



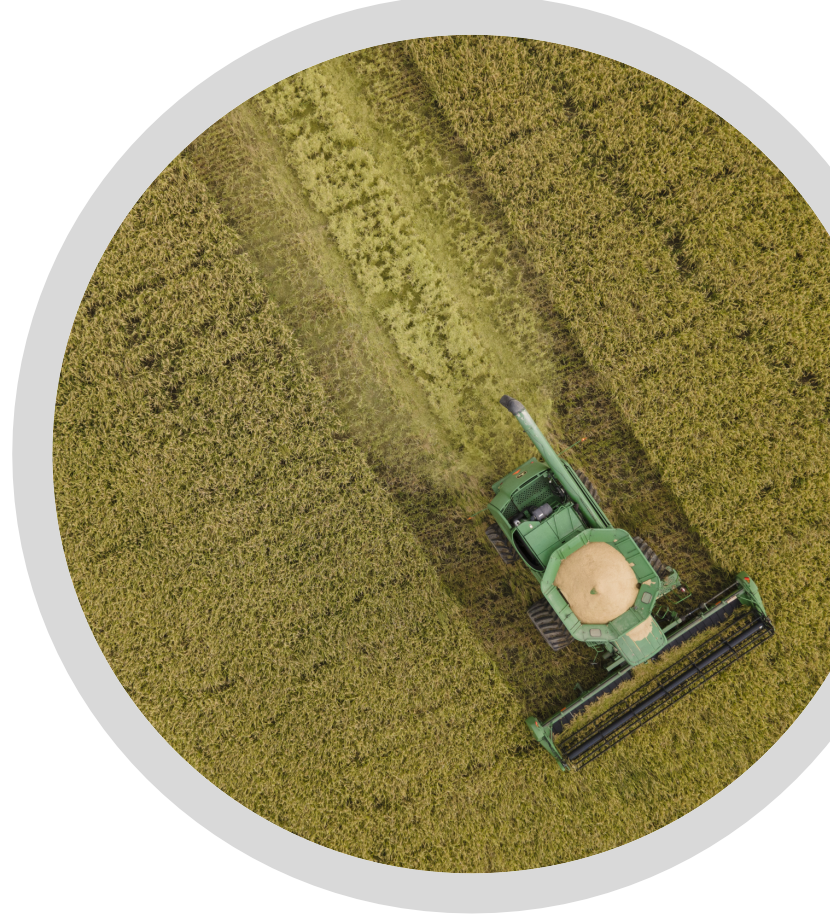
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The Potential of Traceability: A Strategic Tool for Accountability in Supply Chain Management

RETHINKING PRACTICAL PATHWAYS TO MORE
SUSTAINABLE AGRICULTURE & FOOD SYSTEMS

Introduction

The intersecting pressures of climate change, population growth, and ecological degradation are placing unprecedented strain on global food systems¹. Agriculture must undergo a fundamental transformation. The era of opaque, untraceable supply chains is rapidly closing, underscored by a simple reality: sustainability claims without verification lack credibility. Traceability could help address this gap. By creating a verifiable, data-driven link between a product and its path from origin to destination, traceability systems underpin modern environmental, social, and economic governance. When treated as a strategic tool, rather than a standalone solution, traceability could help enable the validation of deforestation-free commitments and regenerative practices, strengthen global accountability, and safeguard a more resilient and sustainable future.



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Key Takeaways

1. Traceability is an enabler, not a silver bullet

While traceability has evolved into a critical instrument for environmental governance, such as enforcing zero-deforestation mandates, traceability technology alone cannot solve ecological degradation². Traceability is only a tool that provides infrastructure for environmentally-focused action. Current traceability frameworks primarily function as point-in-time certification schemes rather than continuous, end-to-end tracking systems.

