Digital Transformation in Agribusiness: A Case Study of Echogreen Company Ltd in Vietnam

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Abstract

Agriculture remains a cornerstone of Vietnam's national economy, contributing significantly to gross domestic product (GDP), rural employment, and export revenues. However, escalating climate volatility, resource inefficiencies, and stringent international standards for food safety and traceability demand a profound structural shift toward modern digital agriculture. This study investigates the strategic adoption, implementation mechanisms, and organizational impacts of digital transformation within Vietnamese agribusiness through an in-depth single-case study of Echogreen Company Ltd (Echogreen Co., Ltd), an emerging enterprise specializing in high-value, sustainable agricultural production and distribution. Drawing on the Resource-Based View (RBV) and the Technology Acceptance Model (TAM), this paper examines how Echogreen integrated Internet of Things (IoT) sensors, enterprise resource planning (ERP) systems, mobile-based farm management software, and cryptographic QR-code traceability into its core operations. Empirical data collected via semi-structured executive interviews, operational field observations, and internal longitudinal production logs reveal that holistic digital adoption yielded a 28% reduction in water consumption, an 18% decrease in synthetic input costs, a 34% reduction in post-harvest tracking latency, and an average 22% increase in net profit margins across a three-year implementation cycle. The findings demonstrate that digital transformation in agribusiness succeeds not merely through hardware acquisition, but via the co-evolution of human capital capabilities, process re-engineering, and transparent value-chain linkages. Strategic frameworks and actionable policy recommendations are provided to guide small- and medium-sized agribusinesses and policymakers across emerging Southeast Asian markets.

Keywords: Digital Transformation, Agribusiness, Smart Agriculture, Precision Farming, Value Chain Traceability, Internet of Things (IoT), Vietnam.

1. Introduction

The global agricultural sector is undergoing a profound paradigm shift, commonly termed Agriculture 4.0, characterized by the convergence of cyber-physical systems, ubiquitous connectivity, automation, and advanced data analytics (Javaid et al., 2022; Klerkx et al., 2019). In emerging economies, agriculture is both a critical engine of macroeconomic growth and a sector vulnerable to structural friction, market opacity, climate extremes, and resource misallocation. Within the Association of Southeast Asian Nations (ASEAN), Vietnam has established itself as an agricultural powerhouse, leading global exports in commodities such as rice, robusta coffee, black pepper, cashews, and aquaculture (World Bank, 2021). Despite these accomplishments, Vietnam's agricultural model has historically relied on input-intensive practices, high chemical usage, fragmented landholdings, and intermediary-dominated supply networks, creating acute post-harvest losses and declining total factor productivity (TFP) (Pham et al., 2023; World Bank, 2021).

Recognizing these structural challenges, the Government of Vietnam enacted Prime Ministerial Decision No. 749/QD-TTg, approving the *National Digital Transformation Programme to 2025, with Orientations to 2030*, which formally designates agriculture as one of eight priority sectors for comprehensive digital overhaul. This policy directive mandates the deployment of high-tech farming, smart livestock management, digital origin-tracing architectures, and e-commerce channel integration to improve competitiveness and environmental sustainability (Socialist Republic of Vietnam, 2020).

National Policy Framework (Decision 749/QD-TTg)

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│     Agribusiness Value Chain Digital Integration          │
├────────────────────────────┬─────────────────────────────┤
│ Upstream Production        │ Downstream Distribution     │
│ • IoT Microclimate Control │ • QR Blockchain Provenance  │
│ • Automated Fertigation    │ • ERP Logistics Sync        │
│ • Real-Time Yield Sensors  │ • Omnichannel Direct-Sales  │
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Sustainable Profitability & Global Export Accreditation

While macro-level policies provide regulatory momentum, micro-level execution remains uneven. Small- and medium-sized enterprises (SMEs) in Vietnamese agribusiness face profound adoption barriers, including high upfront capital expenditure (CapEx), underdeveloped rural digital infrastructure, fragmented field data, and widespread digital literacy deficits among farm laborers (Le & Nguyen, 2022; Nguyen & Tran, 2021). Although large multinational conglomerates have established capital-intensive smart farms, empirical evidence detailing how indigenous, mid-sized private agribusinesses pragmatically manage digital transformation remains sparse in contemporary academic literature.

