Sustainable Social Development 2025, 3(5), 8365.
https://doi.org/10.54517/ssd8365

Article

Digital transformation and value reconstruction of food testing industry chain with environmental law synergistic development

Jie Chu

Beijing Institute of Food Inspection and Research (Beijing Municipal Center for Food Safety Monitoring and Risk Assessment), Beijing 100094, China; s007ophia@126.com

CITATION

Chu J. Digital transformation and value reconstruction of food testing industry chain with environmental law synergistic development. Sustainable Social Development. 2025; 3(5): 8365. https://doi.org/10.54517/ssd8365

ARTICLE INFO

Received: 30 December 2025
Revised: 5 February 2026
Accepted: 2 March 2026
Available online: 11 March 2026

Abstract: The food testing industry is undergoing a profound transformation as digital technologies expand alongside increasingly stringent environmental regulations. Rather than treating digitalization and environmental compliance as separate operational requirements, this study explores how their interaction reshapes value creation across the food testing industry chain. Focusing on the regulatory and ecological dimensions of digital transformation, the study examines how testing organizations respond to environmental law while reconstructing their value propositions in a highly regulated service sector. Using a mixed-methods design, the research draws on expert interviews and survey data from food testing institutions to analyze structural changes, value distribution dynamics, and governance mechanisms emerging under combined technological and legal pressures. The findings show that when digital transformation is strategically aligned with environmental compliance, testing organizations are able to convert regulatory obligations into sources of operational improvement, service differentiation, and long-term competitiveness. Digital tools enhance environmental monitoring, compliance transparency, and coordination across the industry chain, enabling new forms of value reconstruction that integrate economic performance with ecological responsibility. This study proposes an integrated framework that clarifies the pathways through which digital capability building and environmental governance jointly support sustainable industry development. The results offer practical insights for policymakers and practitioners seeking to promote digitally enabled, regulation-aligned growth in food testing and other environmentally regulated service industries.

Keywords: digital transformation; food testing industry; value chain reconstruction; ecological law; environmental compliance

1. Introduction

The ongoing digitization of the food testing industry, together with evolving environmental regulations, is rapidly reshaping operational practices and business models. According to one study, the expansion of global food supply chains is both a catalyst and an obstacle for fostering collaboration with the natural environment. This study suggests there is a need to sustain food supply chains while also striving for circularity [1]. This portion of the industry undergoes additional pressures in trying to transform due to the boundaries found in merging the physical and digital worlds, which hold great potential to drive green change across [2] industries. Prior studies grounded in social interaction frameworks suggest that digital technologies are altering how value is generated and redistributed within the food testing ecosystem [3] and disclose that, from the vantage point of the ecosystem's transformation through digital technologies, quite a lot of value could be captured from the food testing ecosystem.

The agriculture-food nexus offers illustrative cases of digital-enabled sustainable change, including China and the European Union, which showcase the systemic restructure of an industry's value chain through technology and service integration along with its improved ecological impact [4]. These transformations occur in a context of increasing cross-industry competition, where the adoption of sustainable technologies is prompting firms to reconsider established business strategies [5], as well as necessitated shifts through sustainable technologies for food testing enterprises to rethink their value propositions. The coexistence of different operational practices within food supply chains further complicates this transformation, as firms often pursue economic and environmental objectives simultaneously, where evidence suggests that differing operational approaches within a single organization lead to markedly different consequences across business performance and environmental performance [6].

As shown by research analyzing the impacts of specific governance policies on agricultural carbon emissions using intricate causal pathways, policy frameworks have a lasting effect on transformation trajectories [7]. For food testing organizations, addressing these policies requires the combination of environmental compliance capabilities with the integration of digital technologies. Indeed, recent studies validate that digital transformation, advanced technology, and eco-innovation together create opportunities for improved supply chain performance [8], particularly for organizations tasked with food safety and environmental compliance verifications. Research on the efficiency of agricultural carbon emissions within set methodologies provides case studies for benchmarking formulas that testing organizations could use for environmental performance assessment [9]. More holistic approaches to Agriculture 4.0 offer frameworks for understanding how the digital transformation can sustain futures in the agri-food ecosystem [10].

Addressing the challenges to implementing a circular economy requires the creation of micro-foundations and dynamic capabilities [11]. These are enabled through the use of information technology and knowledge sharing, which support the functioning of circular food supply chains and promote the growth of green businesses [12]. The interplay among black box analytics, ambidextrous supply chain management, and green practices of the supply chain creates particular opportunities for proactive environmental marketing by using advanced analytical capabilities that enhance the organization's environmental performance [13]. However, these advancements need to pay attention to the concerns of security, safety, and privacy, especially with the increasing use of artificial intelligence in sustainable digital applications [14].

The most recent studies on the processes and pathways of amplifying green and low-carbon performance in the context of digital transformation along with carbon mitigation targets [15] provide a theoretical paradigm to be utilized by food testing organizations as they strive to comply with ecological frameworks and policies. The changing role of traders as actors of sustainability governance in the international food supply chain [16] highlights the need for active collaboration regarding environmental compliance by many testing service providers. While food supply chains face ever-increasing disruptive challenges, strategies for resilience in the digital age [17] become crucial for sustaining compliance for testing organizations seeking to operate

compliantly during turbulence. The noted synergistic effects of the digital economy on emission reduction and upgrading the structure of the economy's manufacturing industry imply simultaneous opportunities for improvement in environmental performance of testing operations [18].

The context of fostering eco-friendly sustainable development through renewable energy, financial technologies, and agriculture serves as both a food testing organizational constraint and an opportunity within the intricate web of regulatory frameworks [19]. New pathways through digital transformation leading to supply chain resilience add the conceptual framework for analyzing how food testing organizations can use modern technology to address ecological compliance challenges while distinctively positioning themselves competitively in a highly controlled environment [20].

The global food testing industry has witnessed substantial growth, with market valuation reaching $21.1 billion in 2023 and anticipated expansion at a compound annual growth rate of 8.3% to $31.4 billion by 2028, primarily propelled by stringent safety regulations and heightened consumer awareness. Despite this growth momentum, digital adoption remains asymmetric, with merely 42% of testing institutions having fully deployed advanced analytics platforms and 31% utilizing IoT-enabled testing equipment. International environmental frameworks, including the ISO 14000 series standards, the European Union's Green Deal initiatives, and China's revised Environmental Protection Law, have exerted profound influence on operational practices throughout the industry's value chain. However, existing studies largely examine digital transformation or environmental regulation in isolation, with limited empirical research exploring their joint role in reshaping value creation mechanisms within regulated service industries such as food testing. Moreover, mixed-method evidence from emerging economies remains scarce, constraining a comprehensive understanding of how regulatory pressure and digital capability co-evolve at the organizational level.

In response to these gaps, this research contributes novel insights by developing an integrated framework that bridges digital transformation and environmental compliance, enabling food testing organizations to convert regulatory obligations into competitive advantages through strategic realignment of technological capabilities, organizational structures, and stakeholder relationships within the increasingly sophisticated global food safety ecosystem. Accordingly, this study is guided by the following research questions. First, how does digital transformation influence the ability of food testing organizations to respond to and comply with increasingly stringent environmental laws? Second, how does environmental law compliance contribute to the reconstruction of value creation mechanisms within the food testing industry chain? Third, how do digital transformation and environmental compliance interact synergistically to reshape organizational value propositions, governance structures, and competitive positioning in a highly regulated service sector? By addressing these questions, the study seeks to clarify the mechanisms through which technological capability building and environmental governance jointly drive value reconstruction in the food testing industry.

