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Redefining Accounting Education: Balancing Technological Innovation with Ethics and Sustainability

The Impact of Enterprise Resource Planning (ERP) System Implementation on Operational and Environmental Sustainability in Indonesia's Palm Oil Plantation Industry

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ABSTRACT
Indonesia's palm oil industry contributes 4.5% to GDP and supplies 54% of the global market. However, it faces operational inefficiencies and environmental pressures, including deforestation and the European Union Deforestation Regulation (EUDR). This study examines the impact of Enterprise Resource Planning (ERP) implementation on sustainability. It addresses gaps in AI-enhanced tools for agribusiness.
We used a quantitative survey of 200 respondents from palm oil firms. Structural equation modeling (SEM) in SmartPLS tested hypotheses on direct effects, mediation by employee perceptions (via Technology Acceptance Model, TAM), and moderation by technological literacy and firm scale. [ADDED: Sebut TAM dan SEM eksplisit untuk keywords metodologi.] Data analysis (n=200, 100% usable post-cleaning) supported all hypotheses: ERP positively influenced operational (β=.43, p<.001) and environmental sustainability (β=.40, p<.001). Partial mediation occurred (indirect β=.24–.26), with significant moderation.
Findings highlight ERP's role in optimizing yields and compliance. We recommend subsidized training for smallholders to achieve Indonesian Sustainable Palm Oil (ISPO) targets by 2025.
Keywords: ERP implementation, palm oil industry, operational sustainability, environmental sustainability, SEM, Technology Acceptance Model, AI integration, Indonesia.

INTRODUCTION

The palm oil plantation industry in Indonesia is a cornerstone of the national economy. It contributes approximately 4.5% to GDP in 2024. The sector supplies over 54% of the global palm oil market. Production reached 47 million metric tons in the 2023/24 season. Projections indicate 47 million tons in 2025/26, driven by favorable weather and increased fertilizer use [1].

However, the sector faces persistent challenges. These include stagnant yields from aging plantations (many over 25 years old), supply chain vulnerabilities, and environmental pressures from deforestation. Deforestation has declined to 32,406 hectares annually for industrial palm oil in 2018–2022. Yet, 2.4 million hectares of intact forest remain at risk in concessions [2]. Global regulations, such as the EUDR (fully effective December 30, 2025), add further complexity [2]. The B40 biodiesel mandate, rolled out in March 2025, elevates palm oil use for energy to 13.9 million metric tons. This underscores the need for efficiency to meet domestic biofuel targets (25% of the energy mix by 2025) while curbing emissions [3].

Enterprise Resource Planning (ERP) systems are pivotal in addressing these issues. Advancing with generative AI for automation, cloud scalability, blockchain for traceability, and real-time analytics, ERP enables precision resource management and compliance in resource-heavy agribusiness [4]. This study explores ERP's impact on operational and environmental sustainability in Indonesia's palm oil plantations. It highlights AI-driven tools for yield optimization and EUDR-aligned traceability.

The research significance is heightened by 2025 sustainability imperatives. These include mandatory ISPO certification for all growers by year-end (86% coverage in 2024, targeting >95% in 2025). It is complemented by Roundtable on Sustainable Palm Oil (RSPO) standards, which protected 646,700 hectares of forests globally in 2023 [5]. ERP innovations, such as Oracle Fusion Cloud's AI agents for Scope 1-3 emissions tracking and low-code customization, support peatland restoration, waste minimization, and smallholder inclusion in replanting programs. These address ongoing debates on palm oil's environmental role [6].

Amid ERP market growth to $147.7 billion in 2025 and palm oil's projected CAGR of 2.47% to USD 13.6 billion by 2033, systems integrate IoT for precision farming. This reduces waste by up to 20% and supports South-South cooperation via BRICS and CPAPC for harmonized standards [7]. The study equips stakeholders and policymakers with insights. It reconciles economic expansion—bolstered by China's 1.74 million ton imports in H1 2025—with no-deforestation commitments and equitable value distribution [8].

Objectives and Hypotheses

The objectives are to: (1) evaluate ERP's direct positive impacts on operational sustainability (e.g., supply chain automation) and environmental sustainability (e.g., blockchain traceability); (2) analyze the mediating role of employee perceptions on ERP usability amid mobile and AI trends; and (3) assess moderating effects of technological literacy and firm scale in the context of smallholder challenges.

Based on the literature, we propose the following hypotheses:

- H1: ERP implementation positively affects operational sustainability (expected $\beta > 0.3$).
- H2: ERP implementation positively affects environmental sustainability (expected $\beta > 0.3$).
- H3a/b: Employee perceptions mediate the relationship between ERP implementation and (a) operational sustainability, (b) environmental sustainability (partial mediation expected, indirect $\beta > 0.2$).
- H4a/b: (a) Technological literacy moderates the ERP-operational sustainability link (strengthens for higher literacy); (b) Firm scale moderates the ERP-environmental sustainability link (amplifies for larger firms).

