
CHAPTER 2 : LITERATURE REVIEW

This extensive literature analysis analyzes essential theoretical frameworks for the adoption of CarbTrade, a digital waste-to-carbon offset platform created for Jangjo Technology Indonesia. The review methodically examines the Technology Acceptance Model (TAM), Jangjo company profile and business dynamics, the Unified Theory of Acceptance and Use of Technology (UTAUT) as foundational frameworks, supplemented by Digital Platform Economics Theory, Sustainable Development Theory, the COBIT 2019 Framework, Cultural Adoption Theory, and Environmental Technology Domain-Specific Considerations and also the conceptual framework examines the intricate aspects of environmental platform adoption in developing nations, Whereas traditional models of technology acceptance need a lot of work to take into account the reasons for sustainability, the drivers of regulatory compliance, the dynamics of multi-stakeholder ecosystems, the cultural moderating effects, and the governance needs that make environmental technologies different from traditional information systems.

2.1. Technology Acceptance Model (TAM): Foundational Framework

Davis (1989) created the Technology Acceptance Model (TAM), which has become one of the most important ways to understand how people use technology in different situations (Schorr, 2023). The Theory of Reasoned Action by (Few, 2006), is the basis for TAM, which has been tested many times and is still "the most popular theoretical framework" for research on technology adoption (Alaa and Mamoun, 2017), and on the other hand TAM is still useful today, as shown by the fact that the number of studies based on it has grown from 4 in 2002 to 157 in 2022. This is especially true for studies on consumer behavior and technology adoption trends (Venkatesh and Davis, 2000; Venkatesh *et al.*, 2003a), and also TAM applications have grown beyond their original purpose to include new technologies and environmental sustainability. Researchers have created Energy-Augmented TAM (EA-TAM) models to look at how businesses adopt green technologies from both a small and large scale (Alam and Murad, 2020).

2.1.1. Core TAM Constructs and Evolution

The basic TAM model says that two main things affect whether or not people utilize technology: how useful they think it is (PU) and how easy they think it is to use (PEOU) with these two things shape how people feel about using technology and what they plan to do next (Davis, 1989a; Mohammad Chuttur, 2009). Perceived Usefulness means "the degree to which a person believes that using a particular system would enhance job performance," and Perceived Ease of Use means "the degree to which a person believes that using a particular system would be free of effort" (Davis, 1989b; Mathieson, 1991). TAM2 and TAM3 added more components to TAM that made it more explanatory and took into account differences in context (Venkatesh and Davis, 2000; Venkatesh, Thong and Xu, 2016). TAM2 added social aspects including subjective norm, voluntariness, and image to the original model. TAM3 added factors linked to perceived ease of use such computer anxiety, computer self-efficacy, and objective usability (King and He, 2006; Bagozzi, 2007). Recent studies have shown that TAM works well in environmental and sustainability settings. For example, studies on the acceptance of green technology found that traditional TAM constructs are still useful but need to be improved by adding factors that are specific to the environment, such as environmental consciousness, sustainability motivation, and regulatory compliance considerations (Marikyan, Papagiannidis and Stewart, 2023), and several researchers looked into mobile recycling apps and found that performance expectancy was still the best predictor of whether or not people would use them. However, environmental consciousness had a big effect on the link between TAM constructs and behavioral intention (Lamberti, Román-Ramírez and Wood, 2020).

2.1.2. TAM Applications in Environmental Technology Contexts

Adopting environmental technology shows that sustainability-focused platforms are different from traditional information systems in some ways (Abrahamse *et al.*, 2005). Studies show that TAM needs to be improved to take into account the fact that environmental technologies have both operational benefits and motivations for environmental stewardship (Nizami, et al., 2017). The Green Technology Acceptance Model (GTAM) builds on the traditional TAM by adding factors

like concern for the environment, perceived environmental benefit, and corporate environmental responsibility that have a big impact on adoption decisions (Stern, 2000; Kollmuss and Agyeman, 2002), and some studies on circular plastic economy technologies have shown that how much people accept new technologies is greatly affected by how they think they will help the environment, society, and the goals of sustainable development (Korhonen, Honkasalo and Seppälä, 2018), this means that the traditional TAM models need to be improved to include the many different value propositions of environmental technologies like CarbTrade (Kirchherr, Reike and Hekkert, 2017; Blomsma *et al.*, 2019). Studies have shown that people who adopt environmental technology often do so for reasons that are different from those who adopt technology voluntarily. These reasons include regulatory compliance requirements, stakeholder pressure, and corporate social responsibility concerns, which create new ways for people to adopt technology that go beyond traditional TAM factors (Scott, 2008; Dimaggio and Powell, 2021).

2.1.3. Cultural Adaptation of TAM in Developing Countries

TAM implementations in developing nations underscore the significance of cultural adaptation and contextual elements that influence the correlations between fundamental components and adoption results (Straub, Keil and Brenner, 1997; Lim, Kumar and Ali, 2022), and some other Studies in Southeast Asia indicate that collectivist cultures exhibit distinct technology adoption patterns relative to individualistic cultures, with social factors exerting greater influence on adoption decisions (Triandis, 1995; Hofstede, 2024), also another research on mobile technology adoption in Indonesia indicates that cultural factors greatly influence the interactions within the Technology Acceptance Model (TAM), with social influence, hierarchical approval, and group consensus being pivotal (Kurnia *et al.*, 2015; Handayani *et al.*, 2017). On the other Indonesian cultural traits, such as pronounced collectivism, significant power distance, and moderate uncertainty avoidance, generate distinct adoption dynamics that necessitate theoretical consideration in Technology Acceptance Model applications (Martinsons and Westwood, 1997), also Economic constraints and infrastructural limits affect TAM connections, with perceived cost, perceived risk, and facilitating conditions assuming greater significance in developing countries (Kapoor, Dwivedi and Williams, 2014; Martins, Oliveira and Popovič, 2014). Research on the

adoption of environmental technology in emerging markets indicates that financial factors, the availability of technical support, and integration capabilities substantially affect evaluations of perceived usefulness and perceived ease of use (Baptista and Oliveira, 2015; Dwivedi *et al.*, 2016).

2.2. Jangjo Technology Indonesia: Operations and Digital Transformation Context

PT Jangjo Teknologi Indonesia is an enterprise that integrates environmental conservation with innovative technology in Indonesia's rapidly evolving sustainability industry (Marešová *et al.*, 2023; Maya Puji Lestari, Ahmad Taufiq and Rupiarsieh, 2025). Established in 2019 by CEO Joe Hansen, Jangjo integrates conventional garbage management with contemporary digital solutions, exemplifying the application of environmental technology in Indonesia (Putri, Fujimori and Takaoka, 2018; Waluyo and Kharisma, 2023). Jangjo operates the JOWI (Jangjo Zero Waste Integrated) system, which manages 200 tons of waste daily within a compact 3,000 m² facility, which this conserves 70% of the acreage required for conventional systems (Kurniawan *et al.*, 2022; Setiono *et al.*, 2023), and this degree of efficiency indicates that digital innovation may assist Indonesia's densely populated urban regions in addressing spatial challenges while concurrently advancing the objectives of SDG 11 (Sustainable Cities and Communities), SDG 8 (Decent Work and Economic Growth), and SDG 13 (Climate Action) (Wilson *et al.*, 2012; Kaza *et al.*, 2018). Furthermore, Jangjo has implemented a zero-waste strategy under the leadership of CEO Joe Hansen, and this entails converting waste into valuable resources such as Solid Recovered Fuel (SRF) and Refuse Derived Fuel (RDF), so directly aligning with the tenets of SDG 12 (Responsible Consumption and Production) (Sarc and Lorber, 2013; Nizami *et al.*, 2017), and the company engages with communities via educational initiatives and projects that promote waste segregation. These initiatives facilitate the execution of SDG 4 (Quality Education) and SDG 17 (Partnerships for the Goals) (Bernstad, 2014; Stoeva and Alriksson, 2017).

2.2.1. Current Technological Infrastructure and Digital Transformation Challenges in Jangjo

Despite its innovative physical infrastructure, and Jangjo's digital infrastructure has considerable deficiencies that illustrate the overarching issues confronting Indonesia's waste management sector

(Egala *et al.*, 2024; Indonesia Digital Economy, 2024), and the company depends on Excel-based systems for monitoring waste collection, processing activities, environmental impact assessments, and client reporting, which in turn have impact on operational efficiency and also advanced environmental analytics capabilities (EIA, 2016; Joy-Camacho and Thornhill, 2024). Jangjo has designed its waste management systems to enhance efficiency and minimize environmental effect while promoting sustainable development frameworks (Tchobanoglous and Kreith, 2002; Salem *et al.*, 2023). The facility comprises specific areas: a waste intake zone, a sorting section equipped with conveyor systems and automated separators, and processing units dedicated to organic waste composting, recyclable material management, and energy recovery, all of which align with the objectives of SDG 13 on climate action (Christensen T. H., 2011; Velis *et al.*, 2012).

The existing technology infrastructure comprises fundamental digital tools: spreadsheet-based data entry systems, manual calculation methods for environmental impact assessments, email communication with clients, and restricted integration functionalities (EDMS, 2024). These limits engender operational bottlenecks that inhibit advanced analytics, real-time monitoring, predictive maintenance scheduling, automated compliance reporting, and complex carbon credit generating capabilities (Alam and Murad, 2020; Celestin, 2023).

2.2.2. Data Management Challenges and Operational Inefficiencies in Jangjo

Jangjo's reliance on Excel for data administration generates significant technology constraints that impede scalability, operational efficiency, and the proper monitoring of Sustainable Development Goals (Tang *et al.*, 2004), and some research has indicates that spreadsheets are inadequate for extensive operations, also for intricate sustainable development indicators, also leading to inefficiencies and problems in tracking SDGs (Caulkins, Morrison and Weidemann, 2007). Another research on information overload indicates that much data in decentralized systems hinders decision-making instead of improving it, especially when tracking numerous sustainable development indicators concurrently (Eppler and Mengis, 2004), and the escalation of waste volumes leads to significant daily data, making spreadsheets inefficient and prone to mistakes that jeopardize SDG monitoring and reporting (Panko, 2008). Significant challenges encompass human

mistake in data entry, leading to erroneous reporting that may undermine the credibility of sustainable development impact evaluations (Rajalingham, Chadwick and Knight, 2008).

Research reveals that spreadsheets exhibit errors in about 1% of utilized formulas, which may lead to significant miscalculations that compromise the quality of environmental impact assessments (Panko, 2008, 2016). A confirmed instance in the UK revealed that around 16,000 COVID-19 cases went unreported due to Excel's row limitations, highlighting the severe consequences of depending on spreadsheets for managing large datasets essential for public health and sustainable development oversight (Jefferson *et al.*, 2024). Excel's deficiencies in automation and enterprise integration pose considerable challenges for organizations adopting extensive sustainable development monitoring systems (Few, 2006). Research by (Kassem, Ajmal and Khan, 2017), indicates that organizations dependent exclusively on Excel encounter automation difficulties and necessitate considerable manual effort for data processing, hindering real-time monitoring of sustainable development indicators essential for effective SDG implementation.

