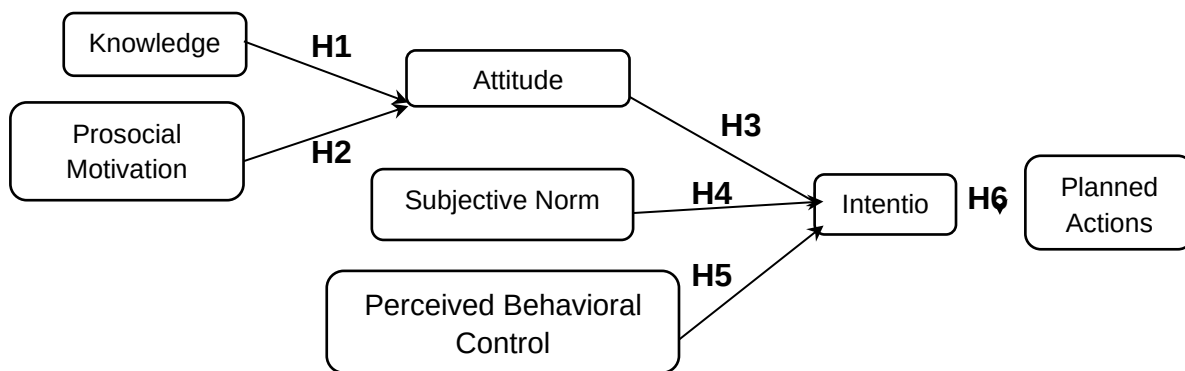


Figure 1 Conceptual Framework

In collectivist settings, social responsibility often mediates cognitive-behavioral processes, where moral obligation and group harmony influence individual decision-making (Triandis 1995). Hence, incorporating prosocial motivation and sustainability knowledge into TPB enhances the model's ability to capture context-specific behavioral drivers. Figure 1 outlines the framework guiding this study. The model draws from the Theory of Planned Behavior (Ajzen 1991), which links intention to attitude, social influence, and perceived control. To better reflect students' role in promoting sustainable palm oil, two new factors *sustainability knowledge* and *prosocial motivation* are added before attitude. Knowledge increases awareness and confidence in acting responsibly toward the environment, while prosocial motivation reflects a willingness to help others and contribute to collective goals, even without personal reward (Grant 2007; Varni et al. 2024; Sundaraja et al. 2021). In line with TPB, attitude, subjective norms, and perceived behavioral control are expected to shape students' intentions to engage in sustainability programs (H3–H5). Intention is then assumed to lead to real

RESULTS & DISCUSSION

Respondents Characteristics

Table 1 presents the demographic characteristics of the 150 student respondents who participated in this study. Most respondents were aged

above 22 years (77.33%), followed by those aged 21–22 years (20.00%), while smaller proportions were found among respondents aged 19–20 years (2.00%) and below 19 years (0.67%). This pattern indicates that the majority were senior students who may have gained broader academic exposure and awareness of sustainability-related issues. In terms of domicile, Jambi Province accounted for the largest share of respondents (48.67%), followed by West Kalimantan (30.00%) and Riau (21.33%). These provinces are among Indonesia's major palm-oil-producing regions, which provides the respondents with a direct understanding of the local context of palm oil cultivation. Regarding educational background, Table 1 also shows that respondents came from various universities. The largest groups were from Universitas Jambi (28.00%), Sekolah Tinggi Teknologi Kelapa Sawit (12.00%), IPB University (10.67%), and Universitas Riau (4.67%), while the remaining 44.66% represented other universities across Indonesia. All respondents (100%) reported that their families were involved in palm oil plantation activities and that they were familiar with the concept of sustainable palm oil and certification schemes such as ISPO and RSPO. Likewise, every respondent indicated active participation in campus or environmental organizations (100%), suggesting strong exposure to environmental and sustainability discussions within their academic environment. Taken together, these

Table 1 Respondents Characteristics.

Respondent Characteristics	Number of Respondents	Percentage (%)
<i>Age</i>		
> 19 years	1	0,67
19-20 years	3	2,00
21-22 years	30	20,00
> 22 years	116	77,33
Total	150	100,00
<i>Province (Domicile)</i>		
Riau	32	21,33
Jambi	73	48,67
West Kalimantan	45	30,00
Total	150	100,00
<i>University</i>		
Universitas Riau	7	4,67
Universitas Jambi	42	28,00
Sekolah Tinggi Teknologi Kelapa Sawit	18	12,00
IPB University	16	10,67
Other universities	67	44,66
Total	150	100,00
<i>Family Involvement in Palm Oil</i>		
Yes	150	100,00
No	0	0
Total	150	100,00
<i>Awareness of "Sustainable Palm Oil / ISPO-RSPO"</i>		
Yes	150	100,00
No	0	0
Total	150	100,00
<i>Active in Campus/Environmental Organization</i>		
Yes	150	100,00
No	0	0
Total	150	100,00

Source: Processed by the author (2025)

characteristics show that the respondents possess relevant background knowledge and personal connection to the palm oil sector, which makes them a suitable group for examining behavioral intentions toward promoting sustainable palm oil practices.

Measurement Model

The reflective measurement model was subjected to a comprehensive assessment encompassing indicator

reliability, internal consistency, and convergent as well as discriminant validity. In line with methodological guidelines by Hair *et al.* (2022), all standardized outer loadings exceeded the minimum acceptable value of 0.70 (ranging from 0.738 to 0.970), demonstrating that each observed indicator loaded strongly on its intended latent construct and contributed meaningfully to the construct's measurement (Table 2).

Table 2 Outer Loadings.

	Attitude	Intention	Knowledge	Perceived Behavioral Control	Planned Actions	Prosocial Motivation	Subjective Norm
ATT1	0.955						
ATT2	0.898						
ATT3	0.947						
INT1		0.952					
INT2		0.777					
INT3		0.903					
INT4		0.943					
KNOW1			0.817				
KNOW2			0.842				
KNOW3			0.853				
KNOW4			0.924				
KNOW5			0.937				
PA1					0.950		
PA2					0.968		
PA3					0.967		
PA4					0.663		
PBC1				0.937			
PBC2				0.856			
PBC3				0.738			
PM1						0.962	
PM2						0.958	
PM3						0.970	
PM4						0.956	
PM5						0.964	
SN1							0.861
SN2							0.928
SN3							0.921
SN4							0.796

Source: Processed by the author (2025)

Internal consistency reliability was established through Cronbach's alpha and composite reliability (CR) (Table 3), which ranged from 0.799 to 0.980 and from 0.883 to 0.984, respectively. These values surpass the recommended 0.70 threshold, confirming that the items capture the underlying conceptual

domain with a high degree of homogeneity. Similarly, the Average Variance Extracted (AVE) values ranged from 0.718 to 0.925, further substantiating convergent validity by showing that more than 50% of the variance in the indicators was accounted for by their respective constructs.

Table 3 Construct Reliability & Convergent Validity.

	Cronbach's Alpha	Rho A	Composite Reliability	Average Variance Extracted (AVE)
Attitude	0.926	0.928	0.953	0.871
Intention	0.916	0.928	0.942	0.803
Knowledge	0.924	0.936	0.943	0.767
Perceived Behavioral Control	0.799	0.836	0.883	0.718
Planned Actions	0.911	0.938	0.941	0.804
Prosocial Motivation	0.980	0.980	0.984	0.925
Subjective Norm	0.901	0.915	0.931	0.771

Source: Processed by the author (2025)

Discriminant validity was established through the Fornell Larcker criterion and the Heterotrait Monotrait (HTMT) ratio (Table 4 & Table 5). The

square roots of the AVEs consistently exceeded the corresponding inter-construct correlations, and all HTMT ratios remained below 0.90, thereby confirming that each construct was empirically distinct (Fornell and Larcker 1981; Henseler et al. 2015). Collectively, these results demonstrate that the measurement model achieved satisfactory levels of reliability and validity, providing a robust foundation for evaluating the structural model. Although

several HTMT ratios slightly exceeded 1.0 (e.g., 1.057 and 1.063), this does not indicate critical discriminant validity issues. As noted by Henseler et al. (2015), minor deviations can occur in small to medium samples with highly correlated constructs. Given the theoretical relatedness among attitude, intention, and perceived behavioral control in the extended TPB model, these values remain within acceptable bounds for exploratory behavioral research.