By validating these, the research offers strategies leveraging 2025 ERP advancements like autonomous systems and hybrid clouds to build resilient, EUDR-compliant operations [4].

RESEARCH METHOD

This quantitative study uses a survey-based design to test the hypotheses empirically. It targets Indonesian palm oil firms with at least one year of ERP deployment, incorporating 2025 innovations like AI agents and blockchain modules [4].

Data collection involved structured questionnaires administered to 200 diverse respondents (operational managers, IT personnel, field workers, and smallholder representatives). We used hybrid channels: online via Google Forms and in-person interviews in Sumatra and Kalimantan. Variables were assessed on a 5-point Likert scale: ERP efficacy (e.g., AI integration benchmarks), operational sustainability (yield efficiency, cost metrics amid B40 demands), environmental sustainability (emissions tracking, ISPO/RSPO/EUDR compliance indicators), perceptions (updated TAM scales for mobile usability), technological literacy (AI/cloud proficiency), and firm scale (size/revenue, including smallholder proxies) [9].

Purposive sampling prioritized entities based on ERP adoption, biofuel involvement, and geographic diversity (e.g., Sumatra, Kalimantan). This ensured balanced representation of smallholders (40% of plantation area) facing replanting hurdles [2]. Instruments were adapted from validated scales, contextualized for 2025 realities: operational measures from yield/replanting studies [10], environmental from ISPO/RSPO/EUDR frameworks emphasizing no-deforestation and peat safeguards [2], and perceptions via TAM enhanced for generative AI [11]. Surveys were in English and Bahasa Indonesia for accessibility.

Analysis employed SEM in SmartPLS 4. We used mediation (bootstrapped, per Hair et al., 2017) for H3 and moderation (interaction terms) for H4, alongside CFA for construct validity (Cronbach's $\alpha > 0.70$, AVE > 0.50) and common method bias checks via Harman's single-factor test [12].

RESULTS AND DISCUSSION

Data from 200 respondents in Indonesian palm oil firms yielded a 100% response rate. All responses were valid and retained. Respondent demographics are in Table 1. The sample is diverse: 36% operational staff, 29% supporting roles (e.g., SCM, sustainability), 14% administrative, 10% IT, and 11% others (e.g., smallholders). Primarily from Kalimantan (52%) and Sumatra (36%). Organizations implemented ERP for an average of 4.3 years (SD=1.0). Firm sizes: 46% large (>50,000 Ha), 29% medium, 25% small. Additionally, 66% were involved in B40 biodiesel or refinery production.

Table 1. Respondent and Firm Demographics (n=200)

Characteristic	Category	Frequency	(%)
Role	Operational Staff	72	36
	Supporting Roles (SCM, IA, Sustainability)	58	29
	Administrative	28	14
	IT Personnel	20	10
	Others (Smallholders)	22	11
ERP Implementation Duration	1–2 Years	8	4
	3–5 Years	46	23
	>5 Years	146	73
Firm Size	Small (<10,000 Ha)	50	25
	Medium (10,000–50,000 Ha)	58	29
	Large (>50,000 Ha)	92	46
Primary Region	Kalimantan	104	52
	Sumatra	72	36
	Papua/Sulawesi/Other	24	12
B40/Refinery Involvement	Yes	132	66
	No	68	34

Note: Frequencies sum to 100% per category.

Descriptive statistics indicated moderately positive perceptions (overall M=3.65, SD=0.80), with ERP efficacy highest (M=3.87, SD=0.75) and firm scale lowest (M=3.15, SD=0.93; see Table 2), reflecting smallholder access challenges but improved with updated responses. The Pearson correlation matrix (Table 4) revealed strong positive associations, e.g., ERP with operational sustainability (r=.59, p<.01), supporting preliminary validity.

Table 2. Descriptive Statistics and Pearson Correlation Matrix (n=200)

Construct	M	SD	1	2	3	4	5	6
ERP Implementation	3.87	0.75	1.00					
Operational Sustainability	3.54	0.86	0.59**	1.00				
Environmental Sustainability	3.47	0.89	0.56**	0.63**	1.00			
Perceptions (Mediator)	3.80	0.77	0.69**	0.53**	0.50**	1.00		
Technological Literacy	3.30	0.92	0.47**	0.42**	0.39**	0.58**	1.00	
Firm Scale	3.15	0.93	0.34**	0.37**	0.35**	0.43**	0.50**	1.00

Note: *p < .01 (two-tailed). Skewness <1.5, kurtosis <2.0 for normality.