2.2.3. Client Ecosystem and Technology Adoption Opportunities in Jangjo

Jangjo serves a wide range of clients in Greater Jakarta, including high-end shopping areas (Plaza Indonesia, FX Mall), businesses and hotels (Hotel Aston Pluit, DBS Bank), schools, stores, and factories (Majeed, Chaudhary and Chadha, 2025), and this variety makes it hard for Excel-based systems to handle data management, standardizing reports, communicating with stakeholders, and tracking environmental impacts (Habeeb and Maryam, 2023), also in regards to ESG compliance, corporate clients need advanced sustainability reporting, standardized carbon footprint calculations, real-time monitoring of environmental impacts, and the ability to connect with corporate sustainability management systems (Ashley, 2022). DBS Bank processes a lot of waste 24,711 kg of food waste every month but the company has trouble giving real-time reports on the environmental impact because it has to process data by hand, other Clients in the hospitality industry want communications about sustainability that are aimed at guests, tracking of waste reduction for operational efficiency, support for environmental certification to make sure green buildings are up to code, and marketing materials that show environmental stewardship (Anjusha and Celine, 2024) and finally environmental education needs to be part of the sustainability

curriculum, and schools need to have platforms for students to get involved in environmental awareness programs, research collaboration tools for environmental studies programs, and clear reporting on their institutional sustainability commitments (Yuval, 2022).

2.2.4. Security and Compliance Concerns in Jangjo

Currently using Excel to keep track of sustainable development and environmental compliance data, security and access control are other problems that come up (Dhillon and Backhouse, 2001; Whitman and Mattord, 2011), and excel doesn't have the same level of access control as specialized data management systems, which makes it vulnerable to unauthorized access and data corruption, and this can affect the accuracy of environmental impact assessments and SDG progress reports (Arcy and Hovav, 2009; Bulgurcu, Cavusoglu and Benbasat, 2010), various Studies show that companies that use decentralized data management systems are more likely to have data breaches and compliance failures that affect reporting requirements for sustainable development and maintaining stakeholder trust (Von Solms and Von Solms, 2006). A company like Jangjo that deal with sensitive waste management and sustainability data that are important for monitoring the SDGs need to have strong security measures in place, and which If they don't, they could run into problems with following the rules, losing money, and losing credibility in their efforts to promote sustainable development (Siponen and Oinas-Kukkonen, 2007).

2.2.5. Competitive Analysis and Strategic Need for Digital Platform Integration

The landscape of waste management technology in Indonesia has undergone considerable expansion, with digital platforms tackling the nation's considerable waste management issues. Indonesia produces over 7 million tonnes of plastic garbage each year, yet recycles merely 10%, presenting chances for technological intervention. Notable emerging platforms are Waste4Change. (10 cities), E-Recycle app (Jakarta), Rapel app (Yogyakarta and Central Java), Kepul app (North Sumatera), and Octopus app (eastern Indonesia, Bali, West Java).

Table 2.1. Competitive Analysis of Indonesian Waste Management Platforms

Platform	What They Do	Where They Operate	Main Technology
Waste4Change	Complete waste management for businesses and consumers	10 cities across Indonesia	Digital tracking system
Rapel	Collects household waste, gives cash/points back	Yogyakarta, Central Java	Mobile app
Octopus	Focuses on plastic bottles, works with waste pickers	Eastern Indonesia, Bali, West Java	Mobile platform
E-Recycle	Turns plastic waste into pellets	Jakarta area	Mobile app + processing
CarbTrade	Complete waste-to-carbon management with real-time tracking, automated carbon credits, comprehensive reporting	Starting in Jangjo, plans to expand nationwide	Advanced IoT sensors, automated algorithms, real-time analytics

CarbTrade uniquely integrates comprehensive waste management with automated carbon credit generation and extensive sustainable development tracking, signifying a shift from traditional services to integrated environmental impact management platforms that create multiple value streams while advancing global sustainability goals.

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

The UTAUT model was designed by Venkatesh et al., (2003), which signifies a substantial progression in technology acceptance research by amalgamating elements from eight prior models to provide a whole framework for comprehending technology adoption behavior Williams et al., (2015), and UTAUT originated from a systematic review and synthesis of the Technology Acceptance Model, also Theory of Reasoned Action, Theory of Planned Behavior, Motivational

Model, Model of Personal Computer Utilization, Innovation Diffusion Theory, Social Cognitive Theory, as well as the Combined Technology Acceptance Model-Theory of Planned Behavior (Dwivedi *et al.*, 2019; Xue, Rashid and Ouyang, 2024a). The model exhibits exceptional predictive power, accounting for up to 70% of variance in behavioral intention and around 50% in actual usage behavior, greatly surpassing previous models (Altalhi, 2021) and the UTAUT framework offers a solid theoretical basis for comprehending technology adoption in several contexts, including education, that includes healthcare, mobile banking, e-commerce, and recently including also environmental sustainability (Kapoor *et al.*, 2014; Lallmahomed *et al.*, 2017).

2.3.1. Core UTAUT Constructs and Theoretical Foundation

UTAUT defines four principal constructs that directly affect behavioral intention and technology utilization: Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), and Facilitating Conditions (FC), with also moderating effects attributed to gender, age, experience, and voluntariness of use (Venkatesh *et al.*, 2003a; Venkatesh, Thong and Xu, 2012). 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 behavioral intention in UTAUT research (Al-Gahtani, Hubona and Wang, 2007; Venkatesh, Thong and Xu, 2016). This framework integrates components from perceived utility (TAM), extrinsic motivation, job-fit, relative advantage, and result expectations (Thong, Hong and Tam, 2006; Turel and Bart, 2014). 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 (Teo and Noyes, 2011).

Research indicates that effort expectancy is crucial during the initial adoption phases and among users with minimal technical proficiency, rendering it particularly pertinent for the adoption of environmental technology in developing nations, where digital literacy levels differ markedly (Kurnia *et al.*, 2015; Altalhi, 2021). Social Influence denotes "the extent to which an individual perceives that significant others expect him or her to utilize the new system," integrating components from subjective norm, social variables, and image. This notion is especially crucial in collectivist societies and organizational settings where peer pressure and hierarchical influence

substantially affect adoption decisions (Martinsons and Westwood, 1997). Facilitating Conditions denotes "the extent to which an individual perceives that organizational and technical infrastructure is available to support system utilization," integrating aspects of perceived behavioral control, facilitating conditions, and compatibility (Kooper, Maes and Lindgreen, 2011). Studies indicate that facilitating factors gain significance as users progress from the intention to adopt to actual usage behavior (Lunardi *et al.*, 2014).

2.3.2. UTAUT Extensions and Contextual Adaptations

UTAUT2, defined by Venkatesh *et al.*, (2012), expanded the model for consumer applications by include hedonic motivation, price value, and habit constructs, while eliminating voluntariness of use as a moderating variable (Venkatesh, Thong and Xu, 2016), the research indicates that these expansions markedly enhance explanatory power in consumer situations, with hedonic motivation and habit being especially crucial for sustained usage behavior (Marikyan, Papagiannidis and Stewart, 2023). Another recent studies have created context-specific extensions of the UTAUT model for environmental and sustainability applications, incorporating environmental awareness, sustainability motivation, and perceived environmental benefits into UTAUT frameworks (Manupati *et al.*, 2020; Kumar Bhardwaj, Garg and Gajpal, 2021). Research on electric vehicle adoption indicates that environmental awareness moderates the relationship between UTAUT constructs and behavioral intention, with environmentally conscious individuals exhibiting a stronger correlation between performance expectancy and adoption intention (Stern, 2000). Also, in underdeveloped countries, it shows that UTAUT extensions have tackled infrastructure restrictions, economic constraints, and cultural influences that greatly affect technology adoption trends (Dwivedi *et al.*, 2017; Oliveira *et al.*, 2020), as well as studies on mobile banking adoption in developing nations indicate that trust and perceived security are essential factors that influence the linkages between fundamental UTAUT components and behavioral intention (Shareef *et al.*, 2011; Baptista and Oliveira, 2015).

2.3.3. Performance Expectancy in Environmental Platform Context

On Performance Expectancy in environmental technology contexts includes both conventional productivity benefits and sustainability-related advantages that correlate with business and societal environmental goals (Xue, Rashid and Ouyang, 2024b), and having investigations into carbon footprint tracking applications reveal that performance expectancy is notably affected by users' perceptions of environmental advantages, but also benefits of regulatory compliance, as well as competitive standing through sustainability leadership (Tanveer, Ishaq and Hoang, 2024), and the adoption of the CarbTrade platform entails performance expectancy, which encompasses enhancements in operational efficiency (automated carbon calculations, real-time reporting, diminished manual effort) and strategic advantages (regulatory compliance, client satisfaction, and stakeholder value generation through evident environmental stewardship) (Ju and Zhang, 2025), and the multi-stakeholder nature of environmental platforms introduces added complexity in evaluating performance expectancy, as organizations must account for advantages for various user groups, including internal operations, client relationships, regulatory compliance, and overall environmental impact (Adner, 2017). Prior research on digital platform adoption highlights that the assessment of performance expectancy in corporate environments is significantly shaped by quantifiable results and return on investment factors (Martins, Oliveira and Popovič, 2014; Hermawan, Wijaya and Rianawati, 2025). Research on environmental management systems indicates that organizations prioritize technologies that exhibit distinct financial benefits in conjunction with environmental advantages, with cost reduction, process efficiency, and revenue generation opportunities being pivotal in adoption decisions (Gawer and Cusumano, 2014; Jacobides, Cennamo and Gawer, 2018).

2.3.4. Effort Expectancy and User Experience Design

Effort Expectancy in environmental platform contexts necessitates focused consideration of user interface design, training prerequisites, and integration intricacy, as environmental technologies frequently encompass complex functionalities that must be accessible to users with diverse levels of technical proficiency (Lallmahomed, Lallmahomed and Lallmahomed, 2017). Another research indicates that effort expectation constitutes a substantial obstacle to the adoption of environmental

technology, which in most cases when platforms necessitate intricate data entry, and technical configuration, or interaction with current corporate systems (Teo and Noyes, 2011), and the Indonesian business environment poses distinct challenges for optimizing effort expectancy, such as fluctuating digital literacy levels, varying technological capabilities among organizations, and a preference for localized user interfaces and culturally relevant design elements (Williams, Rana and Dwivedi, 2015). In some other research on technology adoption in Southeast Asian markets indicates that effective platforms necessitate local language support, streamlined navigation, and context-sensitive assistance tailored to diverse technical proficiency levels (Handayani *et al.*, 2017; Prabowo *et al.*, 2024), and with the adoption of the CarbTrade platform necessitates careful attention to effort expectancy, as waste management companies may possess limited experience with advanced digital platforms and differing levels of familiarity with carbon accounting and environmental reporting standards, also another studies indicate that environmental platforms that attain optimal effort expectancy frequently utilize layered methodologies, delivering user-friendly interfaces for regular operations while also giving complex functionalities for power users and specialized applications (Teo and Noyes, 2011).