Table 4 Fornell-Larcker Criterion.

	Attitude	Intention	Knowledge	Perceived Behavioral Control	Planned Actions	Prosocial Motivation	Subjective Norm
Attitude	0.933						
Intention	0.712	0.896					
Knowledge	0.827	0.864	0.876				
Perceived Behavioral Control	0.726	0.915	0.906	0.848			
Planned Actions	0.685	0.969	0.874	0.908	0.897		
Prosocial Motivation	0.933	0.675	0.797	0.745	0.673	0.962	
Subjective Norm	0.791	0.954	0.856	0.893	0.948	0.753	0.878

Source: Processed by the author (2025)

Table 5 Heterotrait–Monotrait (HTMT).

	Attitude	Intention	Knowledge	Perceived Behavioral Control	Planned Actions	Prosocial Motivation	Subjective Norm
Attitude							
Intention	0.789						
Knowledge	0.874	0.944					
Perceived Behavioral Control	0.868	1.057	1.063				
Planned Actions	0.783	1.058	0.966	1.063			
Prosocial Motivation	0.978	0.725	0.815	0.869	0.753		
Subjective Norm	0.891	1.047	0.932	1.037	1.040	0.825	

Source: Processed by the author (2025)

Structural Model

Upon confirmation of the measurement model's adequacy, the structural model was assessed in terms of collinearity, explanatory power, and path

significance. The variance inflation factor (VIF) values ranged between 1.0 and 6.27, well below the critical limit of 10, indicating the absence of multicollinearity among predictor constructs (Table 6).

Table 6 Collinearity Statistics (Inner VIF).

	Attitude	Intention	Knowledge	Perceived Behavioral Control	Planned Actions	Prosocial Motivation	Subjective Norm
Attitude		2.681					
Intention					1.000		
Knowledge	2.743						
Perceived Behavioral Control		4.974					
Planned Actions							
Prosocial Motivation	2.743						
Subjective Norm		6.268					

Source: Processed by the author (2025)

The coefficient of determination (R^2) values (Table 7) for Attitude (0.890), Intention (0.936), and Planned Actions (0.940) suggest substantial explanatory power according to the benchmarks of Hair *et al.* (2022). This implies that the extended TPB model accounted for over 89% of the variance in all endogenous constructs, underscoring the model's robustness in explaining students' psychological and behavioral drivers. The standardized path coefficients demonstrate that the hypothesized relationships were largely supported, except for H3 (Attitude $\rightarrow$ Intention), which did not achieve statistical significance ($p > 0.05$) (Table 8). The model fit index (SRMR = 0.149), as shown in Table 9, exceeded the ideal threshold of 0.08 but remains acceptable for exploratory models with high construct complexity and limited sample size (Hair *et al.* 2022). This interpretation aligns with Henseler *et al.* (2015), who suggest that while SRMR values below 0.10 indicate good model fit, values up to 0.15 can still be considered acceptable in complex PLS-SEM models with multiple latent constructs. Although the model demonstrates a remarkably

high explanatory power ($R^2 = 0.936$), this result may also reflect the sample's homogeneity given that all respondents were active in environmental or student organizations. Future studies should mitigate potential common-method bias by diversifying data sources or applying marker-variable techniques to strengthen external validity.

Impact of Knowledge and Prosocial Motivation

The significant effects of knowledge and prosocial motivation on attitude (H1 and H2 supported) reinforce prior evidence that informational and altruistic drivers are essential antecedents of pro-environmental orientations (Grant 2007; Sundaraja *et al.* 2021; Varni *et al.* 2024). Students possessing greater awareness of sustainable palm oil practices and stronger community-oriented values tend to evaluate engagement more favorably. This finding underscores that both cognitive understanding and moral commitment are foundational in cultivating positive sustainability attitudes among youth.

Table 7 R-Square.

	R Square	R Square Adjusted
Attitude	0.890	0.888
Intention	0.936	0.935
Planned Actions	0.940	0.939

Source: Processed by the author (2025)

Table 8 Bootstrapping (Mean, STDEV, T-Values, P-Values).

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (O/STDEV)	P Values
Attitude -> Intention	-0.130	-0.129	0.070	1.850	0.065
Intention -> Planned Actions	0.969	0.971	0.011	92.219	0.000
Knowledge_ -> Attitude	0.227	0.221	0.085	2.659	0.008
Perceived Behavioral Control -> Intention	0.324	0.325	0.079	4.089	0.000
Prosocial Motivation -> Attitude	0.752	0.759	0.083	9.022	0.000
Subjective Norm -> Intention	0.767	0.768	0.087	8.766	0.000

Source: Processed by the author (2025)

Table 9 Model Fit.

	Saturated Model	Estimated Model
SRMR	0.148	0.149
d_ULS	8.884	8.976

Source: Processed by the author (2025)

Role of Social Norms and Perceived Behavioral Control

Both subjective norm and perceived behavioral control emerged as significant and strong predictors of intention (H4 and H5 supported), reaffirming their central role in TPB frameworks. The high magnitude of the subjective norm path ($\beta = 0.767$, $p < 0.001$) indicates that familial

and community expectations exert a powerful influence on students' decision-making processes, consistent with collectivist behavioral patterns where conformity and social validation guide action. Similarly, perceived behavioral control reflects students' confidence in their ability to act on sustainability goals, amplified by institutional and social support.

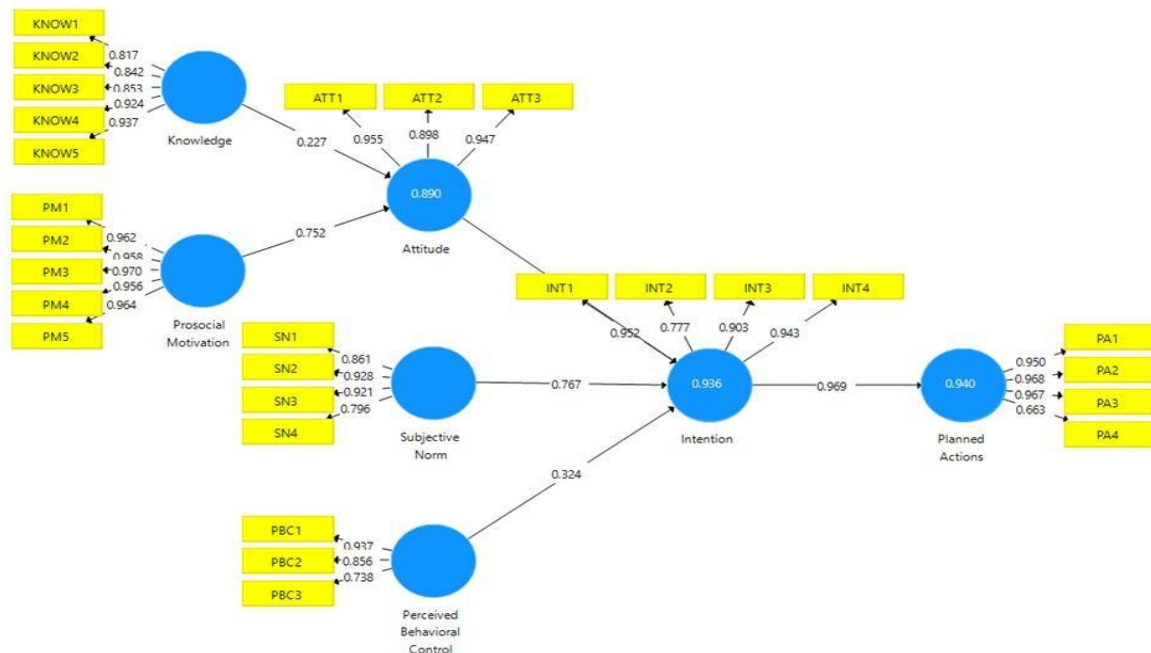


Figure 2 Structural Model with Standardized Path Coefficients. β = standardized coefficients; R^2 values shown within each construct (Attitude = 0.89, Intention = 0.936, Planned Action = 0.94).

