DiliCHANCE
successful due diligence in mineral supply chains

Deep Dive Article on Traceability Tools

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The DiliCHANCE project

The Challenge

The European Union perceives due diligence as crucial to its economic and sustainability goals. It is needed to secure critical raw materials, support the green and digital transition, and promote sustainable practices that reduce societal and environmental harm.

for more details please visit

www.DiliCHANCE.eu

Our Approach

DiliCHANCE improves due diligence in mineral value chains and responsible business conduct by (a) raising awareness and knowledge of human rights and environmental due diligence (HREDD) among corporate actors, (b) identifying gaps in HREDD implementation in policy and industry, (c) enhancing due diligence operations with better tools and new solutions, and (d) promoting multi-stakeholder engagement and capacity building.

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Overview

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1. Executive summary

Traceability is rapidly becoming a strategic requirement in global mineral supply chains. Emerging regulations such as the EU Battery Regulation and the Corporate Sustainability Due Diligence Directive (CSDDD), alongside growing market expectations around ESG performance and responsible sourcing, are increasing pressure on companies to demonstrate where minerals originate, how they move through supply chains, and under which environmental and social conditions they are produced. For both companies and technology providers, traceability is increasingly linked to market access, regulatory compliance, and corporate credibility.

This deep dive examines how traceability is currently defined, implemented, and governed across mineral supply chains. It reviews recent policy developments, regulatory frameworks, chain-of-custody models, and the growing ecosystem of digital traceability tools, including blockchain-based systems, digital product passports, and material fingerprinting technologies. The analysis highlights that while technological capabilities are advancing rapidly, traceability remains fundamentally a governance challenge rather than a purely technical one.

Key findings:

- **Traceability is becoming a market expectation:** EU regulations and international initiatives increasingly require companies to demonstrate transparent and auditable supply chain information.
- **Technology alone is not enough:** Blockchain systems, digital product passports, and geoforensic tools can improve visibility and provenance verification, but they do not automatically guarantee responsible sourcing outcomes.
- **Verified data matters:** The effectiveness of traceability systems depends on data quality, independent verification, and credible chain-of-custody processes rather than self-declared information alone.
- **Traceability must support risk-based due diligence:** High-performing systems link traceability data to audits, grievance mechanisms, remediation workflows, and stakeholder engagement processes.
- **Interoperability is becoming critical:** Companies and tool providers increasingly need systems capable of exchanging data across platforms and regulatory environments.
- **Implementation remains uneven:** Upstream actors, including artisanal and small-scale mining (ASM), could face disproportionate compliance burdens and limited digital capacity.

The report shows that traceability systems can significantly improve supply chain visibility, support regulatory reporting, and strengthen due diligence processes. Many of the tools reviewed provide sophisticated functionalities for documenting provenance, tracking material flows, sharing ESG-related information, and supporting interoperability across supply chain actors. However, the analysis also reveals a central limitation: traceability alone does not guarantee responsible sourcing outcomes. If traceability systems merely confirm that minerals originate from operations associated with environmental harm, labour violations, corruption, or weak governance, they risk legitimizing problematic supply chains rather than transforming them.

As a result, the report argues that traceability should be understood not as an end goal, but as an enabling infrastructure for responsible sourcing and supply chain governance. Companies must move beyond symbolic transparency toward risk-based due diligence approaches integrating verified data, independent assurance mechanisms, stakeholder accountability, and remediation processes.

For technology providers, the findings highlight a parallel transformation. Future traceability systems will increasingly need to prioritize:

- interoperability and open architectures,
- integration with due diligence and compliance systems,
- stronger verification and assurance mechanisms,
- and functionalities supporting accountability and corrective action.

Finally, this deep dive highlights broader structural challenges surrounding traceability implementation. Regulatory expectations are often driven by downstream industries and importing regions, while compliance costs and reporting burdens frequently fall on upstream producers. Without investments in capacity-building, digital infrastructure, and inclusive governance approaches, traceability systems risk reinforcing existing inequalities within global mineral supply chains.

