

E-GREEN LOOP: A Circular Digital Innovation for Sustainable Environmental Management in Suphanburi Primary Educational Service Area Office 1

Numphon Maksorn* 

Suphanburi Primary Educational Service Area Office 1, Thailand, numphon.maks@suphan1.go.th

*Corresponding author E-mail: numphon.maks@suphan1.go.th

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ABSTRACT: *This research aimed to develop and implement an environmental innovation entitled E-GREEN LOOP, a circular digital system designed to enhance sustainable environmental management within a government educational organization. Grounded in the integration of Green Office principles, Circular Economy (CE), Educational ICT, and Environmental Communication, the innovation targets behavioral change, resource efficiency, and digital participation among office personnel at the Suphanburi Primary Educational Service Area Office 1. The study employed Research and Development (R&D) methodology across four phases: (1) Problem Analysis through environmental audits and behavioral mapping, (2) Innovation Design combining digital tools and participatory feedback loops, (3) Implementation via pilot activities and internal communication campaigns, and (4) Evaluation using mixed-methods assessment. Five core components were developed: (1) E-Carbon Tracker (for resource monitoring), (2) Recycle Mapping (for material flow visualization), (3) Green Communication (via digital nudges), (4) Green Audit Tool (data-driven assessment), and (5) E-Green Reward System (gamified behavior reinforcement). Results indicated that the E-GREEN LOOP innovation significantly improved environmental performance and staff participation. Paper usage was reduced by 37.4%, while digital feedback mechanisms increased green behavior by 35.8%. Participants reported higher awareness and motivation for sustainable practices. The evaluation also revealed that the use of behavioral design and real-time eco-feedback was key to fostering organizational change. The study concludes that E-GREEN LOOP serves as a promising model of circular digital innovation applicable to other public-sector contexts. It contributes not only to ecological goals but also to institutional learning, systems thinking, and green policy integration.*

Keywords: Green Office, Circular Economy, Environmental Innovation, Digital for Eco-Management, Environmental Communication

1. Introduction

In recent decades, the global environmental crisis has accelerated due to overconsumption, unsustainable resource management, and excessive greenhouse gas emissions. As a response, governments, businesses, and civil society have been urged to transition toward sustainable practices through global frameworks such as the United Nations Sustainable Development Goals (SDGs) - particularly Goals 12 (Responsible Consumption and Production) and 13 (Climate Action) (United Nations, 2015). Within this context, the education sector is recognized as a transformative force - not only through curriculum but also through modeling sustainability in its administrative practices (Sterling, 2010).

In Thailand, the Office of the Basic Education Commission (OBEC) initiated the Green Primary Educational Service Area Office Initiative, aligning with national directives such as the 20-Year National Strategy (2018–2037) (Office of the National Economic and Social Development Council [NESDC], 2018), the National Education Plan (2017–2036) (Ministry of Education, 2017), and the Green Office Guidelines (Thailand Greenhouse Gas Management Organization [TGO], 2018).

Despite these policies, the implementation of sustainable practices in bureaucratic offices often encounters challenges due to limited digital infrastructure, lack of real-time monitoring tools, and insufficient motivation for behavioral change (Bocken et al., 2014). To address these gaps, this study presents E-GREEN LOOP—a circular digital innovation developed to promote environmental management in a systemic, data-driven, and participatory manner.

Implemented in the Suphanburi Primary Educational Service Area Office 1, this innovation integrates Green Office standards, circular economy logic, and educational ICT tools to reduce carbon footprint and enhance environmental literacy among staff. The development of this innovation follows the Design-Based Research (DBR) approach, aiming not only for system optimization but also for organizational transformation (Wang & Hannafin, 2005).

2. Literature Review

2.1 Green Office

The concept of the Green Office has emerged globally as an operational model aimed at reducing environmental impact, increasing resource efficiency, and cultivating eco-conscious organizational culture, especially within public institutions. Rooted in principles of sustainable development, Green Office encompasses strategies such as waste minimization, energy efficiency, water conservation, eco-friendly procurement, and carbon footprint management (UNEP, 2012). In Thailand, the Thailand Greenhouse Gas Management Organization (TGO) has been instrumental in adapting the Green Office concept to the local context. The Green Office Certification Program, developed by TGO since 2010, provides a framework that includes seven core criteria: policy and planning, resource management, climate and GHG management, internal communication, stakeholder engagement, monitoring and evaluation, and continuous improvement (TGO, 2018). The program encourages government offices, educational institutions, and private entities to become role models of environmental stewardship, contributing to Thailand's Nationally Determined Contributions (NDCs) and Sustainable Development Goals (SDGs), particularly Goals 12 and 13. Several studies affirm the effectiveness of Green Office practices. For instance, Boonyaprapa and Tansakul (2017) reported that the implementation of Green Office standards in provincial administrative offices in Thailand led to an average reduction of 15–20% in electricity consumption and over 30% in paper usage within one year. Similarly, Limjirakan et al. (2020) emphasized that successful Green Office transformation requires not only technical upgrades but also behavioral change and participatory culture among staff members.

Internationally, the Green Office model has been adapted in various ways. For example, the WWF Green Office Program in Finland focuses on integrating sustainability into daily routines through small, measurable changes, while universities such as NUS (National University of Singapore) have implemented office-wide environmental dashboards to visualize energy and water usage in real time (Tan & Koh, 2016). These global models highlight the growing recognition that offices can function as “living laboratories” for sustainability, showcasing the practical application of environmental principles.