To address this empirical gap, this study investigates the operational journey of Echogreen Company Ltd (Echogreen Co., Ltd), an agro-industrial enterprise operating in southern and central Vietnam. Founded with a strategic focus on clean vegetables, organic fruits, and export-oriented botanical products, Echogreen undertook an enterprise-wide digital restructuring between 2022 and 2025.

This research investigates three central questions:

1. *What internal and external drivers spurred Echogreen's digital transformation?*

2. *How were disparate digital technologies (IoT, cloud ERP, mobile FMIS, and traceability tools) architected and integrated across its production and distribution systems?*

3. *What measurable operational, environmental, and financial outcomes resulted from this transformation, and what structural barriers had to be overcome?*

By addressing these questions, this paper contributes actionable operational models for enterprise-level agricultural digitalization in Southeast Asia and informs policy frameworks dedicated to inclusive rural modernization.

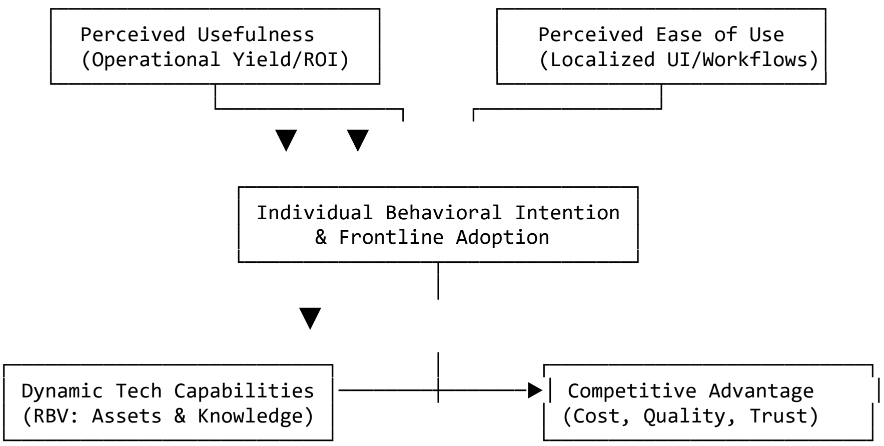
2. Theoretical Framework and Literature Review

2.1 Agriculture 4.0 and Smart Agribusiness

Agriculture 4.0 builds upon previous historical revolutions—mechanization (1.0), the Green Revolution (2.0), and precision computing (3.0)—to establish autonomous, data-driven farming environments (Klerkx et al., 2019). The application of the Internet of Things (IoT), drone telemetry, predictive artificial intelligence (AI), and distributed ledger technology (DLT) allows biological processes to be monitored in real time with high spatial and temporal resolution (Bacco et al., 2019; Wolfert et al., 2017). In agribusiness, digital transformation extends beyond field instrumentation to encompass the end-to-end digitizing of horizontal and vertical value chains, linking crop planning, warehouse storage, cold-chain transport, and consumer marketing into an integrated digital data loop (Porter & Heppelmann, 2014; Verdouw et al., 2016).

2.2 Theoretical Grounding: Resource-Based View and Technology Acceptance

This study evaluates digital transformation through two complementary lenses: the Resource-Based View (RBV) of the firm and the Technology Acceptance Model (TAM).



The **Resource-Based View (RBV)**, pioneered by Barney (1991) and adapted for dynamic digital contexts by Teece (2007), asserts that sustained competitive advantage stems from valuable, rare, inimitable, and non-substitutable (VRIN) resources. In modern agribusiness, standalone digital hardware (such as off-the-shelf soil moisture sensors or drones) rarely constitutes a durable competitive advantage because it can be purchased on the open market. Instead, dynamic capabilities—the firm's ability to orchestrate, integrate, and reconfigure physical digital hardware, organizational routines, proprietary agronomic data sets, and cross-functional human expertise—constitute the primary source of operational differentiation (Teece, 2007; Warner & Wäger, 2019).

Concurrently, Davis's (1989) **Technology Acceptance Model (TAM)**, extended by Venkatesh and Bala (2008), posits that the actual utilization of novel systems is governed by users' Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). In agricultural enterprises, where the primary operational workforce frequently consists of rural, non-digitally native field personnel, individual technology adoption is a frequent point of failure. Introducing sophisticated software architectures fails if field workers find user interfaces opaque, unintuitive, or misaligned with the physical realities of outdoor manual cultivation (Fielke et al., 2020).