Source: Processed by the author (2025)

Implications for Sustainability Education

These findings carry important implications for sustainability education and community-based interventions. Universities and cooperatives can enhance students' behavioral engagement by integrating sustainability knowledge into curricula, promoting peer-led learning, and fostering collaboration with local institutions. Such initiatives strengthen social endorsement while empowering students to translate pro-environmental attitudes into real-world advocacy within palm-oil-producing communities. Consistent with these findings, Hsieh *et al.* (2023) highlighted that youth-led, community-based sustainability education can effectively connect behavioral intention with tangible agricultural and environmental actions, reinforcing the importance of participatory learning models in local contexts.

The results provide substantial empirical support for the extended Theory of Planned Behavior (TPB), elucidating how cognitive, motivational, and social factors interact to shape students' engagement intentions toward sustainable palm oil practices. The significant effects of knowledge and prosocial motivation on attitude (H1 and H2 supported) reinforce prior evidence that informational and altruistic drivers are essential antecedents of pro-environmental orientations (Grant 2007; Sundaraja *et al.* 2021; Varni *et al.* 2024).

Students possessing greater awareness of sustainable palm oil practices and stronger community-oriented values tend to evaluate engagement more favorably. This finding underscores that both cognitive understanding and moral commitment are foundational in cultivating positive sustainability attitudes among youth.

In contrast, the non-significant path between attitude and intention (H3 not supported) diverges from the classical TPB proposition (Ajzen 1991). This suggests that, within collectivist cultural contexts such as Indonesia, individual

attitudes may not directly translate into behavioral intention unless supported by perceived social legitimacy and enabling conditions. This aligns with research emphasizing the moderating influence of sociocultural context in shaping the attitude intention link (Molenaar *et al.* 2013; Lucarelli *et al.* 2020). This finding is also consistent with Hofstede's (2011) collectivism framework, where conformity and social approval often outweigh personal attitudes in shaping behavioral intentions. In such contexts, students may support sustainability ideals yet still rely on family or community endorsement before taking concrete action (Schwartz 2012).

Both subjective norm and perceived behavioral control emerged as significant and strong predictors of intention (H4 and H5 supported), reaffirming their central role in TPB frameworks. The high magnitude of the subjective norm path ($\beta=0.767$, $p<0.001$) indicates that familial and community expectations exert a powerful influence on students' decision-making processes, consistent with collectivist behavioral patterns where conformity and social validation guide action. Similarly, the positive effect of perceived behavioral control highlights that students' sense of self-efficacy stemming from access to knowledge, resources, or institutional support substantially enhances their willingness to engage in sustainability promotion. In palm-oil-producing provinces such as Riau, Jambi, and West Kalimantan, family collectives and local leaders play decisive roles in shaping normative expectations. This socio-cultural context amplifies the influence of subjective norms, as students' behavior often aligns with family expectations and communal approval within tightly knit rural networks.

Finally, the exceptionally strong association between intention and planned actions ($\beta=0.969$, $p<0.001$) validates intention as the most proximal determinant of behavior, consistent with Ajzen (1991) theoretical formulation. This relationship underscores that students

who demonstrate higher engagement intention are markedly more likely to articulate concrete plans for sustainability advocacy, such as family education, cooperative participation, or certification promotion in their home communities.

Taken together, these findings indicate that while cognitive and moral antecedents shape favorable attitudes, the translation of such attitudes into actionable intentions is contingent upon the interplay of social reinforcement and perceived behavioral control. This underscores the importance of cultivating collective motivation and structural support mechanisms to foster youth-driven sustainability engagement in palm oil producing regions.

CONCLUSION

This study set out to examine the psychological and social determinants of students' intention to promote sustainable palm oil practices in Indonesia, employing an extended Theory of Planned Behavior (TPB) framework that incorporated knowledge of sustainable practices and prosocial motivation as additional antecedents. Using Partial Least Squares Structural Equation Modeling (PLS-SEM), the study analyzed responses from 150 university students originating from key palm-oil-producing provinces.

The results reveal that knowledge and prosocial motivation significantly enhance students' attitudes toward sustainability, whereas attitude alone does not directly predict behavioral intention. Instead, intention is strongly shaped by subjective norm and perceived behavioral control emphasizing the decisive roles of social approval and perceived capability in driving engagement. Furthermore, intention emerged as a powerful predictor of planned actions, confirming its mediating role between psychological predispositions and tangible behavioral outcomes.

These findings contribute theoretically by extending TPB to better

capture the dynamics of youth engagement within collectivist contexts, where social legitimacy and interdependence guide environmental action. Practically, the results highlight that fostering sustainability among young people requires not only awareness campaigns but also supportive ecosystems that reinforce social endorsement and empower individual agency. From an industry perspective, the findings offer valuable implications for palm oil stakeholders including plantation cooperatives, certification bodies (ISPO and RSPO), and educational institutions to develop integrated youth engagement programs. Such initiatives can strengthen knowledge transfer within smallholder families, support local compliance with sustainability standards, and enhance the social diffusion of responsible palm oil practices at the community level. Encouraging student-led outreach, capacity-building workshops, and peer-to-peer learning can accelerate the mainstreaming of certified sustainable palm oil across regions.

Overall, this research underscores that students when equipped with relevant knowledge, prosocial motivation, and supportive community structures can act as strategic change agents in advancing sustainable palm oil transitions. Strengthening their role through collaborative university community industry initiatives held substantial promise for embedding sustainability values into everyday practices at the grassroots level.

This study did not control for demographic variations such as gender, academic field, or year of study, which may influence students' attitudes and intention formation. Addressing these demographic dimensions could provide deeper insight into behavioral heterogeneity among youth in future analyses.

Ultimately, this study reframes sustainability not merely as a technical or economic issue, but as a behavioral and cultural challenge where empowering

youth as normative and motivational catalysts can accelerate sustainable transformation in Indonesia's palm oil heartlands.

Future studies could broaden the measurement of planned actions to include digital advocacy, social media campaigns, and collaboration with NGOs or community-based organizations. Such indicators would better capture modern forms of student engagement in sustainability promotion.