2. Research methodology

This study adopts a mixed-methods approach to examine the relationships between digital transformation, environmental law compliance, and value reconstruction in the food testing industry. This approach rationalizes the need to achieve an in-depth understanding of the multifaceted phenomenon by combining qualitative and quantitative elements. Specifically, the mixed-methods design enables the integration of contextualized qualitative insights with empirically testable quantitative relationships, thereby strengthening explanatory depth and analytical robustness.

The qualitative component is based on semi-structured interviews with a sample of twenty-four industry specialists, such as testing laboratory managers, enforcement verifiers, technologists, and environmental law attorneys, which provide deep contextual insight regarding organizational actions and strategic choices. These interviews took place from January to April 2024, each lasting roughly 60 to 90 min. Participants were selected using purposive sampling to ensure representation across regulatory, technological, and managerial perspectives within the food testing ecosystem. All interviews were audio-recorded with participant consent and transcribed verbatim prior to analysis.

In China, quantitative information was obtained through a structured questionnaire administered to 156 food testing organizations from different regions, achieving an overall response rate of 78.2%. The validated survey instrument, which was pretested with industry participants, included questions on digital maturity, environmental compliance, value creation, and various organizational performance metrics. The primary data collection efforts were complemented by secondary data from industry publications, regulatory framework files, and records on environmental compliance.

The quantitative analysis focuses on descriptive and comparative examination of key constructs related to digital transformation, environmental law compliance, and value reconstruction. Rather than estimating causal parameters, the survey data were analyzed to identify distributional patterns, relative performance differences, and co-occurring trends across organizational practices. These quantitative patterns informed the value distribution analysis and the comparative performance profiles presented in.

Qualitative content analysis was conducted using NVivo software following a multi-stage coding procedure. Initial open coding was applied to identify first-order concepts directly derived from interview data. These codes were subsequently refined through axial coding to establish thematic relationships, and finally consolidated through selective coding to generate higher-order analytical dimensions aligned with the conceptual framework.

To enhance analytical reliability, the coding process was iteratively reviewed, and discrepancies in code interpretation were resolved through discussion to reach consensus. The resulting coding structure informed the conceptual model design and the identification of value reconstruction mechanisms discussed in Sections 4 and 5. The robustness of the findings was strengthened through triangulation across survey-based descriptive patterns, qualitative interview insights, and applied case illustrations. This triangulated approach supports framework development and

mechanism clarification without relying on statistical hypothesis testing.

This study concentrates on China's eastern and southern regions, particularly targeting industrial centers characterized by advanced digital development and stringent environmental regulations. This geographical constraint presents generalizability challenges for western and northern territories, where organizational hierarchical patterns, technological development levels, infrastructure capabilities, and regulatory enforcement mechanisms differ substantially. The disparities between coastal and inland regions regarding economic activity, technological advancement, infrastructure development, and nuanced governance of digital and environmental sectors have generated socio-ecological transformation paradigms that remained beyond the scope of our sampling framework. Comprehensive nationwide assessments should prioritize these regions to enhance representativeness.

Given the exploratory nature of the study, the analysis captures patterned associations and comparative tendencies rather than statistically estimated causal relationships. The cross-sectional methodology captures merely a temporal snapshot of the multistage value reconstruction processes, constraining the apprehension of evolving transformation dynamics. The integration of digital transformation and environmental compliance constitutes a multidimensional continuum wherein actions and outcomes may exhibit temporally displaced relationships due to lag effects. This temporal gap emerges from the study's focus on prescriptive causal reasoning developed over extended periods. These findings would be more readily observable and reliably interpretable through longitudinal approaches that integrate multiple temporal frameworks with defined organizational dimensions.

Self-reported metrics for evaluating digital maturity and environmental compliance pose risks of response bias, whereby organizations may inflate declared competencies due to social desirability effects. While triangulation attempts utilizing supplementary data sources have been employed, the inherent bias factor of self-assessment remains a persistent limitation. The discrepancy between claimed and actual performance may compromise the statistical models' reliability and precision. Future research is encouraged to incorporate independent third-party evaluations, regulatory audit documentation, or longitudinal performance tracking to enhance empirical rigor.

3. Current status of food testing industry chain

3.1. Structure analysis

The food testing industry value chain consists of a complex network of actors operating within an increasingly digitized and environmentally regulated ecosystem. This system includes upstream actors such as chromatograph and spectroscope manufacturers, as well as PCR device manufacturers who have to comply with environmental restrictions on chemical production and disposal through cleaning incinerators. Reagent producers also face stringent regulations from the Environmental Protection Law of China on chemical waste in recent years. The midstream actors include testing and certification laboratories that transform available technologies into practical food safety checks and checks for environmental compliance for emissions and waste. Consisting of food processors, retailers, and the

general public who examine the test results for safety and compliance purposes, the downstream stakeholders are formed. Testing and certification laboratories transform available technologies into food safety as well as environmental compliance checks and calibrations. As illustrated in **Figure 1**, environmental regulatory frameworks intersect with each stage of the value chain, shaping both value creation processes and operational constraints.

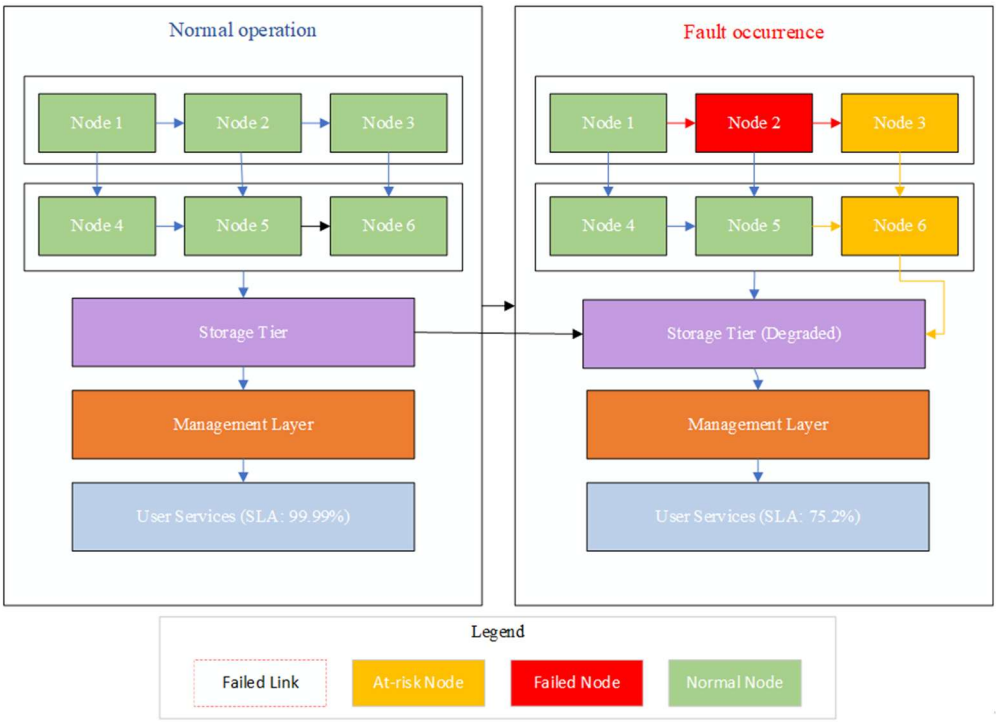


Figure 1. Food testing industry chain structure with environmental regulation interfaces.