2. Technology is ready, broader systems are not

Although tools like high-resolution satellite monitoring, Internet of Things (IoT) sensors, and blockchain ledgers offer advanced, commercially available solutions for end-to-end traceability, these initiatives consistently fail at the socio-technical level. For example, sophisticated digital frameworks frequently stumble due to a lack of digital literacy among smallholder farmers,

inadequate rural broadband connectivity, and fragmented data standards between competing corporate platforms¹. The broader system is undermined by disjointed supply chains, misaligned financial incentives, and severe interoperability issues, creating a dynamic where sophisticated digital infrastructure is rendered unworkable by fragmented, unverified, or falsified point-of-entry data.

3. Sector maturity is highly uneven

The adoption and sophistication of traceability technology vary significantly across agricultural sectors based on market and regulatory pressures. Fisheries benefit from international frameworks targeting illegal fishing³; livestock and forest-linked commodities are rapidly adopting spatial verification due to strict deforestation mandates (e.g. European Union Deforestation Regulation (EUDR))⁴; meanwhile, regenerative farming trails far behind due to a lack of market and policy incentives

and the high complexity of continuously monitoring environmental outcomes.

4. **Traceability constraints from commodity aggregation**

Co-mingling of commodities, particularly in row crop supply chains, poses a significant challenge to traceability. As products are aggregated across multiple farms, the direct link between a commodity and its origin becomes harder to maintain, complicating efforts to verify production practices and ensure transparency. This aggregation also introduces practical limitations: tracing inputs across numerous sources can generate large, diffuse datasets that are difficult to manage and reconcile, often shifting traceability toward mass-balance approaches rather than discrete, product-level tracking⁵.

5. **Culture impacts traceability**

Demands for absolute transparency often clash with the cultural and economic realities of both large and small producers. Mandatory data sharing can violate deep-rooted norms by exposing personal assets, risking competitive advantage, or triggering a deep distrust of oversight. Traceability policy should consider cultural nuance.

6. **Meaningful impact requires a triad of alignment**

For traceability to successfully decouple agricultural production from environmental degradation, it must be supported by an ecosystem approach: nuanced regulatory enforcement, consistent consumer demand, incentivized financial instruments, and tangible on-the-ground support for farmers.

Key Considerations for Policymakers

Traceability vs. Transparency

While often used interchangeably, traceability and transparency are distinct but related.

- Traceability links what data is collected—Key Data Elements (KDEs)—and when that data is collected—Critical Tracking Events (CTEs)—to map a product’s movement through the supply chain⁶.
- Transparency refers to the visibility of KDEs, often at the production level, without necessarily connecting them across actors or stages.

Put simply, transparency exposes practices or behaviors, whereas traceability is the practice of tracking various events, behaviors, and outcomes across various supply chain stages⁷. This distinction is particularly important for environmental monitoring in scenarios where traceability is, for various reasons, impractical.

Determining Traceability’s Efficacy

While traceability is often positioned as the primary mechanism for verifying chain of custody including environmental outcomes, its effectiveness depends on the type, volume, and structure of data being collected. In contexts such as regenerative agriculture, where data is continuous, variable, and context-specific, the demands placed on traceability systems increase significantly. This stands in contrast to deforestation monitoring, which often relies on more binary indicators and is therefore comparatively simpler to track. As a result, questions emerge as to whether end-to-end traceability is always the most feasible or immediate objective, underscoring the need to distinguish between traceability and transparency as related but distinct approaches to managing environmental information⁸.

Traceability in Context

Food traceability was originally, and remains largely, driven by food safety concerns⁹. Outbreaks of foodborne illness prompted the strengthening of national and international traceability requirements to enable rapid product recalls and assign responsibility¹⁰. However, as environmental regulations, such as the EUDR and the World Trade Organization Agreement on Fisheries Subsidies (WTOAFS), take effect, traceability requirements are expanding beyond food traceability frameworks and their conventional KDEs and CTEs to verify that products are not linked to negative environmental outcomes such as deforestation or Illegal, Unreported and Unregulated (IUU) fishing¹¹.