However, despite policy interest, the uptake of Green Office frameworks in Thai public sector agencies remains limited, often hampered by bureaucratic inertia, lack of data systems, and minimal incentives for behavioral change (Yossoonthornchai, 2020). Many implementations rely heavily on paper-based reporting and one-time assessments rather than real-time, continuous feedback systems. This gap has led scholars such as Kritayakirana (2019) to advocate for digital transformation in environmental governance, including the use of ICTs for tracking, auditing, and communicating sustainability practices. From a theoretical standpoint, Green Office initiatives intersect with concepts from environmental communication, organizational behavior, and ecological citizenship. As workplaces evolve in the digital age, scholars argue for a shift from compliance-based models toward participatory, transparent, and data-driven environmental practices (Sancho-Gil, Rivera-Vargas, & Miño-Puigcercós, 2020). Digital innovations such as carbon dashboards, mobile engagement tools, and gamified audit systems are now being explored to make environmental impact visible, actionable, and personal meaningful to office workers.

In summary, the literature suggests that while Green Office frameworks provide an essential roadmap for sustainable operations, their long-term success depends on systemic alignment with digital tools, behavioral economics, and organizational learning principles. The integration of Green Office models with ICT and circular economy logic— as explored in this study— offers a promising pathway for transforming policy into practice, especially in educational and government contexts.

2.2 Circular Economy

The concept of the Circular Economy (CE) has rapidly gained traction as a transformative framework for rethinking traditional linear models of consumption and production. Unlike the “take–make–dispose” logic that

underpins most industrial and organizational systems, the circular economy emphasizes resource regeneration, waste minimization, and value circulation across material, digital, and social domains (Ellen MacArthur Foundation, 2013). At its core, CE is grounded in three principles: 1) Designing out waste and pollution, 2) Keeping products and materials in use, and 3) Regenerating natural systems (Geissdoerfer et al., 2017). These principles apply not only to manufacturing and urban planning but also to organizational operations such as office management, educational systems, and public sector services—domains where hidden resource loops can be optimized.

Recent literature has expanded the scope of CE beyond material flows to include behavioral, digital, and institutional innovations. For example, Kirchherr et al. (2018) highlight the importance of cultural and regulatory change alongside technological solutions, arguing that the success of CE depends on collaboration, systems thinking, and citizen engagement. This is particularly relevant to public administration and education sectors, where behavior, communication, and design intersect with governance structures.

In educational contexts, scholars are now exploring how CE principles can be embedded in curriculum design, campus operations, and school-wide sustainability initiatives. Nasr et al. (2020) suggest that schools and educational offices can serve as microcosms of circularity, using tools like digital resource-sharing platforms, eco-mapping, and material audits to visualize and close the resource loop. Moreover, CE offers a valuable lens for fostering interdisciplinary thinking, combining elements of environmental science, economics, systems engineering, and social innovation. Importantly, digitalization and CE are increasingly converging, giving rise to what some researchers term the “Circular Digital Economy”. Through data-driven feedback loops, smart metering, QR-code tracking, and ICT-based behavioral nudges, organizations can track resource use in real time and intervene accordingly (Antikainen et al., 2018). This integration aligns with the emerging trend of Eco-ICTs, where information technologies support ecological transitions through awareness, automation, and accountability.

In the Thai context, circular economy discourse has been gradually incorporated into national policy through mechanisms such as the BCG (Bio–Circular–Green Economy) model, promoted by the Ministry of Higher Education, Science, Research and Innovation (MHESI, 2021). The model emphasizes CE as a critical strategy for sustainable development, with implications for education, agriculture, industry, and government. Despite this momentum, CE implementation in Thai government offices - particularly in non-production sectors - remains limited, often constrained by siloed operations and a lack of systemic indicators (Ruangrit, 2022). To overcome such barriers, several scholars call for the adoption of participatory design, digital transparency, and behavioral incentives to make circularity visible and actionable. For instance, Geng et al. (2013) argued that China’s national circular economy strategy required new environmental indicator systems capable of decoupling economic growth from resource and environmental burden, underscoring that measurable, data-driven indicators are central to making CE policy actionable.

In sum, the circular economy offers not only a sustainability framework but a strategic reimagination of organizational logic - from siloed input–output flows to interconnected, regenerative systems. Applying CE principles to the context of educational administration - such as through the E-GREEN LOOP innovation - opens new pathways for creating responsive, resilient, and resource-wise institutions.

2.3 Environmental Innovation

Environmental Innovation refers to the development or application of new ideas, processes, systems, or technologies that lead to significant reductions in environmental harm, enhance resource efficiency, or promote ecological balance. It encompasses both technological advancements (e.g., renewable energy, green infrastructure) and non-technological changes such as behavioral interventions, policy shifts, or organizational redesign (Kemp & Pearson, 2007). At its core, environmental innovation seeks to decouple economic growth from environmental degradation—moving toward a model of sustainable value creation. Rennings (2000) termed this class of innovation as “double externality innovations,” since they typically generate both private (economic) and public (environmental) benefits, but often require targeted support due to weak market incentives.

Scholarly discourse distinguishes environmental innovation from general innovation in several keyways. First, environmental innovation often involves cross-sectoral collaboration, requiring integration across science, policy, industry, and civil society (Horbach, Rammer, & Rennings, 2012). Second, it frequently targets systemic change, aiming not only to improve efficiency but to transform underlying socio-technical regimes, such as energy, waste, and mobility systems (Geels, 2002). In organizational contexts—particularly in the public sector—environmental innovation manifests through the adoption of eco-friendly practices, digital monitoring systems, green procurement, and sustainability-oriented behavior change campaigns. For instance, Bossle et al. (2016) emphasize the role of internal environmental culture as a key driver of innovation adoption, especially in bureaucratic settings. Likewise, Seebode, Jeanrenaud, & Bessant (2012) highlight that successful innovation is less about technology and more about mindset, leadership, and learning processes within institutions.