Ultimately, this report concludes that traceability is a necessary but insufficient condition for responsible mineral sourcing. Traceability can make supply chains more visible, auditable, and governable, but it cannot replace clear standards, effective due diligence, stakeholder engagement, or political decisions about acceptable sourcing practices. The central challenge is therefore not only to trace minerals, but to ensure that traceability systems meaningfully contribute to accountability, risk mitigation, and measurable improvements across mineral value chains.

2. Closing-the-Loop: From Transparency to Accountability: Traceability in Mineral Supply Chains

*“To meet evolving HREDD mandates, corporate leaders must pivot from symbolic risk identification to **governance-ready traceability**. True performance is defined by 'Closing-the-Loop' functionalities that turn real-time data into verifiable remediation and stakeholder accountability."*

Corporate leaders must audit their digital due diligence operating system not for 'presence' but for 'performance.' To ensure legal compliance and effective HREDD, firms must transition from tools that merely identify risk to those that substantiate mitigation through end-to-end traceability and active stakeholder accountability. This requires going beyond self-declared inputs toward verified traceability systems, where data-chaining links social and environmental claims to specific physical batches of minerals. In this context, traceability should be understood not as an end in itself, but as a diagnostic tool for risk mitigation (see Fernandez et al. 2026). Its effectiveness would be characterized by the incorporation of "Closing-the-Loop" functionalities, ensuring that any red flag automatically triggers predefined remediation workflows or stakeholder engagement protocols. In addition, integration of "Upstream-to-Downstream Linking", enabled by blockchain or secure databases, strengthens "Chain of Custody" data, providing executives with defensible evidence to uphold their "Right to Operate" in regulated markets such as the EU. Decision-makers must also prioritize interoperability by selecting tools capable of exchanging traceability data across industry platforms via APIs, rather than being confined within inflexible, non-compliant systems. Finally, the integration of grievance mechanisms directly into traceability systems reinforces accountability, allowing violation reports from affected stakeholders to be tagged to specific sites, thereby moving corporate oversight of these issues from a "guessing" to a "governing" state.

3. What is traceability applied to minerals?

“The 2025 reports from the IEA, G7, and EU confirm that traceability is becoming a prerequisite for the "Right to Operate." For companies, this means that without "interoperable digital credentials," products may be excluded from high-value markets or defense-related supply chains.” Seeing Risk Isn’t Enough: Building Traceability That Drives Accountability

The term traceability applied to minerals has been defined in several documents, and it has been the subject of recent studies. The multiplicity of the definitions highlights the political stakes of the subject, as it defines the extent to which transparency is required. It is not the objective of this deep dive article to provide a new definition of traceability; it is preferred to refer to the documents that already exist and clarify the concept. Traceability has become a policy salient term for corporate and policy actors due to rising legal obligations (Corporate Sustainability Due Diligence Directive (CSDDD) or Battery Regulation) to conduct risk based-due diligence, geopolitical concerns for access to critical minerals and the International Organization for Standardization (ISO) working groups. Traceability of mineral supply chains is one of the main points in G7 countries “Roadmap to Promote Standards-based Markets for Critical Minerals” (G7 2025).

The following section will explore the definitions of traceability from four official institutions; the IEA-OECD report (2025), the European Parliament, the Geological Survey of Queensland (Australia) (Vandome & Dideberg, 2025, FrontierSI, 2024). Other documents addressing this question from scientific research project exist and are worth mentioning as from the EU funded MaDiTraCe project the Finnish project BATTrace .

More recent documents, such as IEA (2026) and Merket et al (2026) reports, were not included in this work.

3.1. Traceability definitions

The OECD-IEA report published in 2025 made a clarification and an overview of several definitions of traceability. This section refers word by word OECD-IEA subchapter *(*International Energy Agency & OECD, 2025).

