

Carbtrade Platform: Technology Architecture and User Acceptance in Indonesian Waste Management - a Jangjo Technology Indonesia Case Study

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Abstract- *This research investigates the development and user acceptance of CarbTrade, a comprehensive web-based platform for waste management and carbon offset tracking in Indonesia, using Jangjo Technology Indonesia as a primary case study. The study employs an integrated approach combining technology architecture analysis with Technology Acceptance Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT) frameworks enhanced by COBIT 2019 governance principles. Data collected from 48 respondents across 15 Indonesian waste management companies reveals that performance expectancy ($\beta = 0.690$, $p < 0.001$) and governance quality significantly influence adoption intention, while traditional cultural factors show limited impact. The platform architecture built using Next.js 15, Laravel 10, and PostgreSQL 17, achieved 99.7% system uptime with 73% database optimization improvement. Results demonstrate that governance frameworks and operational maturity are primary drivers of successful environmental technology implementation, explaining 57.3% of variance in behavioral intention. This study contributes novel insights for sustainable technology development in emerging markets.*

Index Terms- *Technology Acceptance Model, UTAUT, COBIT, Waste Management Hierarchy Model, Environmental Technology Adoption*

I. INTRODUCTION

Indonesia faces a critical municipal solid waste management crisis requiring urgent digital and software solutions. The country generates approximately 69.9 million tons of waste annually, with projections reaching 82 million tonnes by 2045. As the world's third-largest contributor of plastic pollution, Indonesia releases over 3.4 million tons of plastic waste annually. This crisis extends beyond disposal issues, encompassing water contamination, greenhouse gas emissions, healthcare costs, and economic losses exceeding \$450 million annually in marine ecosystem damage alone.

Compared to advanced digital systems in developed nations, Indonesia's waste management technology remains fundamentally deficient. Current operations rely heavily on manual labor, Excel-based computing systems, and poorly integrated information architectures, hindering real-time monitoring, accurate environmental impact assessment, and efficient regulatory compliance. This technological gap severely limits Indonesia's capacity to implement advanced carbon tracking systems, participate effectively in global carbon markets, and meet increasingly stringent environmental regulations necessary for achieving sustainable development goals.

The digitalization of environmental management necessitates advanced technological platforms integrating real-time data processing, automated calculation algorithms, comprehensive reporting systems, and multi-stakeholder collaboration within robust governance frameworks. Industry 4.0 technologies—including the Internet of Things (IoT), artificial intelligence, cloud computing, and sophisticated web applications—exhibit considerable potential for comprehensive waste management system digitalization through real-time monitoring, automated carbon accounting, and predictive analytics facilitating transparent reporting and governance-oriented service development.

The fragmentation of Indonesia's waste management information systems further complicates full process digitization. Currently, five different systems operate across government ministries without standardized communication protocols or clear operational governance: SIPSN (Ministry of Environment and Forestry), SI INSAN (Ministry of Public Works and Housing), SIPD (Ministry of Home Affairs), NAWASIS (Ministry of National Development Planning), and AKSARA (Bappenas). This institutional fragmentation leads to operational

inefficiencies, data duplication, differing reporting standards, and administrative limitations hindering coordinated waste management and carbon offset tracking.

The CarbTrade platform represents an advanced digital solution addressing these complex challenges through modern web application architecture combined with COBIT 2019 governance framework. The platform employs Next.js 15 with TypeScript for frontend development, Laravel 10 with PHP 8.2 for robust backend services, and PostgreSQL 17 enhanced with Timescale DB extensions for efficient environmental time-series data management and real-time analytics.

II. LITERATURE REVIEW

A. Technology Acceptance Model (TAM):

Foundational Framework Davis (1989) created the Technology Acceptance Model as one of the most important frameworks for understanding technology usage across different contexts. Based on the Theory of Reasoned Action, TAM has been extensively validated, establishing itself as "the most popular theoretical framework" for technology adoption research. The number of TAM-based studies has grown from 4 in 2002 to 157 in 2022, particularly for consumer behavior and technology adoption trend studies.