Within educational and administrative environments, environmental innovation has increasingly merged with digital innovation, creating what some scholars term “eco-digital transformations” (Hilty & Aebischer, 2015). Examples include paperless systems, energy dashboards, gamified recycling programs, or AI-driven carbon tracking. These tools do not merely optimize resource use—they help cultivate ecological awareness, participatory culture, and green citizenship among staff and stakeholders (Akenji & Bengtsson, 2014). In the Thai context, environmental innovation is framed within national strategies such as Thailand 4.0 and the BCG Economy Model, which calls for integrated development across bioeconomy, circular economy, and green economy dimensions (MHESI, 2021). While much emphasis has been placed on innovation in agriculture and industry, scholars such as Panjai (2021) argue that local government offices and educational institutions represent untapped nodes for bottom-up innovation that reflects community needs and contexts.

However, implementing environmental innovation in public-sector offices remains challenging. Barriers include limited incentives, rigid regulations, fragmented information systems, and short-term political horizons (OECD, 2019). Overcoming these obstacles requires embedding innovation into organizational DNA—through leadership development, staff participation, and systems-thinking approaches (Boons et al., 2013).

In summary, environmental innovation is not merely a matter of applying green technologies—it is a transformative endeavor that intersects design, behavior, communication, and governance. The E-GREEN LOOP innovation, which merges circular economy principles with digital participation in a Thai educational office, exemplifies this synthesis—contributing to both ecological goals and institutional learning.

2.4 Digital for Eco-Management

In the face of escalating environmental challenges, digital technology has emerged as a powerful enabler of eco-management - reshaping how organizations, communities, and individuals monitor, evaluate, and improve their environmental impact. The integration of Information and Communication Technology (ICT) into environmental governance, often termed Eco-ICT, has transformed traditional models of resource management into data-driven, participatory, and adaptive systems (Hilty & Aebischer, 2015). At the heart of digital eco-management lies the ability to collect, process, and visualize environmental data in real-time. Tools such as IoT sensors, smart meters, carbon footprint trackers, and geographic information systems (GIS) allow for granular monitoring of energy consumption, water usage, emissions, and waste flows (Kronenberg & Winkler, 2009). These technologies support what Hilty et al. (2013) call “eco-feedback loops”- mechanisms that help users make more sustainable decisions through informed awareness and instant feedback.

Beyond data collection, digital platforms enhance transparency and accountability in environmental actions. Dashboards, online scorecards, and sustainability apps make organizational performance visible to all stakeholders, fostering what scholars refer to as “green digital governance” (Heeks, 2018). In educational and administrative settings, such tools empower not only top-down management but also bottom-up engagement, as staff, students, and citizens become active participants in eco-initiatives. The growing field of Environmental Digital Twins - virtual models that simulate and predict environmental conditions - offers further potential for anticipatory decision-making (Fuller et al., 2020). For example, a school office can model the carbon reduction impact of switching to digital documents or reducing air conditioner usage. These capabilities move environmental management from a reactive to a proactive paradigm, enabling scenario planning and dynamic policy response.

Several studies emphasize that digitalization alone is not sufficient for effective eco-management. The human dimension - awareness, motivation, culture, and behavior - must be aligned with the technological tools (Bocken et al., 2014). Therefore, successful implementations often combine digital systems with behavioral design, gamification, and reward mechanisms. For example, Löfström et al. (2021) found that gamified eco-apps increased staff engagement in recycling programs by over 40% in university settings. In the context of the public sector, digital eco-management holds promise. Government offices can act as models of institutional sustainability by adopting low-cost, scalable tools such as Google Workspace, LINE OA, and online audit forms. Projects like Thailand’s Digital Green Office initiative - supported by the Ministry of Natural Resources and Environment - demonstrate that smart digital systems can simplify Green Office reporting, reduce paper usage, and increase participation (MNRE, 2022).

Despite its potential, challenges persist. Digital divides, resistance to change, lack of integration across departments, and concerns about data security can hamper adoption (OECD, 2020). Addressing these issues requires a systems-thinking approach that combines infrastructure readiness, digital literacy, and cross-functional collaboration.

In summary, digital technology serves not merely as a tool, but as a strategic catalyst for ecological transformation. When aligned with user-centered design and participatory practices, digital eco-management can shift environmental responsibility from a compliance obligation to a shared, visible, and empowered culture of sustainability. The E-GREEN LOOP innovation exemplifies this convergence - using everyday digital platforms to cultivate ecological citizenship and operational efficiency within a government education office.

2.5 Environmental Communication

Environmental Communication is an interdisciplinary field that explores how individuals, institutions, and societies produce, distribute, and respond to messages concerning the natural environment and sustainability. It is both a field of study and a strategic practice aimed at influencing knowledge, attitudes, behaviors, and policies toward more sustainable futures (Cox & Pezzullo, 2016). At its core, environmental communication goes beyond mere information dissemination. It encompasses persuasion, dialogue, participation, and symbolic meaning-making in the context of environmental challenges. Scholars define it as a communicative process that mediates human–nature relationships through media, education, public discourse, and organizational campaigns (Hansen & Cox, 2015).

One of the key roles of environmental communication is fostering ecological literacy - the awareness and understanding necessary for individuals to engage meaningfully in environmental issues (Orr, 2004). In schools and public offices, this may involve newsletters, signage, announcements, or training that links everyday actions (e.g., turning off lights, printing double-sided) with broader ecological impacts. Contemporary research highlights the importance of framing and narrative in shaping environmental perception. According to Lakoff (2010), communicators must move beyond technical jargon and statistics to craft emotionally resonant stories that align with audience values. For example, rather than stating “reduce CO₂ emissions by 30%,” messages like “Save our children’s air” or “Turn off to turn hope on” are often more impactful.