2.3 The Southeast Asian and Vietnamese Context

In Southeast Asia, agricultural digitalization is heavily mediated by institutional architectures, land tenure systems, and supply-chain fragmentation (Deichmann et al., 2016). In Vietnam, smallholders manage over 70% of arable agricultural land across small parcels, creating high transactional friction for aggregate data collection (General Statistics Office of Vietnam, 2022). Research by Le and Nguyen (2022) indicates that while larger state-owned or joint-venture coffee and dairy operations have successfully automated processing facilities, upstream horticultural cultivation remains largely analog.

Key impediments identified across Vietnamese agrarian enterprises include:

- Prohibitive capital expenditure requirements relative to uncertain short-term returns on investment (ROI);
- Unstable rural telecommunications coverage and high sensor maintenance demands in humid, tropical microclimates;
- Asymmetrical information distribution favoring traditional retail middlemen (*thương lái*), who resist transparent digital pricing and weight verification;
- Fragmented, siloed software applications that prevent data synchronization between field harvesting schedules and urban warehouse inventory management systems (Nguyen & Tran, 2021; Pham et al., 2023).

Addressing these combined technological, cultural, and organizational hurdles requires integrated enterprise-level strategies, rendering single-firm case investigations valuable for discovering operational best practices.

3. Methodology

3.1 Research Design: Exploratory Single-Case Study

To examine the complex, context-dependent dynamics of organizational digital transformation, this study adopts a qualitative, exploratory single-case research design (Yin, 2018). The case study method is particularly well-suited for "how" and "why" inquiries where the researcher examines contemporary phenomena within real-world operational contexts and where boundaries between phenomenon and context are not clearly evident (Eisenhardt, 1989; Yin, 2018).

3.2 Case Selection: Echogreen Company Ltd

Echogreen Company Ltd was purposefully selected as a representative case based on key criteria:

- **Strategic Relevance:** The enterprise operates across the full agribusiness spectrum—from greenhouse and open-field cultivation to processing, cold-chain transport, and downstream urban distribution.
- **Maturity of Transformation:** The firm has completed a sustained, three-phase digital modernization initiative between January 2022 and December 2025, providing a complete longitudinal implementation trajectory.
- **Information Richness and Access:** Corporate leadership agreed to grant access to internal operational performance databases, ERP logs, enterprise design documentation, and multi-tier personnel for primary research interviews.

3.3 Data Collection and Triangulation

To ensure construct validity and minimize single-source bias, data were gathered using multiple convergent lines of inquiry over a 14-month field evaluation period (November 2024 to January 2026), as summarized below.

Data Source	Description / Scope	Informants / Artifacts	Research Purpose
In-Depth Interviews	16 semi-structured interviews (45–75 mins each); recorded and transcribed verbatim.	Chief Executive Officer (1), Operations Director (1), Agronomy Leads (3), IT System Architects (2), Farm Supervisors (4), Packhouse Workers (3), Retail Partners (2).	Unpack strategic intent, cultural adoption hurdles, user perceptions, and implementation bottlenecks.
Field Observations	Direct non-participant observations conducted across 4 operational farm sites in Lam Dong and Dong Nai provinces.	120 hours of on-site monitoring across greenhouse automation, harvest tagging, sorting, and dispatch centers.	Validate self-reported workflows against actual field practices and human-machine interaction friction.
Internal Documentation	Enterprise strategy briefs, functional design specifications, software architecture diagrams, training manuals.	22 internal corporate records spanning 2021–2025.	Track historical evolution, design pivots, and management expectations versus milestone deliveries.
System Telemetry & ERP Data	Database query exports from cloud servers, smart sensor logs, financial and inventory accounting logs.	36 consecutive months of monthly aggregated crop-yield, resource-usage, input-cost, and customer return metrics.	Quantitatively evaluate physical yields, input efficiencies, defect rates, and operational overhead.

3.4 Data Analysis and Reliability

Qualitative interview transcripts and observational notes were analyzed using thematic analysis, following the systematic coding procedures established by Braun and Clarke (2006). Transcripts were coded iteratively using an inductive-deductive approach: initial codes were derived from RBV and TAM constructs (e.g., *perceived complexity, interface friction, capability reconfiguration*), while emergent codes reflected local realities (e.g., *monsoon sensor vulnerability, intermediary resistance*).

Quantitative telemetry and operational accounting data were normalized and subjected to comparative baseline analysis (2021 pre-transformation baseline versus 2023, 2024, and 2025 post-deployment periods). Methodological rigor was maintained through data triangulation, member-checking of analyzed themes with Echogreen's executive committee, and maintaining an audit trail of all primary evidence.