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Basic vs. End-to-End Traceability

Table 1: Basic vs. End-to-End Traceability*

Feature	Basic Tracking	End-to-End Traceability
Scope	Previous Location/Current Location	Farm/Processors/Storage/Grocery Store
Data Focus	Location and status (What is it? Where is it? When did it arrive?)	Identity, Origin, Events, and Attributes (Who made it? How was it processed? Was it sourced from deforested land? What regenerative practices are associate with it?)
Goal	Logistics, inventory management, and food safety	Environmental compliance

Traceability technology across all sectors—fisheries, livestock, forest-linked commodities, and crops—exist and are relatively advanced. The implementation of these technologies, however, lags substantially, and maturity varies by sector. Broadly, the reasons for this are:

- **Limited market pressure:** Consumer demand for deforestation-free, anti-IUU fishing, and

regenerative farming are comparatively lower compared to other concerns, such as non-GMO, organic, or grass-fed beef¹².

- **Interoperability and data-sharing gaps:** While some standards, such as the Global Dialogue on Seafood Traceability (GDST) exist, their adoption remains optional, and national and international databases containing comprehensive environmental

* Table 1 based on TraceX comparative table.

traceability information are either nonexistent or function in isolation¹³. For instance, in Brazil, commodity traders often source more than 40% of commodities indirectly via local intermediaries, and this indirect sourcing is a major blind spot for holistic data tracking¹⁴.

- **Technological limitations in tracing granular products (for instance, rice grains) as a result of product mixing, blending, or grinding:** Product aggregation is a foundational element of modern supply chain management that end-to-end traceability struggles to overcome. When evaluating traceability mandates, policymakers must clearly distinguish between what is technically possible and what is operationally practical at scale.

For heavily aggregated row crops like corn, soy, or wheat, exact traceability is technically achievable through Identity Preservation (IP), where crops are kept physically segregated from farm to final product¹⁵. However, scaling IP is economically and logistically

impractical: it requires dedicated storage, transport, and processing infrastructure, significantly increasing costs, while limited market demand and price premiums for fully traceable bulk commodities fail to justify widespread adoption. For example, in the West African cocoa sector, beans are sourced from millions of disparate, unregistered smallholder plots. These beans are frequently commingled by informal intermediaries before ever reaching a cooperative or export facility, making exact origin tracing nearly impossible without exorbitant costs¹⁶.





To deal with traceability verification and aggregation, the industry currently relies on mass balancing which is estimating the share of a product originating from a verified source based on the volume mix at a facility. Row crops lack geographic constraints and processing choke points, making their granular, commingled nature difficult to trace compared to discrete, highly visible units like cattle.



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Sector-Based Traceability

Table 2: Sector-Based Traceability

Sector	Regulatory Pressure	Standard Tech Deployment	Future Opportunities
 Fisheries	Binding international frameworks such as FAO's PSMA and WTO's AFS	VMS, AIS, and/or paper or digital catch documentation schemes are common	AI-driven EM systems that deliver data to blockchain ledgers
 Livestock	EUDR pressure influencing market access based on agricultural practices	RFID tags, geospatial monitoring, drone-based observation	Interoperable data schemes and ledgers
 Forest-Linked Commodities	EUDR pressure influencing market access based on agricultural practices	Paper or digital logs concerned with basic tracking using barcodes, mass-balancing audits	Further deployment of remote sensing and increased geospatial granularity; automated ledger or database
 Regenerative Farming	No substantial agreements exist; weak market forces and private certifications are the only motivator; Food safety agreements strong	Paper or digital logs concerned with basic tracking using barcodes	IoT sensors, multi-spectral imaging, isotopic analysis, eDNA, etc. can lay the groundwork for transparent farm and ranches practices

Global Fisheries: Interoperable Systems at Scale[‡]

Fisheries represent the most mature sector for international cooperation, driven by the urgent need to combat IUU fishing and human rights abuses at sea.