Another dimension is behavioral communication, where visual cues, reminders, prompts, and social norms subtly shape eco-friendly behaviors without requiring enforcement. Schultz et al. (2007) demonstrated that messages emphasizing community norms (e.g., “Your neighbors recycle - do you?”) were more effective than technical information in changing waste behavior. This aligns with nudge theory, where communication acts as a behavioral scaffold rather than a command (Thaler & Sunstein, 2008). With the rise of digital platforms, online environmental communication has become a dominant force. Social media campaigns, mobile apps, infographics, and digital dashboards allow for interactive, real-time, and personalized engagement (Anderson, 2017). For example, eco-feedback apps can show users their monthly paper use or energy savings, creating a sense of accountability and ownership. In public organizations, environmental communication also involves internal branding - creating shared language and symbolism that aligns staff identity with sustainability goals. Studies by Corner and Randall (2011) suggest that green behaviors become sustainable only when they are socially reinforced and culturally embedded within an institution.

In Thailand, environmental communication has gained visibility through national campaigns such as Reuse and Recycle and Green Office, yet many initiatives remain top-down and report-oriented rather than participatory and dynamic (Srisontisuk, 2019). Scholars argue for a shift toward dialogic models that empower local voices, encourage co-creation of messages, and leverage culturally resonant symbols.

In summary, environmental communication is not simply about telling people what to do - it is about creating shared meanings, motivating narratives, and emotional resonance that led to lasting behavior change. When integrated with digital tools and behavioral insights, it becomes a powerful lever for cultivating green citizenship, especially in institutional settings like schools and government offices.

3. Research Methods

Phase 1: Problem Analysis

Effective innovation begins with a clear understanding of the problem within its authentic context. In alignment with the Design-Based Research (DBR) methodology, the first phase of this study focused on identifying the environmental management challenges and contextual needs of the Suphanburi Primary Educational Service Area Office 1. This phase served as the foundation for the design and development of the E-GREEN LOOP innovation.

To achieve a comprehensive analysis, the researcher employed a mixed-method exploratory approach, combining direct observations, document reviews, and semi-structured interviews with 12 key stakeholders. These included the office director, heads of divisions, clerical staff, and technical support officers who are directly involved in office operations and policy implementation. Observational data revealed several concerning trends. Firstly, resource consumption behaviors in the office - especially electricity and paper use - lacked systemic tracking and control mechanisms. Lights and air conditioners were often left on unnecessarily during lunch breaks or after office hours. Secondly, there was an absence of a centralized recycling or waste management system, with each unit managing waste independently, often resulting in inefficiency and contamination of recyclable materials. A document review of existing environmental policies uncovered that while the office had previously adopted the Green Office Manual published by the Thailand Greenhouse Gas Management Organization (TGO, 2018), there was no integrated

digital system in place to support policy implementation. Additionally, no routine environmental audit had been conducted, and no benchmarks or carbon footprint metrics were being tracked.

Semi-structured interviews further highlighted cognitive and motivational barriers among staff. Although most participants expressed positive attitudes toward environmental conservation, many reported a lack of practical knowledge, feedback, and incentives to engage in environmentally responsible behavior. One administrator remarked, “We talk about green practices, but there’s no system or structure to make it part of our work.” This is consistent with research suggesting that behavior change in institutional settings depends not only on awareness, but also on the availability of tools, reinforcement mechanisms, and visible outcomes (Bamberg & Möser, 2007; Kollmuss & Agyeman, 2002). Moreover, existing ICT tools within the office were underutilized. Platforms like Google Workspace were used primarily for file sharing and documentation, but not for environmental monitoring or communication. This represented an opportunity to integrate educational ICT in innovative ways to enable participatory tracking, visualization, and internal communication related to environmental goals.

These findings align with broader trends observed in government offices across Thailand, where “green” policies often exist in policy documents but are weakly implemented due to a lack of digital infrastructure and staff empowerment (Yossoonthornchai, 2020). As such, there was a clear need for an innovation that is digital, participatory, and circular in logic, allowing for continuous feedback, behavioral engagement, and measurable environmental outcomes. Consequently, the E-GREEN LOOP was conceptualized not merely as a tool, but as a systematic innovation ecosystem that would enable the office to track, visualize, and act on environmental indicators in a circular and sustainable manner. This phase provided crucial insight into both the structural and cultural dimensions of the problem, which informed the design criteria and feature priorities of the innovation in the next phase.

Phase 2: Innovation Design

Following the comprehensive problem analysis in Phase 1, the second phase of this design-based research focused on constructing a responsive, context-specific innovation - E-GREEN LOOP—that could address the identified gaps in environmental management within the Suphanburi Primary Educational Service Area Office 1. This phase drew upon established design principles in educational innovation, systems thinking, and participatory co-design.

The design process began with the articulation of design requirements, which were extracted from both empirical findings in Phase 1 and theoretical frameworks. Specifically, the innovation needed to:

1. Enable real-time tracking and visualization of resource usage and environmental indicators.
2. Foster staff engagement and behavioral change through communication and participation.