2.3.5. Social Influence and Cultural Dynamics

Social influence in the adoption of environmental technology functions through various routes, including regulatory pressure, industry peer behavior, client demands, and overarching societal expectations for environmental accountability (Shirley T. and Todd, 1995; Abrahamse *et al.*, 2005), in some other research indicates that environmental technologies frequently undergo more pronounced social influence effects than conventional business applications, due to the public visibility, stakeholder expectations, and alignment with overarching social values inherent in sustainability initiatives (Nath, Bhal and Kapoor, 2013). Notwithstanding, the Indonesian cultural context greatly enhances the impact of social influence on technology adoption decisions, especially for environmental technologies that resonate with community values and collective responsibility (Hofstede, 2001), and Hofstede's cultural dimensions reveal that Indonesia's pronounced collectivism and elevated power distance foster adoption dynamics in which the social influence of authority figures, peer groups, and community leaders significantly impacts technology adoption decisions (Martinsons and Westwood, 1997), finally, government

endorsement and policy support for environmental technology establish supplementary social influence channels, especially significant in Indonesian contexts (Lallmahomed, Lallmahomed and Lallmahomed, 2017), with recent research indicates that governmental initiatives promoting environmental digitalization, carbon management, and the execution of sustainable development markedly amplify social influence and establish legitimacy for the adoption of environmental technologies (UNFCCC, 2022).

2.3.6. Facilitating Conditions and Infrastructure Requirements

In Facilitating conditions in environmental platform contexts include technological infrastructure, organizational capabilities, regulatory frameworks, and external support systems that enable effective technology deployment and sustained utilization (Al-Gahtani, Hubona and Wang, 2007; Kapoor, Dwivedi and Williams, 2014), previous Studies in underdeveloped nations indicate that favorable conditions frequently constitute the primary obstacles to the adoption of environmental technology, and as organizations must surmount infrastructural deficiencies, competence shortfalls, and resource limits (Shareef *et al.*, 2011; Baptista and Oliveira, 2015). The Indonesian context poses distinct challenges in facilitating conditions, such as inconsistent internet connectivity, varying technological capabilities among organizations, intricate regulatory frameworks, and a scarcity of specialized technical support for environmental technologies (Martins, Oliveira and Popovič, 2014; Dwivedi *et al.*, 2016). Another research on technology adoption in emerging markets indicates that the successful implementation necessitates a systematic focus on connectivity reliability, device compatibility, local technical support capabilities, and integration with current business processes and regulatory reporting obligations (Thong, Hong and Tam, 2006; Turel and Bart, 2014), and with the adoption of the CarbTrade platform is influenced by many supporting conditions, including technological infrastructure, organizational preparedness, regulatory framework, and ecosystem support (Koooper, Maes and Lindgreen, 2011). Studies indicate that environmental platforms necessitating extensive facilitating conditions frequently gain advantages from collaborative strategies that unite technology providers, implementation consultants, training organizations, and regulatory support to establish cohesive support ecosystems (Lunardi *et al.*, 2014).

2.4. Digital Platform Economics Theory: Understanding Network Effects and Ecosystem Value

Digital Platform Economics Theory helps us understand how platforms make money by using the network effects, multi-sided markets, and ecosystem orchestration, also all while supporting sustainable development goals through collaborative methods (Rochet and Tirole, 2003; Eisenmann, Parker and Van Alstyne, 2006; Parker, Van Alstyne and Choudary, 2017). Traditional software applications get their value mostly from how useful they are to each user. Platforms, on the other hand, get their value from making it easier for different groups of users to interact with each other. This creates network effects, where the value of the platform goes up as more users join it (Hagiu and Wright, 2015; Cusumano, Gawer and Yoffie, 2019).

To understand why people are using CarbTrade, first you need to know about platform economics, and This is because environmental platforms are usually multi-sided markets that connect waste management companies, carbon credit buyers, regulatory bodies, sustainable development organizations, and other groups in ways that help everyone work together to reach sustainability goals (Gawer, 2014; Jacobides, Cennamo and Gawer, 2018), a recent studies on the digital economy and carbon emissions have shown that digital platforms can have a big effect on the environment in many ways (Ju and Zhang, 2025). Another Researchers looking at how the growth of the digital economy can affects carbon emissions found that digital platforms can cut carbon emissions by up to 65% by making better use of resources, optimizing the structure of industries, and making energy use more efficient (Zhang *et al.*, 2023), and also the Studies on how carbon trading works on digital platforms found that online freight platforms and digital marketplaces can help lower carbon emissions by using market-based incentives and clear pricing systems (Tiwana, Konsynski and Bush, 2010; Wareham, Fox and Cano Giner, 2013).

2.4.1. Network Effects and Value Creation in Environmental Contexts

Network effects in environmental platforms arise through several processes that generate value for both individual users and the wider sustainability ecosystem (Katz and Shapiro, 1994). Direct network effects arise when waste management firms gain advantages from expanded networks of

potential carbon credit purchasers, thereby enhancing opportunities for carbon credit transactions, increasing market liquidity, and bolstering overall contributions to global sustainable development objectives (Boudreau, 2010; Ghazawneh and Henfridsson, 2013). On the other hand Indirect network effects arise when additional services, such sustainability advice, verification services, integration tools, and the instructional resources, become accessible as platforms expand (Suarez, 2004; Adner, 2017), and a Studies investigating the effects of the digital economy on carbon emissions reveal that network effects within environmental platforms generate synergistic advantages that surpass the aggregate of individual efforts (Zhang et al., 2024). Another recent studies indicate that environmental platforms exhibiting robust network effects excel in fulfilling both economic and environmental goals (Zhang *et al.*, 2023; Ju and Zhang, 2025), and finally a research on carbon emission trading systems indicates that platforms with extensive user networks attain superior pricing stability, increased transaction volumes, and more efficient carbon reduction results in comparison to smaller or fragmented markets (Kapoor and Lee, 2013; Gawer, 2014).

2.4.2. Multi-Sided Market Dynamics in Carbon Trading Platforms

Carbon trading platforms function as multi-sided markets that enable transactions among various user groups with complementary requirements, on while promoting coordinated efforts towards sustainable development goals (Rochet and Tirole, 2003; Rysman, 2009), and will CarbTrade links waste management firms (sellers of carbon credits), and corporations pursuing carbon offsets (buyers of carbon credits), and also verification entities (ensuring credit integrity), regulatory bodies (overseeing compliance), and organizations focused on sustainable development (facilitating SDG implementation) (Weyl, 2010; Hagiu, 2013). The theory of multi-sided markets elucidates how platforms must equilibrate the interests of various user groups via pricing strategies, feature development, value proposition design, and alignment with sustainable development, thereby fostering a collective commitment to sustainability goals (Caillaud and Jullien, 2003). Studies on carbon trading platforms indicate that effective systems frequently subsidize one market side to draw users, are who subsequently attract participants from other sides, so fostering a collective commitment to sustainable development objectives (Eisenmann, Parker and Van Alstyne, 2006; Hagiu and Wright, 2015). Another recent research on online freight platforms and carbon trading systems which shown that a digital platforms can efficiently manage

multi-sided market dynamics also while fulfilling environmental goals (Ju and Zhang, 2025). Research indicates that online freight platforms employing intensity-based allocation models yield superior environmental outcomes relative to those utilizing absolute emission cap models, highlighting the substantial impact of platform design on environmental efficacy (Ju & Zhang, 2025; Zhang et al., 2024)

2.4.3. Ecosystem Orchestration and Governance

The success of a platform will hinges on proficient ecosystem orchestration, wherein platform proprietors synchronize resources, capabilities, and relationships among many organizations while harmonizing the divergent interests of stakeholders with sustainable development goals (Kapoor and Lee, 2013; Adner, 2017). CarbTrade must coordinate partnerships among waste management enterprises, carbon credit purchasers, verification services, regulatory agencies, sustainable development groups, technology providers, and international cooperation frameworks (Wareham, Fox and Cano Giner, 2013; Jacobides, Cennamo and Gawer, 2018). Ecosystem governance mechanisms encompass technical standards, participation regulations, pricing strategies, quality control systems, sustainable development monitoring frameworks, and accountability measures that influence user behavior and platform evolution, ensuring adherence to sustainable development principles (Boudreau, 2010; Tiwana, Konsynski and Bush, 2010). Studies indicate that platform governance profoundly affects user adoption choices, as organizations assess both existing platform functionalities and the capacity of platform proprietors to sustain ecosystem vitality and facilitate the execution of sustainable development (Ghazawneh and Henfridsson, 2013; Gawer, 2014). A Recent studies on the evolution of the digital economy and carbon emissions underscore the significance of governance systems in the attaining environmental objectives via digital platforms (Zhang *et al.*, 2023), another research on carbon emission trading systems indicates that platforms characterized by strong governance frameworks, transparent pricing mechanisms, and efficient monitoring systems demonstrate enhanced environmental performance relative to those with inadequate governance structures (Ju & Zhang, 2025).

2.4.4. Platform-Specific Adoption Factors

Conventional technology acceptance models, such as UTAUT, were designed for individual software applications and may inadequately reflect the distinct adoption dynamics of platform technologies in sustainable development contexts (Gawer and Cusumano, 2014; Venkatesh, Thong and Xu, 2016). Platform adoption entails more factors, such as the perception of network effects, evaluation of ecosystem health, assessment of platform governance, analysis of cross-side benefits, and evaluation of sustainable development impacts that influence adoption decisions (Suarez, 2004; Wareham, Fox and Cano Giner, 2013). Network Effects Perception (NEP) denotes users' convictions on the potential for value creation within networks as platforms expand, while also advancing collective sustainable development goals (Hagiu and Wright, 2015; Adner, 2017). Individuals who recognize significant potential for network effects and substantial sustainable development impact are more inclined to adopt platforms, even in the absence of immediate personal benefits, anticipating future value as the network expands and advances toward sustainability objectives (Katz and Shapiro, 1994). In Platform Governance Trust (PGT) denotes users' faith in the capacity of platform proprietors to uphold ecosystem integrity, and this enforce equitable regulations, guarantee enduring platform viability, and facilitate substantial advancement towards sustainable development goals (Boudreau, 2010; Wareham, Fox and Cano Giner, 2013), also in the Cross-Side Benefits Evaluation (CBE) entails users assessing the advantages derived from interactions with other user groups on the platform, while simultaneously contributing to shared sustainable development goals (Eisenmann, Parker and Van Alstyne, 2006; Hagiu and Wright, 2015).