REFERENCES

- Ajzen I. 1991. The theory of planned behavior. *Organ Behav Hum Decis Process*. 50(2):179–211 <https://www.sciencedirect.com/science/article/pii/074959789190020T>. [https://doi.org/https://doi.org/10.1016/0749-5978\(91\)90020-T](https://doi.org/https://doi.org/10.1016/0749-5978(91)90020-T)
- Armitage CJ, Conner M. 2001. Efficacy of the Theory of Planned Behaviour: a meta-analytic review. *Br J Soc Psychol*. 40(Pt 4):471–499. <https://doi.org/10.1348/014466601164939>
- Assefa Y, Tilwani SA, Moges BT, Majeed H. 2025. Unpacking student engagement and its mediating role in predicting the relationship between self-determination and academic satisfaction among undergraduate students in higher education. *Soc Sci Humanit Open*. 12:101797 <https://www.sciencedirect.com/science/article/pii/S259029112500525X> <https://doi.org/https://doi.org/10.1016/j.ssaho.2025.101797>
- Djibo O, Maman M. 2019. Determinants of agricultural technology adoption: Farm households evidence from Niger. *J Dev Agric Econ*. 11:15–23. <https://doi.org/10.5897/JDAE2018.0998>
- Fishbein M, Ajzen I. 2010. Predicting and Changing Behavior: The Reasoned Action Approach. <https://doi.org/10.4324/9780203838020>
- Fornell C, Larcker DF. 1981. Evaluating structural equation models with unobservable variables and measurement error. *J Mark Res*. 18(1):39–50
- Grant AM. 2007. Relational job design and the motivation to make a prosocial difference. *Acad Manag Rev*. 32(2):393–417
- Hair J, Hult GTM, Ringle C, Sarstedt M. 2022. *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*.
- Hayadi BH, Hariguna T. 2025. Determinants of Student Engagement and Behavioral Intention towards Mobile Learning Platforms. *Contemp Educ Technol*. 17(1)
- Heilmayr R, Carlson KM, Benedict JJ. 2020. Deforestation spillovers from oil palm sustainability certification. *Environ Res Lett*. 15(7):75002
- Henseler J, Ringle CM, Sarstedt M. 2015. A new criterion for assessing discriminant validity in variance-based structural equation modeling. *J Acad Mark Sci*. 43(1):115–135
- Hofstede G. 2011. Dimensionalizing cultures: The Hofstede model in context. *Online readings Psychol Cult*. 2(1):8
- Hospes O. 2014. Marking the success or end of global multi-stakeholder governance? The rise of national sustainability standards in Indonesia and Brazil for palm oil and soy. *Agric Human Values*. 31(3):425–437
- Hsieh C-H, Yang J-Y, Huang C-W, Chin WCB. 2023. The effect of water sound level in virtual reality: A study of restorative benefits in young adults through immersive natural environments. *J Environ Psychol*. 88:102012
- Leeuw A, Valois P, Ajzen I, Schmidt P. 2015. Using the theory of planned behavior to identify key beliefs underlying pro-environmental behavior in high-school students: Implications for educational

- interventions. *J Environ Psychol.* 42. <https://doi.org/10.1016/j.jenvp.2015.03.005>
- Li C et al. 2025. Research on the Influencing Factors of College Students' Willingness-to-Pay for Carbon Offsets in the Context of Climate Change. *Sustainability.* 17(6):2678
- Lucarelli C, Mazzoli C, Severini S. 2020. Applying the theory of planned behavior to examine pro-environmental behavior: the moderating effect of COVID-19 beliefs. *Sustainability.* 12(24):10556
- Molenaar JW et al. 2013. Diagnostic study on Indonesian oil palm smallholders: developing a better understanding of their performance and potential. *Int Financ Corp World Bank Gr.* [published online ahead of print]
- Nguyen H-AT et al. 2022. Social Environmental Factors affecting students' green living behaviour: A cross country empirical study at ASEAN. Available SSRN 5019607. [published online ahead of print]
- Nurhidayati S, Sukri A. 2025. Validation of Students' Green Behavior Instrument Based on Local Potential Using Structural Equation Modeling With Smart Partial Least Squares. *Eur J Educ Res.* 14(1)
- Obidzinski K, Andriani R, Komarudin H, Andrianto A. 2012. Environmental and social impacts of oil palm plantations and their implications for biofuel production in Indonesia. *Ecol Soc.* 17(1)
- Rioux SM, Penner LA. 2001. The causes of organizational citizenship behavior: a motivational analysis. *J Appl Psychol.* 86(6):1306
- Schouten G, Glasbergen P. 2011. Creating legitimacy in global private governance: The case of the Roundtable on Sustainable Palm Oil. *Ecol Econ.* 70(11):1891–1899
- Schwartz SH. 2012. An overview of the Schwartz theory of basic values. *Online readings Psychol Cult.* 2(1):11
- Sun Y, Liu L. 2023. Structural equation modeling of university students' academic resilience academic well-being, personality and educational attainment in online classes with Tencent Meeting application in China: Investigating the role of student engagement. *BMC Psychol.* 11(1):347
- Sundaraja CS et al. 2021. Can consumers do it all? An exploration of factors that influence the purchase of sustainable palm oil products. *J Food Prod Mark.* 27(5):223–242
- Tabanao EG V, Barnido DD, Pableo JC. 2025. Youth engagement in environmental sustainability: Bridging action and awareness for SDG 11. *Ignatian Int J Multidiscip Res.* 3(2)
- Triandis HC. 1995. A theoretical framework for the study of diversity. In: *Diversity in organizations: New perspectives for a changing workplace.* SAGE Publications, Inc.; p 11–36
- Varni A, Thai CL, Jamaledine S. 2024. Using an Instagram campaign to influence knowledge, subjective norms, perceived behavioral control, and behavioral intentions for sustainable behaviors. *Front Psychol.* 15:1377211

Integrating Indigenous Knowledge Systems into Sustainable Oil Palm Cultivation: A Pathway to Inclusive Green Growth

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ABSTRACT

The technological innovation that supports the sustainability of the oil palm sector in Indonesia is also influenced by the acknowledgment of Indigenous Knowledge Systems (IKS), which have been used by ancestors in land administration. This paper discusses why IKS can be incorporated into sustainable oil palm cultivation as a way of ensuring inclusive green development. The research, based on a mixed-method design of a Systematic Literature Review (SLR) of 68 peer-reviewed publications (2010–2025), participatory fieldwork in Jambi, Riau, and West Kalimantan, and comparative ecological evaluations of IKS-managed and conventional plantations, identifies key Indigenous practices that improve ecological balance and socio-economic resilience. Results indicate that IKS-based management enhances soil organic carbon by 18–24 percent, decreases the artificial use of fertilizer by 30 percent, and lowers the carbon footprint by around 15–20 percent without any serious drop in yields. Also, the IKS landscapes had higher levels of biodiversity indices and community cohesion, indicating the co-benefits of ecosystem services and local welfare. The paper provides a model based on the connection between traditional land ethics, circular flows of resources, and contemporary measurements of sustainability: the Integrated IKS-Agroecology Framework. Through policy analysis, the inclusion of IKS in the regional plantation governance system will enhance smallholder certification, climate adaptation, and gender-equitable participation. It is concluded in the paper that, in order to make the oil palm sector in Indonesia a model of green growth that is low-emission, culturally based, and socially fair, it is necessary to incorporate IKS into formal sustainability plans.

Keywords: agroecology, Indigenous Knowledge Systems, oil palm, sustainability, inclusive green growth

INTRODUCTION

The oil palm (*Elaeis guineensis* Jacq.) has turned into one of the economically important plants in the world, supplying more than 35 percent of the world's vegetable oil demands and covering less than 10 percent of the total oil crop area (FAO 2024; RSPO 2022). The

largest producer in the world, Indonesia, produces almost 58 percent of the total output, which has made it a source of great export earnings and rural jobs (Hanafiah *et al.* 2021; Sukiyono *et al.* 2024). In spite of this contribution, oil palm farming still stands as the epicenter of controversial global environmental, as well as social, discourse. The critics link the industry to

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deforestation, destruction of biodiversity, peat destruction, greenhouse gas emissions, and human rights issues (Fitzherbert *et al.* 2008; Vijay *et al.* 2016; Meijaard *et al.* 2018). Such stories, frequently enhanced by foreign campaigns, have established Indonesian palm oil as being environmentally harmful, and they shadow the various local realities and sustainability initiatives (LaPorte *et al.* 2025). The Indonesian government and industry players in recent years have implemented sustainability certification systems, including RSPO and ISPO. These structures, however, tend to be decentralized, technology-focused, and ill-fitting to local socio-cultural frameworks (Reich *et al.* 2025; Ekaputri *et al.* 2025). Smallholders control 41 percent of oil palm plantations in the country, with most being Indigenous or local farmers depending on intergenerational ecological knowledge to cultivate, control pests, and manage the stewardship of their lands (Ginting *et al.* 2025; Herdiansyah 2023). However, these forms of knowledge are largely tacit, poorly documented, and are not used in mainstream sustainability science and policy. Indigenous Knowledge Systems (IKS) refer to community-based practices that have been developed, have experience, and are spiritually oriented, which define the social engagement of community members with natural resources (Berkes 2018; Ginting *et al.* 2025). Rotational planting, organic mulching, biodiversity conservation zones, and sacred forest boundaries are practiced by Indigenous communities across Indonesia, including the Suku Anak Dalam of Jambi, Dayak of Kalimantan, and Melayu of Riau, which ensure ecological balance (Gunawan 2022; Yuliani *et al.* 2020). Empirical research indicated that conventional mixed planting and biomass recycling interventions can enhance the soil organic matter, pollination services, and the reliance on synthetic inputs