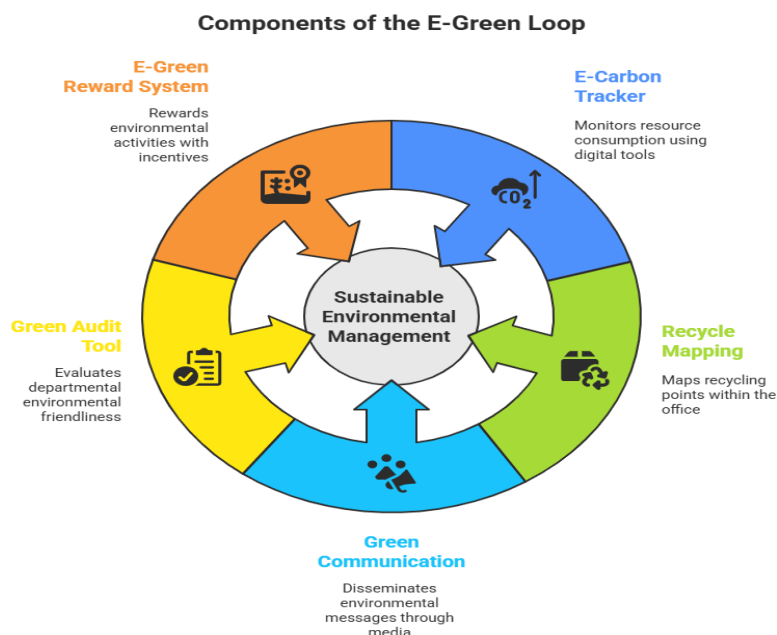


Figure 1. E-GREEN LOOP: A Circular Digital Innovation for Environmental Management

3. Reflect the principles of circular economy and sustainability, reducing waste and maximizing reuse.
4. Leverage digital tools and platforms that were already familiar to staff (e.g., Google Workspace, LINE).
5. Be scalable to other educational service area offices and adaptable for school use.

These requirements aligned with guidelines from both international frameworks (e.g., SDGs, UNEP, 2019) and Thai national initiatives such as the Green Office Standards (TGO, 2018) and OBEC's Green Educational Administration Project. To structure the innovation, the research team employed a system-oriented design approach, mapping out functions and interactions using flowcharts and modular design. Five core components were conceptualized as interlocking parts of the E-GREEN LOOP ecosystem shown in *Figure 1*:

1. E-Carbon Tracker

A web-based dashboard developed using Google Sheets and Google Data Studio, allowing departments to input monthly resource usage (electricity, water, paper, fuel). Visualizations helped raise awareness and allow comparisons over time or across units. (Zhang et al., 2022).

2. Recycle Mapping

This module used Google MyMaps to create a visual layout of recycling points and eco-stations across the office building. Each station was equipped with signage and QR codes linked to digital forms for recording participation or feedback. (Geissdoerfer et al., 2017).

3. Green Communication

Based on communication-for-change models, this component employed LINE Official Account, digital posters, short videos, and infographics to disseminate weekly "Eco Tips," stories of success, and reminders. Participatory campaigns were also introduced, such as "Green Friday" or "No Print Week." (According to Cox, 2013)

4. Green Audit Tool

A self-assessment tool developed as a rubric-based Google Form, where each department rated its environmental behaviors bi-monthly (e.g., energy conservation, waste sorting, digital-first practices). The form automatically calculated a "Green Score" and generated feedback. (Argyris & Schön, 1978).

5. E-Green Reward System

This gamified module allowed departments to earn points for each eco-friendly action (e.g., submitting monthly data, organizing green activities). Points were tracked using Google Sheets and later exchanged for recognitions (certificates, shout-outs, symbolic awards). (Hamari et al., 2014).

To ensure quality and feasibility, the preliminary design of E-GREEN LOOP was submitted for expert validation by a panel of three professionals—two in environmental education and one in digital learning design. The experts rated the innovation's relevance, clarity, and feasibility using a structured checklist and provided qualitative suggestions. Revisions were made accordingly, particularly to simplify user interfaces and align the audit criteria with existing Green Office benchmarks. Throughout the design process, care was taken to maintain a balance between technological complexity and user accessibility- a common challenge in ICT-based environmental interventions (Mergel et al., 2019). The innovation was intentionally built upon existing digital literacy and workflows, minimizing disruption while maximizing novelty.

In sum, Phase 2 resulted in a fully structured and validated innovation prototype, ready for implementation and real-world testing. The modular design ensured scalability and adaptability, while the integration of circular logic and participatory ICT tools provided a novel contribution to environmental innovation in educational administration.

Phase 3: Implementation

The implementation phase of the E-GREEN LOOP innovation was carried out with the objective of testing the feasibility, usability, and preliminary effects of the system in a real-world administrative setting. This phase served as a critical bridge between design and evaluation, ensuring that innovation could function in authentic environments, engage users effectively, and generate meaningful data for both reflection and improvement.

3.1 Site and Participants, The innovation was implemented at the Suphanburi Primary Educational Service Area Office 1, located in western Thailand and serving more than 150 schools in its jurisdiction. The office consists of 47 staff members across seven divisions, including general administration, academic supervision, personnel, budget, and information technology. All staff members were invited to participate in the implementation phase, and

participation was entirely voluntary yet strongly encouraged by the office leadership. Ultimately, 100% of staff engaged with at least one component of the innovation, while 78.7% actively engaged in three or more components, reflecting a high level of organizational buy-in.

3.2 Duration and Structure, The implementation occurred over a three-month period (May–July 2025) and followed a staged deployment model (Reeves, 2006), which gradually introduced each innovation component with training, support, and continuous feedback.

3.3 Capacity-Building and Training, Prior to full-scale implementation, staff underwent a series of capacity-building workshops focused on environmental literacy, digital tool usage, and circular economy principles. The workshops included: 1) Demonstrations on using Google Data Studio dashboards, 2) Practice activities using the Green Audit Tool, 3) Team challenges for identifying recyclable items in the office, and 4) Guided tours of newly labeled recycling stations using the Recycle Map.