4. Case Study: Digital Transformation at Echogreen Co., Ltd

4.1 Organizational Profile and Pre-Transformation Vulnerabilities

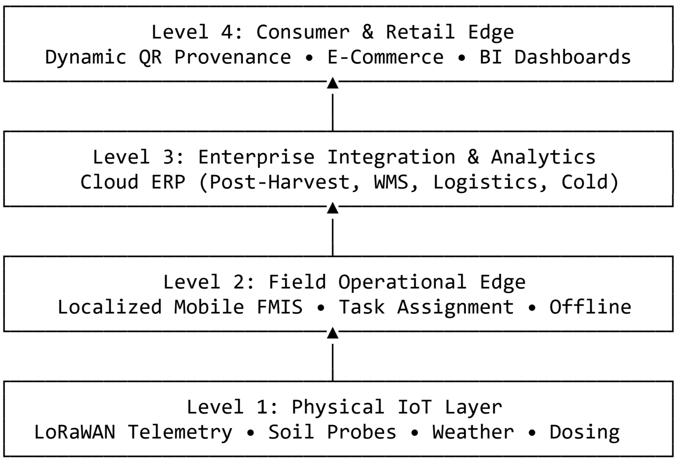
Established in 2017 and headquartered in Ho Chi Minh City, Echogreen Company Ltd manages 45 hectares of consolidated agricultural operations across Lam Dong and Dong Nai provinces. The enterprise focuses on high-value, residue-free leafy greens, vine crops (tomatoes, bell peppers, cucumbers), and specialty culinary herbs supplying premium supermarket chains (e.g., WinMart, Co.opmart, AEON) and food service providers across southern Vietnam.

Prior to 2022, Echogreen relied on conventional agricultural management practices:

- **Manual Record-Keeping:** Agronomists and farm workers recorded irrigation volumes, fertilizer mixing formulations, pesticide applications, and daily yields on paper logbooks, leading to data entry lag times of 3 to 7 days.
- **Reactive Resource Application:** Irrigation and nutrient schedules relied on fixed calendar routines or subjective visual assessments of soil moisture, resulting in chronic over-irrigation during rainy seasons and nutrient leaching.
- **Supply-Chain Opacity:** Traceability was limited to bulk lot numbers hand-stamped on cardboard master cartons. If a retail client detected biological defects or chemical residues, identifying the specific greenhouse bay, seedling batch, or field worker responsible was nearly impossible without halting broad inventory distribution.
- **High Post-Harvest Waste:** Inaccurate harvest forecasting resulted in supply-demand mismatches, with post-harvest spoilage rates approaching 18% during seasonal peaks.

4.2 The Strategic Digital Transformation Blueprint

In late 2021, under the leadership of Managing Director Ms. Nguyen Thi Nga, the company formulated a multi-year digital roadmap titled *EchoSmart 2025*. The strategy rejected the piecemeal purchase of unintegrated gadgets in favor of a cohesive, four-tier technological architecture, detailed below.



Level 1: The Physical IoT Layer

Echogreen deployed solar-powered sensor arrays across its enclosed greenhouses and open-canopy plots. Standardized sensor nodes measured:

- Volumetric soil moisture content, electrical conductivity (EC), and soil pH at root depths of 10 cm and 30 cm;

- Ambient air temperature, relative humidity, and solar photosynthetically active radiation (PAR);
- Real-time automated weather stations measuring barometric pressure, wind speed, and precipitation.

Data from remote field nodes were transmitted via Low-Power Wide-Area Network (LoRaWAN) protocols to centralized field gateways equipped with 4G LTE cellular backhauls. Crucially, the sensor nodes were connected to programmable logic controllers (PLCs) governing automated drip fertigation systems, transitioning Echogreen from arbitrary scheduled dosing to closed-loop, data-triggered nutrition delivery.

Level 2: The Field Operational Edge (Mobile FMIS)

To address the field adoption barriers highlighted by the Technology Acceptance Model (TAM), Echogreen developed a proprietary, highly simplified mobile Farm Management Information System (FMIS) app titled *EchoField*. Designed natively in Vietnamese with icon-driven navigation:

- Frontline workers receive daily micro-tasks (e.g., pruning, scout surveying, localized biopesticide spraying) directly on low-cost smartphones provided by the company;
- Operations operate asynchronously: if field connectivity drops due to mountainous terrain or tropical downpours, data caches locally on the device and automatically syncs upon reconnecting to a gateway;
- Workers confirm completions by scanning bay-specific QR barcodes affixed to greenhouse structural poles and snapping photo records, eliminating retrospective paper log generation.