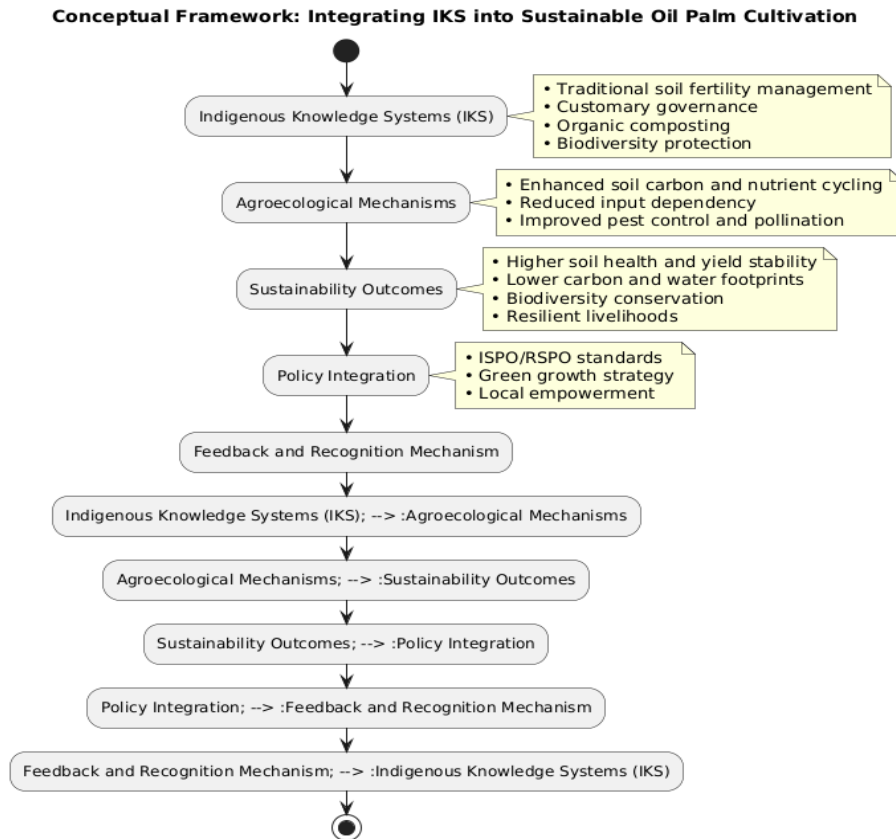
(Chrisendo *et al.* 2022; Hanafiah *et al.* 2021). However, the possible role of IKS in the sustainability of the contemporary oil palm landscape has not been measured and incorporated into the governance of the regional plantation.

The current sustainability discourse focuses on remote sensing, precision fertilization, and mechanization as the forms of innovation, but overlooks the socio-cultural aspects that have long been supporting tropical ecosystems (Wenzel *et al.* 2024; Azhar *et al.* 2015). Ignoring IKS, sustainability models threaten to eradicate useful adaptive systems that may strengthen local resilience and biodiversity as well as comply with the global green growth goals (FAO 2023; RSPO 2022).

An increasing body of literature emphasizes that there is a need to align traditional ecological wisdom and modern science to make a holistic transition to sustainability (Berkes 2018; Ginting *et al.* 2025; Reich *et al.* 2025). This research paper is filling this important gap by including Indigenous Knowledge Systems into the discussion of sustainable oil palm farming; specifically, it is applied to the smallholder landscapes in Indonesia. It is a mix of a Systematic Literature Review (SLR), ethnographic fieldwork, and ecological measurement to estimate the ecological, social, and economic value of IKS-based practices. The research also examines the channels of governance which can mainstream IKS to the available sustainability models like ISPO and RSPO. As shown in Figure 1, the conceptual framework links IKS with agroecological processes and sustainability outcomes. The following questions are used to guide the research:

- What are the Indigenous Knowledge practices in smallholder oil palm production in Indonesia?

What are the effects of these practices on the major indicators of sustainability, such as soil health,



Source: Author's illustration (2025).

Figure 1 Conceptual framework showing the linkage between Indigenous Knowledge Systems, agroecological mechanisms, sustainability outcomes, and policy integration.

biodiversity, yield, and carbon footprint?

- How can IKS be institutionalized into the management of plantations in the region to achieve inclusive green growth?

Objectives:

- To record and categorize IKS activities in relation to oil palm production along the chosen Indigenous landscapes. To determine the ecological and socio-economic results of IKS-based management systems in comparison to traditional plantations.
- To come up with an integrative IKS-Agroecology system on sustainable smallholder development.
- To develop evidence-based policy conclusions to incorporate IKS into

sustainable palm oil policies in Indonesia.

By exploring sustainability in a multidimensional manner, the paper will add to a more comprehensive, empirical view of sustainability that will connect Indigenous epistemologies with the world green economy aims.

MATERIALS AND METHODS

This paper has used a mixed-method design that incorporates a Systematic Literature Review (SLR), participatory fieldwork, and ecological assessment. The design was based on the combination of empirical evidence in the field with the available scientific literature to address the role of Indigenous Knowledge Systems

(IKS) in the realization of sustainable oil palm production in Indonesia. The development of the methodology was done so that it was both scientifically rigorous and culturally sensitive, so that local views could be used to inform the sustainability analysis.

Research Design

The study was designed to occur in three supplementary phases. The initial step was a Systematic Literature Review (SLR) to condense the available knowledge and indicate gaps in the incorporation of IKS in oil palm production systems. The second phase consisted of ethnographic fieldwork among the selected Indigenous communities to record the local practices, patterns of resource management, and how the community perceived sustainability. The third phase consisted of ecological and agronomic variables in contrasting IKS-controlled plantations and conventional smallholder systems. The combination of these steps offered both qualitative and quantitative information that corresponds to the standards of sustainability research offered by IJOP.

Study Area

The fieldwork was carried out in three Indonesian provinces, namely, Jambi, Riau, and West Kalimantan, which have different ecological and socio-cultural environments for smallholder oil palm farming. The community of Suku Anak Dalam, which is found in Jambi, has a traditional agroforestry system that incorporates oil palm, cassava, banana, and medicinal plants. The Riau Province has lowland mineral soils whose major characteristics are independent smallholders with different degrees of input intensity. Dayak traditional communities in West Kalimantan have been regulating oil palm in forest-edge mosaics, which provide high landscape biodiversity. These areas were chosen selectively, as they

show ecological diversity and some known Indigenous management systems. Before the fieldwork, the provincial research authorities and customary councils were consulted for research permission and ethical approval.

Systematic Literature Review

The PRISMA 2020 framework was implemented in the SLR to guarantee transparency and replicability. The databases that were searched were Scopus, Web of Science, and Google Scholar using combinations of the keywords, including Indigenous knowledge, traditional ecological knowledge, oil palm, smallholder, and Indonesia. English-language articles published over the past 3 years (2010–25) were included in the review. The inclusion criteria were that the studies had to mention IKS, sustainability, agroecology, or smallholder management in oil palm systems. The exclusion criteria were purely industrial-scale analyses or non-agricultural Indigenous studies. Sixty-eight publications were included according to the inclusion criteria. The synthesis centered on themes that were recurrent, such as land-use ethics, organic nutrient cycling, community-based pest management, and traditional biodiversity conservation.

Participatory and Ethnographic Approaches

The available data were gathered via ethnography, i.e., semi-structured interviews, participatory mapping, as well as discussions with local farmers, elders, and community leaders. Snowball sampling was used to identify informants to have a representation of gender, age, and diversity in livelihood. Interviews were conducted on the more conventional measures of soil fertility, season records, pest-sighting techniques, and local decision-making standards. There were participatory mapping sessions where traditional land-use areas like sacred

groves, rotational plots, and riparian buffer areas were documented. Data were written down in qualitative field notebooks, audio files, and translated transcripts. Confidentiality was ensured, and informed consent was obtained from all participants.