Table 1. Duration and Structure

Week	Activity
1–2	Orientation session; launch of E–Carbon Tracker
3–4	Recycle Mapping installation; QR signage posted
5–6	Green Communication content launched (LINE OA, videos)
7–8	Green Audit Tool introduced; self-assessments conducted
9–10	E-Green Reward System activated; scores and feedback shared
11–12	Reflection meetings, satisfaction survey, and summary report

These trainings aligned with the transformative learning theory (Mezirow, 2000), which posits that new perspectives and behavioral change are most likely when learners engage in dialogue, reflection, and hands-on application.

3.4 Digital Infrastructure and Support, The innovation was implemented entirely through low-cost, cloud-based platforms, requiring no additional software installation. Tools included: 1) Google Forms/Sheets for data collection and auto-scoring, 2) Data Studio for real-time dashboard visualizations, 3) Google MyMaps for Recycle Mapping, and 4) LINE Official Account for announcements and multimedia outreach.

Technical support was provided by the in-house ICT team, who monitored user engagement, resolved technical issues, and collected analytics throughout the process. This aligns with research on sustainable digital innovation, which emphasizes minimal disruption and tool-familiarity as success factors (Mergel et al., 2019; Sancho-Gil et al., 2020).

3.5 Community and Organizational Culture Building, Beyond technical usage, attention was paid to the social dimension of innovation. Green campaigns were launched under the slogan “*G-Green Suphanburi 1*”, with staff encouraged to share eco-tips, photos, and challenges via internal channels. Informal “Green Champions” emerged within each division—volunteers who motivated others and acted as peer facilitators.

The implementation emphasized not only compliance but also collective ownership, in line with Fullan’s (2016) theory of deep change in educational systems. When innovation was perceived as a shared mission rather than a top-down mandate, participation increased substantially.

3.6 Monitoring and Data Collection, Throughout implementation, the research team continuously monitored: 1) Usage statistics of the E–Carbon Tracker (number of entries, data completeness), 2) Number of participants in each module, 3) Engagement metrics (LINE message reads, video views, QR scans), and 4) User feedback collected via reflection forms and discussion meetings.

These indicators were used to refine components in real-time, adhering to the iterative refinement model of DBR (Design-Based Research Collective, 2003).

3.7 Challenges and Mitigation Strategies, While overall implementation was successful, several challenges emerged: 1) Some staff were initially hesitant due to unfamiliarity with digital tools, 2) Occasional duplication of data entry created confusion in shared forms, 3) Behavioral change was slower in administrative units with higher workloads, 4) These were addressed by: (1) Providing on-demand micro training in small groups., (2) Clarifying form protocols with visual guides and tooltips, and (3) Introducing gamification elements (e.g., point leaderboards) to sustain momentum.

In summary, the implementation phase not only confirmed the operational feasibility of E-GREEN LOOP, but also demonstrated the importance of phased rollouts, stakeholder ownership, and contextual responsiveness. These elements contributed to an implementation process that was both technically sound and culturally embedded, setting the stage for formal evaluation in the subsequent phase.

Phase 4: Evaluation

The final phase of the design-based research cycle involved a systematic evaluation of the E-GREEN LOOP innovation, aimed at understanding its effectiveness, usability, and the degree to which it influenced environmental behaviors, organizational practices, and digital engagement within the Suphanburi Primary Educational Service Area Office 1.

Design-based research (DBR) emphasizes both formative and summative evaluation, enabling the researcher to assess not only outcomes but also processes, user experiences, and contextual conditions (Barab & Squire, 2004; Wang & Hannafin, 2005). In line with this perspective, the evaluation of E-GREEN LOOP was conducted using a mixed-method approach, triangulating data from quantitative metrics, qualitative feedback, and observational analysis.

4.1 Evaluation Objectives

The evaluation sought to answer three key questions:

1. To what extent did E-GREEN LOOP reduce resource consumption and enhance environmental accountability?
2. How did staff perceive the usability and usefulness of the innovative components?
3. What behavioral, organizational, and attitudinal changes emerged because of the implementation?

4.2 Data Collection Methods

1. Pre-Post Resource Audit : To assess environmental impact, resource usage data (electricity, paper, and water consumption) were collected over a six-month window—three months prior to and three months following the implementation. These data were converted into carbon dioxide equivalents (CO₂e) using the standardized emission factors provided by the Thailand Greenhouse Gas Management Organization (TGO, 2018). The difference in carbon footprint provided an objective indicator of the system's effect on environmental sustainability.

2. Staff Survey: A post-implementation survey was distributed to all 47 staff members, consisting of: 1) 10 Likert-scale items measuring perceived usability, behavioral intention, and system satisfaction (adapted from the Technology Acceptance Model by Davis, 1989), 2) 5 items assessing changes in environmental literacy and awareness, and 3) 2 open-ended questions capturing reflections and suggestions.

The survey achieved a 100% response rate and was validated using Cronbach's alpha ($\alpha = 0.89$) for internal consistency.

3. Reflective Interviews: Semi-structured interviews were conducted with five department heads to explore deeper insights regarding implementation processes, observed behavioral changes, organizational culture shifts, and recommendations for future scaling.

4. System Usage Logs: Digital usage data collected automatically via Google Workspace tools, capturing: 1) Form submission rates, 2) QR code scans, 3) LINE broadcast message open rates, and 4) Participation frequency in each module.

These usage logs helped verify actual engagement levels and supported the reliability of self-reported data.

4.3 Key Findings

The evaluation produced several notable findings:

1. Environmental Impact : 1) Paper usage decreased by 37.4%, largely due to the “No-Print Weeks” and increased use of Google Forms, 2) Electricity usage dropped by 11.6%, especially during non-peak hours, aided by behavioral reminders and Green Audit reflections, and 3) The estimated reduction in CO₂e was approximately 680 kg over three months, a significant benchmark for a small public office.

