# Digital-Enabled Sustainable Management of County-Level Specialty Agricultural Value Chains: An Evidence-Tier Analysis of the Pujiang Citrus Industry in China

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**Abstract.** Digitalization is spreading through county-level specialty crop value chains, but public proof of implementation is often treated as proof of sustainability results. Using Pujiang citrus as an explanatory case, this study identifies where digital applications occur and examines the institutional conditions required for economic, environmental, and social outcomes. The evidence base comprises 11 traceable public documents issued by nine organizations between 2019 and 2026. The Evidence-Tier Framework sorts claims into five levels: planning, public deployment, multiple-source corroboration, local statistics, and verified performance. Available sources document a smart-orchard platform plus localized monitoring, irrigation, early warning, precision fertilization, and traceability. They describe Wanguo and several area expansions only as planned or cooperatively developed. The record does not verify county-wide input savings, lower postharvest losses, or higher farmer income. Digital deployment evidence does not equal verified sustainability performance. Outcome pathways depend on interoperability, smallholder access, data governance, contracts, benefit distribution, risk response, and continuing evaluation.

**Keywords:** evidence-tier assessment; digital agriculture; Pujiang citrus; agricultural value chain; sustainability

## 1 Introduction

Digital agriculture integrates sensors, analytical tools, platforms, and services that extend beyond the farm (Klerkx et al., 2019; Wolfert et al., 2017). Although such systems can support productivity and more precise input management, their development may also create socio-ethical risks (Eastwood et al., 2019). Digitalization can further expose tensions among agricultural stakeholders whose priorities differ (Fielke et al., 2020). Evidence of implementation must therefore be distinguished from evidence of outcomes.

Because citrus is perishable and production is spatially dispersed, traceability must preserve links among farms, batches, logistics, and markets (Astill et al., 2019).

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Sustainable value-chain analysis treats governance as the organizing element of a changing, market-oriented system (Neven, 2014). Contracts, coordination, bargaining positions, and distributional arrangements influence both value creation and who captures it (Barrett et al., 2012; Gereffi et al., 2005).

Research in China connects digitalization, chain-wide standards, and specialty agriculture with development, but these general relationships do not demonstrate local performance (Sun, 2025; Yan et al., 2024; Yang & Wang, 2025; Zhu et al., 2022). This study asks where digital tools appear in the Pujiang citrus chain, what claim strength the available evidence permits, which conversion mechanisms are plausible, and which governance conditions matter. The Evidence-Tier Framework evaluates the support behind a claim. It does not rate deployment intensity or estimate causal effects.

## 2 Materials and Methods

An explanatory single-case study applied qualitative document analysis to sources dated 1 January 2019–13 July 2026, emphasizing local digitalization, green-transition, and standardization materials from 2023–2026. Searches of government websites, institutional portals, and major Chinese news outlets combined Pujiang citrus with smart orchard, digital agriculture, traceability, and Wanguo. Table 1 lists 11 documents from nine identifiable organizations. Inclusion required a clear source and date, direct case relevance, and concrete details on scale, function, status, practice, or institutions. Reposts, unattributed items, self-media, and unverifiable promotion were excluded. The corpus serves claim traceability, not statistical representativeness.

Coding captured actor, technology or institution, coverage, timing, claimed outcome, and evidence boundary. Items were assigned to planning or proposal, public deployment, multiple-source corroboration, local statistics, or verified performance. Higher tiers support stronger claims but do not rank source quality universally. Cross-source comparison preserved inconsistent scopes rather than merging them. Without an intervention baseline or attribution design, local statistics remained contextual, and corporate or media accounts supported only deployment or bounded observations. No interviews, surveys, firm operating records, comparable baseline, longitudinal indicators, or causal identification were used.

**Table 1.** Core local materials and evidence boundaries.

| Code | Year | Content covered | Source type | Evidence status/use boundary |
|---|---|---|---|---|
| S1 | 2019 | Industrial park; processing, logistics, standardization | People's Daily App | Confirmed; historical foundation |
| S2 | 2023 | Industrial systems; green and organizational development | Provincial agriculture dept. | Confirmed; multi-industry measure |
| S3 | 2023 | GI, production standards, brand governance | Provincial agriculture dept. | Confirmed |
| S4 | 2024 | "Two substitutions"; value-chain standards | Provincial government | Confirmed; partly multi-industry |

