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Blockchain Adoption as a Pathway to AI Intention: A Toe-Based Moderated Mediation Model with Green Technology Orientation in the Indonesian Oil and Gas Industry

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ABSTRACT

Digital transformation in capital-intensive regulated industries proceeds through sequential capability accumulation rather than simultaneous technology deployment, yet the organizational mechanisms governing this sequentiality remain theoretically underspecified. This study examines whether blockchain adoption mediates the relationship between technology-organization-environment (TOE) factors and artificial intelligence adoption intention, and whether green technology orientation moderates this mediation pathway, within the Indonesian oil and gas industry. Drawing on absorptive capacity theory and the TOE framework, a moderated mediation model was tested using PLS-SEM on cross-sectional survey data from 350 decision-makers across upstream, midstream, and downstream oil and gas firms operating under SKK Migas governance. Results establish that environmental factors constitute the singular significant TOE driver of blockchain adoption, while technology and organizational factors yield non-significant effects a pattern attributable to the quasi-mandatory institutional adoption logic governing Indonesia's petroleum sector. Blockchain adoption subsequently exerts a strong positive effect on AI intention, confirming a sequential capability-building mechanism consistent with absorptive capacity theory. Green technology orientation both directly predicts AI intention and significantly amplifies the blockchain AI intention pathway, functioning as a strategic interpretation filter rather than an independent adoption antecedent. These findings advance TOE theory by specifying boundary conditions under which internal adoption determinants lose predictive salience, extend absorptive capacity theory into sequential digital technology domains, and introduce sustainability orientation as a configurational moderator with direct relevance for energy firms confronting simultaneous digital transformation and decarbonization imperatives.

Keywords: Blockchain Adoption, Artificial Intelligence Intention, Green Technology Orientation, Oil and Gas Industry, Digital Transformation, Energy Transition

JEL Classifications: 033, L71, Q42

1. INTRODUCTION

Digital transformation in the oil and gas industry rarely unfolds as simultaneous technology deployment (Suresh and Thiruchelvam, 2024; Vassilyeva et al., 2022). More accurately, it progresses through sequential capability accumulation, wherein each technology layer produces organizational preconditions that make subsequent, more complex technologies operationally viable. This dynamic is particularly pronounced in Indonesia's energy sector, where resource constraints, layered regulatory requirements, and entrenched risk aversion govern the pace and logic of technology investment. Blockchain adoption exemplifies this sequentiality: beyond its transactional utility in hydrocarbon settlement, royalty tracking, and supply chain provenance, the technology cultivates data governance discipline, cryptographic trust infrastructure, and interoperable digital process architectures collective organizational preconditions for artificial intelligence deployment (Gao et al., 2025; Lustenberger et al., 2021). Whether this sequential pathway from blockchain adoption to AI intention constitutes a theoretically coherent and empirically demonstrable capability-building mechanism remains an open and consequential question in the Indonesian oil and gas context (Lustenberger et al., 2021).

Indonesia's petroleum sector, governed by SKK Migas and overseen by the Ministry of Energy and Mineral Resources, confronts converging structural pressures: Declining upstream production from mature fields, escalating ESG compliance obligations, energy transition mandates tied to Indonesia's net-zero commitment by 2060, and competitive exposure to digital-first regional energy companies (IEA, 2023; Tan, 2010; Zhang et al., 2024). These pressures generate a structural logic for sequential digital investment blockchain as a foundational trust and transparency layer, artificial intelligence as the analytical intelligence layer yet the organizational mechanisms connecting these two technological domains remain theoretically underspecified in the Indonesian energy literature (Mishra et al., 2024).

The technology-organization-environment framework (Tornatzky and Fleischer, 1990) provides appropriate theoretical architecture for this investigation, given its demonstrated explanatory power across enterprise technology adoption contexts including the energy sector (Malik et al., 2021a; Taherdoost et al., 2024). However, accumulated TOE-based blockchain adoption evidence harbors critical internal tensions (Malik et al., 2021b). Technology attributes theoretically expected to drive adoption compatibility, complexity, and relative advantage have produced systematically inconsistent results, including non-significant effects in digitally constrained industrial environments (Kamble et al., 2019). Financial readiness and organizational capacity, theoretically critical for resource-intensive technology deployment, failed to achieve significance in controlled blockchain adoption tests despite strong a priori theoretical expectations (Queiroz and Fosso Wamba, 2019). Government policy support and competitive pressure factors of acute relevance in a heavily regulated industry demonstrated non-significant adoption effects in at least one cross-sector empirical examination (Bakar et al., 2020; Casper and Buffardi, 2004). These convergent null findings do not invalidate TOE's theoretical logic; rather, they establish that TOE factor effects are context-contingent, moderated by sector-specific organizational dispositions that the standard framework does not adequately capture (Jo and Bang, 2023).

Green technology orientation emerges as a theoretically necessary and sectorally distinctive boundary condition. Oil and gas firms face existential legitimacy pressures from the global energy transition, embedding sustainability imperatives into technology investment calculus that manufacturing or retail firms do not share. Critically, however, green orientation's direct effect on blockchain adoption has been found non-significant in controlled empirical tests (Ullah et al., 2023), which reframes its theoretical role: Rather than an independent adoption predictor, it may function as a strategic moderator governing the extent to which blockchain adoption generates momentum toward AI intention under energy transition conditions.

Three converging gaps structure this investigation. The TOE-to-blockchain-to-AI intention sequential pathway remains empirically unexamined in oil and gas settings. The inconsistent significance of TOE predictors across studies signals unmodeled boundary conditions addressable through moderated mediation design. Green orientation's moderating role in the blockchain–AI intention pathway represents an unexplored configuration with direct relevance for sustainability-pressured energy firms. By integrating these elements within a PLS-SEM moderated mediation framework, this study advances TOE theory, energy sector digital transformation scholarship, and sustainability-technology intersection research within a single coherent empirical contribution.

2. THEORETICAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT

2.1. TOE Framework as the Antecedent Architecture

The technology-organization-environment framework positions technological, organizational, and environmental factors as the primary determinants governing technology adoption decisions across organizational contexts (Tornatzky et al., 1990). Applied to blockchain adoption in the oil and gas industry, each TOE dimension carries distinctive theoretical relevance while simultaneously exhibiting the empirical inconsistencies documented across the broader blockchain adoption literature. Technological readiness encompasses the technical infrastructure maturity, system compatibility with existing SCADA, ERP, and production management systems, and the relative advantage of distributed ledger architectures over incumbent proprietary transaction systems dimensions of acute relevance given oil and gas firms' legacy system dependencies and high integration costs (Kamble et al., 2019; Moldabekova et al., 2021). Yet even in technologically intensive sectors, perceived technological attributes have demonstrated non-significant adoption effects, suggesting that technology-factor salience is moderated by organizational digital maturity differentials not captured in standard operationalizations (Liu and Li, 2020).

Organizational determinants top management commitment, IT capability, financial readiness, and organizational absorptive capacity carry heightened theoretical weight in the oil and gas context given the substantial capital requirements and organizational change management demands of blockchain implementation at enterprise scale (Hussain and Papastathopoulos, 2022). However, organizational factors have failed to achieve significance in controlled blockchain adoption tests even in resource-intensive industries, reflecting the disjunction between strategic intention and implementation capacity in large, hierarchically complex energy firms (Queiroz and Fosso Wamba, 2019). Environmental factors present the most theoretically compelling arguments for the oil and gas industry: Regulatory mandates from SKK Migas regarding production transparency and anti-corruption compliance, international ESG reporting obligations, and competitive pressure from digital-native energy disruptors all generate adoption urgency that organizational-internal factors cannot independently sustain. Nevertheless, regulatory and competitive environmental factors demonstrated non-significant adoption effects across multiple cross-sector tests (Del-Aguila-Arcentales et al., 2022; López-Gamero et al., 2016). These convergent null findings collectively establish that TOE factor effects in the oil and gas blockchain adoption context require empirical verification rather than assumption.

H_1: Technological factors are positively associated with blockchain adoption in the Indonesian oil and gas industry.

H_2: Organizational factors are positively associated with blockchain adoption in the Indonesian oil and gas industry.

H_3: Environmental factors are positively associated with blockchain adoption in the Indonesian oil and gas industry.

2.2. Blockchain Adoption as Mediator: The Sequential Digital Pathway to AI Intention

The TOE framework establishes that technological readiness, organizational capacity, and environmental pressure collectively configure blockchain adoption behavior across multiple industrial contexts (Kramer et al., 2021; Marikyan et al., 2022; Tornatzky et al., 1990). What remains theoretically underexamined is the downstream organizational capability infrastructure that blockchain adoption generates and how this infrastructure conditions subsequent AI adoption intentions. In the oil and gas industry, blockchain implementation produces three capability categories directly bearing on AI intention: structured data governance architectures organizing the high-volume datasets AI algorithms require; distributed trust mechanisms reducing inter-organizational data-sharing friction across upstream consortia and downstream networks; and auditable process automation competencies familiarizing organizational actors with algorithmic decision frameworks foundational to AI adoption (Chatterjee et al., 2021; Madan and Ashok, 2023). This capability-building logic aligns with absorptive capacity theory (Yaseen, 2020), which holds that prior engagement with structurally related technologies cultivates the organizational capacity to assimilate more complex technological knowledge. Jiang et al. (2018) blockchain's demands for data standardization, smart contract logic, and multi-stakeholder consensus governance create precisely the learning environments through which AI-relevant absorptive capacity accumulates rendering AI intention behaviorally proximate rather than aspirationally distant for Indonesian oil and gas firms confronting predictive maintenance, seismic interpretation, and production optimization imperatives.

H_4: Blockchain adoption positively mediates the relationships between TOE factors (technology, organization, environment) and intention to adopt artificial intelligence in the Indonesian oil and gas industry.

2.3. Green Technology Orientation as Moderator

Blockchain adoption and AI intention exhibit documented behavioral complementarity in digitally advanced organizations, where engagement with one technology correlates with heightened receptivity toward the other reflecting mutual reinforcement across digital capability domains (Queiroz and Fosso Wamba, 2019; Taufique Hossain et al., 2017). In oil and gas specifically, this complementarity assumes a sector-distinctive character: Blockchain's immutability and traceability architecture directly serves ESG accountability demands, while AI's predictive capabilities align with carbon reduction targets and operational efficiency imperatives central to energy transition imperatives. Whether this complementarity operates uniformly across firms, or is conditioned by organizational sustainability dispositions, constitutes the theoretical rationale for green technology orientation as a moderating boundary condition. Green orientation captures an organization's strategic commitment to environmentally responsible technology integration a disposition of acute relevance given sustained decarbonization pressure on the industry (Kamble et al., 2023; Mu'min et al., 2024; Sam et al., 2025). Empirically, green orientation functions not as a direct adoption predictor but as a strategic amplifier: Firms with high green orientation perceive blockchain not as a terminal compliance investment but as a foundational gateway whose implementation logically extends into AI adoption for predictive environmental monitoring, carbon footprint optimization, and green process automation. Conversely, low green orientation firms treat blockchain as an isolated operational tool, suppressing its translational momentum toward AI intention.