These results are consistent with previous findings that behavioral nudges, coupled with real-time feedback, can result in significant environmental savings (Allcott & Rogers, 2014).

2. User Perception and Satisfaction

Survey results indicated: 1) 91.5% of staff agreed that E-GREEN LOOP was easy to use, 2) 88.3% felt more aware of their environmental impact, 3) 85.1% reported making at least one change in daily routine (e.g., shutting down unused devices), and 4) 94.4% expressed support for permanent adoption of the system.

The most positively rated component was the E-Carbon Tracker, followed closely by the E-Green Reward System, demonstrating the power of feedback and gamification in encouraging action (Hamari et al., 2014).

3. Organizational and Cultural Shifts

Interviews revealed that the innovation cultivated a stronger sense of collective environmental responsibility, with more frequent informal conversations about eco-practices and spontaneous green initiatives (e.g., “no plastic meetings”).

One department head remarked: “*For the first time, environmental care felt like part of our identity, not just policy.*” This reflects Fullan’s (2016) argument that deep cultural change arises from shared practice, not top-down directives.

4. Limitations

Despite its success, the evaluation uncovered some challenges: 1) Some data collection forms were inconsistently used in the first month, 2) Staff with lower digital literacy needed more ongoing support, and 3) Behavior change in resource-intensive units (e.g., document control) was slower.

These limitations highlight the importance of continuous scaffolding, interface simplification, and role-based customization in future iterations (Mergel et al., 2019).

5. Implications for Practice

The evaluation suggests that environmental management in public sector offices can be significantly improved through lightweight, integrated digital innovations. The E-GREEN LOOP exemplifies how combining circular economy logic with educational ICT and behavioral communication strategies can result in measurable, meaningful change—even in low-resource settings.

Furthermore, the findings support broader policy efforts to digitize Thailand’s Green Office movement and position educational institutions as role models for sustainability, in alignment with the SDGs and the Thailand 20-Year National Strategy (NESDC, 2018).

4. Results

This study aimed to develop, implement, and evaluate the E-GREEN LOOP digital innovation for sustainable environmental management within a public educational administration context. The results are presented according to the three research objectives:

Objective 1: To develop a circular digital innovation (E-GREEN LOOP) integrating Green Office standards, circular economy logic, educational ICT, and environmental communication.

The research successfully developed the E-GREEN LOOP innovation, consisting of five interlinked modules: 1) E–Carbon Tracker, 2) Recycle Mapping, 3) Green Communication, 4) Green Audit Tool, and 5) E-Green Reward System.

The innovation was designed through a participatory co-design process and validated by three experts using a structured validation form. The average item-content validity index (I-CVI) across all five modules was 0.97, indicating a high degree of appropriateness, feasibility, and alignment with environmental and educational goals. The innovation was mapped using flowcharts and digital mockups, and all components were deployed using low-cost, cloud-based platforms (e.g., Google Workspace, LINE OA). This structure enabled circular interaction, user participation, and real-time environmental feedback.

Objective 2: To implement the E-GREEN LOOP within Suphanburi Primary Educational Service Area Office 1 and promote engagement in environmentally responsible behavior.

The implementation took place over a 12-week period and involved all 47 staff members. Participation and engagement levels were tracked through system analytics and digital logs:

Qualitative feedback and reflective interviews revealed that: 1) Staff developed greater awareness of their environmental footprint, 2) There was increased dialogue and collaboration around sustainability goals, and 3) Staff reported a shift in workplace culture, with environmental behavior seen as part of professional identity.

Table 2. Participation and engagement levels were tracked through system analytics and digital logs.

Module	Participation Rate	Most Active Division
E–Carbon Tracker	100% (47/47)	Personnel Unit
Recycle Mapping	87.2%	Administration Unit
Green Communication (LINE)	97.8%	All units equally
Green Audit Tool	93.6%	Supervision Group
Reward System	91.5%	Finance Unit

Objective 3: To evaluate the effectiveness of E-GREEN LOOP in reducing resource consumption and enhancing environmental awareness and satisfaction.

1. Environmental Impact

Table 3. A pre–post comparison of resource use showed.

Indicator	Before (avg/month)	After (avg/month)	% Change
Electricity (kWh)	2,610	2,308	-11.6%
Paper usage (reams)	85	53	-37.4%
Water usage (m ³)	96	82	-14.6%
Estimated CO ₂ e reduction	-	~680 kg CO ₂ e / 3 months	-

These results demonstrate the effectiveness of E-GREEN LOOP in reducing resource waste and promoting behavioral change in an organizational setting.

2. Staff Perceptions and Satisfaction.

A post-implementation survey (N = 47) yielded the following: 1) 91.5% agreed or strongly agreed that the system was easy to use, 2) 88.3% reported increased environmental awareness, 3) 85.1% indicated they had made specific behavioral changes (e.g., shutting off unused electronics, reducing printing), and 4) 94.4% supported continued use and scaling of the system.

The most highly rated component was the E–Carbon Tracker, followed by the Reward System, showing that feedback and recognition mechanisms significantly influenced behavioral adoption.

3. Qualitative Insights

Semi-structured interviews with department heads revealed: 1) E-GREEN LOOP helped establish visible feedback loops, making sustainability more tangible, 2) Interdepartmental collaboration increased because of shared environmental goals, and 3) Staff began integrating green thinking into non-environmental tasks, such as meetings, budgeting, and school support.

5. Discussion

The results of this study demonstrate that the E-GREEN LOOP innovation effectively addressed the need for an integrated, low-cost, and behaviorally engaging solution for environmental management within a government educational administration context. The discussion below elaborates on the significance of these findings considering existing literature, explores possible explanations for outcomes, and identifies new insights that emerged from the implementation.