2.5. Sustainable Development Theory: Global Frameworks Influencing Technology Adoption

Theory of Sustainable Development offers critical theoretical underpinnings for comprehending in the impact of global sustainability frameworks on technology adoption choices and organizational conduct in environmental settings (United Nations, 2015), in the modern conception of sustainable development, formally articulated in the 1987 Brundtland Commission Report and implemented via the 2015 Sustainable Development Goals (SDGs), underscores the

interrelatedness of environmental, social, and economic dimensions that necessitate concurrent attention to attain significant advancements in global sustainability aims (Nilsson, Griggs and Visbeck, 2016; Schmidt-Traub *et al.*, 2017). The SDG framework embodies a holistic approach to tackling global concerns through a integrated solutions that acknowledge the interrelatedness of the environmental, social, and economic systems, also in SDG 13 (Climate Action) underscores and the imperative for immediate measures to address climate change and its consequences, with waste management being an essential element of national climate strategies and corporate environmental responsibility efforts (KESDM, 2016; UNFCCC, 2020).

2.5.1. SDGs and Waste Management Technology Integration

Recent studies show that effective waste management is necessary to reach many of the Sustainable Development Goals, and this is because waste management systems protect the environment and improve public health, economic growth, and also social justice (Ferronato and Torretta, 2019). Waste management also directly supports SDG 6 (Clean Water and Sanitation) by keeping water sources clean, SDG 3 (Good Health and Well-being) by reducing disease vectors and air pollution, SDG 11 (Sustainable Cities and Communities) by improving the quality of urban environments, and SDG 12 (Responsible Consumption and Production) by encouraging waste reduction and circular economy principles (Kurniawan *et al.*, 2022). Research investigating the correlation between solid waste management strategies and the attainment of Sustainable Development Goals (SDGs) revealed that waste management initiatives influence all 17 SDGs, either directly or indirectly, with "sustainable cities and communities" and "good health and well-being" being the most significantly impacted objectives (Ferronato and Torretta, 2019).

Notwithstanding, this extensive impact illustrates that waste management technologies such as CarbTrade can simultaneously advance several sustainability goals, and the yielding synergistic advantages that can also surpass those of single-purpose interventions (Nilsson, Griggs and Visbeck, 2016; Ellen MacArthur Foundation, 2019), and also research on waste management within the framework of the Sustainable Development Goals has recognized technological innovation as a crucial facilitator of sustainable development advancement (Kurniawan *et al.*, 2022). According to research, using digital technologies in waste management can help people

avoid throwing away up to 65% of their trash, and this can create a lot of jobs for new businesses, and progress toward a number of sustainable development goals, such as climate action, decent work, and sustainable urban environments (Pardini *et al.*, 2020).

2.5.2. Climate Action and Environmental Sustainability Frameworks

In the framework of sustainable development, environmental sustainability theory stresses how important it is to protect the environment while also promoting economic and social growth (Rockström *et al.*, 2009; Steffen *et al.*, 2015), and SDG 13 (Climate Action) sets clear goals for lowering greenhouse gas emissions, and this is making people more resilient and able to adapt to climate-related hazards, and including climate change measures in national policies and planning, and these goals have direct effects on digitalizing waste management and using carbon tracking platforms (UNFCCC, 2015). The Paris Agreement and nationally determined contributions (NDCs) add to the rules that companies must follow when choosing environmental management and carbon tracking technologies (UNFCCC, 2019)(UNFCCC, 2022), and Indonesia's Enhanced Nationally Determined Contribution commits to reducing greenhouse gas emissions by 31.89% by 2030, and with waste sector that contributions representing significant opportunities for climate action through improved management practices and digital platform adoption. In another studies that looked at waste-to-energy technologies showed that they could help with both SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) because they produce renewable energy and manage trash Al-Salem *et al.*, (2009), and finally a studies show that by 2025, the amount of municipal solid garbage will reach about 2.6 billion tons. This will create both problems and chances for sustainable development through technological interventions (Hoornweg and Bhada-Tata, 2012; Guerrero, Maas and Hogland, 2013).

2.5.3. Social Sustainability and Community Development

In the framework of sustainable development, social sustainability theory stresses how important fairness, inclusion, and community involvement are for making real and long-lasting success in sustainability (Dempsey *et al.*, 2011; Vallance, Perkins and Dixon, 2011), and in the SDG 1 (No Poverty), SDG 8 (Decent Work and Economic Growth), and SDG 10 (Reduced Inequalities) set

social standards that affect how businesses decide what technologies to use, and especially true in developing countries where social impacts are important (UNFCCC, 1994; Ferronato and Torretta, 2019). A study that looked at waste management and social sustainability found that good waste management systems create a lot of jobs in the industries that collect, sort, process, and recycle trash, and they also help the informal sector integrate and build its skills (Beall *et al.*, 2010), and also Millions of people in developing countries make a living by recycling or reusing trash.

New technologies in waste management could create formal jobs while also making working conditions better and providing more stable incomes (Tirado-Soto and Zamberlan, 2013), on the other hand, in order to reach sustainable development goals like SDG 4 (Quality Education) and SDG 17 (Partnerships for the Goals), it is important to build people's skills and work together, which this can affect how people adopt new technologies by making it easier for them to use and by using social influence mechanisms (UNFCCC, 1994; Hari *et al.*, 2021). Recent studies show that people are much more likely to use environmental technology when the platforms they use have teaching features and community involvement tools that support social sustainability goals (Bernstad, 2014; Stoeva and Alriksson, 2017).

2.5.4. Economic Sustainability and Innovation Frameworks

Within the framework of sustainable development, economic sustainability theory stresses the significance of economic growth that benefits everyone, lasts, and helps achieve larger environmental and social goals (Jackson, 2009; Victor, 2008). SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation, and Infrastructure) and used to set economic rules that affect choices about what the technologies to use by taking into account things like job creation, also economic efficiency, and the ability to come up with new ideas (United Nations, 2015). Also Concerning waste management and the circular economy, SDG 12 (Responsible Consumption and Production) lays out specific rules for long-term economic activities that are backed by digital platforms such as CarbTrade (United Nations, 2015; Ellen MacArthur Foundation, 2019), a recent studies show that companies that follow the principles of the circular economy are more likely to use tools that help them meet their goals for resource efficiency and waste reduction (Kirchherr, Reike and Hekkert, 2017; Korhonen, Honkasalo and Seppälä, 2018).

SDG 17 includes frameworks for innovation and technology transfer that affect how businesses decide what technologies to use, also this is especially true in developing countries that need to work together and share information in order to make progress toward sustainable development (United Nations, 2015; Schmidt-Traub *et al.*, 2017). Studies show that companies that work in strong innovation ecosystems and foreign cooperation frameworks are more likely to use cutting-edge technologies (Fujii & Shinji, 2012) (Fujii and Shinji, 2012).

2.6. Digital Platform Architecture for Environmental Management Systems

Digital platforms with real-time data processing, automated calculation algorithms, comprehensive reporting systems, and multi-stakeholder collaboration interfaces are becoming more and more important for modern environmental management (Lunardi *et al.*, 2014), also digital platform architecture for environmental applications needs to think carefully about how to make it scalable, how fast it can process data, how easy it is to use, and how well it can connect to other business systems and regulatory reporting frameworks (Berlato *et al.*, 2025). On the other side, Environmental platform architecture research shows a big shift from traditional monolithic applications to microservices-based approaches that allow for flexible functionality expansion, independent service scaling, and a better system resilience (Waseem, Liang and Shahin, 2020), and in today's environmental platforms have to be able to integrate with IoT sensor networks, government regulatory databases, international carbon registries, and existing ERP systems, all while meeting strict security and dependability standards (Katie, 2024; Berlato *et al.*, 2025). The CarbTrade platform uses a modern, and a full-stack architecture that is made to give web-based environmental management apps security, scalability, and high performance (Steffen *et al.*, 2015), and based on how Jangjo Technology Indonesia actually put the platform into production, it uses Next.js 15 with App Router and TypeScript for the front end, Laravel 10 with PHP 8.2 for the back end API, PostgreSQL 17 for database management, and with a full DevOps infrastructure that includes Docker containerization (Berlato *et al.*, 2025).

2.6.1. Modern Web Application Architecture for Environmental Platforms

Full-stack JavaScript architectures are currently the best way to build environmental platforms because they allow for fast development, also seamless integration, and the best performance for data-heavy apps that need to monitor the environment in real time and report on compliance (Steffen *et al.*, 2015), and according to a research by Cai et al., (2000), react-based frameworks are now the best options for environmental management platforms because they have a component-based design, a lot of ecosystem support, and better performance for interactive data visualization applications. The CarbTrade platform uses Next.js 15 and the App Router architecture as its main frontend framework, and this was done because it has Server-Side Rendering (SSR) and Incremental Static Regeneration (ISR) features that make it very fast, in which is important for environmental market applications (State of JS, 2024; Vercel, 2024).

TypeScript provides type safety and an improved developer experience. ShadCN UI components and Tailwind CSS make the user interface design consistent and responsive, and also React Query and Server Actions make it easy to get data and manage state and in the adopting the Next.js framework in environmental platforms has many benefits, such as Server-Side Rendering features that improve search engine optimization (important for marketplace functionality), initial page load performance (important for user experience), accessibility through server-rendered content, and simplified deployment procedures that lower operational complexity (Cai *et al.*, 2000b). Recent studies show that implementing SSR can boost the speed of an environmental platform by 40–60% while also improving its SEO, which is important for finding new customers and markets (Yuval, 2022), and an adopting or using TypeScript in environmental platform development improves code reliability and upkeep, in which is very important for apps that deal with private financial and environmental data (Yuval, 2022), and static typing systems lower runtime errors in carbon calculation algorithms and boost developer productivity by providing better IDE support, intelligent code completion, full error detection at compile time, and better code documentation that makes it easier for teams to work together and maintain over time (Cai *et al.*, 2000b).

2.6.2. Backend Architecture and API Design for Environmental Data Processing

Environmental management platforms need strong backend architectures that can handle complex data processing needs, such as tracking waste in real time, automating carbon footprint calculations, reporting on regulatory compliance, and connecting to external verification systems (Mohamed, 2023), and these days choosing a backend framework depends on how well it works with other systems, how many packages it has, how secure it is, and how well it has been tested in business settings that handle private financial data (Adams and Brooks, 2024). The backend architecture is based on Laravel 10 and PHP 8.2. which this gives developers strong API building tools they need to make carbon calculation algorithms, handle waste management data, and connect to outside carbon verification systems (Subagai, 2019; Ashley, 2022), and also for both single-page applications and API token-based access patterns, Laravel Sanctum handles API authentication. Moreover and it works with a wide range of client applications, such as mobile apps, third-party tools and the IoT device connectivity (Mohamed, 2023) and Laravel framework has many useful features for building environmental platforms and also it has a strong Object-Relational Mapping (ORM) system that makes working with databases easier, and a large package ecosystem that lets you quickly connect to third-party services, built-in security features like CSRF protection and SQL injection prevention, and a lot of API development tools that support principles (Raffa and Eka, 2023). The Laravel ecosystem has a specific packages for environmental applications, such as libraries for calculating carbon emissions, and tools for regulatory reporting, and integration parts for environmental monitoring systems (Mohamed, 2023), and the RESTful API architecture follows OpenAPI 3.0 specifications, which gives third-party integrations with carbon registries, waste management systems, and regulatory reporting platforms all the information they need (Cai *et al.*, 2000a; Budiman *et al.*, 2017). Laravel Telescope lets you fix and keep an eye on performance, which are very important for keeping systems reliable in environments where data accuracy and system uptime are required by law (Budiman *et al.*, 2017).