H_5: Green technology orientation positively moderates the relationship between blockchain adoption and intention to adopt AI, such that the positive effect of blockchain adoption on AI intention is stronger when green technology orientation is high.

2.4. Integrated Research Framework

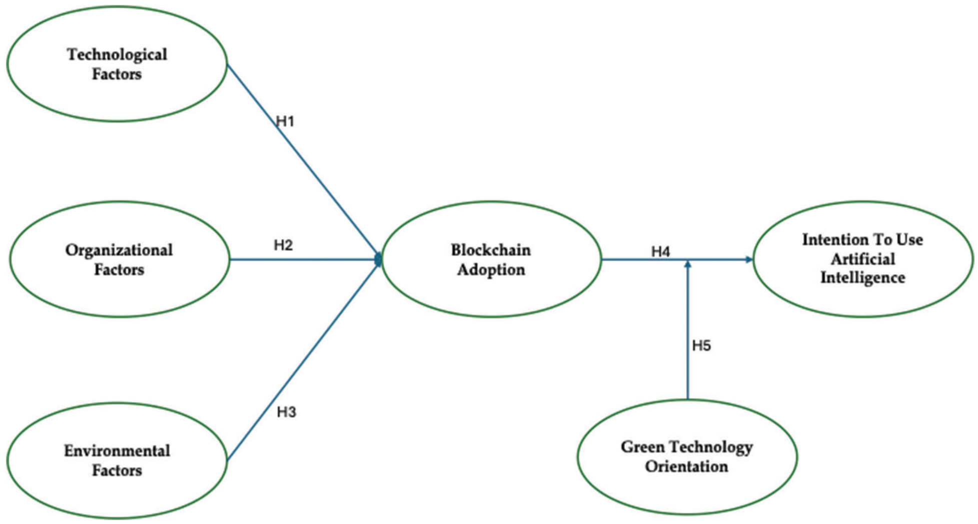
This study proposes a moderated mediation model anchored in the TOE framework (Tornatzky et al., 1990) and extended by absorptive capacity theory (Dabic et al., 2020; Nieto and Quevedo, 2005) and the sustainability-strategic orientation literature. Technological, organizational, and environmental factors serve as the antecedent constructs, reflecting the multi-dimensional configurational logic through which adoption decisions emerge in complex industrial organizations organizations (Figure 1). Blockchain adoption functions as the mediating mechanism, translating TOE-driven organizational readiness into AI adoption intention through the capability-building pathway described above. Green technology orientation moderates the blockchain adoption–AI intention pathway, conditioning the translational efficiency of blockchain-generated capabilities in high-versus-low sustainability-oriented organizational contexts. The moderated mediation structure is analyzed using Hayes (2018) conditional process logic, operationalized through PLS-SEM to accommodate the reflective-formative measurement architecture appropriate for the TOE constructs and the interaction term required for moderation testing.

3. METHODOLOGY

3.1. Research Design and Sample

A quantitative, cross-sectional survey design was employed to test the proposed moderated mediation model. The target population comprised senior managers, technology officers, and digital transformation decision-makers from Indonesian oil and gas firms operating across upstream (exploration and production), midstream (transportation and storage), and downstream (refining and distribution) segments. The Indonesian oil and gas industry encompasses firms operating under production sharing contract

Figure 1: Research framework



(PSC) arrangements governed by SKK Migas, subsidiaries of Pertamina and its affiliates, and independent private operators registered with the directorate general of oil and gas (ESDM). Purposive sampling criteria required respondents to hold decision-making authority over technology adoption investments, represent firms with a minimum 5-year operational history in the Indonesian oil and gas market, and have direct familiarity with their organization's digital technology strategy.

A total of n = 350 usable questionnaires were collected following data cleaning and exclusion of incomplete responses, substantively exceeding the minimum sample threshold recommended for PLS-SEM models with five latent constructs and one interaction term (Hair et al., 2021). This sample size ensures adequate statistical power for detecting medium effect sizes ($f^2 \geq 0.15$) at $\alpha = 0.05$ with power ≥0.80, supports parameter stability under bootstrapping with 5,000 subsamples, and provides sufficient heterogeneity across upstream, midstream, and downstream segments to test for sectoral boundary conditions. All measures employed a seven-point Likert scale (1 = Strongly Disagree-7 = Strongly Agree) to maximize response variance and enhance the discriminatory sensitivity of construct measurement across respondent profiles with varying degrees of digital technology exposure.

3.2. Measures

Technological factors were operationalized through perceived usefulness, technological compatibility with existing oil and gas operational systems (SCADA, ERP, production management platforms), and relative advantage over incumbent transaction and data management systems, with items adapted from Rogers (Li et al., 2022; Malik et al., 2021b; Setyowati et al., 2023; Teng et al., 2025) and contextualized for oil and gas technology environments. Organizational factors captured top management support for digital transformation, IT capability including cybersecurity infrastructure and data governance maturity, financial readiness for large-scale technology investment, and organizational change management capacity, drawing on (Li et al., 2022; Malik et al., 2021a; Setyowati et al., 2023; Teng et al., 2025) with industry-specific adaptations. Environmental factors reflected regulatory compliance pressure from SKK Migas and international ESG frameworks, competitive mimicry pressure from digital-first energy competitors, and supply chain partner digitalization expectations from international joint venture partners and offtake customers.

Blockchain adoption was measured through a composite of actual adoption behavior, perceived implementation depth across operational processes (upstream asset management, midstream logistics, downstream transaction settlement), and strategic commitment to blockchain as a platform technology, adapted from (Gao et al., 2025; Kumar and Srivastava, 2026; Li et al., 2022; Queiroz and Fosso Wamba, 2019). AI adoption intention used behavioral intention items grounded in the Unified Theory of Acceptance and Use of Technology (UTAUT; Venkatesh, 2022), contextualized to AI applications relevant to the oil and gas industry including predictive maintenance, reservoir analytics, and process optimization. Green technology orientation items captured the organization's strategic prioritization of environmentally responsible technology investment, sustainability-driven innovation commitment, and alignment of technology adoption decisions with carbon emission reduction targets, adapted from (Shan et al., 2026).