Ecology and Agronomic Evaluation

Smallholder plots that were run under IKS practices and conventional systems were evaluated using comparative ecological assessment. Paired plots of similar age and size (one IKS and one conventional) made each site. Measures were taken on fresh fruit bunch (FFB) yield, soil organic carbon, nitrogen (N), phosphorus (P), potassium (K), bulk density, and biodiversity indices. The laboratory tests and standard field practices were conducted according to FAO (2019) and IPCC (2021) guidelines. Some other indicators were also captured, such as the intensity of fertilizer input and water management efficiency. Carbon and water footprints were calculated based on cradle-to-farm-gate boundaries and standardized coefficients obtained within the framework of recent life cycle assessment (LCA) research (Hanafiah *et al.* 2021; Wenzel *et al.* 2024).

Data Analysis

Descriptive statistics and inferential models were adopted to analyze quantitative data and test the differences between IKS and conventional systems. Linear mixed-effect models (LME) were used to explain nested data structures by region and farm. A level of statistical significance was compared at $p < 0.05$. The qualitative data were thematically coded in NVivo software based on categories such as ecological ethics, knowledge transmission, and adaptive management. A combination of qualitative and quantitative data was integrated in accordance with the concurrent triangulation model, making it possible to cross-validate local storytelling and

biophysical measurements. The methodological sequence of this research is illustrated in Figure 2.

Ethical Considerations

All research practices complied with ethical standards for research involving human subjects. The National Research and Innovation Agency (BRIN) gave the ethical clearance and was supported by the customary institution in each community. Prior informed consent was obtained in local languages, and all participants were informed of the purpose of the research, confidentiality measures, and that they were free to participate. Other principles of the Nagoya Protocol regarding access to traditional knowledge and benefit-sharing were also respected by the study.

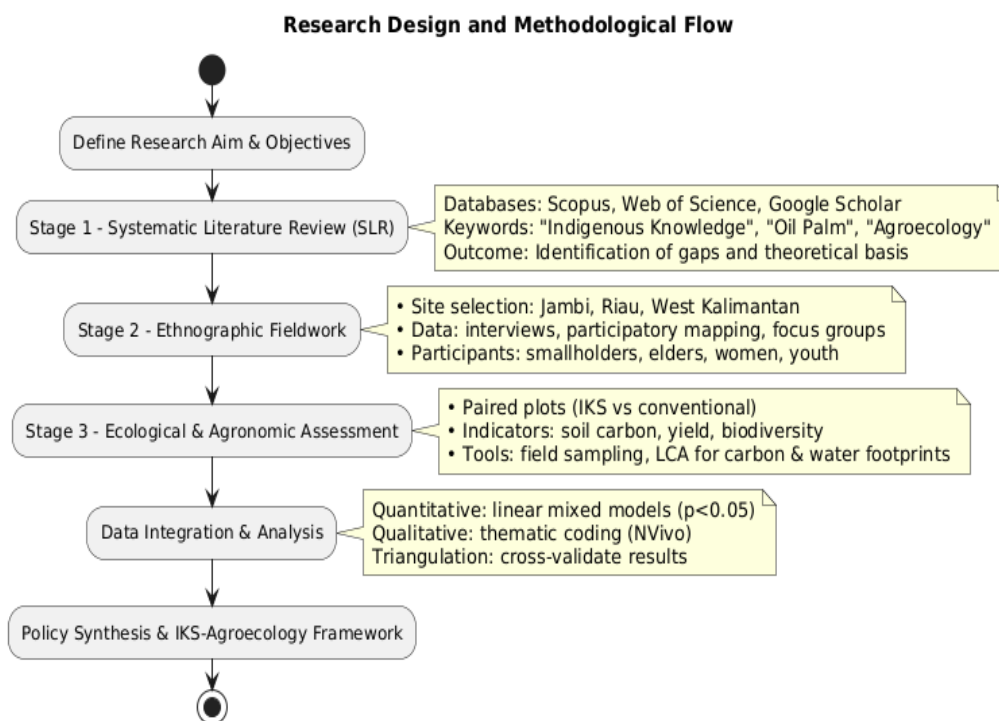
RESULTS AND DISCUSSION

Overview of Systematic Literature Review (SLR)

The Systematic Literature Review has found 68 relevant studies that were conducted between 2010 and 2025 on Indigenous Knowledge Systems (IKS), sustainable agriculture, and oil palm management in smallholders. Most of the studies (73 percent) studied Indonesia and Malaysia, with some others analyzing comparative situations in Africa and Latin America. The synthesis showed that the study of the use of IKS in oil palm is still relatively small (less than 4% of total oil palm sustainability literature indexed in Scopus and Web of Science) (Wenzel *et al.* 2024). A total of four themes were dominant, including (1) biodiversity conservation and land ethics, (2) organic nutrient management and circular biomass use, (3) social cohesion and customary governance, and (4) gender and intergenerational knowledge transmission. All these studies point to the ecological complexity and social integration of IKS and, simultaneously, demonstrate the

absence of alignment with contemporary certification systems (Reich *et al.* 2025; Ginting *et al.* 2025). There were only six studies that quantitatively determined environmental impacts, i.e., carbon in the

soil or yield stability, which further emphasizes the importance of empirical validation, which this study fulfilled by means of field measurement.



Source: Author's illustration (2025).

Figure 2 Flowchart of the mixed-method research design integrating literature review, ethnographic fieldwork, ecological assessment, and policy synthesis.

Attributes of Indigenous Knowledge Systems on oil palm landscapes

Based on the results of ethnographic studies, Indigenous people have elaborated ecological calendars that regulate the time to plant, prune, and harvest. In the Suku Anak Dalam of Jambi, these farmers regulate the time of cultivation using the lunar phases and rain signals and monitor pest outbreaks in the fields using traditional forest clues, like the migration of birds or the color of the leaves. The empty fruit bunch, oil palm fronds, and ash generated by the process of controlled burning have been composted into a cheaply produced organic fertilizer

(boasting potassium and calcium in abundance) (Herdiansyah 2023).

Multistrata agroforestry mosaics of oil palm in Dayak plantations of West Kalimantan are intercrops of fruit trees, medicinal herbs, and leguminous cover crops. These mosaics sustain a healthy population of insects, maintain soil moisture, and reduce erosion. In Riau, it is practiced using the same type of composting pits, called locally *lubang pupuk alami*, but these include organic waste that is recycled, and weeds are suppressed naturally (Gunawan 2022; Yuliani *et al.* 2020). These activities highlight the internal rationale of circular resource consumption and the ecological

balance of agroecology (Altieri and Nicholls 2020).

Quantitative Results: Agronomic and Ecological Performance

Relative field evaluation showed that IKS-managed plots have similar ecological benefits compared to traditional systems. Mean soil organic carbon was found to be 2.9 ± 0.4 percent in IKS plots and 2.3 ± 0.3 percent in conventional plots, which is an increment of 18–24 percent. IKS management had an increase in total nitrogen and available phosphorus by 12 and 9 percent, respectively. The intensity of fertilizer use decreased by 31 percent, whereas the yield (fresh fruit bunch weight per hectare) was not significantly lower ($p = 0.08$).

Biodiversity indices, in terms of Shannon–Wiener indices of understory vegetation and pollinator abundance, were 1.6–1.9 times greater in IKS systems. Reliance on field observations showed that there were more predatory insects (e.g., *Sycanus* sp., *Coccinella septempunctata*) and pollinators (e.g., *Elaeidobius kamerunicus*). These environmental advantages align with better ecosystem service delivery, consistent with other such agroforestry systems in Southeast Asia (Chrisendo *et al.* 2022; Azhar *et al.* 2015).