The basic TAM model posits that two main factors affect technology usage: perceived usefulness (PU) and perceived ease of use (PEOU). These factors shape attitudes toward technology use and subsequent behavioural intentions. Perceived Usefulness represents "the degree to which a person believes that using a particular system would enhance job performance," while Perceived Ease of Use means "the degree to which a person believes that using a particular system would be free of effort."

TAM has evolved through TAM2 and TAM3, incorporating additional components including social aspects (subjective norm, voluntariness, and image) and factors linked to perceived ease of use (computer anxiety, computer self-efficacy, and objective usability). Recent studies demonstrate TAM's effectiveness in environmental and sustainability settings, though traditional constructs require enhancement through environment-specific factors

such as environmental consciousness, sustainability motivation, and regulatory compliance considerations.

B. Unified Theory of Acceptance and Use of Technology (UTAUT)

The UTAUT model, designed by Venkatesh et al. (2003), represents substantial progression in technology acceptance research by amalgamating elements from eight prior models to provide a comprehensive framework for understanding technology adoption behaviour. UTAUT originated from systematic review and synthesis of the Technology Acceptance Model, Theory of Reasoned Action, Theory of Planned Behaviour, Motivational Model, Model of Personal Computer Utilization, Innovation Diffusion Theory, Social Cognitive Theory, and Combined Technology Acceptance Model-Theory of Planned Behaviour.

The model exhibits exceptional predictive power, accounting for up to 70% of variance in behavioural intention and approximately 50% in actual usage behaviour, greatly surpassing previous models. UTAUT defines four principal constructs directly affecting behavioural intention and technology utilization: Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), and Facilitating Conditions (FC), with moderating effects attributed to gender, age, experience, and voluntariness of use.

Performance Expectancy, characterized as "the extent to which an individual perceives that utilizing the system will enhance job performance," consistently ranks as the most significant predictor of behavioural intention in UTAUT research. Effort Expectancy denotes "the extent to which the utilization of the system is regarded as largely devoid of effort," encompassing aspects of perceived ease of use, complexity, and usability. Social Influence represents "the extent to which an individual perceives that significant others expect him or her to utilize the new system," while Facilitating Conditions denotes "the extent to which an individual perceives that organizational and technical infrastructure is available to support system utilization."

C. COBIT 2019 Framework for IT Governance and Management

The Control Objectives for Information and Related Technologies (COBIT) framework embodies a thorough methodology for IT governance and management, having developed to tackle modern challenges in digital transformation, platform development, and environmental technology implementation. COBIT 2019 offers systematic governance and management approaches enabling enterprises to maximize value from information and technology while ensuring equilibrium among benefit realization, risk mitigation, and resource allocation.

For environmental management platforms like CarbTrade, COBIT deployment proves essential for maintaining data integrity, ensuring regulatory compliance, fostering stakeholder confidence, and upholding accountability in sustainable development. Recent studies indicate environmental technology platforms necessitate strong governance frameworks addressing specific challenges including data precision for carbon assessments, adherence to regulations across jurisdictions, stakeholder confidence in environmental assertions, and enduring viability of technology investments.

COBIT 2019 presents a flexible methodology for governance and management via design principles allowing enterprises to develop bespoke governance systems aligned with unique context, strategy, and requirements. The framework differentiates governance from management operations, with governance assessing stakeholder needs to establish balanced objectives, while management organizes, executes, and oversees activities in accordance with governance directives.

III. RESEARCH METHODOLOGY

A. Research Framework and Philosophical Approach

This study employs a pragmatic research philosophy utilizing mixed-methods integrating quantitative technology acceptance metrics with qualitative assessments of Agile technology development, governance implementation, and four-tier use case validation to investigate intricate technology adoption phenomena within measurable and observable parameters, augmented by robust

governance frameworks. The pragmatic approach facilitates systematic examination of theoretical relationships among technology acceptance constructs, governance quality indicators, cultural moderators, and environmental context variables, while ensuring objectivity and reproducibility crucial for technology adoption research in governance-enhanced settings.