| Code | Year | Content covered | Source type | Evidence status/use boundary |
|---|---|---|---|---|
| S5 | 2025 | Smart-orchard platform; 1+1+1+N | People.cn Sichuan | Confirmed launch |
| S6 | 2025 | Monitoring, irrigation, warning, fertilization, traceability | Provincial SASAC repost | Deployed; effects unverified |
| S7 | 2025 | Wanguo: six systems, 16 scenarios | Rural property exchange | Cooperative development |
| S8 | 2025 | 200/3,000/5,000-mu area statements | China.com.cn | Deployment and planning coexist |
| S9 | 2025 | >130-mu orchard; equipment and labour observation | Government-site media report | Single site; not generalizable |
| S10 | 2026 | Harvest output and value forecast | People.cn Sichuan | Forecast, not final statistic |
| S11 | 2026 | Industry scale, certified area, cold chain | Media citing county bureau | Context; not official bulletin |

### 2.1 Case Context and Data Definitions

Processing, logistics, and standardization infrastructure originated in the industrial park (People's Daily App, 2019). A report from April 2026, citing the county bureau, gave an industry scale of 450,000 mu, annual output of 1.03 million tonnes, value of RMB 7.3 billion, 44,600 mu under certification, and a 50,000-mu standardized base (West China City Daily, 2026). A separate January forecast reported 1.10 million tonnes, RMB 7.2 billion in direct production value, and RMB 10.0 billion across the chain (People.cn Sichuan, 2026). These figures retain their original periods and definitions. The two-substitutions program, certification, and standards are treated as institutional conditions rather than measured performance (Department of Agriculture and Rural Affairs of Sichuan Province, 2023a, 2023b; People's Government of Sichuan Province, 2024).

## 3 Results

### 3.1 Deployment, Scope, and Evidential Boundary

The January 2025 launch comprised a data platform, command display, production mini-program, and several scenarios. Sources document localized monitoring, irrigation, warnings, precision fertilization, and traceability, but not comparable coverage, sustained use, costs, or input changes (People.cn Sichuan, 2025; State-owned Assets Supervision and Administration Commission of the Sichuan Provincial Government, 2025). Reported areas of 200, 3,000, and 5,000 mu refer to different scopes or development stages (China.com.cn, 2025). A media account for one orchard exceeding 130 mu contrasted 10–15 conventional workers with 3–5 under combined digital and mechanized management. Lacking a baseline and cost definition, the observation is neither

county-representative nor platform-attributable (Tianjin Commission for Discipline Inspection and Supervision, 2025).

The Wanguo agreement specifies six systems and 16 scenarios, indicating development commitment rather than stable operation or market results (Chengdu Rural Property Rights Exchange, 2025). Figure 1 locates observations by value-chain stage and claim strength; Table 2 pairs each scenario with its evidence status. None qualifies as verified performance.