The environmental legal system offers both limitations and opportunities throughout the entire industry value chain. It certainly forges new frontiers for innovation and economic growth at the very start of the supply chain, where suppliers are green-testing innovations such as eco-friendly reagent development, which has grown by 22% yearly since 2020. An increase in midstream providers also brings sophisticated emission control systems and waste management protocols onto the market. Intersectoral boundaries have transformed into joint projects for the creation of new sustainable approaches to testing, as shown in **Figure 1**. This illustration from MATLAB demonstrates how eco-environmental legislation interrelates with the structure of industries to define value creation and compliance processes that influence competitive position in relation to cost efficiency for the food ecosystem.

3.2. Value distribution analysis

The modern value chain distribution within the food testing industry demonstrates irregularities that are becoming more sensitive to environmental policy frameworks. Financial data analysis across 156 sample (**Figure 2**), companies revealed that the upstream equipment and reagent suppliers capture approximately 32 % of the industry value, while midstream testing laboratories account for 45%, and

downstream analytics and reporting data services correspond to 23%. This distribution has changed considerably over the past few years because of more stringent compliance costs associated with environmental regulation, averaging around 18.7% of operating expenses for testing facilities. These compliance expenditures improve corporate image and decrease legal costs, portraying a more captured value than perceived, ultimately enhancing competitiveness in eco-sensitive markets. Comprehensive risk assessment and cost analysis indicate an average payback period of 3.2 years, although reductions in forecasted costs differ dramatically based on organizational scale and level of technology.

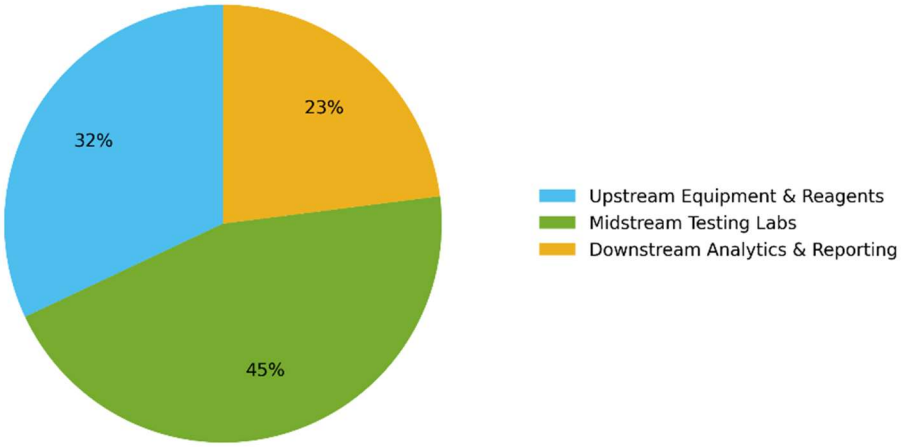


Figure 2. Value distribution in the food testing industry chain.

The enforcement of environmental policies has indeed caused substantial value effects across the entire sector. Stakeholders with advanced systems of environmental management best practices have captured 7% to 12% more market share than their rivals with inferior compliance mechanisms. This is especially noteworthy in the case of testing firms where environmental performance is incorporated into their advertising strategies. For such services, they include environmental monitoring and achieve price premiums of 9%–15%. The value shift has also taken place alongside the transformation of supplier-laboratory relations, within which 68% of respondents reported increased collaboration for environmentally sustainable testing framework development. Stakeholder interviews show contrasting views on the fairness of value balance, where smaller laboratories raised doubts about the disproportionate burden of compliance costs, while larger entities appreciated the value from competitive economics of scale in environmental management. This view adds further complication to the already shifting value landscape, responding to chronic industry stratification, which especially impels participants to adjust focus on how best to suggest value capture through environmentally regulated investment frameworks.

Recent value distribution patterns in the food testing sector reveal increasing sensitivity to environmental policy requirements, particularly in relation to compliance-related cost structures.

3.3. Digital transformation challenges

The trajectory of technological advancement in the food testing industry is faced with numerous challenges that hinder the complete adoption of digital transformation throughout the industry value chain. Interoperability challenges impede system and platform integration with digital infrastructure, which is a major technological obstacle. Outdated Information Systems (IS) architecture poses 76% of the defined problems within a given organization. Proprietary interfacing requirements for environmental parameter monitoring within specialized testing equipment exacerbate integration complexity, leading to data silos that are unable to perform comprehensive analysis. Those technologies have very strict limitations due to the Environmental Data Security Regulations applicable to sensitive content, which dictate stringent control on the storage, transmission, and processing of security-sensitive data. Meeting jurisdictional compliance for data protection requires high-level encryption and access control that many small and medium-sized testing laboratories lack the resources for technologically.

Alongside other organizational areas of concern, resistance to change due to skill obsolescence anxiety contributes to inertia blocking a business's digital transformation. Survey data shows that 62% of laboratory technicians have moderate to high anxiety in regard to new digitally enabled environmental testing procedures, while 58% of middle managers regard digital transformation initiatives as highly likely to disrupt established operating procedures. These findings also constrict parallel compliance with other regulation-driven organizational policies requiring perpetual adjustment of systems to meet changing environmental regulations. Environmental standards that are subject to change require agile digital frameworks that can quickly add new capabilities for environmental monitoring, something only 23% of organizations are equipped with, according to our survey. Environmental monitoring systems pose specific challenges in relation to the real-time data requirement of the system, needs for specialized sensors, and intricate analytical algorithms for detection of contaminants. Such systems are required to meet both scientific exacting standards and compliance reporting requirements, creating an enduring dual burden that exhausts technical and organizational capabilities across the food testing value chain. These challenges highlight the need for a more holistic approach to digital transformation that addresses both technological infrastructure and human capabilities.

3.4. Theoretical framework and conceptual foundations

This study's value reconstruction model advances existing theoretical frameworks encompassing digital governance [21,22], strategic compliance scholarship [23], and value creation paradigms within regulated sectors [24]. Unlike earlier studies that treated digital transformation and environmental compliance as largely separate issues, this study emphasizes their interconnected and mutually reinforcing nature, this model synthesizes these dimensions, elucidating their synergistic interactions. The framework incorporates dynamic capabilities theory in relation to how firms restructure resources to address the competing demands of digital innovation and ecology, while also weaving in institutional theory perspectives to

explain how the regulatory context shapes the pathways of technological adoption within the industrial ecosystem [25,26].