The research philosophy amalgamates various established theoretical frameworks, including UTAUT, TAM, Digital Platform Economics Theory, Cultural Dimensions Theory, COBIT 2019 governance framework, and Environmental Technology Adoption models, augmented by Sustainable Development Goals (SDG) considerations and thorough governance integration. This multi-theoretical integration offers thorough knowledge of technology adoption complexities while considering domain-specific characteristics peculiar to environmental platforms within Indonesian cultural contexts, bolstered by systematic governance implementation.

B. Technology Development and System Architecture

The CarbTrade platform development uses Agile methodology and DevOps methods ensuring platform improvement, stakeholder involvement, and robust deployment critical for environmental marketplace applications. The Agile approach provides flexible framework enabling rapid response to changing market needs, emerging carbon offset trading regulations, and user feedback while following systematic process for developing new features and ensuring quality.

The development process uses two-week sprint cycles including daily stand-up meetings, sprint planning sessions, full sprint reviews, and retrospective meetings ensuring stakeholder involvement and continuous improvement. This iterative method enables quick response to changing needs in fast-paced carbon trading and waste management regulations while focusing on user experience improvement and Indonesian organizational culture adaptation.

C. Platform Architecture and Technology Stack

The CarbTrade platform uses contemporary full-stack architecture with Next.js 15 with TypeScript for

frontend development, Laravel 10 with PHP 8.2 for backend API services, and PostgreSQL 17 with TimescaleDB extensions for database administration. Technology stack selection prioritizes scalability, security, user experience optimization, and performance characteristics critical for environmental marketplace applications requiring reliable carbon calculation algorithms and comprehensive waste management tracking capabilities.

The frontend layer uses Next.js 15 with App Router for Server-Side Rendering (SSR) features improving search engine optimization critical for marketplace functionality and enhancing data-heavy environmental application performance. TypeScript integration ensures code reliability through static type checking and extensive error detection vital for applications handling sensitive financial and environmental data.

The backend layer uses Laravel 10 featuring comprehensive API architecture including Laravel Sanctum for authentication, Laravel Horizon with Redis for queue management enabling asynchronous carbon calculation processing, and Laravel Telescope for debugging and performance monitoring essential for maintaining system reliability in environmental compliance situations.

D. Data Collection and Analysis

Data collection employed comprehensive mixed-methodology approach combining quantitative survey distribution with qualitative focus group discussions, user validation sessions, and governance maturity assessment providing thorough picture of technology adoption dynamics using Agile validation methods. The quantitative component utilized validated questionnaire distributed to 48 respondents across 15 Indonesian waste management companies, while qualitative component included Focus Group Discussions with carefully chosen experts providing deeper understanding of governance implementation problems and strategic suggestions.

Statistical analysis utilized SPSS version 29 for descriptive statistics, reliability assessment, preliminary analysis, and data preparation, with SPSS AMOS version 29 for advanced Structural Equation Modeling (SEM) capabilities necessary for studying complex relationships between multiple

theoretical constructs enhanced by governance quality indicators and user implementation success factors.

IV. RESULTS AND DISCUSSION

The comprehensive demographic study of 48 respondents offers essential information into readiness and potential for CarbTrade platform adoption across Indonesian waste management industries. Industrial distribution indicates broad sample with retail/services sector greatest share at 22.9%, followed by manufacturing at 20.8% and business districts at 16.7%. Incorporation of hospitality (14.6%), education (12.5%), waste management (8.3%), and additional sectors (4.2%) illustrates platform's capacity for cross-sectoral application.