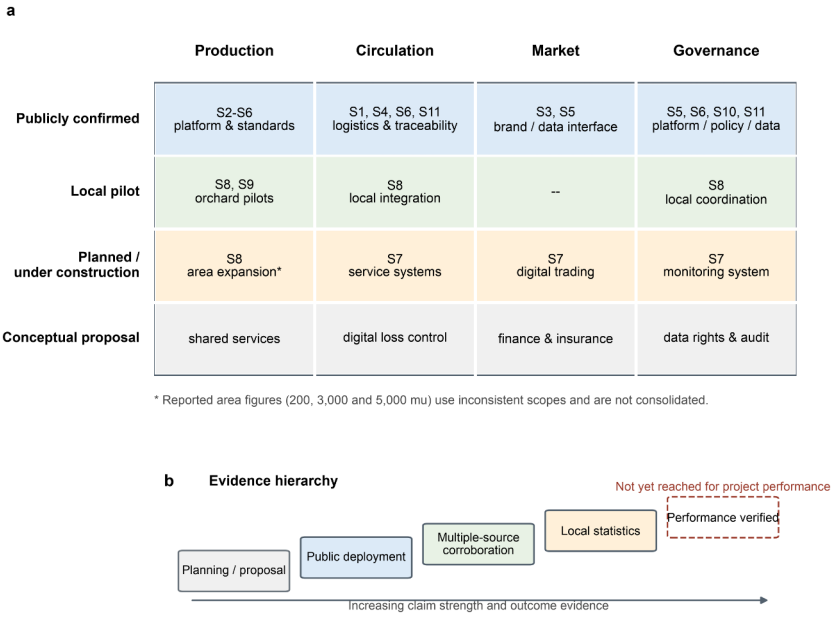



**Fig. 1.** Value-chain evidence map and hierarchy of claim strength.

**Table 2.** Digital application scenarios and evidence status in the Pujiang citrus value chain.

| Stage | Identified scenario | Evidence status | Source |
|---|---|---|---|
| Production | Forecasts; monitoring; irrigation; warnings; precision fertilization; drones | Confirmed functions; localized/single-site deployment | S5, S6, S9 |
| Circulation | Sorting, cold storage, cold-chain logistics | Existing industrial foundation | S1, S11 |
| Circulation | Traceability, production data, batch linkage | Functions deployed | S5, S6 |
| Market | Wanguo six systems and 16 scenarios | Cooperative development | S7 |
| Governance | Data aggregation, standards, monitoring, early warning | Partly deployed/planned | S5, S7 |
| Governance | Credit, insurance, price warning | Conceptual proposal | Literature |

*Note.* The 200-, 3,000-, and 5,000-mu figures have different statistical objects or temporal status and are not combined.

# 4 Mechanisms and Constraints

## 4.1 Conditional Transformation Pathways

Technology adoption alone does not produce positive impacts; intervening conditions matter (Trendov et al., 2019, p. 93). Sensors, warnings, and water-fertilizer tools can connect plot conditions with agronomic decisions. Environmental results additionally require calibrated advice, execution, and plot records comparing inputs and outcomes over time. Precision crop protection may improve targeting or exposure elsewhere, depending on adoption, behavior, and measurement (Finger, 2026). Pujiang sources show capacity, not verified changes in water, fertilizer, pesticide, energy, or emissions.

Smart-farming data can affect the full food chain, not only production (Wolfert et al., 2017, p. 69). Sorting, cold storage, batch traceability, and logistics coordination could reveal anomalies and accelerate responses. Lower losses would require comparable pre- and post-deployment measures by loss type, grade, storage period, and channel. No continuous series exists, so infrastructure and deployed functions do not establish postharvest performance.

In marketing, information and transaction matching could widen buyer access or reduce search effort. Farmer returns also depend on grading, prices, commissions, service charges, rejection, payment timing, and bargaining power. Wanguo remains under cooperative development, without evidence of regular transactions or settlement results. Aggregated data might support standards, risk alerts, service coordination, and accountability only with interoperable identifiers and enforceable rules for rights, permissions, corrections, and exit. These mechanisms remain conditional, not observed net effects.

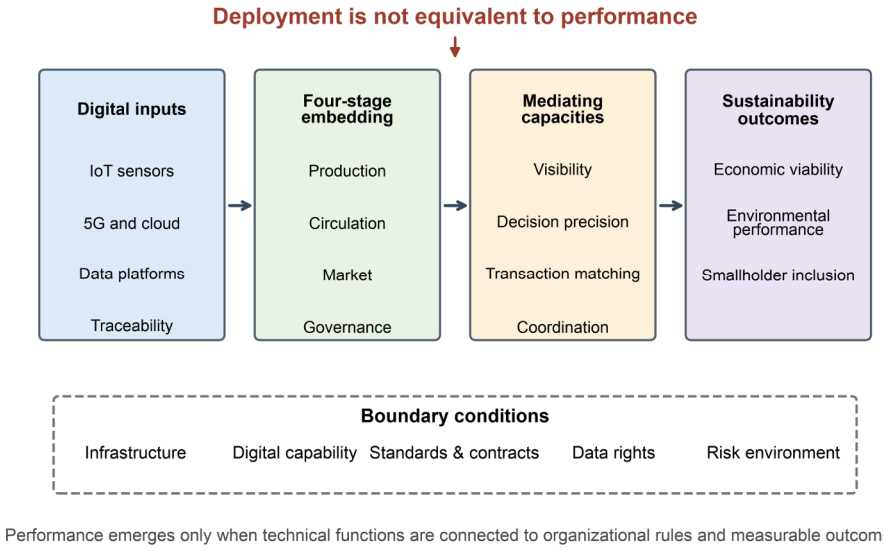



**Fig. 2.** Analytical framework of digital-enabled sustainable value-chain management.

Figure 2 distinguishes deployment, mediating capabilities, and sustainability outcomes. Access, interoperability, contracts, benefit sharing, risk response, and evaluation connect these layers. Their variation can change results across farms or value-chain stages. The diagnostic framework specifies evidence needed for stronger claims instead of presuming that a platform or device has produced economic, environmental, or social benefits.