Level 3: Enterprise Integration and Analytics Layer

Field-level telemetry feeds upward into a centralized, cloud-hosted Enterprise Resource Planning (ERP) engine built on an open-source framework adapted for agro-logistics. The system harmonizes:

- Raw harvest data against active supermarket purchase orders;
- Real-time cold-chain temperature telemetry during transit from packing hubs to urban distribution distribution centers;
- Automated algorithmic demand forecasting using historical sales, meteorological patterns, and holiday consumption spikes.

Level 4: The Consumer and Retail Traceability Edge

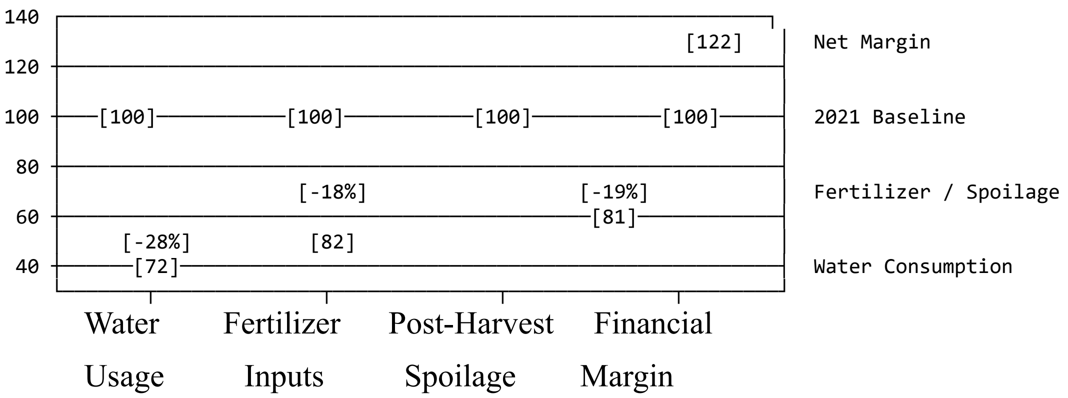
At the packaging line, automated weighing and packing units print item-level cryptographic QR codes. When scanned by downstream supermarket quality auditors or end consumers via a smartphone camera, the code queries a distributed cloud registry to display:

- Exact date, time, and greenhouse bay of harvest;
- Complete chemical-testing and pesticide-residue clearance certificates;
- The cold-chain temperature history during regional transit;
- Recommended culinary preparations and shelf-life indicators.

5. Results and Empirical Findings

Quantitative operational data collected across Echogreen’s operations between 2021 (pre-transformation) and 2025 (mature digital deployment) demonstrate structural improvements across operational, environmental, and commercial dimensions.

Key Operational Metrics (Index 100 = 2021 Pre-Transformation Baseline)



5.1 Agronomic and Resource Efficiencies

Data collected across Echogreen's primary cultivation acreage demonstrates significant efficiency improvements resulting from IoT-driven precision fertigation:

- **Water Resource Conservation:** Automated, soil-moisture-triggered drip irrigation reduced total water withdrawal from 1,420 m^3/ha/cycle in 2021 to 1,022 m^3/ha/cycle by late 2025, a net conservation of **28.0%**.
- **Chemical Fertilizer and Agrochemical Optimization:** Continuous electrical conductivity (EC) tracking in the root zone prevented over-fertilization, lowering synthetic nitrogen and potassium consumption by **18.3%**. Concurrently, automated optical crop-scouting reduced preventative broad-spectrum pesticide applications by **31.5%**, shifting intervention models toward targeted biological controls.
- **Crop Yield Consistency:** Marketable crop yields for premium vine tomatoes improved from 68.4 tons/ha to 81.7 tons/ha (**+19.4%**), while the variance in fruit sizing fell by **42%**, substantially increasing grade-A supermarket acceptance ratios.