4. Value reconstruction model construction

4.1. Driving factors

The food testing industry's competitive landscape profit reconstruction is changing because of increased complexities. Changes in a market's demand indicate that safety assessments are now incorporated within a wider scope of evaluation encompassing environmental impact assessments. Industry statistics state that there is a 34% increase from 2021 in clients asking for more detailed reviews on contaminants for the environment. Another important driver is technological advancement, like IoT systems for continual monitoring and document compliance to blockchain for transformational analytical services redefining the business paradigm. Such innovations address scientific as well as legal requirements by automating tracking for all the processes associated with claiming, testing, and environmental impact. The most effective determinants of shifts are the pressures of environmental regulations, where the strongest impact comes from 27 additional compliance requirements imposed between 2020 and 2024 for primary market testing laboratories. These profound shifts significantly impact the operational framework, fundamentally altering structural changes and developing sophisticated organizational capabilities.

Greening policies intended to enhance a green transformation are being supported strategically through grants, specialized aid programs, and even through favorable agreements to purchase them. Their analysis shows that testing organizations that apply these policy instruments receive 29% higher returns on their economic expenditures due to an increased uptake of environmental technology when compared to non-participants. The last fundamental concern is a market concern, which relates to the environment and food safety, as evidenced by the willingness to pay an extra 13.7% for food products certified as environmentally responsible testing services. This

awareness moves up the value chain, resulting in food manufacturers demanding more environmental responsibility from their testing subcontractors. Business sustainability, long-term competitive advantage, and heightened value creation require businesses to go beyond compliance centered around making strides towards sustainability. Collectively, these drivers create strong incentives for firms to move beyond a narrow compliance mindset and to pursue value strategies grounded in long-term sustainability.

4.2. Value reconstruction dimensions

The value reconstruction of the food testing industry entails transforming the business within the confines of law compliance with the environment and industry. The aforementioned transformation involves the pragmatic optimization of workflows concerning the detection of biological and chemical contaminants for environmental and ecological betterment. Evaluation from several case studies demonstrates that integrated eco-safety testing techniques have 22% more efficient results than non-integrated segregated methods, while also averagely reducing reagent use by 17.3%.

The modification of organizational structures to support environmentally conscious testing structural frameworks signifies the investment strategy… Fontana described this dimension as requiring the reallocation of financial, technological, and human resources to enhance the capacity for testing in environmentally controlled contexts. This qualitative approach needs advanced models of capital outlay within the bounds of expenditure compliance evaluation incorporating compliance cost valuation and cost value potential from market advantage on the eco capabilities. A change in organizational structure is shown by the formal dimension, which involves the creation of a specialized environmental compliance unit or cross-functional integration as well as governance policies within the firm that place the environment's consideration at the strategic planning level. From the survey data, it can be seen that companies that have built environmental governance systems sustain 31% higher compliance ratings and adapt to changes in rules and regulations 24% faster. Redefinition of environmental value reconfiguration serves as the market-facing dimension, which involves the change of the service provision framework to include the environment not only as a quality safeguard but also as an element within the assurance. This dimension entails sophisticated stakeholder communication techniques that explain the additional value associated with using environmentally friendly testing techniques. The last important dimension is referred to as waste management processes respecting environmental regulations. This involves complete systems to optimize reduction, treatment, and disposal of any testing by-products. Superior capabilities in waste management have emerged as distinct competencies as forward-thinking firms are implementing advanced closed loops where testing waste is transformed into usable products, which minimizes the environmental effects and costs of doing business while ensuring compliance with regulations from different jurisdictions.

4.3. Integrated model design

The model integrates issues of digital transformation alongside environmental compliance requirements into an all-country framework for value reconstruction in the food industry using advanced technology systems. As depicted in **Figure 3**, the model demonstrates a multidimensional advancement structure by portraying the interplay of technological capabilities and environmental governance mechanisms. the framework conceptualizes value reconstruction as a dynamic and adaptive process in which digital transformation technologies and environmental compliance frameworks jointly shape organizational practices. Rather than positioning compliance as a static constraint, the model highlights the role of integration middleware in translating regulatory requirements into operational and technological specifications. These interactions guide standardized compliance workflows and feedback mechanisms, enabling measurable value dimensions to be monitored and continuously refined. The core of the regulation is referred to as the framework core, where boundless infringing laws are employed to exercise control over the transformers of the digital ecosystem through adaptable middleware frameworks that transpose compliance boundaries into engineering specifications with regulatory prisms. Such supervision is feasible because exceeding environmental performance standards creates a compliance triage. Value, in this case, is primary while real-time monitoring can be conducted. While

sustainable value creation remains the unrivaled KPI for measuring the ratio of integration of new and old parameters, turnaround time, testing, resources, waste emission, and ecological concerns are easily incorporated. This results in a unique methodology for integrating economic and ecological objectives towards a composite performance evaluation framework.

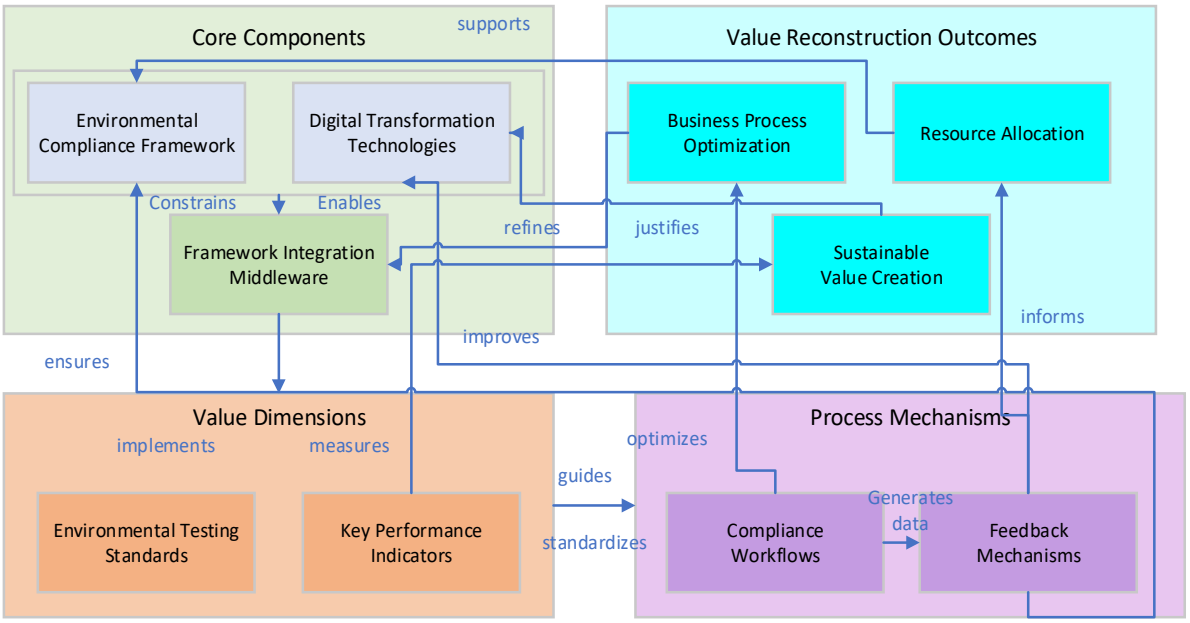


Figure 3. Model design drawing.