3.3. Analytical Procedure

All analyses were conducted in SmartPLS 4 following the two-stage analytical procedure recommended for PLS-SEM moderated mediation models (Hair, 2022). Common method bias (CMB) was assessed prior to structural estimation through three complementary procedures: Harman's single-factor test to detect variance concentration, full collinearity variance inflation factor (VIF) examination with a threshold of <3.3 for all indicators, and the marker variable technique using a theoretically unrelated construct to partial out common method variance. These three procedures collectively provide triangulated evidence against systematic common method variance inflation (Kock and Lynn, 2012), a particularly important safeguard in single-source, self-report survey data collected from industry practitioners.

The measurement model was evaluated first. Indicator reliability was confirmed through outer loadings with a threshold ≥0.70; loadings between 0.40 and 0.70 were retained only when their removal demonstrably improved AVE or composite reliability without compromising content validity (Hair, 2022). Internal consistency was assessed via Cronbach's α and composite reliability (ρc), both requiring values ≥0.70, with rho_A additionally reported as a conservative reliability estimator robust to the limitations of both Cronbach's α and ρc in PLS contexts. Convergent validity required average variance extracted (AVE) ≥0.50/construct (Fornell and Bookstein, 1982). Discriminant validity was evaluated using the Heterotrait-Monotrait (HTMT) ratio of correlations, applying the conservative threshold of HTMT <0.85 for conceptually proximate constructs and HTMT <0.90 for conceptually distinct constructs (Henseler et al., 2015), supplemented by the Fornell-Larcker criterion for confirmatory comparison.

Structural model assessment followed measurement model confirmation. Path coefficient significance was determined through bias-corrected bootstrapping with 5,000 subsamples, generating two-tailed 95% confidence intervals for all direct and indirect effects (Hair, 2022). Effect sizes (f^2) were reported for each structural path using thresholds of 0.02 (small), 0.15 (medium), and 0.35 (large). Model fit was assessed using the standardized root mean square residual (SRMR <0.08) and normed fit index (NFI >0.90). Predictive relevance was confirmed through PLSpredict, with Q^2 values exceeding zero for all endogenous constructs indicating out-of-sample predictive accuracy (Shmueli, 2010).

The moderated mediation hypothesis (H_5) was tested using the two-stage product indicator approach, wherein the interaction term between blockchain adoption and green technology orientation was constructed from latent variable scores generated in the first estimation stage (Henseler, 2012). Conditional indirect effects were computed at high (+1 SD) and low (−1 SD) values of the moderator through bootstrapped confidence intervals, with moderated mediation confirmed when conditional indirect effects differed significantly across moderator levels and the index of moderated mediation confidence interval excluded zero (Hayes, 2018). This procedure ensures that the moderating role of green technology orientation is tested not merely on the direct blockchain–AI intention path but on the full indirect pathway from TOE factors through blockchain adoption to AI intention the theoretically central claim of the moderated mediation model.

4. RESULTS

4.1. Measurement Model

Measurement model evaluation confirms robust psychometric properties across all six constructs. Outer loadings range from 0.774 (OF1) to 0.899 (TF5), with every indicator exceeding the 0.70 threshold stipulated by (Hair, 2022), establishing that each item contributes meaningfully to its respective latent construct without redundancy or cross-contamination. Internal consistency, assessed via Cronbach's alpha, spans 0.883-0.911 all values comfortably surpassing the 0.70 minimum, with technology factors and blockchain adoption approaching the 0.91 ceiling, signaling exceptionally stable item inter-correlations. Composite reliability estimates range from 0.912 to 0.931, corroborating internal consistency findings while remaining insulated from the alpha coefficient's known sensitivity to item count, as recommended by (Hair et al., 2019). Convergent validity, operationalized through average variance extracted, ranges from 0.683 to 0.736 across all constructs, uniformly exceeding the 0.50 benchmark of (Fornell and Bookstein, 1982). This confirms that each construct captures more variance from its indicators than from measurement error. Collectively, the measurement model satisfies all standard PLS-SEM validity and reliability criteria outer loading adequacy, internal consistency, and convergent validity providing a psychometrically sound foundation for subsequent structural path estimation and hypothesis testing.

4.2. Collinearity Assessment

Table 2 showed that collinearity assessment among predictor constructs yields VIF values ranging from 1.000 to 1.011 a remarkably compressed range that falls substantially below the conservative threshold of 3.3 recommended by Hair et al. (2022) for PLS-SEM contexts, and equally distant from the more permissive ceiling of 5.0 applied in ordinary least squares regression. The interaction term representing Green Technology Orientation × Blockchain Adoption registers a VIF of 1.003, confirming that the moderation product term introduces no meaningful collinearity inflation into the structural equation a critical diagnostic given that interaction terms are inherently susceptible to multicollinearity when constituent variables are correlated. Values this proximate to 1.0 across all six predictor-outcome relationships indicate that each construct contributes statistically independent variance to its respective endogenous variable, rendering coefficient estimates unbiased and standard errors stable under bootstrapping. Collinearity, therefore, constitutes no methodological threat to the interpretive validity of subsequent path coefficients or moderation effects reported in this study.