Organizational profile indicates substantial presence of individual stakeholders (62.5%) relative to firm representatives (37.5%), implying robust grassroots involvement and heightened individual understanding of sustainability concerns. Analysis of organizational scale indicates firm largely comprises small-to-medium enterprises with mean score of 2.44 (SD=1.398) on organizational size scale, suggesting majority of participating firms function under resource-constrained situations.

Technical readiness assessment indicates very favorable circumstances for platform adoption with average digital platform experience of 3.08 (SD=1.366) on five-point scale. Advanced and expert users together account for 39.6% of responses (20.8% advanced, 18.8% expert), with intermediate users comprising additional 29.2%, suggesting approximately 68.8% of prospective users exhibit moderate to high levels of digital proficiency.

B. Structural Equation Modeling Results

The structural equation modeling analysis revealed significant relationships supporting 5 of 9 primary hypotheses. Performance Expectancy demonstrated strongest relationship with Behavioral Intention ($\beta = 0.690$, $p < 0.001$), indicating Indonesian waste management organizations significantly more inclined to use CarbTrade platform when perceiving obvious operational and financial advantages. Substantial impact size shows performance expectation constitutes main reason for technology

acceptance in this situation, aligning with previous research findings demonstrating Indonesian firms' practical matter focus.

COBIT Governance Quality Moderation ($\beta = 0.324$, $p = 0.005$) proved significant, demonstrating governance quality strengthens relationship between performance expectation and adoption intention. Organizations with well-established governance frameworks better able to utilize technology, with interaction impact stronger for administrative users ($\beta = 0.456$) than operational users ($\beta = 0.287$), proving governance frameworks and technology acceptance models can be integrated theoretically.

Waste Management Hierarchy Model demonstrated strong support ($\beta = 0.560$, $p < 0.001$), confirming organizations using organized waste management methods significantly more likely to utilize digital platforms. This connection shows systematic operational frameworks facilitate technology integration, suggesting platform implementation should focus on firms with established waste management procedures.

Surprisingly, several traditional technology acceptance factors proved non-significant. Effort Expectancy showed no significant negative effect on behavioral intention ($\beta = -0.145$, $p = 0.168$), contrary to standard TAM predictions. This result implies Indonesian waste management professionals value functionality more than simplicity of use, possibly because waste management constitutes specialist field where users ready to handle complexity for substantial rewards.

Social Influence demonstrated no significant impact on adoption intention ($\beta = -0.146$, $p = 0.164$) despite Indonesia's collectivist culture, indicating professional settings may prioritize technical knowledge and organizational advantages over social pressure. Cultural characteristics showed no significant moderating effect ($\beta = 0.222$, $p = 0.111$), suggesting professional environments may neutralize cultural effects, with technological nature of waste management operations enabling adoption standards applying across cultures.

C. Platform Technology Development Results

The CarbTrade platform development successfully established robust full-stack architecture employing

Next.js 15 with TypeScript and Laravel 10, attaining exceptional performance metrics including average page load time of 2.1 seconds, 98.7% accessibility compliance surpassing WCAG 2.1 AA standards, and 47% enhancement in search engine optimization scores. Backend solution included 52 RESTful endpoints achieving average response time of 138 milliseconds and reliability uptime of 99.8% during six-month testing period.

PostgreSQL 17 database implementation with TimescaleDB additions resulted in 78% improvement in query performance for temporal analytics while ensuring ACID transaction compliance critical for carbon trading scenarios. Security solution included AES-256 encryption, TLS 1.3, and extensive audit logging, with no serious flaws detected during penetration testing.

User interface design achieved usability scores of 4.4/5.0 for administrative interfaces and satisfaction ratings of 4.6/5.0 for client dashboards, resulting in 71% reduction in data input time compared to Excel-based systems. Cultural adaptation components including Indonesian language assistance received feedback ratings of 4.5/5.0. Platform integration capabilities included 28 third-party endpoints achieving dependability rate of 99.2%, facilitating carbon registries and IoT sensor networks. Carbon computation algorithms exhibited 99.8% accuracy according to certified standards, achieving 94% decrease in error compared to human techniques.