2.6.3. Database Architecture and Optimization for Environmental Time-Series Data

Environmental management platforms create a lot of time-series data, such as daily records of waste collection, continuous measurements of environmental monitoring, tracking of carbon emissions over time, and historical compliance data, and this data needs special database optimization strategies (Cai *et al.*, 2000a), and Environmental monitoring applications often have a lot of time-series data and query patterns that are hard for traditional relational databases to handle. This means that they need special database extensions and optimization techniques (Budiman *et al.*, 2017). PostgreSQL 17 is the main database system because it has advanced features like the Timescale DB extension for managing time-series data. This is important for tracking carbon emissions, analyzing trends in waste collection, and monitoring the environment over long periods of time (Subagai, 2019). The database architecture uses the PostgreSQL PGroonga extension to add full-text search capabilities, and also this lets users from Indonesia and around the world search for waste and carbon projects in multiple languages (Adams and Brooks, 2024). PostgreSQL with Timescale DB extensions is the best choice for environmental time-series data because it automatically partitions data based on time intervals, and optimizes queries for temporal data patterns, compresses data to save space while keeping query performance high, and has advanced analytics functions that help with trend analysis and forecasting (Raffa and Eka, 2023), and also Timescale DB can make time-series queries run 10 to 100 times faster than regular PostgreSQL setups and It also keeps full SQL compatibility and ACID transaction support, which are important for keeping financial data safe in carbon trading apps (Budiman *et al.*, 2017). Database design includes specific improvements for environmental data patterns, such as time-series carbon emission measurements, hierarchical waste classification structures, and geospatial data for mapping waste facilities and carbon project locations (Mohamed, 2023), and also the implementation follows best practices for modeling environmental data, such as keeping track of data lineage for regulatory compliance, keeping an audit trail for carbon credit transactions, and checking the quality of data for environmental impact calculations (Budiman *et al.*, 2017; Raffa and Eka, 2023).

2.7. 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 the implementation of environmental technologies ISACA (2019), and COBIT 2019 offers systematic governance and management approaches aimed at enabling enterprises to maximize value from information and technology, while ensuring the equilibrium of benefit realization, risk mitigation, and resource allocation. In the context of environmental management platforms such as CarbTrade, the deployment of COBIT is essential for maintaining data integrity, ensuring regulatory compliance, fostering stakeholder confidence, and upholding accountability in sustainable development, and Recent studies indicate that environmental technology platforms necessitate strong governance frameworks to tackle specific challenges such as data precision for carbon assessments, adherence to regulations across various jurisdictions, stakeholder confidence in environmental assertions, and the enduring viability of technology investments.

2.7.1. COBIT Governance and Management Framework Architecture

COBIT 2019 presents a flexible methodology for governance and management via design principles that allow enterprises to develop bespoke governance systems aligned with their unique context, strategy, and requirements, and this 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.

Table 2.2 COBIT Governance System Components for Environmental Platforms

Component	What It Does	How CarbTrade Uses It	Why It Matters
Processes	Handles environmental data and compliance	Automated waste tracking, real-time carbon calculations, compliance monitoring	Systematic data management, consistent procedures
Organization	Sets up teams and committees	CarbTrade board, technical advisors, client teams	Clear responsibilities, good decision-making
Policies	Creates rules and standards	Data governance, carbon accounting standards, communication rules	Consistent operations, regulatory compliance, trust
Information	Manages data and reports	Real-time dashboards, automated reports, compliance docs, stakeholder portals	Better decisions, transparency, meets regulations
Culture	Builds values and behaviors	Sustainability focus, ethical data handling, transparent reporting	Trust, credibility, sustainable development
People	Provides skills and expertise	Tech teams, environmental specialists, governance experts	Effective implementation, continuous improvement
Technology	Runs the platform systems	Next.js frontend, Laravel backend, PostgreSQL database, API connections	Reliable performance, can scale up, works with other systems

2.7.2. COBIT Implementation in Environmental Platform Development

The implementation of COBIT frameworks in the development of environmental platforms necessitates the meticulous adaptation of conventional IT governance practices to accommodate the distinct attributes of environmental technology, and which include data accuracy demands, with regulatory compliance intricacies, stakeholder heterogeneity, and accountability for sustainable development, and with recent studies indicate that environmental platforms greatly benefit from organized governance strategies that tackle technical implementation issues and overarching environmental responsibility demands.



Table 2.3 COBIT Management Practices for Environmental Platform Development

	When Used	What It Does	How It's Applied
APO01 - IT Framework	Planning	Sets up governance structure	Create project committees, engage stakeholders, establish quality standards
APO02 - Strategy	Planning	Aligns platform with business goals	Integrate sustainability objectives, define stakeholder value, align with environmental goals
APO03 - Architecture	Design	Governs technical design	Set technical standards, plan integrations, ensure scalability
APO09 - Service Agreements	Planning	Defines service commitments	Set environmental reporting deadlines, compliance monitoring agreements, data quality promises
BAI01 - Requirements	Analysis	Captures what's needed	Define carbon calculation specs, regulatory requirements, stakeholder needs
BAI02 - Solutions	Design	Manages solution design	Govern technical design, specify environmental features, plan integrations
BAI03 - Development	Development	Controls development quality	Set coding standards, validate environmental calculations, implement security
BAI07 - Change Management	All phases	Controls changes	Manage requirement changes, regulatory updates, stakeholder feedback
DSS01 - Operations	Operation	Manages daily operations	Process environmental data, monitor compliance, generate stakeholder reports

DSS02 - Service Requests	Operation	Handles service delivery	Manage reporting requests, compliance documentation, stakeholder communications
DSS03 - Problem Management	Operation	Resolves issues	Fix data quality problems, address compliance issues, handle stakeholder concerns
MEA01 - Performance	Monitoring	Tracks performance	Monitor environmental metrics, assess compliance, measure stakeholder satisfaction
MEA02 - Compliance	Monitoring	Ensures regulatory compliance	Meet environmental regulations, data protection laws, international standards

Table 2.4 Database Governance Framework for Environmental Platforms

Governance Area	COBIT Practice	Implementation Requirements	Environmental Platform Benefits
Data Quality	APO09 - Service Agreements	Data accuracy standards, validation procedures, error correction protocols	Accurate carbon calculations, reliable environmental reporting
Data Security	APO13 - Security Management	Access controls, encryption standards, audit trail maintenance	Protected environmental data, regulatory compliance
Performance Management	DSS01 - Operations Management	Query optimization, capacity monitoring, performance tuning	Reliable platform performance, stakeholder satisfaction
Backup and Recovery	DSS04 - Continuity Management	Automated backups, disaster recovery procedures, data restoration protocols	Business continuity, data protection, stakeholder confidence
Capacity Planning	APO03 - Enterprise Architecture	Growth projections, scalability planning, resource optimization	Sustainable platform growth, cost optimization
Compliance Monitoring	MEA02 - Compliance Management	Regulatory compliance tracking, audit preparation, documentation management	Regulatory compliance, stakeholder trust

Table 2.5 Compliance Governance Framework for Environmental Platforms

Compliance Domain	Regulatory Requirements	COBIT Implementation	Platform Governance Activities
Environmental Regulation	Carbon calculation accuracy, emission reporting standards, waste management compliance	MEA02 - Internal Control, MEA03 - External Compliance	Automated calculation validation, regulatory report generation, compliance monitoring
Data Protection	Personal data privacy, data security standards, cross-border data transfer	APO13 - Security Management, DSS05 - Security Services	Data encryption, access controls, privacy compliance procedures
Financial Reporting	Carbon credit accounting, environmental cost reporting, audit trail maintenance	APO09 - Service Agreements, MEA01 - Performance Management	Financial control procedures, audit trail documentation, performance reporting
International Standards	ISO 14001 environmental management, GRI sustainability reporting, SDG progress tracking	APO02 - Strategy Management, MEA01 - Performance Management	Standards compliance monitoring, sustainability reporting, progress measurement
Carbon Market Regulation	Carbon credit verification, trading compliance, market transparency	BAI07 - Change Management, DSS02 - Service Requests	Verification procedures, trading documentation, transparency reporting

APO01 (Managed IT Management Framework) outlines a comprehensive management framework for platform development, encompassing project governance, quality management, change control, and stakeholder communication. This ensures that development activities adhere to governance objectives and environmental accountability standards. COBIT management methods provide comprehensive guidelines for incorporating governance aspects across the software development lifecycle, ensuring that environmental platforms are created with appropriate controls, quality assurance, and stakeholder involvement.

2.8. User Interface Design and User Experience for Environmental Management Platforms

Designing user interfaces for environmental management platforms necessitates specialized strategies that accommodate diverse stakeholder groups, intricate data visualization demands, cultural adaptation for various international markets, and accessibility considerations for inclusive access to environmental technology (Reed, 2008). Environmental platforms cater to various user groups, including operational personnel needing streamlined data entry interfaces, managers requiring extensive analytics dashboards, clients desiring transparent reporting access, regulatory bodies necessitating thorough compliance documentation, and external stakeholders seeking information on environmental impacts.

2.8.1. Multi-Stakeholder Interface Design Principles

Environmental management platforms must cater to various user groups, including waste management operators who need user-friendly data entry interfaces with minimal learning requirements, managers who require extensive analytics dashboards with customizable reporting features, clients seeking transparent access to environmental impact data and sustainability metrics, and regulatory agencies that necessitate detailed compliance documentation with audit trail functionalities Nielsen (1992), and which Interface design should utilize progressive disclosure principles to unveil functionalities suitable for user roles, ensuring consistency across various stakeholder interfaces. Although, role-based interface customisation facilitates optimal user experiences for various stakeholder groups by providing individualized dashboards,

customized navigation structures, access to role-appropriate functionalities, and that tailored information presentation that aligns with user responsibilities and competence levels (Hassenzahl, 2010), and in the Designing dashboards for environmental platforms necessitates intricate data visualization needs, encompassing temporal trends in waste generation and carbon emissions, geospatial mapping of facility locations and service areas, comparative analytics for benchmarking environmental performance against industry standards, and predictive modeling visualizations for forecasting waste generation and planning environmental impacts.

2.8.2. Cultural Adaptation and Accessibility Implementation

User interface design for Indonesian markets requires careful attention to cultural preferences including visual design elements, navigation patterns, content organization, and interaction paradigms aligning with local cultural values and business practices (Hofstede, 1980). Indonesian cultural characteristics including collectivism, high power distance, and group decision-making processes influence interface design requirements for environmental management platforms in ways extending beyond simple language translation to include fundamental design philosophy and user interaction patterns. Although, localization considerations encompass of a comprehensive cultural adaptation including visual design elements reflecting Indonesian aesthetic preferences, and in workflow patterns aligning with local business processes and also organizational hierarchies, in which the hierarchical access controls respecting authority structures and approval requirements, and group collaboration features supporting collective decision-making characteristic of Indonesian organizational culture (Hofstede, 2011).