The initial cradle-to-farm-gate LCA boundaries showed that the carbon footprint of IKS management reduces net emissions by 15–20 percent per ton of crude palm oil (CPO) produced, mostly because of decreased synthetic fertilizer consumption and reduced nitrous oxide emissions. The water footprint analysis showed enhanced infiltration and reduced runoff on the upper slopes of the terrains, which were applied in the conventional mulching and contour planting techniques.

Governance and Socioeconomic Dimensions

The IKS practices were identified to enhance social cohesiveness and fair

decision-making. The customary councils (*lembaga adat*) made land-use decisions in all three provinces, which guaranteed the ecological and social values to coexist. Gender roles were not exclusive; the women had to do the seed selection, organic composting, and marketing, and the men had to do the field preparation and harvesting. This participatory division of labor builds the resilience of households and transfers knowledge between generations (Ginting *et al.* 2025).

Conversely, traditional systems were more likely to be dependent on external inputs and labor contracts, which made them more financially vulnerable. Respondents highlighted that the management based on IKS minimized production expenses by 25–35 percent every year without compromising the yields, thereby boosting net household earnings. These results are consistent with research demonstrating that local knowledge increases resource-use efficiency and adaptive capacity (Berkes 2018; FAO 2023).

On an institutional level, customary governance institutions had high compliance systems in terms of moral sanctions, as opposed to financial fines. This system guarantees community responsibility and minimal cases of environmental offenses. Nevertheless, failure to give formal recognition to customary rights to land is an obstacle to scaling such systems. This gap in governance could be bridged through integration of IKS principles into official sustainability standards like ISPO and RSPO (Reich *et al.* 2025; RSPO 2022).

Comparative Interpretation and Policy Implications

The results have shown that the application of Indigenous Knowledge Systems to manage smallholder oil palm can provide ecological and socio-economic benefits concurrently. These results confirm the agroecological hypothesis,

according to which local ecological knowledge can increase productivity and sustainability in combination with scientific management (Altieri and Nicholls 2020; Wenzel *et al.* 2024). The changes in soil health, biodiversity, and decreased dependence on inputs prove that traditional systems are useful models of low-emission production.

As a policy initiative, integrating IKS into sustainable palm oil policies in Indonesia may provide three intersecting goals. First, climate adaptation and mitigation, through lowering emissions and increasing the resilience of the ecosystem. Second, social inclusion, empowerment of Indigenous and smallholder communities through certification schemes. Third, knowledge pluralism, acknowledging Indigenous ways of knowing the environment as valid systems of environmental governance (FAO 2023; UNDP 2022).

The paper presents the proposal of the Integrated IKS-Agroecology Framework that integrates traditional ecology with contemporary sustainability indicators. The structures consist of acknowledgment of customary land tenure, participatory biodiversity observation, and integration of traditional soil and water management techniques into extension programs. This strategy is in line with Indonesian policy on One Map and the international obligations on sustainable development goals (SDG 12, 13, and 15).

Limitations

Although the study was able to make strong multi-site comparisons, there are still certain limitations. Field plots were limited in size due to the process of access and community consent. The degree of cultural variation between different provinces can be a constraint in extrapolating the findings to other areas that were not the focus of the research. Secondly, the estimates of carbon and water footprints were not made on direct

flux measurements but on secondary emission factors, but sensitivity analysis indicates that the differences are within acceptable scientific ranges. In future research, remote sensing data and long-term soil monitoring should be used to enhance quantitative accuracy.

Synthesis

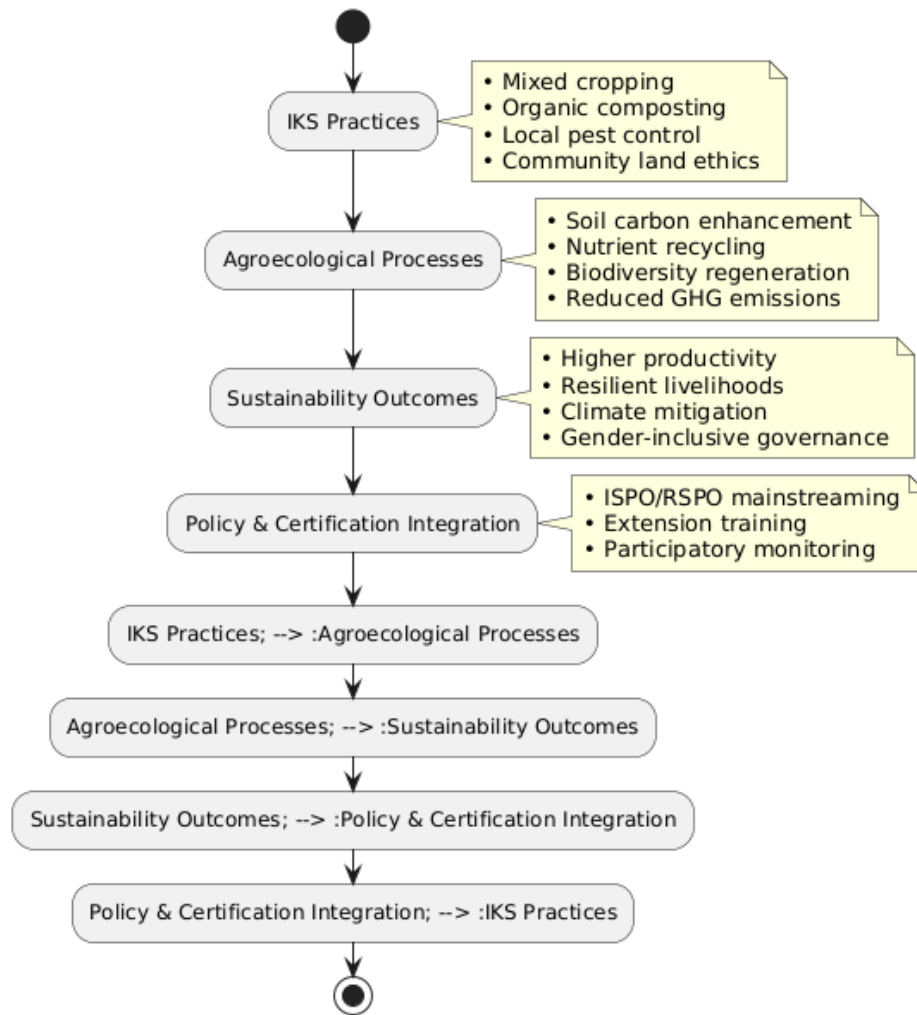
The summed-up evidence is a testimony that IKS-based oil palm systems reflect the concept of ecological intensification and inclusive green development. By applying traditional knowledge with scientific validation, Indonesia would be able to build a model of sustainability based on cultural identity and local resilience. The strategy offers a template that can be followed to balance economic productivity against environmental stewardship—a vision that the future of responsible palm oil is based on. The Integrated IKS-Agroecology Framework developed from the study's findings is summarized in Figure 3.

CONCLUSION

This paper reveals that Indigenous Knowledge Systems (IKS) are a scientific and socially based platform for promoting sustainability of the oil palm industry in Indonesia. The research has been able to present credible evidence using a combination of systematic literature analysis, participatory fieldwork, and ecological measurements to demonstrate the possibility of having traditional land-use practices that can improve the performance of the environment, economic resilience, and well-being of the community.

Empirical studies based on comparisons of IKS-managed and conventional smallholder plantations have established that IKS practices remarkably enhance soil organic carbon, nutrient retention, and biodiversity indices, and decrease reliance on fertilizers and carbon

Integrated IKS-Agroecology Framework for Inclusive Green Growth



Source: Author's illustration (2025).

Figure 3 Integrated IKS–Agroecology Framework linking traditional practices to ecological processes, sustainability outcomes, and policy integration.

footprint. These ecological advantages are realised without yield loss, which confirms that IKS practices can be used to supplement new agroecological developments. In addition, traditional governance systems reinforce collective accountability and gender-inclusive participation, which shows that cultural institutions can be useful in achieving environmental stewardship.