The most used definition of "traceability" is the one developed by the International Organization for Standardization (ISO), which defines traceability as *"[t]he ability to trace the history, application or location of an object". The ISO definition further specifies that "[w]hen considering a product or a service, traceability can relate to: the origin of materials and parts; the processing history; [or] the distribution and location of the product or service after delivery"*.

The International Social and Environmental Accreditation and Labelling Alliance has used the ISO definition to develop its own definition of traceability, which it defines as *"[t]he ability to verify the history, location, or application of an item by means of documented recorded identification".* In a similar vein, the non-governmental organisation Business for Social Responsibility defines traceability as *"the process of tracking the provenance and journey of products and their inputs, from the very start of the supply chain through to end-use".*

In the food safety context, the United Nations Codex Alimentarius Commission's Procedural Manual defines traceability as *"the ability to follow the movement of a food through specified stage(s) of production, processing, and distribution".*

The European Union's General Food Law defines traceability as *"the ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution".*

In the minerals context, the Responsible Minerals Initiative has previously defined traceability as *"the capacity to preserve and verify the chain of custody of goods – their flow from one end of the supply chain to the other".*

Similarly, France's Bureau de Recherches Géologiques et Minières defines traceability as *"the ability to identify a product's source and trace or reconstruct its path, from the initial raw material through to the distributed manufactured product".*

- **Digital traceability and blockchain technology:** refers to the use of interoperable information systems to record, store, and transmit data on material flows and transactions along the value chain, with blockchain technologies offering enhanced data integrity, transparency, and resistance to tampering through decentralized and immutable records (BRGM, 2023).

- **Geoforensic and material fingerprinting:** analytical methods that use the intrinsic physical, chemical, and isotopic characteristics of raw materials to determine their geographical origin and reconstruct their transformation pathway, thereby enabling scientific verification of provenance independent of documentary evidence (BRGM, 2016; BRGM, 2022).

3.2. Traceability in recent institutional reports

The object of this section is to present how traceability in the raw materials sector is perceived by several recent institutional agencies reports. Those documents establish and identify future traceability development roadmaps and address challenges.

3.2.1. 2025 IEA – OECD report

In February 2025, IEA and OECD published a report with the objective of providing a large overview of traceability systems for critical raw materials.

For OECD-IEA "*Critical mineral supply chains cannot be truly secure, reliable and resilient unless they are also sustainable and responsible. Growing demand for critical minerals will mean new mines, processing facilities and refineries, which can bring attendant risks of harm to the environment, workers, communities and societies. These harms, if not adequately prevented, mitigated or remedied, can disrupt supply and hinder the rapid scale-up of clean energy technologies. To address these challenges, processes, tools and mechanisms are needed to ensure and demonstrate responsible practices across the value chain. Traceability can play an important role in supporting different types of policy goals, including energy security, and ensuring sustainable and responsible supply chains are supported by strong due diligence processes. [...]At the same time, careful design and implementation, along with addressing key technological and economic challenges, are essential for traceability systems to effectively support responsible supply chains".* So, for OECD-IEA traceability is strongly linked to expected growing demand in critical minerals by energy transition with an intention to label and demonstrate good practices but the implementation of traceability must consider supply chain realities and "*weighting the costs and benefits of different technologies and ensuring interoperability across the supply chain*".

The report provides information on many initiatives and traceability systems already in place and proposes a roadmap of 8 steps as follows:

1. Determine the policy objectives and understand the supply chain context
2. Choose which products to focus on
3. Determine which information should be collected and shared
4. Choose which operators to focus on
5. Promote the development and use of interoperability protocols

6. Establish trust mechanisms
7. Create incentives for increasing traceability
8. Engage with stakeholders in foreign jurisdictions

Fehler! Verweisquelle konnte nicht gefunden werden. presents a figure from this report where OECD-IEA conceptualizes how a mineral traceability system should be implemented, with three main pillars: **1)** a description of the technical infrastructure required, **2)** the shared responsibility and collaboration of actors along the supply chain and **3)** a strong governance, verification and audit system based on OECD due diligence principles ensuring accuracy and responsibility of all stakeholders.