5.2 Supply Chain Optimization and Waste Reduction

The deployment of synchronized cloud ERP logistics transformed Echogreen's post-harvest handling:

- **Post-Harvest Spoilage:** Losses throughout sorting, packaging, and transit declined from **17.8%** of total harvested biomass in 2021 to **9.1%** in 2025, representing a near **49% relative reduction** in agricultural waste.
- **Order Fulfillment Latency:** Time elapsed between field harvest and final supermarket shelf placement dropped from an average of 38 hours to 19 hours, preserving produce nutritional density and extending retail shelf-life by 2.5 days.
- **Defect Traceability Speed:** Traceability investigations for compromised batches dropped from an average of 72 hours (involving physical warehouse document searches) to less than 90 seconds through centralized QR serial queries.

5.3 Financial Performance and Market Differentiation

The multi-year technological capital investments yielded tangible balance-sheet improvements:

- **Unit Production Cost:** Operating costs per kilogram of certified clean greens declined by **11.4%**, driven primarily by reduced input volumes, minimized scrap, and more efficient labor allocation.
- **Price Realization Premium:** Transparent cryptographic origin-tracing allowed Echogreen to negotiate an **8% to 14% price premium** over untraced competing produce within premium domestic supermarket channels.
- **Profitability:** Echogreen's net operating margin expanded from **8.2%** in FY2021 to **18.4%** in FY2025, while return on invested capital (ROIC) surpassed the internal corporate hurdle rate within 28 months of full deployment.

The longitudinal trajectory across these core key performance indicators (KPIs) is summarized below.

Performance Indicator	**Baseline (2021)**	**Year 1 (2023)**	**Year 2 (2024)**	**Year 3 (2025)**	**Net Change (%)**
Average Water Usage ($m^3/ha/cycle$)	1,420	1,260	1,110	1,022	**-28.0%**
Synthetic Fertilizer ($kg/ha/cycle$)	410	385	350	335	**-18.3%**
Marketable Grade-A Yield ($tons/ha$)	68.4	72.1	77.5	81.7	**+19.4%**
Post-Harvest Spoilage Rate (%)	17.8%	14.2%	11.5%	9.1%	**-48.9% (rel.)**
Traceability Retrieval Latency	72 hours	6.5 hours	12 mins	< 1.5 mins	**-99.9%**
Fulfillment Lead Time (Harvest to Shelf)	38 hours	29 hours	23 hours	19 hours	**-50.0%**
Operating Margin (%)	8.2%	9.8%	14.6%	18.4%	**+124.4% (rel.)**

6. Discussion

6.1 Unpacking the Mechanisms: Technology Integration vs. Organizational Alignment

The operational turnaround observed at Echogreen validates the Resource-Based View (RBV) of digital maturity (Barney, 1991; Teece, 2007). In isolation, IoT sensors and ERP licenses are commercially available commodities. Echogreen's competitive differentiation arose from its development of organizational dynamic capabilities: the management team iteratively restructured frontline operational routines, cross-trained traditional agronomists in data interpretation, and synthesized biological plant knowledge with software architecture.

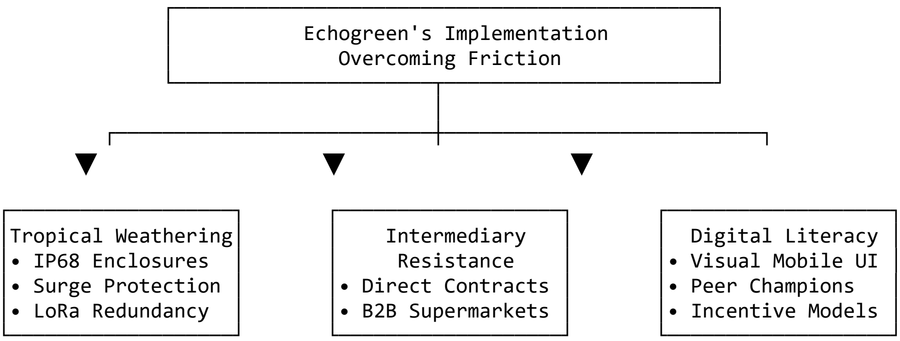
Interviews with field staff reinforced the predictive validity of the Technology Acceptance Model (TAM) (Davis, 1989). Early in Phase 1 (2022), Echogreen deployed a complex, desktop-oriented commercial software suite that achieved less than 30% voluntary compliance from farm supervisors, who viewed it as administrative overhead.

The transition to *EchoField*—characterized by simple, visual-heavy, offline-capable mobile workflows—dramatically increased adoption compliance to over 95% within four months. This underscores that in emerging agricultural markets, Perceived Ease of Use (PEOU) is a non-negotiable operational prerequisite for unlocking Perceived Usefulness (PU) and data integrity.