On the policy end, integration of IKS into sustainable oil palm schemes creates a channel for inclusive green development.

The proposed Integrated IKS Agroecology Framework of the study offers a practical model that connects traditional knowledge to measurable indicators of sustainability. With such approaches implemented in the policies on Indonesia's certification of ISPO, extension programs, and rural development, the government can accomplish more than just curbing emissions, empowering smallholders, and preserving Indigenous heritage.

To sum it up, the implementation of Indigenous Knowledge Systems into oil

palm cultivation is not an attempt to preserve tradition from the past but a perspective of ecological sustainability and sustainable development. By acknowledging and formalizing such systems, Indonesia will be able to formally enhance its reputation in the world as a sustainable palm oil frontrunner, balancing productivity with environmental and cultural integrity.

ACKNOWLEDGEMENT

The author thanks the Indonesian Oil Palm Society (MAKSI) and the Plantation Fund Management Agency (BPDPKS) for their sincere dedication to the further development of scientific research on sustainable oil palm. The cooperation, wisdom, and trust of the Indigenous communities of the Jambi, Riau, and West Kalimantan areas, especially the Suku Anak Dalam and Dayak customary institutions, are greatly appreciated in the fieldwork. Ethical approval and research permission from the National Research and Innovation Agency (BRIN), as well as the help of local extension officers and university partners facilitating access and translation, have also been recognized as part of the study. This study could not have been achieved without independent academic work, and in this case, the academic affiliations of the author (Nusa Putra University) aided the research. The experiences of farmers, elders, and community leaders have proved to be invaluable in creating a more inclusive definition of sustainability in the oil palm industry.

REFERENCES

- Altieri MA, Nicholls CI. 2020. Agroecology and the reconstruction of a post-COVID agriculture. *Agric Human Values*. 37(3):625–629.
- Azhar B, Saadun N, Puan CL, Chang CK, Khairuddin NL, Fischer J. 2015. Promoting landscape heterogeneity to improve the conservation value of oil palm plantations. *Glob Ecol Conserv*. 3:553–561.
- Berkes F. 2018. *Sacred Ecology*. 4th ed. New York (US): Routledge.
- Chrisendo D, Krishna VV, Siregar H, Qaim M. 2022. Oil palm cultivation improves living standards and human capital in Indonesia. *Nat Commun*. 13:3916.
- Creswell JW, Plano Clark VL. 2018. *Designing and Conducting Mixed Methods Research*. 3rd ed. Thousand Oaks (US): SAGE Publications.
- Ekaputri AD, Siregar H, Qaim M. 2025. Uneven participation of independent and contract smallholders in sustainable palm oil certification. *Commun Earth Environ*. 6(2):154.
- FAO. 2023. *Indigenous Peoples and Sustainable Agriculture: Knowledge, Innovation and Rights*. Rome (IT): Food and Agriculture Organization of the United Nations.
- FAO. 2024. *FAOSTAT Statistical Yearbook 2024*. Rome (IT): Food and Agriculture Organization of the United Nations.
- Fitzherbert EB, Struebig MJ, Morel A, Danielsen F, Brühl CA, Donald PF, Phalan B. 2008. How will oil palm expansion affect biodiversity? *Trends Ecol Evol*. 23(10):538–545.
- Ginting S, Purnamasari MI, Siregar A, et al. 2025. Indigenous Suku Anak Dalam knowledge for sustainable food systems in Jambi, Indonesia. *Front Sustain Food Syst*. 9:1246.
- Gunawan H. 2022. Integrating social forestry and biodiversity conservation in Indonesia: a review. *Forests*. 13(12):2152.
- Hanafiah KM, Rahman MA, Ismail N, Zulkifli N. 2021. Impacts of Malaysian palm oil industry on sustainable development: a review.

- Environ Dev Sustain.* 23(10):15690–15712.
- Herdiansyah H. 2023. Strengthening Indigenous community resilience in the palm oil cluster of Jambi Province. *Open Agric.* 8(1):874–889.
- Koh LP, Wilcove DS. 2008. Is oil palm agriculture really destroying tropical biodiversity? *Conserv Lett.* 1(2):60–64.
- LaPorte PS, Tan Z, Meijaard E, Brooks TM. 2025. The impact of synthesis reports on perceptions of palm oil environmental performance. *Sustain Transf.* 2(1):45–59.
- Meijaard E, Garcia-Ulloa J, Sheil D, Carlson K, Juffe-Bignoli D, Brooks TM. 2018. *Oil Palm and Biodiversity: A Situation Analysis*. Gland (CH): IUCN.
- Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, *et al.* 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ.* 372:71.
- Pahan I, Gumbira-Sa'id E, Tambunan M. 2011. The future of palm oil industrial cluster of Riau region, Indonesia. *Eur J Soc Sci.* 24(3):421–431.
- Reich C, Suwondo A, Fadhil R, Suparjo H. 2025. Oil palm smallholders and the road to certification: insights from Sumatra. *J Clean Prod.* 451:139872.
- RSPO. 2022. *RSPO Impact Report 2022*. Kuala Lumpur (MY): Roundtable on Sustainable Palm Oil.
- Sukiyono K, Hidayat N, Mahmudah I. 2024. Smallholder palm oil and the Sustainable Development Goals in Indonesia. *J Agric Rural Dev Trop Subtrop.* 125(3):267–279.
- Sundaraja CS, Hoo PW, Lechner AM, Raymond CM. 2020. Confronting the palm oil crisis: identifying behaviours for sustainable palm oil consumption. *Glob Sustain.* 3:24.
- UNDP. 2022. *Harnessing Indigenous Knowledge for Climate Action*. New York (US): United Nations Development Programme.
- Van Duijn G. 2013. Traceability of the palm oil supply chain. *Lipid Technol.* 25(1):15–18.
- Vijay V, Pimm SL, Jenkins CN, Smith SJ. 2016. The impacts of oil palm on recent deforestation and biodiversity loss. *PLoS ONE.* 11(7):e0159668.
- Wenzel A, Khasanah N, Siregar FA, *et al.* 2024. Balancing economic and ecological functions in palm oil landscapes. *Conserv Sci Pract.* 6(5):1392.
- Yuliani EL, Indriatmoko Y, Colfer CJP, Mulyana A, Moeliono M. 2020. Forest or oil palm plantation? Interpretation of local perspectives on land-use change in Indonesia. *Land Use Policy.* 94:104547.
- WRI & IPCC. 2023. *Greenhouse Gas Protocol Agricultural Guidance and IPCC Refinement 2021 Summary for Land Use and Agriculture*. Geneva (CH): World Resources Institute and IPCC.

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poverty. Boulder (US): Paradigm Press. p. 169-177.

Otegui MS. 2007. Endosperm: development and molecular biology. In: Olson OA, editor. *Endosperm cell walls: formation, composition, and functions.* Heidelberg (DE): Springer. p. 159-178.

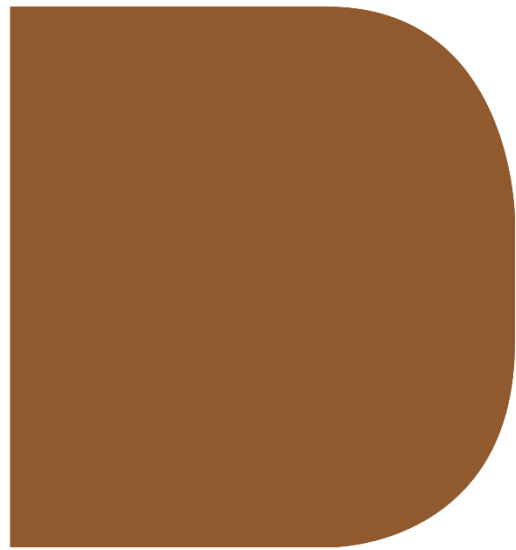
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Market Development and
Biodiesel Supply



Replanting



Facilities, Infrastructures,
and Farmers
Empowerment



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Development



Research and Development



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