- **Regulatory Pressure:** High. The sector is governed by binding international frameworks (e.g., FAO Port State Measures Agreement, WTOAFS). As of 2026, systems like the EU CATCH portal have made digital catch certificates a mandatory "license to operate" for global imports¹⁷.
- **Tech Deployment:** Currently relies on a *layered* approach. Baseline tech includes VMS (encrypted satellite tracking) and AIS (public vessel tracking)

with paper or electronic-based catch documentation schemes¹⁸.

- **Future Opportunities:** While documentation is increasingly digitized, high-fidelity verification is the new frontier. Electronic Monitoring (EM), using onboard cameras and AI-driven machine vision, is gaining traction to provide objective, transparent proof of key data such as catch volume and species identification that can be uploaded into blockchain-based ledgers^{17,19}.

[‡] While this report focuses on agriculture commodities, global fisheries serve as an essential precedent. Because fishing operations frequently

span international waters, the sector has already been forced to build the multinational collaboration and traceability frameworks that land-based agricultural commodities currently lack.



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Livestock: High-Stakes Deforestation Compliance

Livestock traceability, primarily focused on cattle, is pivoting from simple sanitary and disease control to rigorous land-use compliance. While decoupling beef production from illegal deforestation remains a primary global focus, significant regional variations in supply chain structures and ecological risks dictate how traceability is applied.

- *Regulatory Pressure:* High/Rising. Driven by mandates like the approaching EUDR deadline, international focus has shifted to closing the indirect supplier loophole by demanding proof that an animal was not raised on deforested land at any point in its lifecycle. However, in regions like the United States, Australia, and New Zealand, regulatory and market pressures are increasingly focused on native grassland conversion and soil health rather than tropical canopy loss²⁰.
- *Tech Deployment:* Cattle traceability relies on RFID ear tags, which see high adoption globally, though their application for environmental monitoring is

[§] Enacted in 1900 and significantly amended in 2008, the U.S. Lacey Act is a conservation law that prohibits the import, export, and sale of illegally harvested wildlife, fish, and plants. The 2008 amendment specifically

highly variable. In South America, GIS mapping and centralized national databases (like Brazil's CAR) are frequently used to cross-reference animal movement with satellite-detected environmental changes. Conversely, in the US and Oceania, traceability data often resides in fragmented, private systems focused on production and health metrics rather than integrated environmental monitoring²¹.

- *Future Opportunities:* Technology implementation in high-priority areas, such as the Selva Maya, are necessary. Even despite technology advances, cattle laundering, a massive loophole where cattle raised on illegally deforested land are moved to clean farms just before slaughter to scrub their environmental footprint, remains a prevailing issue even in places with strong technology implementation programs and policies (e.g. Para, Brazil)^{22, 23}.

Forest-Linked Commodities: Solving the First-Mile

While geographically clustered, forest-linked commodities are primary drivers of global deforestation, their amenability to traceability diverges sharply based on supply chain structures. Palm oil achieves a high degree of traceability due to biological constraints that create natural processing choke points at registered local mills²⁴. Conversely, commodities such as cocoa and rubber, despite geographic density of producers, face severe traceability bottlenecks driven by extreme smallholder fragmentation, opaque middleman networks, and physical product transformations that obfuscate origin data.

- *Regulatory Pressure:* High/Rising. Historically, timber has faced strict unit-level regulations (e.g., the Lacey Act[§]), while cocoa is now under intense pressure from the EUDR to prove supply bases are decoupled from national park encroachment. Rubber, previously lagging in market pressure, is increasingly being swept into these broad,

targeted illegal logging by requiring importers of timber and wood products to formally declare the species and country of origin, establishing one of the world's first strict legal frameworks for global timber traceability.

international deforestation mandates. Across all three, regulators are demanding visibility into opaque networks.

