

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

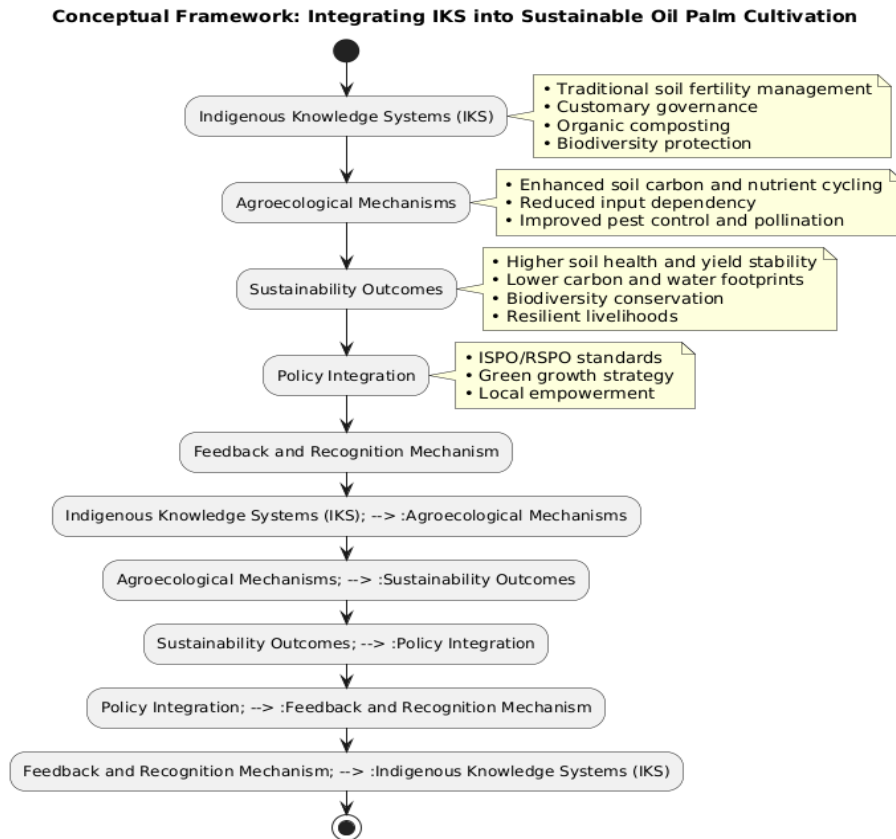
(Chrisendo *et al.* 2022; Hanafiah *et al.* 2021). However, the possible role of IKS in the sustainability of the contemporary oil palm landscape has not been measured and incorporated into the governance of the regional plantation.

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.