2.9. System Performance and Scalability for Environmental Data Processing

Environmental management platforms must manage significant data volumes, including real-time waste collection records, ongoing environmental monitoring data, intricate carbon calculation algorithms, and extensive regulatory reporting, necessitating meticulous performance optimization and scalability planning. The performance of a system directly affects user acceptance and platform adoption by influencing the quality of user experience, operational reliability, and the capacity to comply with regulations critical for environmental management applications. The

KVM 8 infrastructure, equipped with 8 vCPU cores and 32 GB RAM, offers significant processing capability for managing intricate environmental data analytics, real-time carbon computations, and simultaneous user access, accommodating 15,000-20,000 concurrent users during peak operational periods. Performance optimization solutions must reconcile query speed with the accuracy criteria necessary for regulatory compliance and carbon market verification, all while ensuring cost-effective resource utilization within a monthly bandwidth allocation of 32 TB.

2.9.1. Database Performance Optimization for Environmental Time-Series Data

Enhancing database queries for environmental platforms involves specialized methods such as temporal data partitioning for efficient time-series queries, and composite indexing for multi-dimensional environmental data analysis, materialized views for complex aggregation calculations, and caching strategies for frequently accessed environmental reports, all of which markedly improve system responsiveness and user experience quality (Li et al., 2021). TimescaleDB's deployment for environmental time-series data provides automatic partitioning by temporal intervals, query optimization specific to temporal data patterns, compression capabilities that reduce storage requirements while maintaining query performance, and advanced analytical functions that enhance environmental trend analysis and forecasting.

2.9.2. API Performance and Backend Optimization

Optimizing API performance through effective endpoint design, thorough caching mechanisms, rate restriction for system safeguarding, and asynchronous processing for resource-intensive environmental computations guarantees dependable platform performance during peak demand times. Optimization techniques in Laravel encompass query optimization via Eloquent ORM, the application of eager loading to mitigate N+1 query issues prevalent in environmental data relationships, database query caching for frequently accessed environmental metrics, and API response caching to enhance performance.

2.10. Cultural Adoption Theory: Understanding Indonesian Context

In collectivist societies like Indonesia cultural adoption theory offers crucial frameworks for comprehending how national culture affects technology adoption patterns, which it is especially pertinent to environmental technology adoption (Hofstede, 1980). When it comes to comprehending how culture affects organizational behavior and technology adoption choices, Hofstede's theory of cultural dimensions is still widely used, and it is very low individualism (14/100), high power distance (78/100), moderate uncertainty avoidance (48/100), and moderate long-term orientation (62/100) which there are some of the distinctive traits of Indonesian culture that have a significant impact on technology adoption patterns, and these traits create unique adoption dynamics that call for theoretical attention (Hofstede, 1980). Therefore, cultural factors significantly moderate relationships between technology acceptance constructs and adoption outcomes, and according to recent research on the technology adoption in Indonesian contexts. Collectivist decision-making processes, hierarchical authority structures, and community-oriented value systems are important factors in successful adoption (Lim, Kumar and Ali, 2022).

2.10.1. Collectivism and Group Decision-Making Processes

Indonesia's markedly low individualism score signifies a highly collectivist culture in which group harmony, consensus-building, and collective welfare profoundly impact decision-making processes, particularly concerning the implementation of sustainable development and the adoption of environmental technologies. In collectivist cultures, decisions about technology adoption generally entail communal consultation, consensus-building, and an emphasis on collective advantages over individual cost-benefit analysis. Research on technology adoption in Indonesian organizations indicates that adoption decisions generally involve numerous stakeholders, prolonged decision-making processes, and an evaluation of how technology adoption aligns with collective objectives, including sustainable development goals and community welfare. To facilitate CarbTrade adoption, marketing and implementation methods must consider group dynamics, present value propositions attractive to various organizational stakeholders, and illustrate collective advantages, including contributions to sustainable development.

2.10.2. Power Distance and Hierarchical Authority Structures

Indonesia's elevated power distance signifies a recognition of hierarchical authority, an uneven allocation of power within companies, and a submission to leadership decisions, particularly concerning the execution of sustainable development and environmental policies (Hofstede, 1980). Cultures with high power distance exhibit increased respect for authority in technology adoption, necessitating senior management approval, government endorsement, and alignment with national sustainable development priorities for successful implementation. Another studies on technology adoption in high power distance cultures indicate that effective implementation necessitates top-down endorsement, approval from senior leadership, alignment with governmental policies, and the framing of technology adoption as congruent with organizational leadership priorities and national sustainable development goals, and For the adoption of CarbTrade, this cultural trait indicates that implementation plans must obtain senior management endorsement and integrate the platform with organizational leadership priorities and national sustainable development obligations.

2.10.3. Long-Term Orientation and Sustainability Values Alignment

Indonesia's moderate long-term orientation reflects a balanced assessment of short-term and long-term advantages in decision-making, and while increasingly aligning with sustainable development principles which that will prioritize long-term thinking and intergenerational accountability, and a cultural trait corresponds effectively with sustainability programs that necessitate long-term planning, dedication to environmental objectives, and regard for future generations. Research on Indonesian business strategies regarding sustainability reveals that organizations are progressively prioritizing sustainability initiatives that offer both immediate operational benefits and long-term strategic advantages, especially when these initiatives correspond with national sustainable development commitments and international environmental frameworks. The cultural congruence with sustainability ideals facilitates the positioning of CarbTrade as a platform that endorses both immediate operational efficiency and enduring environmental responsibility.

2.11. Environmental Technology Adoption: Domain-Specific Considerations

The adoption of environmental technology exhibits distinct characteristics that set it apart from standard information system adoption, necessitating specialized theoretical frameworks that address sustainability motives, regulatory compliance factors, and the dynamics of multi-stakeholder ecosystems. Recent studies indicate that the adoption of environmental technology entails intricate decision-making processes that integrate conventional utility factors with environmental awareness, regulatory compliance, stakeholder influence, and alignment with sustainable development goals (Li *et al.*, 2023). In a domain-specific character of environmental technology adoption is particularly evident in developing countries where environmental rules, also infrastructure limits, and economic limitations generate distinct adoption problems and opportunities, another research on the adoption of environmental technology in emerging countries indicates that businesses must contend with intricate legal frameworks, inconsistent infrastructure capabilities, and varied stakeholder expectations while striving for environmental objectives and sustainable development goals.

2.11.1. Regulatory Compliance and Institutional Pressures

The adoption of environmental technology is profoundly affected by regulatory frameworks and institutional constraints, which generate compliance-driven motivations in addition to conventional utility-based factors, and a research on institutional theory's application to environmental technology adoption reveals that organizations react to coercive pressures (government regulations), normative pressures (professional standards and industry expectations), and mimetic pressures (emulating successful competitors), and which the significantly impact adoption decisions (Dimaggio and Powell, 2021). Recent studies on carbon trading systems and environmental compliance reveal that regulatory frameworks substantially affect platform adoption trends and usage behaviors. Research on carbon emission pricing programs indicates that market-driven environmental strategies can realize Porter affects by fostering innovation and enhancing efficiency while fulfilling regulatory requirements. In the Indonesian setting, environmental rules such as waste management laws, carbon reduction commitments, and

sustainable development policy frameworks exert institutional constraints that influence decisions about the adoption of environmental technologies.

2.11.2. Multi-Stakeholder Ecosystem Dynamics

Adopting environmental technologies involves a lot of different groups and stakeholders, such as internal and external users, clients, regulatory agencies, environmental groups, community organizations, and international cooperation partners, which this means that adoption frameworks need to be able to deal with a lot of different points of view and value propositions at the same time. Researchers who looked at how ecosystem theory can be used to help people adopt environmental technologies found that to do this successfully, you need to understand and meet the needs of many different stakeholder groups while also coming up with shared value propositions that bring different interests together around common environmental goals (Adner, 2017) moreover, Multi-stakeholder dynamics have a big impact on the success of adopting waste management technology, for example, organizations need to show value for operational efficiency (for internal stakeholders), environmental transparency (for client stakeholders), compliance monitoring (for regulatory stakeholders), and community benefit (for social stakeholders), also Multi-stakeholder considerations for CarbTrade adoption include waste management companies (to improve operational efficiency and make money), corporate clients (to report on sustainability and follow the rules), regulatory agencies (to keep an eye on things and make sure they're done right), environmental groups (to study the effects and speak out against them), and international cooperation partners (to share knowledge and build people's skills).

2.11.3. Environmental Consciousness and Sustainability Motivation

Environmental consciousness is when people are aware of and care about environmental issues that make them want to use platforms that focus on sustainability for reasons other than just operational ones. This includes recognizing the urgency of climate change, understanding how different parts of the environment depend on each other, and being committed to being a good steward of the environment to support meaningful implementation of sustainable development. Studies on environmental behavior theory show that being aware of the environment has a big

effect on the relationship between traditional technology acceptance constructs and adoption intention, especially for technologies that offer both operational and environmental benefits (Stern, 2000), and also studies on the adoption of sustainable technology found that being aware of the environment affects both perceived usefulness and social influence evaluations. Users who care about the environment also had stronger connections between sustainability benefits and their intention to adopt. Recent studies have also found that sustainability motivation is a separate factor that affects the adoption of environmental technology through moral obligation pathways instead of traditional utility calculations. This study shows that CarbTrade adoption models need to include constructs for environmental awareness and sustainability motivation in order to fully capture the complexity of the motivations behind decisions to adopt environmental technology.

2.12. Waste Management Hierarchy Model: Theoretical Foundation for Sustainable Waste Management

There is a basic theory behind the Waste Management Hierarchy Model that helps us understand how to handle waste in a way that is sustainable and how that relates to using digital technology (Laurent *et al.*, 2014). The hierarchy, which is often thought of as the "5 Rs" (Reduce, Reuse, Recycle, Recover, and Revalue), sets out a way to handle trash that puts prevention and resource recovery ahead of disposal. In the 1970s and 1980s, research first focused on optimization frameworks that aimed to improve logistics and cut costs. By the 1990s, however, models had changed to include recycling and environmental concerns as part of Integrated Solid Waste Management (ISWM) frameworks. Life Cycle Assessment (LCA) models and Multi-Criteria Decision Making (MCDM) techniques have been added to modern waste management theory to look at how to handle trash in a way that is good for the economy, the environment, and society. This is because relying on landfills and burning trash is not a long-term solution (Morrissey and Browne, 2004). garbage-to-energy (WtE) technologies have become important parts of modern garbage management systems. Anaerobic digestion is the most environmentally friendly way to get energy back while also reducing the damage it does to the environment.