### 4.2 Main Constraints

The public record lacks continuous information on coverage, equipment failure, service cost, active use, and retention. Evidence from localized sites cannot establish ordinary-farmer access across 450,000 mu. Fragmented systems and incomplete identifiers may also prevent plot, batch, standard, transaction, and risk data from linking across the chain. Public sources leave ownership, platform control, authorization, correction, portability, and withdrawal rules unspecified. They provide too little detail on contracts, grades, premiums, commissions, and settlement to assess bargaining power or benefit allocation. Warnings generate value only when connected to agronomic services, storage, alternative markets, or insurance. Comparable baselines for inputs, labour, losses, prices, and income are also missing. Deployment announcements cannot convert these intermediate capacities into outcome evidence.

## 5 Governance Pathways and Evaluation Design

Governance priorities include sustained use, data interoperability, access for smallholders, clear contracts, transparent benefit allocation, and auditable evaluation. Table 3 presents a future monitoring design and should not be read as evidence of current performance.

**Table 3.** Constraints, governance actions, and suggested monitoring indicators.

| Constraint | Priority action | Suggested indicator | Verification source |
|---|---|---|---|
| Coverage/outcome gaps | Baselines, annual tracking, public evidence table | Actors; monthly activity; inputs/mu; online rate | Logs, farm records, comparative surveys |
| Smallholder barriers | Shared equipment, service officers, offline agents | Coverage; unit cost; two-season continued use | Cooperative records; stratified surveys |
| Silos/data rights | Common IDs, interfaces, authorization, portability | Field completeness; interface success; withdrawal time | Permission logs, tests, independent checks |
| Green value return | Link green records, grades, contracts, settlement | Green batches; farmers receiving premiums; premium/mu | Files, tests, settlement records |
| Overlapping risks | Link warnings to services, storage, channels, insurance | Lead/response time; disaster and postharvest loss; claims | Warning logs, event reviews, insurer records |

*Note.* Indicators require explicit denominators and definitions. Losses should distinguish natural-disaster, postharvest, and market-related unsold output.

A county data layer should connect actor, plot, batch, standard, weather, and disaster identifiers and define update and exit rules. Shared services should follow citrus phenology, while contracts state grades, premiums, appeals, and settlement terms. Evaluation requires baselines and comparable samples for inputs, output, prices, losses, service costs, and benefit distribution (Yan et al., 2024).

## 6 Discussion

The evidence chain is designed to discipline benefit claims rather than enumerate them. Persistent uncertainty about digital agriculture partly reflects divergent perspectives and insufficient impact evidence (MacPherson et al., 2025, p. 1). In Pujiang, deployment is observable, but continuous series on coverage, use, inputs, losses, prices, and farmer income are unavailable. Public records can therefore locate technology, whereas sustainability claims need defined denominators, repeated time points, comparison groups or credible baselines, and a transparent attribution strategy.

Recent studies support this distinction. Crop-protection benefits vary with digital-tool governance and use (Finger, 2026), while adoption also depends on trust and institutional support (Ishaque et al., 2026). Chinese provincial evidence finds conditional income relationships (Liu et al., 2026), but cannot replace performance data from Pujiang farms or chain actors. The studies inform mechanisms and measurement, not missing case outcomes.

Inclusive digital agriculture requires policy and research to place equitable, non-exploitative development at the center of technology choices (Rotz et al., 2019, p. 120). Transfer to another county would depend on comparable crop characteristics, service organizations, infrastructure, contracts, and governance capacity. The Evidence-Tier Framework is portable, but the performance of the Pujiang case is not.

A subsequent study should combine platform logs, stratified surveys, farm records, defined losses, and repeated observations around adoption. Comparable users and non-users, explicit selection rules, and distributional analysis could separate technology effects from scale, mechanization, management, weather, and markets. Until then, the governance proposals remain an evaluation agenda rather than demonstrated solutions.

## 7 Conclusion

The 11 traceable documents establish a platform and localized functions. They neither make the 200-, 3,000-, and 5,000-mu areas comparable nor generalize the >130-mu orchard observation; Wanguo remains under cooperative development. County-wide input or loss savings and farmer-income gains remain unverified. Digital deployment evidence does not equal verified sustainability performance. In the absence of primary or longitudinal data and causal identification, Pujiang documents deployment, not sustainability success.

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