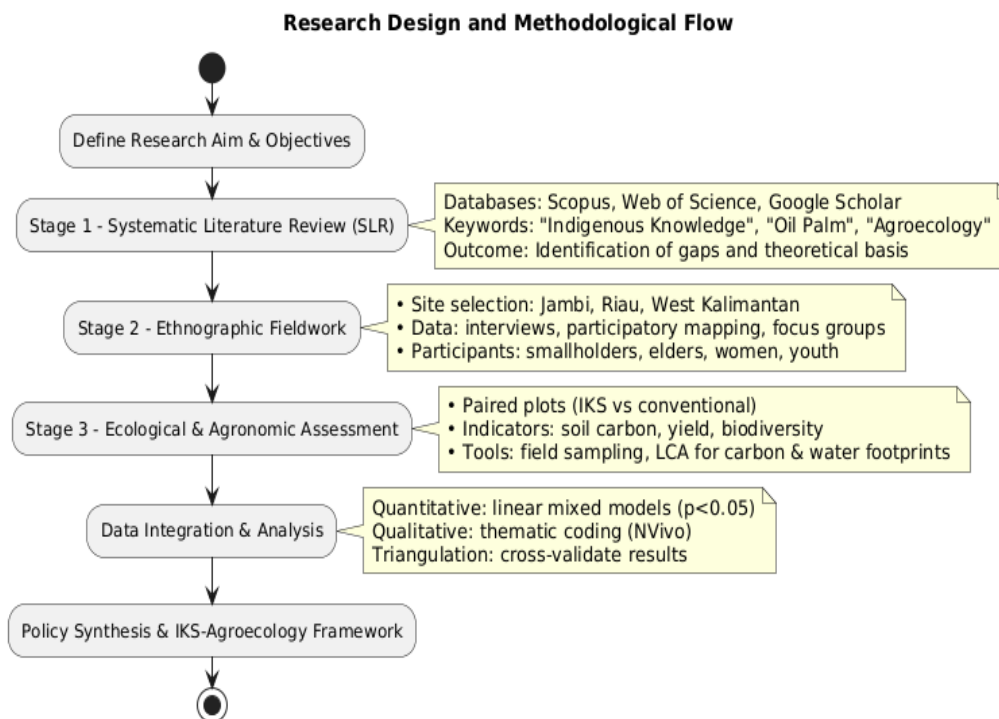
RESULTS AND DISCUSSION

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

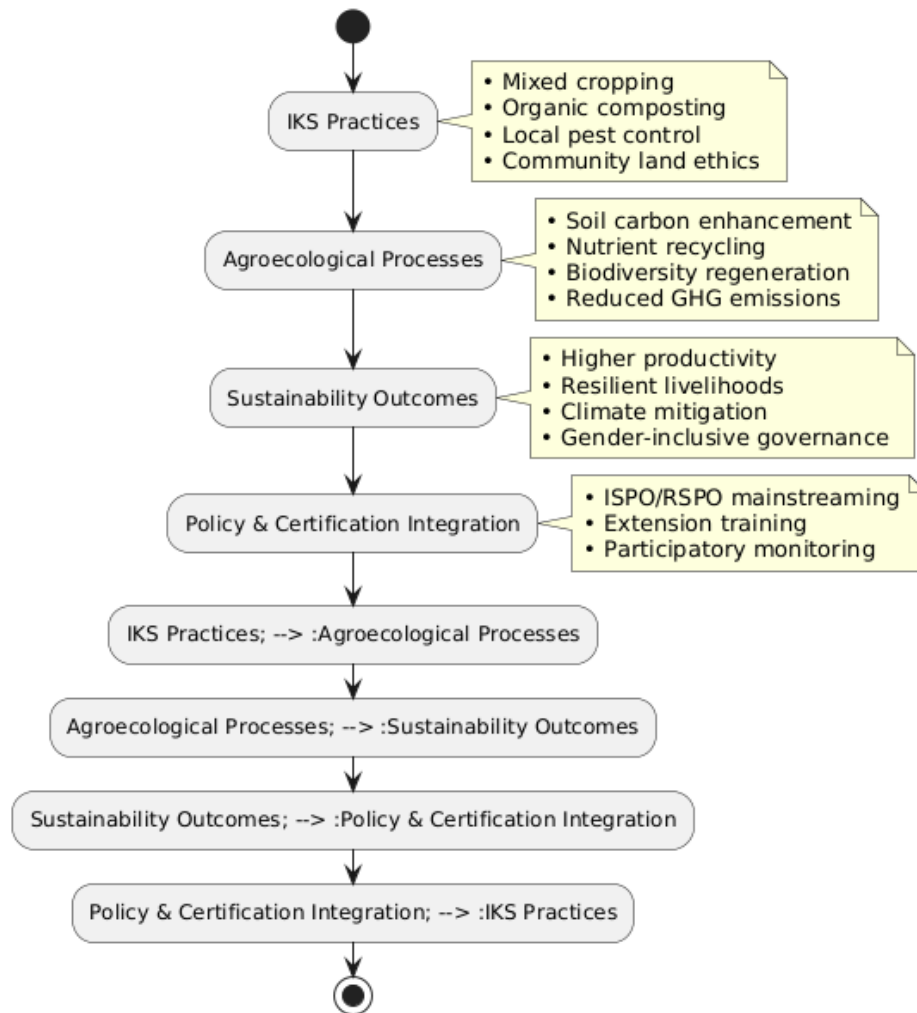
The summed-up evidence is a testimony that IKS-based oil palm systems reflect the concept of ecological intensification and inclusive green development. By applying traditional knowledge with scientific validation, Indonesia would be able to build a model of sustainability based on cultural identity 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.

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