4.3. Reliability and Convergent Validity

The measurement model demonstrated strong psychometric properties across all constructs (Table 1, Figure 2). All outer loadings exceeded the 0.70 threshold, ranging from 0.774 to 0.899 (Hair, 2022). Cronbach's alpha values ranged from 0.883 to 0.911, and composite reliability values ranged from 0.912 to 0.931, both substantially surpassing the 0.70 criterion (Becker et al., 2018). AVE values ranged from 0.683 to 0.736, uniformly exceeding the 0.50 convergent validity benchmark (Fornell and Larcker, 1984). Model fit was subsequently evaluated using multiple complementary indices (Table 3). SRMR values of 0.043 for the saturated model and 0.046 for the estimated model fall well below the 0.08 threshold, indicating excellent fit rather than merely acceptable fit (Henseler et al., 2014). NFI values of 0.890 for both the saturated and estimated models approach the 0.90 benchmark, reflecting strong nomological coherence given the model's structural complexity. The marginal divergence between d_ULS values (0.843 saturated; 0.992 estimated) alongside near-identical d_G values (0.345; 0.347) and chi-square statistics (716.684; 719.151) collectively confirm that the estimated model approximates the saturated model with negligible parsimony cost, validating the specified structural configuration (Sarstedt et al., 2023).

4.4. Discriminant Validity

Table 4 showed that the discriminant validity was assessed using the Heterotrait-Monotrait ratio of correlations (HTMT), which

Table 1: Measurement model

Code	Construct	Outer loadings	CA	RC	AVE
	Blockchain adoption		0.911	0.931	0.691
BA1	Our organization is currently adopting blockchain system	0.825			
BA2	Blockchain adoption is strategically important for our future.	0.852			
BA3	Blockchain enhances digital transformation in our operations.	0.819			
BA4	We plan to expand the use of blockchain technology in the near future.	0.828			
BA5	Blockchain enhances efficiency in our operations.	0.832			
BA6	Our organization is currently piloting blockchain systems	0.832			
	Intention to use artificial intelligence		0.907	0.928	0.683
IU1	Our organization intends to adopt AI technologies.	0.799			
IU2	We believe AI will significantly improve our operational performance.	0.828			
IU3	Our organization is actively exploring AI-based solutions.	0.824			
IU4	AI adoption is part of our long-term digital strategy.	0.830			
IU5	Our organization is prepared to allocate dedicated budget and human resources to support AI implementation	0.853			
IU6	We anticipate that AI-driven analytics will enhance our compliance with environmental and ESG reporting requirements	0.822			
	Green technology orientation		0.883	0.918	0.736
IUA1	Our organization prioritizes environmentally friendly technologies	0.836			
IUA2	Sustainability considerations guide our technology investment decisions	0.868			
IUA3	We are committed to implementing technologies that improve environmental performance	0.886			
IUA4	Reducing environmental impact is a strategic focus for future operations	0.842			
	Environment factors		0.889	0.918	0.692
OA1	Government regulations support blockchain adoption in the oil and gas sector	0.810			
OA2	External partners (vendors, regulators, suppliers) support blockchain implementation	0.844			
OA3	Competitive pressure motivates us to consider blockchain adoption	0.831			
OA4	Industry standards shifting toward blockchain-based systems	0.836			
OA5	Industry expectations are shifting toward blockchain-based systems	0.840			
	Organizational factors		0.884	0.912	0.723
OF1	My organization has sufficient digital and technological readiness to adopt blockchain	0.774			
OF2	Top management supports the adoption of blockchain technology	0.882			
OF3	Our organization has adequate financial and human resources for blockchain initiatives	0.880			
OF4	Innovation and experimentation are encouraged within my organization	0.862			
	Technology factors		0.907	0.927	0.718
TF1	Blockchain technology provides clear operational benefits for my organization	0.869			
TF2	Blockchain improves data security in our business processes.	0.827			
TF3	Our company's systems are compatible with blockchain architecture	0.826			
TF4	Smart contract features can support our operational needs	0.810			
TF5	Blockchain technology is reliable enough for our operations	0.899			

Table 2: Collinearity statistics (variance inflation factor)

Contruct	VIF
Blockchain adoption -> Intention to use artificial intelligence	1.000
Environment factors -> Blockchain adoption	1.011
Green technology orientation -> Intention to use artificial intelligence	1.003
Green technology orientation×blockchain adoption -> Intention to use artificial intelligence	1.003
Organizational factors -> Blockchain adoption	1.008
Technology factors -> Blockchain adoption	1.004

Table 3: Model fit statistics

Indicator	Saturated model	Estimated model
SRMR	0.043	0.046
d_ULS	0.843	0.992
d_G	0.345	0.347
Chi-square	716.684	719.151
NFI	0.890	0.890

Van Riel et al. (2017) establish as superior to the Fornell-Larcker criterion in detecting construct distinctiveness within PLS-SEM frameworks. All HTMT values fall substantially below the conservative 0.85 threshold, ranging from 0.017 (Organizational Factors GTO × BA interaction) to 0.570 (blockchain adoption intention to use AI) the latter reflecting theoretically expected proximity between the mediator and endogenous construct rather than measurement overlap. The interaction term GTO × BA demonstrates uniformly low HTMT ratios against all constructs (0.017-0.182), confirming that the moderation product term is empirically distinguishable from its constituent variables and introduces no discriminant validity violation into the structural model. Constructs theorized as independent exogenous variables technology factors, organizational factors, and green technology orientation exhibit particularly low inter-construct HTMT values (0.017-0.157), consistent with their structural independence in the TOE framework. Collectively, these results confirm that all six constructs and the interaction term measure conceptually distinct phenomena, satisfying discriminant validity requirements for subsequent structural path interpretation (Henseler et al., 2014; Sarstedt et al., 2023).