5.1 Integration of Circular Digital Innovation in Public Sector Offices.

The successful deployment of all five modules of E-GREEN LOOP—ranging from the E–Carbon Tracker to the Green Reward System—highlights the feasibility of applying circular economy principles and digital tools within bureaucratic structures. Unlike many digital solutions that require expensive infrastructure or steep learning curves, the innovation leveraged tools (Google Workspace, LINE) already in use by office staff, thus minimizing resistance and reducing implementation barriers. This approach aligns with findings by Mergel et al. (2019), who assert that digital sustainability projects in public organizations are more effective when built upon existing platforms and workflows.

The participatory co-design process and modular architecture also contributed to the high adoption rate, consistent with the principles of design-based research (DBR) that emphasize iterative development and user feedback (Barab & Squire, 2004; Wang & Hannafin, 2005). These findings affirm that innovation in sustainability need not be technologically disruptive, but culturally embedded and operationally seamless.

5.2 Environmental Impact and Behavioral Change

The measurable reductions in electricity, paper, and water usage - especially the 37.4% decrease in paper use - suggest that even simple interventions, such as visible dashboards and “no-print” campaigns, can drive substantial behavior change. These findings mirror earlier behavioral economics research (e.g., Allcott & Rogers, 2014) indicating that real-time feedback and low-friction nudges are powerful drivers of environmental action.

Moreover, the staff survey revealed that over 85% of participants modified their daily behavior, suggesting that the innovation affected not only knowledge but also motivation and habit formation. This is in line with the Theory of Planned Behavior (Ajzen, 1991), which posits that intention, perceived control, and social norms are key predictors of behavior. In this case, the reward system and internal communication created a shared culture that normalized green behavior within the workplace.

5.3 Organizational Learning and Cultural Shift

Perhaps the most striking finding was the emergence of a green organizational identity. Staff no longer viewed environmental responsibility as a peripheral task but as an integral part of their role. Informal champions emerged, and inter-departmental collaboration increased. This reflects Fullan's (2016) perspective that sustainable change requires cultural alignment, not just structural reform.

Compared to previous "Green Office" projects in Thai governmental agencies—which often focused only on policy compliance and static self-assessment forms (Yossoonthornchai, 2020) - E-GREEN LOOP introduced dynamic digital participation, visibility, and feedback loops. This suggests a paradigm shift from policy-as-document to policy-as-practice, with digital innovation acting as a catalyst.

5.4 New Insight: Circular Digital Citizenship in Administrative Contexts

A noteworthy theoretical contribution from this study is the emergence of what might be termed "circular digital citizenship"—a concept where public employees act not only as policy implementers but also as engaged digital citizens who monitor, reflect, and co-shape their environmental footprint using data, collaboration, and communication tools. This idea expands the boundaries of digital citizenship, traditionally discussed in the context of students or online communities (Choi, 2016), to include public sector actors as ecological stewards within digital ecosystems.

This insight opens a new line of inquiry: Can government offices become learning organizations for sustainability using lightweight, circular digital tools? The results of this study suggest that they can, provided that the innovation is context-sensitive, participatory, and reinforced with behavioral science principles.

5.5 Limitations and Future Research

While the results are promising, several limitations remain. The innovation was implemented in a single office over a relatively short period (3 months), and long-term sustainability was not fully assessed. Additionally, some behavioral changes may reflect novelty effects rather than deep habit transformation.

Future research should explore: 1) Longitudinal impact of circular digital innovations, 2) Scaling the system to school levels or cross-district offices, 3) The role of leadership and peer networks in sustaining behavior change, and 4) Quantitative modeling of environmental return-on-investment (e.g., CO₂e savings per dollar of implementation).

6. Conclusion

This study introduced and validated the E-GREEN LOOP as an integrated, circular digital innovation designed to enhance sustainable environmental management within a government educational office. Anchored in Green Office principles, circular economy logic, educational ICT, and environmental communication, the innovation comprised five interlocking components that promoted behavioral change, resource efficiency, and digital participation. Through a design-based research approach, the innovation was not only successfully developed and implemented but also demonstrated measurable impact. Resource consumption decreased notably - especially paper usage (-37.4%) and electricity use (-11.6%) - while staff engagement reached over 90% across all modules. Survey responses and interviews indicated high usability, satisfaction, and a shift in organizational culture toward sustainability.

Most significantly, the findings suggest that public sector offices, often perceived as rigid and slow to innovate, can serve as living laboratories for digital environmental innovation - if tools are user-centered, behaviorally informed, and culturally embedded.

In conclusion, the E-GREEN LOOP demonstrates that digital transformation and ecological sustainability are not separate agendas - but mutually reinforcing pathways to more intelligent, participatory, and responsible public service. Through thoughtful design and systemic engagement, even the most traditional offices can become catalysts of green change.

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This work is dedicated to all public servants who believe that innovation and sustainability can thrive - hand in hand - within the everyday practices of government.

8. Authors' information

Numphon Maksorn is an educational supervisor at the Suphanburi Primary Educational Service Area Office 1, under the Office of the Basic Education Commission (OBEC), Ministry of Education, Thailand. With over 5 years of experience in educational supervision, technology integration, and instructional innovation, he specializes in designing and implementing area-based supervision models, environmental education, and digital learning ecosystems. He is also pursuing doctoral research in the field of Technology and Educational Innovation, with a focus on InnoImagineering Learning and Robotics Innovator Competency Development. His work combines policy, practice, and participatory design to foster sustainable and future-ready education systems. ORCID ID: <https://orcid.org/0009-0006-1644-8717>

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