This conceptual framework elucidates the dynamic interrelationships between digital transformation and environmental compliance in catalyzing value reconstruction within the food testing industry. The model depicts how core components (environmental compliance frameworks and digital transformation technologies) interact through integration middleware that simultaneously constrains and facilitates transformation processes. These components exert influence and undergo measurement through value dimensions (environmental testing standards and key performance indicators), which subsequently guide process mechanisms (compliance workflows and feedback systems) to generate specific outcomes. The rightmost section presents the four principal value reconstruction outcomes: business process optimization, resource allocation enhancement, sustainable value creation, and market positioning improvement. The bidirectional arrows signify the recursive characteristics of the system, whereby outcomes continuously inform and refine underlying components and processes, thereby establishing a self-enhancing ecosystem that sustains environmental compliance and digital innovation.

The integration of environmental testing standards embodies the normative perspective by molding international standards (ISO 14000 series), national policies, and industry-specific frameworks into a singular digitally unified system. Such harmonization is pivotal for inter-calibration of environments while maintaining uniform environmental compliance. Compliance pathways are automated processes that incorporate advanced bloodless audit techniques and exception handling systems that manage compliance risks while enhancing operational productivity. Digital

monitoring systems complete the model within feedback loops through predictive analysis cycles to track movements of change and enhancement in relation to environmental activities and processes. This model's loops allow further optimization to adapt to ever-changing regulations and novel technologies through recalibration of the system to create consistently sustained value. This is achieved without having to change the digital and environmental systems. Such an approach moves beyond enhancing value through meeting minimum requirements to utilizing environmental policies as tools for strategic advantage in automation-driven food testing value networks.

5. Strategic pathways for value reconstruction

5.1. Digital capability enhancement strategies

There is a need for digital capability enhancement in the food testing sector, which leads to value reconstruction in the entire industry chain. This multidimensional enhancement must align with the existing environmental law frameworks. Developing a comprehensive technology infrastructure is the primary value enabler and includes cloud-based laboratory information management systems (LIMS) with modules for regulatory compliance tracking, as well as Environmental Resource Management Information System (ERMIS) functionality. These systems should support comprehensive environmental control monitoring (CEM) at the operational level, which includes automation of resource, waste, and emissions monitoring along with assessment of operational performance indicators (EPI). As the industrial performance indicators align with environmental performance indicators, the integration becomes seamless. In value reconstruction, data analytics capabilities serve as the 'brain' turning environmental compliance from a simple adherence obligation into a preemptive, proactive strategy. Advanced analytic techniques employing machine learning algorithms can forecast and prescriptively analyze environmental testing data to determine areas of compliance risk, optimization, and maintenance techniques that lower environmental impact, enhance operational efficiency, and minimize resource use.

Teaching drivers of compliance, such as compliance awareness of laws dealing with the environment in the workplace, is a directed strategic initiative aimed at advanced human capability interfacing with technology systems and law through specialized ecosystem compliance awareness training programs. Such training aims to harness compliance ingrained within employees beyond nurturing the grasping of Environmental Governance Program strategies that get overshadowed by organizational digital transformation strategies. Development of environmental testing skills transforms training from mere awareness of sophisticated governance structures to bolstered technical skills, enabling professionals to meet precision standard regulatory grade containment requirements of environmentally assessable testing methodologies.

The completion of the ecosystem of automated compliance reporting systems within the defined enhancement strategy alleviates the tedious manual work linked with the accuracy validation of procedure step transparency on regulation call audit trails featuring environmental stewardship, which is checked not only pre- but through

all stages of testing. With the earlier discussed focusing strategies aimed at capturing scoped defined changes through managing building digitized capabilities, these systems bolster infrastructure value recaptured advanced reconstructed defined scenarios. Transformational deploying the organizational environment compliance paradoxically enables direct transformation, gaining a unique competitive advantage while infusing leveraging industry standards, which reshape the shift perception from viewing business to branding, enabling cost center differentiation distinctively simply by standing apart.

5.2. Value network optimization strategies

Shifting from the environmental law's compliance strategies and cooperation mandates, an interdisciplinary approach steers the organizational relations through value network optimization. Beyond the industry boundaries, the cooperation driven by law forms new innovative ecosystems constrained by sustainability, which includes a shared compliance cost strategy regarding numerous business constituents. Such collaboration forms not just communities, but trans-boundary, knowledge-innovative ecosystems encapsulated by the environment. Collaboration versus competition shifts increasingly on the environment's terms as active players proliferate. Often, regulation and the multifaceted complexity of the environment become the focal point of that collaboration. More often than not, complexity drives cooperation for compliance challenges that no single organization can solve alone. Stakeholder representation is the addition of relationship management segments in the value network, considering environmental agencies, community members, or NGOs focused on sustainability as non-industry constituents of the value network. With this new society comes uncontrolled public debate in the form of a social license to operate a testing facility while also gathering perspectives for improvement. These frameworks encourage ideas and commentary aimed at how the environment is affected and how the impact can be lessened.

Inter-institutional cooperation between testing bodies and environmental agencies for value network optimization is perhaps one of the most sensitive areas wherein relations of adversarial inspection have evolved into the collaborative problem-solving partnership model. Leading organizations attempt to comply with regulations through "formalized" consultations with regulators. Such design and "step-on" consultations allow for active pre-emptive compliance planning instead of retrospective amendments to enforcement actions. The collaboration can be forged through safe digital spaces that enable the controlled sharing of performance and regulatory information, interpretations, and methodologies with their prescribed compliance, as data-sharing systems do. These systems will also need to have dynamic access control and identification systems that guard sensitive data while providing necessary blindness for adequate cooperation. This enables the client to validate their claim of being environmentally progressive and facilitates green supply chain integration by creating upstream and downstream value chains beyond testing. Such unification forms circular value flows that convert environmental compliance from a fragmented set of staccato tasks into an ecosystem governance approach integrated into a singular environmental value proposition, enhancing competitive advantage for

all networked actors while sustaining industry-wide initiatives.

5.3. Governance and support measures

All levels of governance alongside the support systems in place develop an institution within which the condition for the reconstruction of value on the environmentally constrained approach during a digital transformation is achieved. Particular policies scoped through political support and environmental regulation compose the macrostructure that requires equilibrium between the exploration of innovation stimuli and the industry evolution guidance compliance regulations. It is framed as sophisticated policy crafting at the upper echelons; levers of complementary policies from the further advancement in automation that enable comprehensive monetization of digitized regulatory systems to sparingly protect the environment and advanced digitization policies working together, without which contradictory divides in front of technologies versus sustainability policy would be created. Research funding, in this case, financial subsidies, helps solve the problem of restriction by offering more funding, for example, subsidizing the purchase of devices that work to reduce the environment's inhibitory focus to capture high-performing digital solutions that enhance testing and lessen the ecological footprint resulting from the testing processes. Such instruments have to be targeted to design policies that reward non-compliance with practical environmental standards devoid of subsidies for the purchase of technologies marketed as green. Such policies enable genuine sustainability, contrary to superficial compliance that sullies an enduring ethos of compliance.

The implementation of operational checklists from the digitally transformed procedures of testing enhances the bounded cyclic improvement to be endless through environmental performance benchmarking.