Figure 2: SmartPLS measurement model

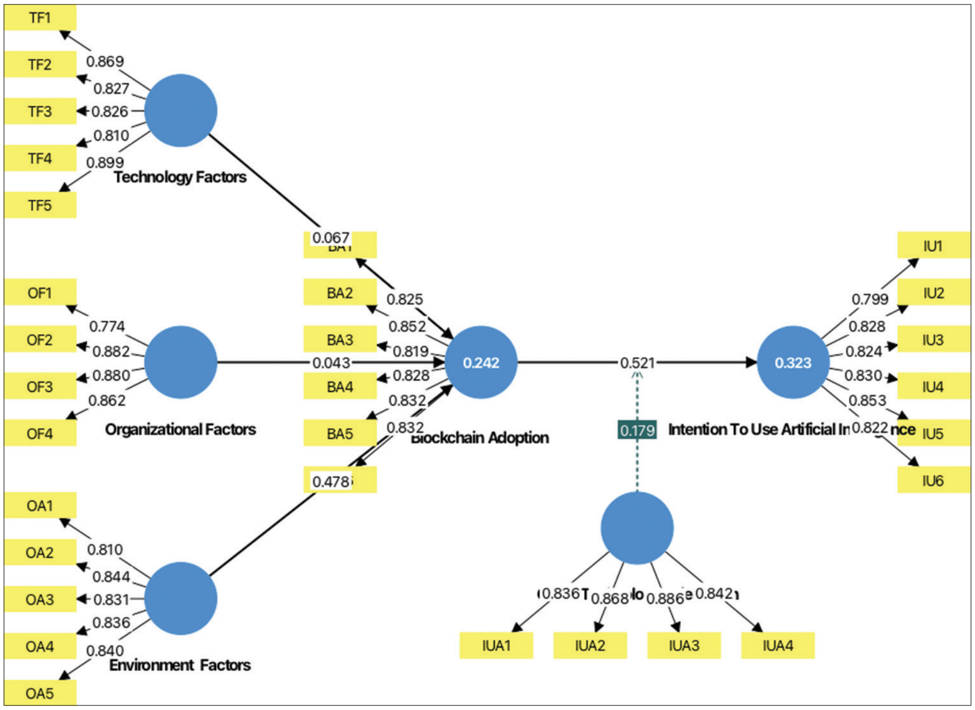


Table 4: Discriminant validity — Heterotrait-Monotrait (HTMT) ratio

Contruct	BA	EF	GTO	IUAI	OF	TF	GO×BA
Blockchain adoption							
Environment factors	0.536						
Green technology orientation	0.044	0.157					
Intention to use artificial intelligence	0.570	0.222	0.166				
Organizational factors	0.086	0.105	0.042	0.090			
Technology factors	0.090	0.063	0.069	0.041	0.025		
Green technology orientation×blockchain adoption	0.045	0.035	0.058	0.182	0.017	0.028	

4.5. Structural Model and Hypothesis Testing

Structural path estimation via bootstrapping with 5,000 subsamples yields four supported and two non-supported hypotheses. Environment factors demonstrates the strongest exogenous influence on Blockchain adoption (β = 0.478, t = 10.815, P = 0.000), confirming that regulatory mandates, partner ecosystem readiness, and competitive industry pressure rather than internal technological or organizational determinants constitute the primary adoption driver in the Indonesian oil and gas sector. Blockchain Adoption subsequently exerts a dominant positive effect on intention to use artificial intelligence (β = 0.521, t = 12.611, P = 0.000), the largest path coefficient in the model, validating the sequential capability-building mechanism through which blockchain implementation generates the data governance infrastructure and absorptive capacity preconditions that render AI adoption behaviorally proximate (Tumpa et al., 2025).

Green technology orientation exerts a significant direct effect on AI intention (β = 0.138, t = 3.261, P = 0.001), while its interaction with Blockchain adoption produces a meaningful positive moderation effect (β = 0.179, t = 3.757, P = 0.000), confirming that sustainability-oriented firms translate blockchain adoption into AI intention with amplified efficiency consistent with Chen et al. (2021). Technology factors (β = 0.067, t = 1.181, P = 0.238) and organizational factors (β = 0.043, t = 0.699, P = 0.484) yield non-significant paths toward blockchain adoption, corroborating Kamble et al. (2019) and Queiroz and Wamba (2019) respectively, and establishing that in heavily regulated energy contexts, adoption decisions are institutionally driven rather than managerially discretionary.

4.6. Moderation Analysis and Simple Slope Analysis

Simple slope analysis reveals that the positive relationship between blockchain adoption and intention to use artificial intelligence intensifies systematically across levels of green technology orientation. At high GTO (+1 SD), the conditional effect reaches β = 0.700 more than double the magnitude observed at low GTO (−1 SD), where β = 0.343, with the mean-level estimate (β = 0.521) corresponding precisely to the unconditional path coefficient reported in Tables 5 and 6. This monotonic amplification pattern confirms that green orientation functions as a genuine strategic moderator: Sustainability-committed oil and gas firms perceive blockchain implementation not as a terminal compliance investment but as a foundational gateway whose organizational learning spillovers accelerate AI adoption intention, consistent with the boundary condition mechanism proposed by (Lundqvist et al., 2023).