- *Tech Deployment:* Technological feasibility is highly fractured across these commodities. For raw timber, unit-level tracking of high-value logs from stump to port using barcodes or RFID tags is highly practical. Conversely, for cocoa, overwhelmingly produced by millions of smallholders in informal economies, digital tools face severe adoption barriers¹⁶. In these sectors, raw materials (cocoa beans, rubber "cup lump") are aggregated and mixed with hundreds of registered and unregistered micro-plots before the first processing facility ever sees the product.
- *Future Opportunities:* The prevailing loophole across these commodities is middleman aggregation and physical laundering. To scale realistic compliance, policy must decouple

transparency from traceability and enforce non-compliance consequences. Rather than demanding a highly infeasible standard of an unbroken physical chain of custody through informal networks and sawmills, policies should mandate baseline transparency at the production level (e.g., establishing digital identities and polygon mapping for smallholders) coupled with technologically aided, rigorous mass balance auditing at the regional aggregator and factory levels.

Regenerative Farming: the Nascent Frontier

Regenerative farming, which includes regenerative ranching as well as regenerative practices for all crops, including forest-linked commodities, is currently the least mature sector, as traceability is still largely built for food safety (e.g., adhering to FDA food safety rules focused on rapid recalls) rather than end-to-end sustainability outcomes²⁵.

- *Regulatory Pressure:* Low. Market incentives are currently driven by voluntary carbon credits and weak, private regenerative certifications rather than hard government mandates²⁶.
- *Tech Deployment:* Adoption of advanced tools remains limited. Most traceability still consists of low-tech paper logs or basic digital spreadsheets used for simple food safety certification audits unrelated to regenerative farming. Product aggregation and the lack of standardized definitions for regenerative practices further complicate traceability^{27, 28, 29}.
- *Future Opportunities:* To achieve true "practice-based verification," the sector requires political and economic incentives to implement existing technologies capable of measuring regenerative practices and outcomes, such as IoT sensors, multispectral imaging, isotopic analysis, eDNA, etc. can lay the groundwork for transparent farm and ranches practices^{30, 31, 32, 33}.



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Policy Recommendations for Scaling Traceability Technology within Agri-Food Systems

Scaling environmental traceability requires governments, industry actors, and partners to embed standards, incentives, and technology into food and commodity production systems. To ensure successful adoption, policymakers should avoid demanding immediate, end-to-end compliance and instead pursue a phased approach: establishing the foundation through transparency and standardization, followed by long-term scaling and strict enforcement.

Phase 1: Immediate Actions (Establishing the Foundation)

- *Prioritize farm-level transparency before full traceability:* In aggregated commodities (e.g., corn, wheat, cocoa beans, or rubber), full supply chain integration is currently too costly and technically challenging. Policies should first focus on making key environmental data visible and verifiable at the farm level in priority locations, using field reporting, drones, or in-situ sensors. This provides rapid verification and lays the groundwork for future traceability³¹.
- *Establish regionally specific definitions and standards:* Governments should co-develop regenerative criteria tailored to local ecological and production contexts with farmers and researchers. Simultaneously, they must mandate standardized Key Data Elements (KDEs), Critical Tracking Events (CTEs), and digital reporting protocols across all sectors to ensure interoperability between future auditing platforms.
- *Provide targeted incentives and implementation support:* Financial incentives (e.g., concessional loans, grants) should be explicitly tied to the adoption of traceability technologies and the verification of regenerative outcomes, such as soil carbon sequestration or deforestation-free land

use. Linking subsidies to measurable environmental performance can help offset upfront costs associated with monitoring equipment and potential short-term yield declines during the transition to regenerative practices³⁴. These efforts should be complemented by regionally based support centers that provide hands-on technical training and guidance for producers undertaking practice conversion.