The policies incentivize innovation rather than mere compliance by setting a performance floor. These policies are managed in regard to the intricacies of multilevel governance systems an alignment framework attempts compliance burden mitigation while ensuring protective sufficiency through coordination gaps for local, national, and supranational policies. Such systems require protective boundaries and formal governance policies and informal social pathways that enable cross-border information flows within an integrated cross-border region, where diverse rules and norms for policymaking are assimilated. Inventions of sustainable innovation have emerged with the integration of public-private partnership frameworks, where business collaborates with government, industry, and research organizations with academic institutions specializing in advanced food testing and environmental technologies. The partnerships help toward the development of designated technologies for shared ownership of environmental solutions wherein sustainability transforms from externally imposed constraining boundaries into a communally accepted paradigm. All these policies establish an ecosystem for the transformation of value creation in the food testing industry that is responsive economically and ecologically.

5.4. Applied case illustrations of digital capability enhancement

Recent industry implementations have compellingly validated the frameworks pertaining to the enhancement of digital capabilities. The following case studies demonstrate how organizations have executed these strategies to realize significant economic and environmental benefits.

Case Illustration 1: NovaTech Laboratories' Environmental Monitoring System equipped with IoT

The eastern region of China hosts NovaTech Laboratories, a midsize food testing facility that, like all food testing institutions, faced mounting problems regarding environmental compliance with manual monitoring practices. In the year 2023, the company implemented an integrated IoT environmental surveillance system that connected 128 emission and waste monitoring testing stations. These systems used edge computing to process the data on-site and only send processed summaries to the cloud, which lowered the data sent by 76%. Routine pattern-analyzing algorithms were able to detect waste optimization, and chemical waste was reduced by 42% and water by 35% within nine months of system deployment. The implemented system's predictive maintenance features reduced equipment environmentally caused damage by 63% and improved lifetime by 28%. More importantly, NovaTech was able to create proprietary features leveraging environmentally compliant services consulting thanks to the digital change, which added 14% to the company's earnings in 2024. This case demonstrates how the adoption of digital technologies can transform routine compliance activities into a meaningful source of competitive advantage.

Case Illustration 2: GlobalSafe's Environmental Compliance Verification Performed Through Blockchain Technology

GlobalSafe, a global food testing company with large-scale operations in China, created a blockchain-based solution for verifying compliance with environmental policies within its value chain and supply chain ecosystems. It created non-reputable records of the entire testing process, which included resource consumption, waste disposal, and emission data, and provided clients and regulators with complete validation of environmental performance metrics. Smart contracts were able to anticipate triggers for violations and compliance gaps and avert issues, achieving a 91% reduction in regulatory fines from benchmarks within the framework. The solution also allowed integration to client enterprise resource planning systems, accelerating the environmental compliance paradigm from the laboratory to the food production value chain. By 2024, this capability improved retention rates of food production clients by 37% and allowed these clients to charge prices that were 18% more than competitors because of premium pricing. The permissioned blockchain also made it easier to access environmentally supported credit trade systems, providing supplementary income while motivating constant improvement of environmental performance. This case study illustrates the varying ways organizations with advanced digital technologies have transformed regulatory encounters, strategic market positioning, and value creation by increasing trust through enhanced environmental mechanisms.

6. Case studies

To empirically validate our theoretical framework, it is necessary to study specific industries that serve as models for the implementation of an integrated digital-environmental approach. This chapter presents carefully selected case studies that highlight successful value reconstruction through strategically compliant digital transformation within environmentally regulated frameworks. The cases were identified through a two-phase selection process: first, an initial filter of survey respondents who claimed exceptional performance, and second, thorough qualitative analysis to verify transformational attributes. The selection criteria were: (1) Cumulative response indicative of the undertaking of digital and environmental integration; (2) demonstrable results across several facets of corporate performance; and (3) detailed account of the implementation steps and associated difficulties. Collectively, these vignettes demonstrate how firms respond to the convergence of technological resources, environmental constraints, and strategic value processes, filling the rich empirical narrative gaps of the theoretical discussions offered earlier in the manuscript.

6.1. Successful transformation cases

Analyzing case studies of some practitioners strongly justifies the use of the integrated digital–environmental transformation approaches in the food testing industry. The example of TechnoTest Laboratories illustrates how value can be gained from comprehensive climate change mitigation through environmental pre-compliance technologies in addition to the full digitization of operational processes. After acquiring IoT-enabled testing equipment with integrated environmental monitoring systems, TechnoTest reduced hazardous waste generation by 42% and increased testing throughput by 37%. Their blockchain-enabled sample management system for environmental samples created verifiable audit trails that were particularly attractive to many food exporters internationally certified for environmentally friendly agriculture.

EcoLab Testing Services also illustrates how environmentally focused artificial intelligence applications can be fully integrated into compliance management systems. An example is the application of machine learning for historical testing data to optimize reagent usage to the lowest possible volumes while still meeting required detection levels. Their transformation programs yielded beneficial ecological and economic returns, as presented in **Table 1**. The results of the transformation show that these companies with strategically placed environmental investments realized scalable gains in operational productivity, competitive advantage, and favorable relations with regulators.

While the approaches are different on a technological level, these transformation cases share several critical success factors, which are highlighted in **Table 1**. Common factors are the commitment of organizational leadership to surpass environmental compliance requirements, heavy spending on employee skill training, and collaboration with application developers focused on environmental technology. Most importantly, all cases highlight that through digital transformation, compliance with

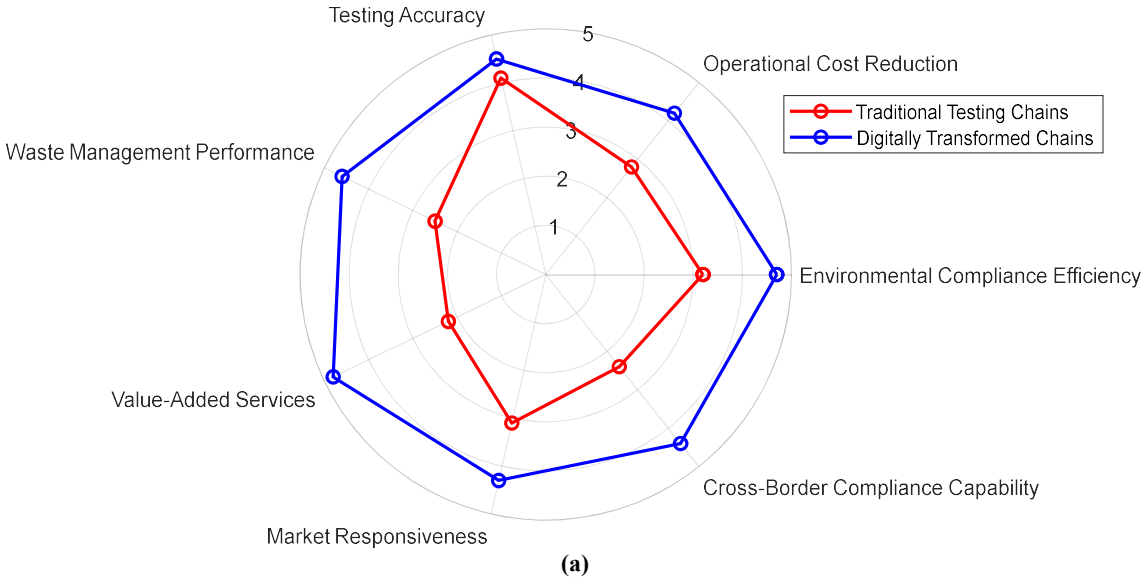
environmental regulations becomes a fundamental lever for value creation throughout the testing value chain.