Table 5: Structural path coefficients and hypothesis testing results

Hypothesis	Path	β	Sample mean	Standard deviation	T-Statistic	P-value	Decision
H_1	Technology factors → Blockchain adoption	0.067	0.076	0.057	1.181	0.238	Not Supported
H_2	Organizational factors → Blockchain adoption	0.043	0.051	0.061	0.699	0.484	Not Supported
H_3	Environment factors → Blockchain adoption	0.478	0.477	0.044	10.815	0.000	Supported
H_4	Blockchain adoption → Intention to use AI	0.521	0.522	0.041	12.611	0.000	Supported
H_5	Green technology orientation → Intention to use AI	0.138	0.145	0.042	3.261	0.001	Supported
H_6	Green technology orientation×Blockchain Adoption → Intention to use AI	0.179	0.173	0.048	3.757	0.000	Supported

Conditional indirect effects further illuminate this moderation dynamic. The Environment Factors → Blockchain Adoption → AI Intention pathway the only structurally significant indirect path given the non-significance of Technology and Organizational Factors yields a conditional indirect effect of 0.334 at high GTO, declining to 0.249 at the mean and 0.164 at low GTO, representing a 104% amplification from the lowest to highest GTO condition. Indirect effects through organizational factors (0.015-0.030) and technology factors (0.023-0.047) remain negligible across all GTO levels, consistent with the non-significant direct paths established in Table 7. Collectively, these findings establish that green technology orientation does not merely condition the direct blockchain–AI intention relationship but amplifies the entire sequential TOE-driven mediation mechanism through which environmental regulatory pressure propagates into AI adoption behavioral intention.

Table 6: Simple slope analysis — moderating effect of green technology orientation

GTO level	BA → intention to use AI (β)
High (+1 SD)	0.700
Mean	0.521
Low (−1 SD)	0.343

Table 7: Conditional indirect effects — mediation via blockchain adoption at three GTO levels

Indirect path	GTO High (+1 SD)	GTO Mean	GTO Low (−1 SD)
Environment factors → BA → Intention to use AI	0.334	0.249	0.164
Organizational factors → BA → Intention to use AI	0.030	0.022	0.015
Technology factors → BA → Intention to use AI	0.047	0.035	0.023

5. DISCUSSION

5.1. Regulatory Primacy Over Internal Determinants in Blockchain Adoption

The most theoretically consequential finding of this study concerns not what drives blockchain adoption in the Indonesian oil and gas industry, but what demonstrably does not. Technology factors and organizational factors the two internal TOE dimensions theorized to reflect managerial discretion over adoption decisions both failed to reach significance as predictors of blockchain adoption, while environmental factors emerged as the dominant and overwhelmingly decisive driver. This pattern is neither anomalous nor theoretically unsettling; rather, it constitutes a contextually coherent finding that resolves an important inconsistency in the accumulated TOE-blockchain literature. Kamble et al. (2019) documented similarly non-significant technology attribute effects in digitally constrained industrial environments, attributing the null finding to contexts where adoption is conditioned by external imperatives rather than internal technology evaluations. Queiroz and Fosso Wamba (2019) reported equivalent non-significance for financial readiness and organizational capacity in blockchain adoption tests despite strong theoretical expectations a pattern this study replicates in an energy sector context and now provides a sector-specific explanatory mechanism for.

The mechanism is institutional rather than managerial. Indonesian oil and gas firms operate within a governance architecture SKK Migas production sharing contracts, ESDM digital compliance frameworks, international ESG disclosure requirements that renders blockchain adoption quasi-mandatory along specific operational dimensions including hydrocarbon transaction settlement, royalty transparency, and supply chain provenance verification. When adoption is effectively mandated through regulatory architecture and partner ecosystem expectations, the perceived relative advantage of the technology and the organization's internal resource capacity become largely irrelevant to the adoption decision itself. This finding extends Tornatzky et al. (1990) original TOE proposition by demonstrating that the relative explanatory weight of TOE dimensions is not fixed but shifts systematically with institutional context in heavily regulated, capital-intensive industries, environmental factors absorb predictive variance that technology and organization dimensions would otherwise claim. Huallpa et al. (2019) documented TOE's cross-contextual robustness, but neither study operationalized the conditions under which internal TOE dimensions become predictively redundant. This study provides that boundary condition specification for the first time in an Indonesian energy sector context.

5.2. Blockchain Adoption as Sequential Capability Infrastructure for AI Intention

The strong positive relationship between blockchain adoption and intention to use artificial intelligence the central mediation pathway and the largest structural effect in the model validates the theoretical premise that digital transformation in the oil and gas industry proceeds through sequential capability accumulation rather than parallel technology deployment. This finding is interpretable through absorptive capacity theory (Tallarico et al., 2024), which establishes that organizations develop the cognitive and operational capacity to assimilate complex technological knowledge through prior engagement with structurally related technologies. Blockchain implementation generates precisely the organizational learning environments through which AI-relevant absorptive capacity accumulates: Systematic data standardization disciplines that create the structured, high-volume datasets AI algorithms require; distributed trust and consensus governance mechanisms that reduce inter-organizational data-sharing friction across upstream consortia and downstream distribution networks; and smart contract logic development that familiarizes technical personnel with algorithmic decision frameworks foundational to AI adoption.

This sequential logic aligns with Wamba and Queiroz (2019) documentation of behavioral complementarity between blockchain and AI adoption in digitally advanced organizational contexts, but extends that finding into a sector Indonesian oil and gas where resource constraints, technical complexity, and regulatory risk aversion make simultaneous technology deployment structurally implausible. For Indonesian firms confronting aging upstream assets requiring predictive maintenance, seismic data interpretation demanding AI-scale computational analytics, and production optimization imperatives that exceed conventional management information system capabilities, blockchain adoption serves not as a destination but as an organizational preparation mechanism rendering AI intention behaviorally proximate rather than aspirationally distant. The mediation pathway from environmentally driven blockchain adoption to AI intention therefore traces a plausible and theoretically grounded capability-building trajectory that prior TOE-blockchain studies neither hypothesized nor tested.