- *Target smallholders with inclusive compliance pathways:* To prevent market exclusion, reporting requirements must account for the limited technical capacity of small-scale producers. Simplified reporting tools, cooperative data-sharing models, and group-level auditing reduce the administrative burden and ensure equitable participation³⁵.
- *Harmonize regulations across demand markets:* Consumer countries must accelerate policies (e.g., the EUDR) while fostering international cooperation. Aligning global traceability requirements will help close regulatory gaps, promote the sharing of best practices, and ensure fair, equitable compliance pathways for smallholder producers.

Phase 2: Long-Term Goals (Scaling & Enforcement)

- *Centralize traceability databases under government management:* To reduce administrative friction and enforce quality control, governments should eventually own and maintain interoperable national or regional traceability databases (similar to Uruguay's livestock registry), shifting the data management burden away from individual producers³⁶.

- *De-risk frontier technology through public investment:* Governments have a well-established precedent of funding high-risk technology to catalyze private-sector innovation (e.g., U.S. Department of Energy programs). Public institutions must subsidize pilot programs for frontier tools like eDNA, advanced drone sensing, and blockchain ledgers to bridge the gap between what is technically possible and operationally practical for aggregated commodities.
- *Scale access to existing, high-potential commercial solutions:* Shared satellite platforms and open-access geospatial data should be expanded to make land-use verification affordable. In discrete supply chains, unit-level tracking (like RFID for cattle or AI-powered electronic monitoring for fisheries) should be strengthened and integrated with cloud-based analytics for real-time compliance alerts.
- *Adopt verification-oriented, technology-mandated regulation:* Manual log-reporting must eventually be phased out. Import regulations, procurement policies, and retailer sourcing standards should be modeled on frameworks like the EUDR, legally requiring the use of verifiable monitoring technologies and embedding traceability requirements directly into global market access.

Cultural Interpretations of Data Privacy

End-to-end traceability may contradict localized, cultural interpretations of data privacy and ownership. For many producers, agricultural data such as farm boundaries, herd size, yield metrics, and management practices are not merely operational; it is deeply intertwined with property rights and economic security. In regions like the United States, independent ranchers often view centralized, government-managed environmental databases with deep skepticism, interpreting them as a precursor to regulatory overreach or punitive surveillance³⁷. Conversely, in the

Global South, marginalized smallholders may fear that high-fidelity traceability could be weaponized by state or corporate actors to facilitate penalties or justify exclusion from markets. Policymakers must recognize that data privacy in agriculture is not simply a technical hurdle to be solved with encryption. It is a foundational issue of trust. Ensuring processes reflect local preferences and values related to data ownership and security is important for sustainable and fair traceability initiatives.

Conclusion

Traceability is a critical tool for advancing environmental accountability across global agri-food systems. When effectively deployed, it enables governments, landowners, and consumers to verify deforestation-free supply chains, support regenerative practices, and align production with sustainability goals. However, its limitations are not primarily technological, but structural, rooted in fragmented supply chains, misaligned incentives, and the complexities of real-world production systems.

To unlock its full potential, policymakers must treat traceability as a strategic instrument within a broader

governance framework, rather than a standalone solution. This requires a phased and pragmatic approach: prioritizing farm-level transparency, establishing clear and regionally relevant standards, and investing in the systems, and support needed to enable widespread adoption. Over time, these foundations can support greater interoperability, stronger enforcement, and more comprehensive traceability across sectors.

Meaningful impact depends on alignment across regulatory mandates, market incentives, and producer support. Without this alignment, traceability systems

risk limited uptake, inconsistent data quality, and unintended exclusion, particularly among smallholders and producers operating in informal or resource-constrained contexts.

As environmental regulations continue to expand and reshape global markets, traceability will increasingly determine both compliance and competitiveness.

Policymakers now have a critical opportunity to shape its role, ensuring that systems are not only technically robust, but also equitable, scalable, and grounded in operational reality. When embedded effectively, traceability can serve as a powerful lever for driving more sustainable and accountable agricultural systems.

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