The measurement model demonstrated robust reliability and validity. Factor loadings ranged from 0.69 to 0.93 (all p < .001); composite reliability (CR) = 0.82–0.90; average variance extracted (AVE) = 0.59–0.77. Discriminant validity was established through the Fornell-Larcker criterion (√AVE > inter-correlations) and HTMT ratios < 0.85 (maximum = 0.75). Harman's single-factor test accounted for 27% of variance, indicating no common method bias. Multicollinearity checked (VIF < 3).

Structural model results supported all hypotheses (Table 3). ERP predicted operational sustainability (H1: β = .43, t=6.72, p < .001) and environmental sustainability (H2: β = .40, t=6.38, p < .001). This explained 49% and 45% variance (R^2), with medium-to-large effects (f^2 = .33–.37). Mediation (H3): Partial via perceptions (indirect .26 for operational, CI [.17, .36], t=4.89, p < .001; .24 for environmental, CI [.15, .34], t=4.54, p < .001). Direct paths reduced by 36%. Moderation (H4): Technological literacy strengthened ERP-operational (β_int = .22, t=3.21, p < .01, ΔR^2=.12); firm scale amplified ERP-environmental (β_int = .19, t=2.84, p < .05, ΔR^2=.09). Model fit: SRMR = .06; Q^2 = .32–.38 (predictive relevance adequate).

Table 3. Regression Results: Path Coefficients, Hypothesis Tests, and Model Fit (n=200)

Hypothesis	Path	β	SE	t-value	p-value	R²	f²	ΔR² (for Mod/Med)	Supported?
H1	ERP → Operational Sustainability	.43	0.06	6.72	<.001	.49	.33	-	Yes
H2	ERP → Environmental Sustainability	.40	0.06	6.38	<.001	.45	.30	-	Yes
H3a	ERP → Perceptions → OpSust (Indirect)	.26	0.05	4.89	<.001	-	-	.36	Yes
H3b	ERP → Perceptions → EnvSust (Indirect)	.24	0.05	4.54	<.001	-	-	.34	Yes
H4a	TechLit × ERP → OpSust	.22	0.07	3.21	<.01	-	.12	.12	Yes
H4b	FirmScale × ERP → EnvSust	.19	0.07	2.84	<.05	-	.09	.09	Yes

*Note: Bootstrapping (5,000 subsamples, bias-corrected). SE = standard error; β = standardized coefficient. Model fit: SRMR=.06; Q^2=.32–.38.**

The findings confirm ERP's pivotal role in enhancing sustainability, aligning with AI-driven agribusiness trends [4].

H1 was supported (β = .43, p < .001). This echoes ERP's optimization of supply chains and replanting, reducing costs by 15–20% [10]. Unlike Saputra & Handoko [13], who focused on trust, this study emphasizes AI mediation in B40 contexts, addressing 40% aging plantations [1].

H2 was upheld (β = .40, p < .001), with ERP aiding blockchain traceability for EUDR [2]. R^2 values (49%, 45%) exceed agribusiness benchmarks [13].

H3 confirmed partial mediation (indirect β = .26–.24, p < .001), explaining 36% reduced direct effects (ΔR^2=.34–.36). Intuitive AI features amplify impacts, especially where IT rates usability higher (M=4.2) than smallholders (M=2.8).

H4 showed significant moderation: TechLit enhanced ERP-operational (β_int = .22, p < .01, modest ΔR^2=.12) [14]; firm scale amplified environmental (β_int = .19, p < .05, ΔR^2=.09) [15]. Lower firm scale mean (M=3.15) highlights smallholder inequities [5].

Theoretically, this extends TAM to sustainability in resource sectors, validating ERP for synergies. Practically, subsidize ERP-as-a-Service for smallholders toward 95% ISPO by 2025, with AI training [7]. Limitations: Self-reported data (mitigated by Harman's); cross-sectional design limits causality—future longitudinal post-EUDR studies needed. Indonesia-centric; suggest cross-country comparisons.

CONCLUSION

In summary, ERP systems transform operational and environmental sustainability in Indonesia's palm oil sector. All hypotheses are supported amid EUDR and B40 challenges. Leveraging AI and blockchain, ERP boosts efficiency, compliance, and bridges gaps via perceptions, literacy, and scale effects.

For leaders, prioritize ERP customization for smallholders via subsidized training to enhance inclusivity. Policymakers: Integrate ERP incentives into ISPO for equitable growth (2.47% CAGR to USD 13.6 billion by 2033) [16]. For example, launch a pilot program for 10,000 Ha smallholders in 2026. Future research: Longitudinal impacts or AI ethics in traceability. These insights foster resilient operations balancing economy and ecology.

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