5.3. Green Technology Orientation as Strategic Amplifier of the Sequential Digital Pathway

The moderating role of green technology orientation in amplifying the blockchain–AI intention relationship constitutes perhaps the most theoretically nuanced contribution of this study, and one that requires careful interpretation against contradictory prior evidence. Ullah et al. (2022) documented a non-significant direct effect of green orientation on blockchain adoption a null finding this study incorporates into its theoretical framing by repositioning green orientation not as an adoption antecedent but as a strategic moderator operating downstream in the capability-building chain. The significant direct effect of green orientation on AI intention confirms that sustainability-committed firms maintain an independent disposition toward AI adoption that operates through channels distinct from the blockchain mediation pathway — likely reflecting these firms' broader strategic integration of digital and environmental agendas into unified transformation roadmaps.

More theoretically significant is the moderation finding itself: The blockchain–AI intention relationship strengthens substantially at high levels of green orientation and weakens at low levels, producing conditional effect magnitudes that differ dramatically across the moderator distribution. This pattern is interpretable through the sustainability-strategic lens that Van Holt et al. (2020) describe: For firms with deeply internalized green orientation, blockchain adoption is perceived not as an isolated operational efficiency investment but as the foundational transparency layer of a broader sustainability-digital integration architecture, within which AI adoption for carbon footprint optimization, predictive environmental compliance monitoring, and green process automation represents a natural and strategically coherent progression. The blockchain–AI sequential pathway is therefore not merely instrumentally valuable for high-GTO firms it is strategically legible within their existing sustainability logic, dramatically reducing the cognitive and organizational distance between blockchain implementation and AI adoption intention.

Conversely, for firms with low green technology orientation, blockchain adoption remains anchored to operational compliance and transactional efficiency objectives, generating far weaker momentum toward AI intention because the strategic narrative connecting these two technologies sustainability-driven digital transformation is absent from their organizational decision-making framework. This finding reframes green orientation's theoretical role in the technology adoption literature: Rather than functioning as a direct predictor of any specific technology adoption, it operates as a strategic interpretation filter that conditions how organizations translate prior technology investments into subsequent adoption intentions. This moderating mechanism has not previously been theorized or tested within a TOE-blockchain-AI sequential framework, representing a novel configurational contribution to both sustainability-technology intersection research and energy sector digital transformation scholarship.

5.4. Theoretical Contributions and Boundary Conditions

Synthesizing across these three thematic findings, this study advances TOE theory along dimensions that accumulated blockchain adoption evidence had left unresolved. The demonstration that TOE's predictive structure is context-contingent with environmental factors dominating in heavily regulated, institutionally constrained industries while technology and organizational dimensions lose predictive salience establishes boundary conditions that Aarabi et al. (2013) identified as necessary but did not empirically specify. The sequential blockchain–AI capability-building pathway provides a theoretically grounded mechanism connecting two digital technology domains that the literature had documented as complementary but had not explained through organizational learning dynamics. The moderating role of green technology orientation introduces sustainability orientation as a configurational boundary condition that determines whether sequential digital investments generate compounding strategic momentum or remain isolated operational interventions a distinction of acute practical consequence for energy firms navigating simultaneous digital transformation and energy transition imperatives. Taken together, these contributions position Indonesian oil and gas firms as a theoretically generative empirical context rather than merely a regional application of established frameworks demonstrating that sector-specific institutional configurations can fundamentally reshape the predictive architecture of widely validated technology adoption theories.

6. CONCLUSION

This study examined the sequential digital transformation pathway from blockchain adoption to AI intention within Indonesian oil and gas firms, integrating the TOE framework with absorptive capacity theory and green technology orientation as a moderating boundary condition. Four principal conclusions emerge from the empirical evidence. Environmental regulatory pressure operationalized through SKK Migas governance mandates, partner ecosystem digitalization expectations, and competitive industry dynamics constitutes the singular significant driver of blockchain adoption, displacing technology attributes and organizational capacity as meaningful predictors in institutionally constrained energy contexts. Blockchain adoption subsequently functions as an organizational capability infrastructure rather than a terminal technology investment, generating the data governance discipline, distributed trust architecture, and algorithmic process familiarity through which AI adoption intention becomes behaviorally proximate. Green technology orientation amplifies this sequential pathway non-uniformly sustainability-committed firms extract substantially greater AI intention momentum from equivalent blockchain investments than their low-orientation counterparts, establishing green orientation as a strategic interpretation filter rather than an independent adoption antecedent.

Collectively, these findings respecify TOE's boundary conditions for capital-intensive regulated industries, extend absorptive capacity theory into sequential digital technology domains, and introduce sustainability orientation as a configurational moderator with direct implications for energy firms navigating simultaneous digital transformation and decarbonization imperatives under Indonesia's net-zero commitment.

7. ETHICAL STATEMENT

This study adhered to the ethical principles articulated in the Declaration of Helsinki governing research involving human participants, whereby all respondents received a clear explanation of the study's objectives, procedures, and their unrestricted right to decline or withdraw without consequence, and informed consent was secured from every participant prior to questionnaire administration, with no personally identifying information solicited at any stage to ensure complete anonymity throughout data collection, storage, and analysis; because the investigation relied exclusively on self-reported perceptual data gathered through a structured survey instrument, without physical intervention, deception, or exposure to psychological, social, or occupational risk, the protocol satisfies criteria for minimal-risk research involving competent adult professionals, and was accordingly reviewed and granted exemption from full ethics committee evaluation by the Sekolah Interdisiplin Manajemen Teknologi, Institut Teknologi Sepuluh Nopember, with all collected data used strictly for academic purposes, securely maintained, and accessible only to the research team, and no conflicts of interest influencing study design, execution, or interpretation.

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