V. CONCLUSION AND RECOMMENDATIONS

This research demonstrates that successful CarbTrade platform adoption by Indonesian waste management organizations requires integrating governance frameworks, technological acceptability considerations, and environmental awareness. Governance skills help organizations maintain compliance with changing environmental regulations as stakeholder expectations evolve rapidly. To remain competitive, businesses need capacity to identify, capture, and manage environmental opportunities.

The study reveals that performance expectancy, governance moderation, and sustainability alignment show strongest relationships, while traditional technology acceptance criteria demonstrate mixed findings. Performance Expectancy and Behavioral

Intention exhibited strongest link ($\beta = 0.690$, $t = 4.004$), indicating Indonesian waste management firms value functional advantages over convenience of use, showing performance-focused designs superior in professional settings.

COBIT Governance Moderation ($\beta = 0.324$, $t = 2.801$) and COBIT-Platform Trust ($\beta = 0.560$, $t = 3.514$) both demonstrated strong associations showing governance frameworks crucial for generating trust. Association between governance and trust proves stakeholders' trust increases substantially when governance implementation becomes visible. Waste Management Hierarchy Model demonstrated high support ($\beta = 0.560$, $t = 3.514$), confirming companies with well-organized operational frameworks more likely to use digital platforms.

The total model explained 57.3% of differences in behavioral intention, with main drivers being performance expectation, governance quality, and operational structure alignment. This result supports combined TAM-UTAUT-COBIT paradigm showing professional settings in emerging economies need changes fitting individual needs.

A. Theoretical Contributions

This research significantly enhances understanding of environmental technology uptake, governance integration, and digitalization of sustainable development in emerging economy contexts. Study illustrates pivotal function of governance frameworks in technology adoption providing empirical data from Indonesia's waste management industry, expanding known technology acceptance theories to include environmental compliance contexts.

Research introduces comprehensive theoretical framework amalgamating TAM-UTAUT components with COBIT governance concepts and sustainable development factors, illustrating governance quality, operational maturity, and performance focus substantially affect platform adoption choices in professional environmental management settings. Study enhances comprehension of how institutional variables influence conventional technology adoption dynamics.

B. Practical Contributions

Research provides extensive managerial and practical contributions for environmental technology implementation demonstrating governance quality, performance expectancy, and operational structure alignment play critical roles in platform adoption success, requiring managers prioritize these factors during implementation planning. Organizations must embrace governance framework implementation to successfully deploy environmental management platforms.

Managers must understand significance of COBIT governance principles in building stakeholder trust and enhancing adoption outcomes, particularly recognizing governance maturity significantly impacts competitive advantages and platform performance. Research demonstrates CarbTrade platform implementation can provide substantial benefits regarding regulatory compliance, stakeholder confidence, and environmental impact reporting capabilities.

Based on findings, manufacturing and waste management organizations should systematically examine governance frameworks before platform deployment, immediately addressing governance maturity requirements to enhance user trust and adoption outcomes. Senior management engagement proves crucial for effective environmental platform implementation, facilitating change management initiatives aligning with governance and sustainability mandates.

C. Research Limitations and Future Directions

Research limitations include cross-sectional design making difficult to determine causal links between user understanding and adoption outcomes, self-reported data potentially biased by social desirability especially in user category familiarity self-assessments, limited geographic scope hindering application of findings to other Indonesian regions with different technology readiness levels, and focus on established client relationships limiting generalizability to other market contexts.

Future research should clarify how technologies like AI, IoT sensors, blockchain, and automated carbon tracking systems can be used, allowing researchers to test how governance frameworks, cultural factors,

and environmental awareness affect platform adoption. Additional study should include other factors potentially affecting environmental platform adoption including senior management support, regulatory confusion, absorptive capacity, and sustainability competency.

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