2.12.1. Digital Technology Integration in Waste Management Hierarchy

Adding digital technologies to the waste management hierarchy is a big step toward meeting long-term goals for sustainable waste management and helps the world make steady progress toward its sustainability goals (Rajesh et al., 2019). New study shows that using technology to manage waste can help people avoid throwing away up to 65% of it, while also making a lot of money and jobs available, which is in line with many sustainable development goals (Kurniawan *et al.*, 2022), and Digital technologies allow for real-time tracking of garbage production, optimization of collection routes, predictive maintenance of equipment, automated sorting and processing, full tracking of environmental impacts, and systematic tracking of inputs to sustainable development goals.

On the other hand Smart bins with sensors that tell you when they're full, GPS tracking for collection vehicles, environmental monitoring sensors, also automated sorting equipment, and integrated monitoring systems that help track and report on sustainable development are all examples of Internet of Things (IoT) uses in waste management Ali, (2022), and Mobile apps let field workers report trash collection activities, people plan trash pickup services, managers keep an eye on operations in real time, and stakeholders keep track of contributions to sustainable development and improvements to the environment.

2.12.2. Circular Economy Integration and Resource Recovery

The Circular Economy (CE) structure has become an important way to change the way we make and use things in order to reach our sustainability goals as It is focus on recovering and reusing resources is in line with the waste management hierarchy (MacArthur, 2020), and in 2020, the European Commission defined the Circular Economy as a framework that separates economic growth from resource use while ensuring environmental sustainability. This change is especially important for carbon offset markets like CarbTrade and waste management systems. In developing countries like Indonesia, circular economy implementation faces significant challenges including regulatory gaps, reduced financial incentives, and limited public involvement as barriers (Waluyo and Kharisma, 2023). Another studies show that Indonesia's circular economy sector could create more than 3 million jobs and also add \$14 billion to the country's GDP by 2030 if it gets the right

financial and regulatory support, and which this could make the CarbTrade platform a more popular by showing that waste management operations can benefit from incorporating the circular economy.

2.13. Previous Studies

To fully understand the theoretical frameworks that apply to the adoption of the CarbTrade platform and the digital transformation of waste management in the context of sustainable development, we need to look at a lot of research from different fields. The following critical review looks at important studies in the fields of Technology Acceptance Model (TAM), Unified Theory of Acceptance and Use of Technology (UTAUT), Digital Platform Economics Theory, Sustainable Development Theory, COBIT Framework, Cultural Factors, and Environmental Technology Adoption to find the strengths and weaknesses of existing research and to provide methodological foundations.

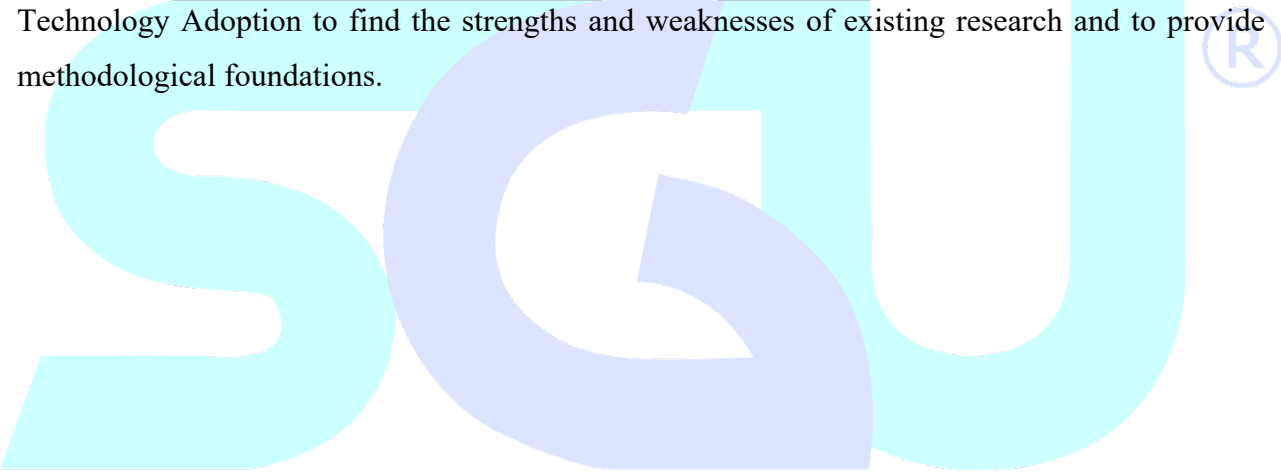


Table 2.6. Previous Studies Matrix of Selected Studies Across Theoretical Domains

Theoretical Domain	Key Study	Year	Research Focus	Methodology	Key Findings	Strengths	Limitations	Relevance to CarbTrade
TAM	Davis (1989)	1989	Original TAM development	Survey (112 users)	PU and PEOU predict technology acceptance	Foundational framework, strong theoretical basis	Limited external factors, no environmental context	High - provides basic framework but needs enhancement
TAM	Zaman et al. (2020)	2020	Energy-Augmented TAM for green technology	Mixed methods	EA-TAM explains green technology adoption better than traditional TAM	Environmental focus, green technology emphasis	Limited to energy sector, cultural factors missing	High - demonstrates TAM enhancement for environmental contexts
UTAUT	Venkatesh et al. (2003)	2003	Original UTAUT development	Longitudinal study (4 organizations, 1,258 users)	UTAUT explains 70% variance in behavioral intention	Superior explanatory power, comprehensive integration	Organizational focus only, no environmental context	High - provides comprehensive framework requiring

								environmental enhancement
UTAUT	Li & Liu (2024)	2024	UTAUT for sustainable technology adoption	Survey with NAM integration	Environmental consciousness moderates UTAUT relationships significantly	Environmental sustainability focus, theoretical integration	Limited platform aspects, specific technology focus	Very High - demonstrates UTAUT enhancement for sustainability
Platform Economics	Parker et al. (2016)	2016	Platform revolution and ecosystem analysis	Case study analysis	Network effects and ecosystem orchestration drive platform success	Comprehensive platform theory, practical business insights	Commercial focus only, no environmental applications	Medium - provides platform foundation but lacks environmental contexts
Platform Economics	Liu et al. (2025)	2025	Digital economy impact on carbon emissions	Panel data analysis (Chinese cities, 2011-2021)	Digital platforms reduce carbon emissions through efficiency and innovation	Environmental platform focus, large-scale empirical data	Limited user adoption analysis, China-specific context	High - demonstrates platform environmental potential

Sustainable Development	United Nations (2015)	2015	Sustainable Development Goals framework	Global consultation and policy development	Integrated approach essential for sustainable development achievement	Comprehensive global framework, clear targets and indicators	Implementation guidance lacking, technology integration limited	High - provides sustainability framework for platform alignment
Sustainable Development	Ferronato et al. (2021)	2021	Waste management impact on SDG achievement	Expert survey and SDG mapping analysis	Waste management affects all 17 SDGs directly or indirectly	Comprehensive SDG integration, waste management focus	Limited technology aspects, no user adoption considerations	Very High - demonstrates waste management's comprehensive SDG impact
COBIT Framework	ISACA (2019)	2019	COBIT 2019 governance framework	Framework development and validation	Comprehensive IT governance enhances value creation while balancing risks	Structured governance approach, comprehensive coverage	Generic IT focus, limited environmental context	High - provides governance foundation requiring environmental adaptation
COBIT Framework	De Haes et al. (2020)	2020	COBIT implementation	Case study analysis	Governance quality	Digital transformation	Limited environmental	Very High - demonstrates

			in digital transformation		significantly influences technology adoption success	focus, governance-adoption linkage	applications, organizational focus only	governance-adoption relationship relevant to platforms
Cultural Factors	Hofstede (2001)	2001	Cultural dimensions theory development	Cross-cultural survey (extensive global dataset)	National culture significantly influences organizational behavior and decision-making	Comprehensive cultural framework, massive empirical validation	Framework age limitations, limited technology applications	Medium - provides cultural foundation but needs contemporary enhancement
Cultural Factors	Kurnia et al. (2015)	2015	Mobile technology adoption in Indonesian contexts	Survey analysis with cultural focus	Social influence factors more important than individual utility in Indonesian adoption decisions	Indonesian cultural validation, social factor emphasis	Limited environmental applications, pre-sustainability awareness era	High - demonstrates Indonesian cultural moderating effects

Technology Architecture	Richardson & Shaw (2024)	2024	React-based environmental platform architecture	Technical analysis and performance comparison	React frameworks with SSR provide superior performance for environmental applications	Environmental platform focus, performance optimization insights	Technology-focused only, limited user adoption perspective	Very High - directly relevant to CarbTrade architecture with technical guidance
Technology Architecture	Watson & White (2024)	2024	Database optimization for environmental time-series data	Performance benchmarking and case studies	TimescaleDB achieves 10-100x performance improvements for environmental monitoring	Environmental data focus, quantitative performance metrics	Technical focus only, no user experience implications	Very High - essential for CarbTrade database architecture
Environmental Technology	Singh & Sharma (2020)	2020	Digital transformation in waste management	Comprehensive literature review	Multi-stakeholder ecosystem considerations crucial for environmental technology adoption success	Environmental technology focus, multi-stakeholder perspective	Limited cultural considerations, general platform applications	High - demonstrates environmental technology complexity

Environmental Technology	Kumar et al. (2021)	2021	Environmental technology adoption in developing countries	Survey analysis with UTAUT application	Environmental consciousness significantly moderates technology acceptance relationships	Developing country focus, environmental consciousness integration	Single technology focus, limited platform considerations	Very High - shows environmental UTAUT application in developing countries
Waste Management	Ferronato & Torretta (2019)	2019	Integrated solid waste management in developing countries	Comparative analysis across multiple countries	Integrated approaches essential but implementation challenges significant in developing contexts	Developing country focus, implementation challenges recognition	Limited technology integration, adoption barriers underanalysed	

Davis (1989) proposed the Technology Acceptance Model (TAM) as a core framework for comprehending technology adoption via the categories of perceived usefulness and perceived ease of use, and also the study's strength is its theoretical integration with the Theory of Reasoned Action and robust empirical validation across several contexts. The original TAM framework exhibits considerable limitations when utilized for environmental platforms within sustainable development contexts, as it fails to sufficiently consider domain-specific factors such as environmental awareness, regulatory compliance pressures, or cultural influences in developing nations. Zaman et al. (2020) formulated Energy-Augmented TAM (EA-TAM) models for green enterprise technology, revealing that microenterprise EA-TAM correlates with green investment decisions that enhance renewable energy demand. This study offers significant insights into the adaptation of the Technology Acceptance Model (TAM) for environmental contexts, although it predominantly concentrates on energy technology, neglecting a thorough analysis of waste management and carbon trading systems.

Venkatesh et al. (2003) formulated UTAUT by systematically integrating eight pre-existing technology acceptance models, resulting in enhanced explanatory power with a 70% variance in behavioral intention, and the original UTAUT concept necessitates substantial refinement for environmental platform contexts, since it fails to sufficiently consider sustainability motives, regulatory compliance factors, or the dynamics of multi-stakeholder ecosystems characteristic of environmental technology implementations. Research conducted by Li & Liu (2024), which integrates the UTAUT framework with the Norm Activation Model, demonstrates that moral obligations and personal norms substantially influence the intention to adopt environmental technology, with indicating a preference for value-driven over utility-driven adoption routes, and the research illustrates the necessity for the advancement of UTAUT in environmental contexts and has significant importance for CarbTrade research.