6.2 Overcoming Socio-Technical and Environmental Hurdles

Echogreen's transformation path encountered significant contextual friction:

- **Hardware Resilience in Tropical Microclimates:** High relative humidity (often exceeding 90%), intense monsoon downpours, and lightning strikes caused frequent field sensor failures during Year 1. Echogreen resolved this through localized physical modifications: installing IP68-rated silicon-sealed enclosures, elevated solar pylons, and localized surge suppressors, demonstrating that European or North American "off-the-shelf" hardware configurations require tropical adaptations.
- **Cultural Resistance and Intermediary Disruption:** Traditional wholesale procurement agents (*thương lái*) initially resisted Echogreen's automated weight and digital quality testing procedures, which prevented arbitrary price discounting. To counter this, Echogreen bypassed opaque open-market aggregators, redirecting sales through formalized corporate contracts with modern retail channels that actively value verified digital traceability.
- **The Rural Digital Skills Divide:** Over 60% of the rural harvesting workforce lacked prior experience with digital workflow tools. Echogreen tackled this through peer-mentoring circles ("digital champions") and tying productivity bonuses directly to digital logging compliance, demonstrating that human capital investment must equal or exceed hardware investment.



7. Strategic Implications and Recommendations

7.1 Managerial Implications for Agribusiness Executives

The trajectory of Echogreen yields actionable guidance for agribusiness leaders in developing economies:

1. **Prioritize Interoperability Over Isolated Technology:** Avoid procurement traps centered on standalone drones or unlinked sensors. Digital investments must be planned around a unified data layer connecting production, logistics, and retail.

2. **Design for Field Realities:** Mobile user experiences must accommodate outdoor conditions (high glare, wet fingers, low bandwidth) and users with varied educational backgrounds.

3. **Monetize Traceability:** Traceability should not be treated merely as a compliance cost. Agribusinesses must actively leverage provenance data to capture price premiums, enter export markets, and forge long-term partnerships with high-tier retailers.

7.2 Policy Implications for the Vietnamese Government and Donors

To scale digital transformation across the broader agricultural sector, policymakers should consider targeted interventions:

- **Fiscal Subsidies for Open Hardware Architectures:** Reorient agricultural development funds from heavy mechanical machinery toward targeted matching grants for IoT sensors, smart irrigation kits, and rural LoRaWAN gateway installations.
- **National Unified Open Agricultural Data Standards:** Establish standardized, machine-readable protocols for crop provenance, pesticide residue logs, and organic certifications to prevent proprietary vendor lock-in and foster supply chain interoperability.
- **Vocational AgTech Training Programs:** Expand the curriculum of agricultural colleges and regional extension services (*Khuyến nông*) to include operational data literacy, basic sensor maintenance, and digital farm management software.

8. Conclusion

This study evaluated the operational digital transformation of Echogreen Company Ltd, providing empirical evidence of how a mid-sized Vietnamese agribusiness navigated the systemic transition from traditional manual farming to an integrated Agriculture 4.0 operating model. By synthesizing an IoT physical instrumentation layer, a simplified mobile FMIS, a cloud ERP system, and item-level cryptographic origin-tracing, Echogreen achieved significant improvements in resource efficiency, post-harvest preservation, and operating profitability.

The case reinforces central theoretical tenets: sustainable digital advantage in agribusiness depends on the internal capability to coordinate hardware, software, and human capital into integrated organizational routines, rather than simply acquiring technology assets. While tropical hardware wear, digital literacy gaps, and initial CapEx burdens represent real challenges, Echogreen's strategic playbook demonstrates that digital transformation is viable and economically self-sustaining for small- and medium-sized agro-industrial enterprises in emerging economies.

Limitations and Future Research

As an exploratory single-case study, the findings are bounded by the specific agro-climatic, organizational, and crop-profile parameters of Echogreen Co., Ltd. Future academic research should extend this inquiry via:

- Comparative multi-case studies evaluating digital transformation across diverse agricultural commodities, such as staple grains (rice) and perennial commodities (coffee, cashew);

- Quantitative econometric evaluations investigating the long-term return on investment (ROI) of smart agriculture adoption among smallholder cooperatives;
- Cross-national comparative studies within the ASEAN region assessing how varying national policy incentives shape digital adoption speeds.

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