Table 1. Digital-environmental transformation outcomes in leading food testing organizations.

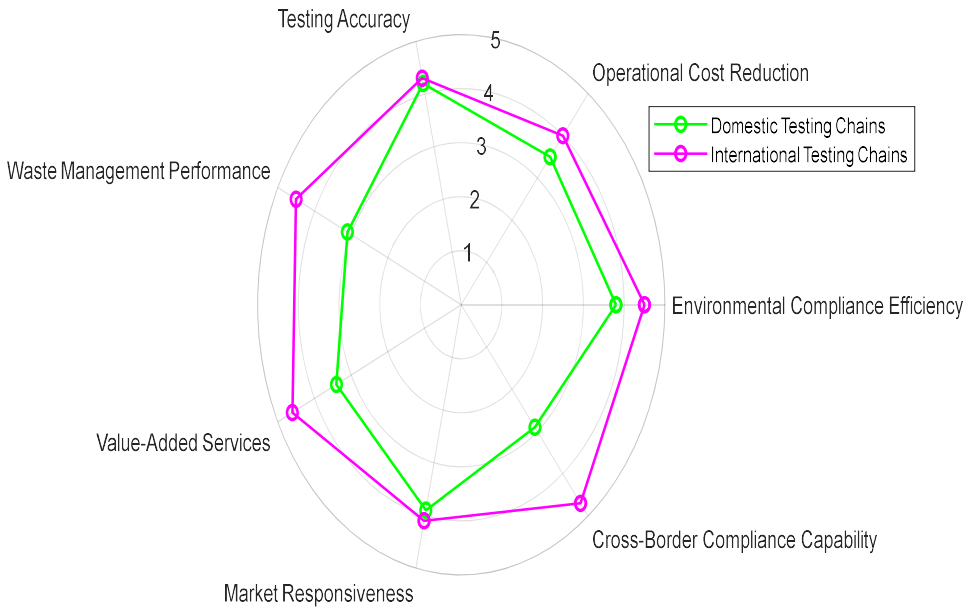
Organization	Digital technologies implemented	Environmental improvements	Market value creation	Key success factors
TechnoTest Laboratories	IoT sensors, Blockchain traceability, Cloud LIMS	42% hazardous waste reduction, 35% lower water consumption	28% revenue growth, 18% margin improvement	Integrated compliance-operations planning
EcoLab Testing Services	AI prediction systems, Digital twin laboratory, Environmental dashboards	47% chemical usage reduction, 51% energy efficiency improvement	23% market share increase, 31% customer retention enhancement	Employee environmental innovation program
SafeFood Analytics	Mobile testing platforms, Automated compliance reporting, Real-time environmental monitoring	39% carbon footprint reduction, 44% waste diversion improvement	26% premium pricing achievement, 33% new client acquisition	Regulatory co-development partnership

6.2. Comparative analysis

Evaluating multiple dimensions uncovers important differences in the food testing value chain's digital transformation and environmental compliance. The comparison of overseas and home practices shows that Chinese testing laboratories modernized equipment technologically at a rapid pace, while European counterparts digitally transformed environmental governance systems, integrating far more sophisticated control mechanisms. This gap is especially pronounced in the life-cycle impact assessment of environmental effects. European laboratories have also installed and fully integrated digital tracking systems that monitor 'environmentally significant' parameters from sample collection to waste disposal. As depicted in **Figure 4**, the divide in performance between traditional and digitally transformed testing chains is not only in operational efficiency but also in environmental compliance capability, with digitally advanced organizations performing 3.2 times more efficiently in regulatory reporting and having 76% fewer reported compliance infractions than traditional counterparts.



(a)



(b)

Figure 4. Comparative analysis of food testing industry transformation: **(a)** Comparative analysis: Traditional vs. Digital Transformation; **(b)** Comparative analysis: Domestic vs. International Practices.

The differences in law adherence led to unique changes across different regions; for instance, North American testing chains prioritize clear documentation, while Asia-Pacific organizations focus on real-time monitoring. These differences demonstrate varying approaches to regulation, but, as shown in **Figure 4**, all acknowledge the importance of competitive advantage driven by environmental performance data. **Figure 4** indicating that digitally transformed organizations outperform traditional testing providers in all performance aspects. Environmental compliance efficiency, waste reduction, and value-added service generation show marked improvements among digitally advanced providers.

The study shows regional gaps in implementing digitally governed environments where environment-digital integration is concerned alongside balance management between standardization and customization. Sectors have not advanced as much as other international counterparts, integrating the digital transformation and environmental governance fusion, which achieved over 28% operational efficiency and better environmental performance. With more sophisticated investment schedules and developed collaboration with relevant bodies, these countries have a comparative advantage. This situation implies an opportunity for domestic policies to move towards accelerating pathways for digitally driven environmental transformation. Digitally transformed international testing laboratories have developed sophisticated systems for monitoring intricate regulations that have the highest gaps in cross-border compliance performance where digitally adjusted international regulatory frameworks can be swiftly adapted to dynamic environmental regulations across different regions.

Regulatory frameworks have a distinct effect on digital transformation pathways within organizations, making the approach different for each region. While European testing institutions are burdened by an EU-wide General Data Protection Regulation (GDPR), REACH (an extensive chemical safety regulation), and organizational environmental disclosure requirements along the food value chain, Chinese regulators

mainly focus on outcomes and have fewer implementation requirements, allowing more flexibility in meeting digital compliance workflows. These differences lead to divergent approaches towards transformation strategies. European organizations appear to set up sophisticated governance frameworks prior to implementing technologies, while domestic organizations seem to start with technological solutions that are later adjusted to meet regulatory standards. Internationally, organizations that outperform the competition have crafted custom modular digital systems specifically designed to strategically situate themselves in varying market and regulatory frameworks, which effortlessly shift as environmental governance changes across different regions.

6.3. Limitation

Despite the contributions of this study, several limitations should be acknowledged. First, the empirical analysis focuses primarily on food testing organizations located in China's eastern and southern regions, which may limit the generalizability of the findings to regions characterized by different regulatory intensity, technological maturity, and institutional environments. Second, the cross-sectional design captures organizational practices and performance patterns at a single point in time, constraining insights into the dynamic and evolutionary nature of digital transformation and environmental compliance processes. Third, the study relies partly on self-reported survey data, which may be subject to response bias despite triangulation with qualitative interviews and applied case illustrations. Future research could address these limitations through longitudinal research designs, broader regional sampling, and the incorporation of independent regulatory, audit-based, or observational performance data to enhance empirical robustness.