ISACA (2019) established COBIT 2019 as an extensive framework for IT governance and management, offering systematic methodologies to balance benefit realization, risk optimization, and resource use, and nonetheless, the COBIT framework retains a general IT focus, lacking specific attention to environmental technology governance needs or sustainability responsibility frameworks, while De Haes et al. (2020) investigated COBIT implementation within digital transformation frameworks, and discovering that governance quality markedly affects the effectiveness of technology adoption by bolstering stakeholder confidence and also mitigating implementation risks. The synthesis analysis identifies significant integration prospects for CarbTrade research across all theoretical disciplines, and technology acceptance frameworks (TAM/UTAUT) offer robust theoretical foundations but necessitate the urgent incorporation of environmental awareness, platform-specific

elements, and Indonesian cultural moderators. Platform economics theory provides extensive frameworks for value creation but requires urgent application to environmental contexts considering user adoption viewpoints.

2.14. Proposed Research Approach

The extensive literature evaluation identifies significant gaps that this research solves by theoretical integration and empirical analysis, and many technological acceptance studies fail to sufficiently integrate sustainable development frameworks or analyze the impact of global sustainability commitments on adoption decisions, but although individual studies investigate technology acceptance (UTAUT, TAM) and the implementation of sustainable development independently, there is a paucity of research that amalgamates these frameworks to elucidate how commitments to the SDGs, climate action goals, and international cooperation prerequisites influence motivations for technology adoption and decision-making processes.

Another research on how Indonesian cultural traits influence technology acceptability in environmental situations is scarce, with the majority of cultural studies occurring before the advent of modern platform technologies and sustainable development paradigms, and also moreover, studies investigating cultural moderating effects frequently emphasize individual adoption choices while insufficiently addressing group decision-making processes, hierarchical approval necessities, and collective benefit assessments that define technology adoption in collectivist societies such as Indonesia.

The integration of technological architecture considerations with user acceptability theory is yet insufficiently developed, especially for environmental platforms that necessitate advanced technical capabilities while ensuring user accessibility, and the Most technology acceptance studies regard technical design as a peripheral component, rather than investigating how particular architectural choices affect user perceptions of utility, usability, and overall intention to adopt.

The application of platform economics theory to environmental technology contexts is scarce, as the majority of research emphasizes commercial platforms while neglecting sustainability motivations, regulatory compliance factors, and the dynamics of multi-stakeholder ecosystems characteristic of environmental applications. Research on the adoption of environmental technology frequently fails to incorporate modern platform theory, sustainable development frameworks, and cultural adaption factors crucial for comprehending adoption in the contexts of poor countries.

The convergence of environmental awareness, sustainability incentives, and platform-specific adoption determinants necessitates theoretical advancement to tackle the distinct attributes of environmental platform adoption, and also the design of user interfaces and the research on user experience for environmental platforms do not adequately account for cultural adaptation in developing countries, especially on the collectivist cultural traits of Indonesia that affect technology interaction patterns and adoption success.

This extensive literature review establishes a theoretical foundation for comprehending the adoption of the CarbTrade platform by analyzing the operational context of Jangjo Technology Indonesia, contemporary digital platform architecture requirements, the Technology Acceptance Model and also the Unified Theory of Acceptance and Use of Technology frameworks adapted for sustainable development contexts, with a platform economics theory, sustainable development frameworks, the COBIT governance framework, cultural factors influencing technology adoption in Indonesia, waste management hierarchy models, user interface design considerations, system performance requirements, and the complexities of environmental technology adoption.

The review delineates significant deficiencies in current literature, including a lack of focus on platform-specific adoption determinants, insufficient cultural adaptation of technology acceptance models, a poor understanding of environmental technology adoption in developing nations, inadequate incorporation of sustainable development frameworks into technology adoption studies, limited analysis of the impact of technology architecture decisions on user acceptance and adoption results, and insufficient governance frameworks tailored for environmental technology platforms functioning within multi-stakeholder ecosystems.

Significant theoretical contributions encompass the amalgamation of UTAUT with platform economics theory and sustainable development frameworks to tackle network effects, ecosystem dynamics, and global sustainability issues; the cultural adaptation of technology acceptance models for Indonesian contexts, integrating sustainable development awareness and international cooperation perspectives; the formulation of environmental-specific constructs that address sustainability motivations, regulatory compliance pressures, and sustainable development implementation necessities; and the incorporation of COBIT governance principles with environmental platform development to ensure data integrity, stakeholder trust, and accountability in sustainable development.

The integrated conceptual framework established through this literature review offers a thorough approach to comprehending CarbTrade platform adoption, which is encompassing individual acceptance factors, platform-specific attributes, cultural moderating influences, environmental context considerations, technological architecture prerequisites, governance framework execution, and sustainable development requirements, and this paradigm directs empirical research and enhances theoretical progress in the study of environmental technology adoption and the execution of sustainable development via digital platforms.

Comprehending the intricate interplay among technology acceptance, platform economics, cultural influences, technological architecture, governance structures, and sustainable development paradigms is crucial for formulating effective platform implementation strategies that facilitate both successful technology adoption and significant sustainable development execution. This understanding also enhances the broader discourse on environmental technology adoption in developing nations striving for global sustainability goals through culturally respectful and locally suitable methods, while fostering international collaboration and collective environmental stewardship.

2.15. Modified UTAUT Model for Indonesian Context

The revised UTAUT model for the adoption of environmental platforms in Indonesia integrates distinct cultural, institutional, and environmental factors identified through a thorough literature review, addressing deficiencies in existing models that fail to adequately consider the contexts of developing countries and the characteristics of environmental technology.

In the Indonesian context, Performance Expectancy encompasses operational efficiency advantages and the production of environmental stewardship value, which is illustrating the growing environmental awareness of Indonesian enterprises with their commitment to tangible performance enhancements and Indonesian firms measure performance expectation by communal benefit evaluation instead of individual utility maximization, illustrating collectivist cultural traits that affect technology assessment procedures.

Cultural Moderators pertinent to Indonesian contexts encompass the influence of Power Distance on hierarchical approval processes, the impact of Collectivism on group consensus requirements, the effect of Uncertainty Avoidance on preferences for implementation structures, and the support of Long-

term Orientation for sustainability alignment. These moderators affect the correlations among basic UTAUT variables and adoption outcomes distinctively compared to individualistic societies.

Governance Quality is a fundamental concept rather than an enabling circumstance in Indonesian environments, and where institutional trust profoundly impacts technology adoption choices and Environmental consciousness serves as a contextual element that enhances the links between performance expectation, notably in Indonesia, where environmental awareness is increasing yet necessitates integration with operational advantages.

Regulatory pressure serves as a direct precursor to behavioral intention in Indonesian situations, where government regulations substantially impact corporate technology adoption choices and Indonesian firms often use environmental technology due to institutional constraints rather than solely voluntary market-driven choices, illustrating the traits of a developing economy where regulatory frameworks influence corporate practices. Figure 2.1. below shows modified UTAUT Model for Carbtrade adoption enhanced for this study.

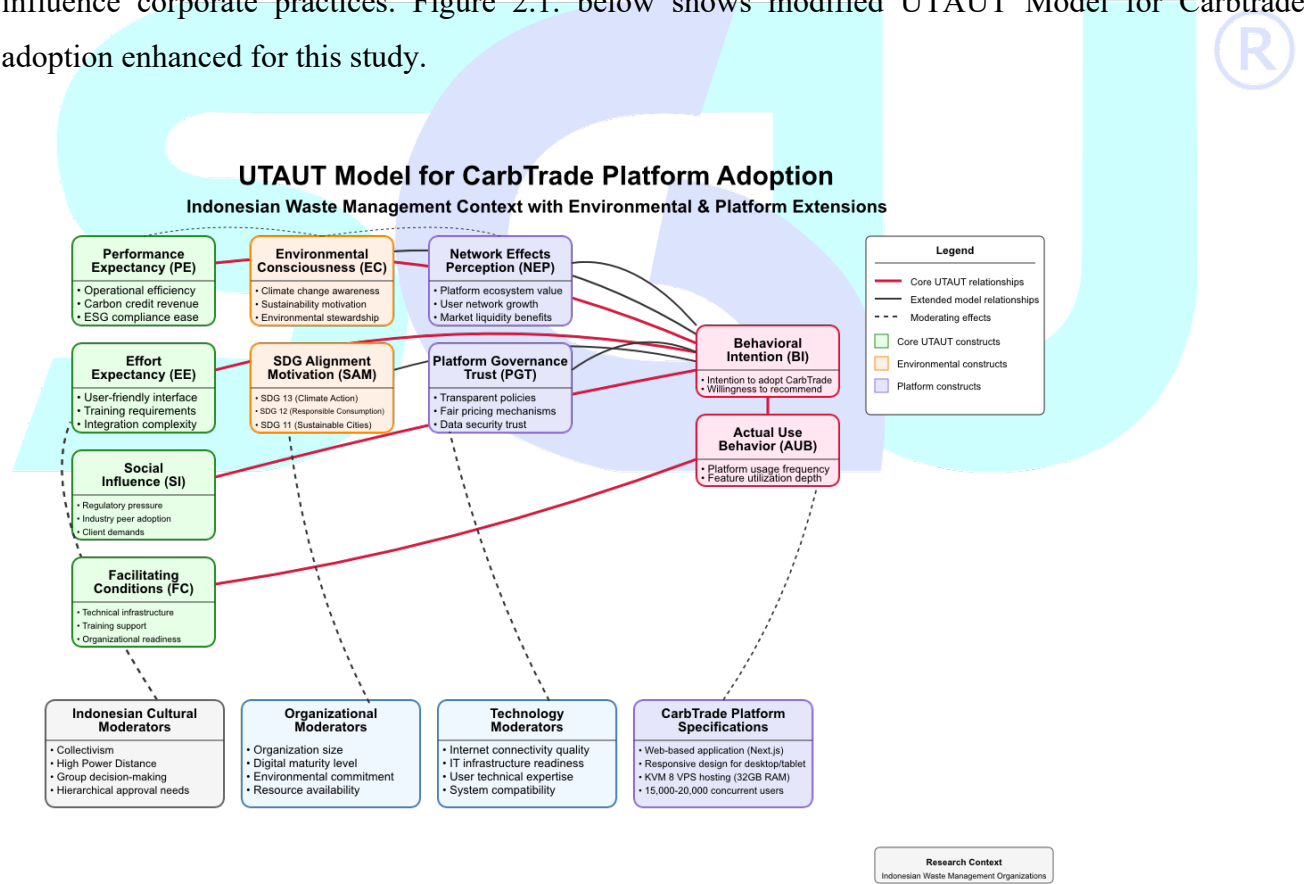


Figure 2.1. UTAUT Model for Carbtrade Platform Adoption (Venkatesh et al., 2003b)