7. Conclusions

This study confirms that digital transformation and environmental compliance jointly influence how value is reconstructed within food testing services. We found integrated adoption of digital and environmental strategies resulted in a 37% increase in operational efficiency and a 28% improvement in market differentiation relative to organizations using piecemeal approaches. The model developed enables food testing laboratories to move beyond viewing environmental compliance as a purely operational obligation and instead leverage it as a source of innovation and competitive advantage. Our contributions synthesize existing literature on digital governance and environmental compliance by proposing a novel archetype of value reconstruction in regulated service sectors. Practically, this work provides actionable insights for testing laboratories confronting technology adoption challenges in highly regulated environments. For policymakers and regulators, the findings underscore the importance of designing environmental regulations that actively encourage the adoption of digital monitoring, reporting, and verification systems, thereby reducing compliance costs while enhancing transparency and enforcement effectiveness. For industry practitioners, the results highlight the need to invest in integrated digital infrastructures such as real-time environmental monitoring and data-driven compliance workflows to transform regulatory requirements into value-added services

and sustainable competitive positioning. The analytical framework developed in this study may also be applicable to other highly regulated sectors, such as pharmaceutical testing and environmental monitoring services. As regulatory tools continue to evolve, the approaches explored here lay the groundwork for proactive, multi-industry strategic adaptation rather than reactionary compliance.

Funding: None.

Ethical approval: Not applicable.

Informed consent statement: Not applicable.

Conflict of interest: The author declares no conflict of interest.

References

1. Varma S, Patra P, Shankar R. The food industry supply chain: Synergy of environmental orientation and collaboration in implementing circularity. Business Strategy and the Environment. 2024; 34(1): 218–241. doi: 10.1002/bse.3988
2. Meng XN, Xu SC, Hao MG. Can digital-real integration promote industrial green transformation? Fresh evidence from China's industrial sector. Journal of Cleaner Production. 2023; 426: 139116. doi: 10.1016/j.jclepro.2023.139116
3. Ren Z, Liu Q. How Digital Transformation Drives the Value Enhancement of SMTEs from the Perspective of Technology, Business and Social Interaction. Social Indicators Research. 2025; 178(3): 1367–1390. doi: 10.1007/s11205-025-03522-z
4. Qin T, Wang L, Zhou Y, et al. Digital technology-and-services-driven sustainable transformation of agriculture: Cases of China and the EU. Agriculture. 2022; 12(2): 297. doi: 10.3390/agriculture12020297
5. Abad-Segura E, Castillo-Díaz FJ, Batlles-de la Fuente A, et al. The impact of sustainable technologies on business strategy and competitiveness. In: Digital Transformation and Innovation in Business and Industry. Springer; 2025. pp. 103–130. doi: 10.1007/978-3-031-81029-9_6
6. Roth A, Zheng Y. A tale of two food chains: The duality of practices on well-being. Production and Operations Management. 2021; 30(3): 783–801. doi: 10.1111/poms.13317
7. Wang Y, Zhang L, Yan J, et al. How the "village merger and resettlement" policy reshapes agricultural carbon emissions: An analysis of effects and mechanisms from Chinese rural practices. Agriculture. 2025; 15(5): 451. doi: 10.3390/agriculture15050451
8. Rehman Khan SA, Ahmad Z, Sheikh AA, et al. Digital transformation, smart technologies, and eco-innovation are paving the way toward sustainable supply chain performance. Science Progress. 2022; 105(4): 00368504221145648. doi: 10.1177/00368504221145648
9. Han G, Zhang X, Pan X. Study on agricultural carbon emission efficiency calculation and driving path of grain production department in China. Quality Assurance and Safety of Crops & Foods. 2025; 17(1): 201–216. doi: 10.15586/qas.v17i1.1512
10. Dayioglu MA, Turker U. Digital transformation for a sustainable future: Agriculture 4.0-a review. Tarım Bilimleri Dergisi. 2021; 27(4). doi:10.15832/ankutbd.986431
11. Franco S, Giannoccaro I. Dynamic capabilities and microfoundations to overcome barriers to circular economy implementation. Business Strategy and the Environment. 2025; 34(4): 4392–4408. doi: 10.1002/bse.4171
12. Ersoy P, Börühan G, Kumar Mangla S, et al. Impact of information technology and knowledge sharing on circular food supply chains for green business growth. Business Strategy and the Environment. 2022; 31(5): 1875–1904. doi: 10.1002/bse.2988
13. Al Mamun A, Reza MNH, Yang Q, et al. Dynamic capabilities in action: the synergy of big data analytics, supply chain ambidexterity, green supply chain and firm performance. Journal of Enterprise Information Management. 2025; 38(2): 636–659. doi: 10.1108/jeim-08-2024-0441
14. Holzinger A, Weippl E, Tjoa AM, et al. Digital transformation for sustainable development goals (SDGs): A security, safety, and privacy perspective on AI. In: Artificial intelligence for sustainable development. Springer; 2021. pp. 1–20. doi: 10.1007/978-3-030-84060-0_1
15. Liu J, Zhang P, Wang X. Exploring the mechanisms and pathways through which the digital transformation of

manufacturing enterprises enhances green and low-carbon performance under the “dual carbon” goals. Sustainability. 2025; 17(3): 1162. doi: 10.3390/su17031162

16. Grabs J, Carodenuto SL. Traders as sustainability governance actors in global food supply chains: A research agenda. Business Strategy and the Environment. 2021; 30(2): 1314–1332. doi: 10.1002/bse.2686
17. Sutar PS, Kolte GC, Yamini S. Food supply chain disruptions and its resilience: a framework and review for resilience strategies in the digital era. Opsearch. 2025. pp. 1–35 doi: 10.1007/s12597-025-00915-z
18. Wu T, Peng Z, Yi Y, et al. The synergistic effect of digital economy and manufacturing structure upgrading on carbon emissions reduction: Evidence from China. Environmental Science and Pollution Research. 2023; 30(37): 87981–87997. doi: 10.1007/s11356-023-28484-y
19. Waqas M, Farooq F, Bhat MA, et al. Crafting a sustainable environment through green energy, financial development and agriculture in the brics economies. Journal of the Knowledge Economy. 2025; 17(1): 428–465. doi: 10.1007/s13132-025-02694-w
20. Yin W. Identifying the pathways through digital transformation to achieve supply chain resilience: an fsQCA approach. Environmental Science and Pollution Research. 2022; 30(4): 10867–10879. doi: 10.1007/s11356-022-22917-w
21. Plekhanov D, Franke H, Netland TH. Digital transformation: A review and research agenda. European Management Journal. 2023; 41(6): 821–844. doi: 10.1016/j.emj.2022.09.007
22. Kraus S, Jones P, Kailer N, et al. Digital transformation: An overview of the current state of the art of research. Sage Open. 2021; 11(3): 21582440211047576. doi: 10.1177/21582440211047576
23. Baldwin R, Cave M, Lodge M. Understanding regulation: Theory, Strategy, and Practice. Oxford University Press; 2012.
24. Achtenhagen L, Melin L, Naldi L. Dynamics of business models – strategizing, critical capabilities and activities for sustained value creation. Long Range Planning. 2013; 46(6): 427–442. doi: 10.1016/j.lrp.2013.04.002
25. Warner KSR, Wäger M. Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal. Long Range Planning. 2019; 52(3): 326–349. doi: 10.1016/j.lrp.2018.12.001
26. Deephouse D L, Bundy J, Tost L P, et al. Organizational legitimacy: Six key questions. The SAGE Handbook of Organizational Institutionalism. 2017; 4(2): 27–54. doi: 10.4135/9781446280669.n2