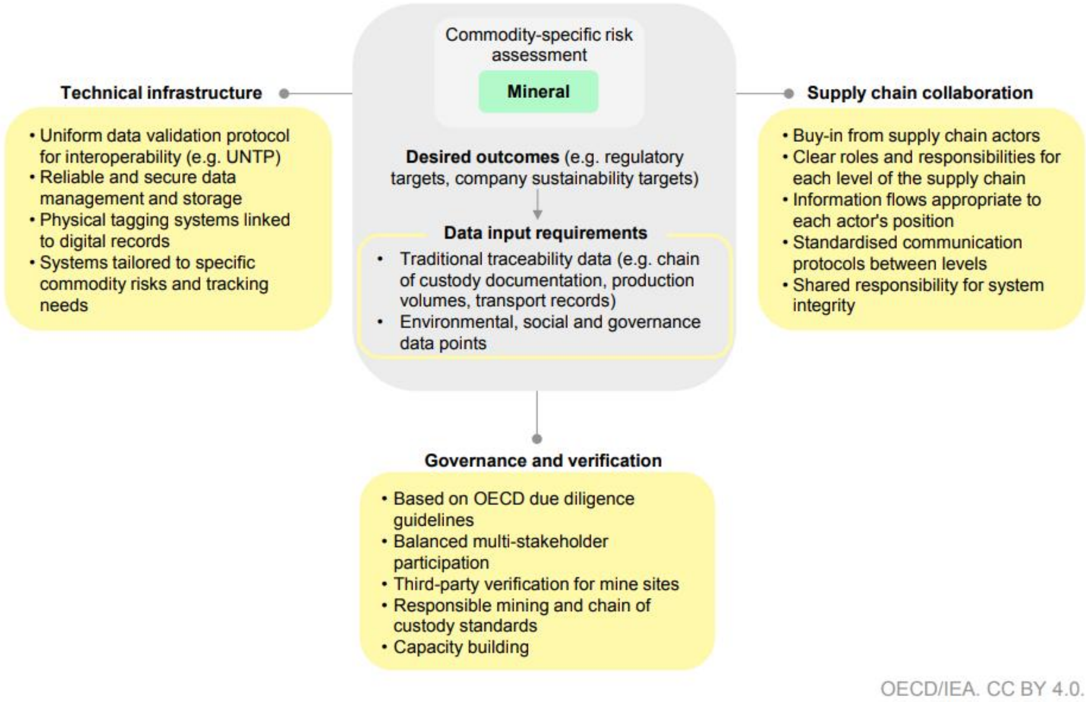

Figure 1: Conceptualizing a critical mineral traceability system (International Energy Agency & OECD, 2025).

3.2.2. EU Parliament 2025 (Vandome & Dideberg 2025)

This study commissioned by the EU Parliament (Vandome&Dideberg 2025), External Policies Analysis and Support Unit, examines the traceability of critical raw materials (CRMs) in Africa, focusing on technical, logistical, and policy considerations. It highlights the importance of traceability for responsible sourcing, in compliance with EU regulations, and ensures corporate sustainability. The study explores challenges such as complex supply chains, limited infrastructure, and the inclusion of artisanal and small-scale mining (ASM). It evaluates the strengths and limitations of different technological innovations like blockchain and geochemical analysis, while addressing their socio-economic impacts and potential enablers or barriers to their adoption. The final recommendations include:

- fostering EU-African partnerships,
- supporting ASM formalization,
- investing in digital infrastructure,

- and promoting regulatory harmonization to ensure traceability benefits both African producers and global supply chains.

3.2.3. Australian traceability roadmap - Geological survey of Queensland

This report (FrontierSI 2024) outlines a vision and roadmap for critical minerals provenance and traceability in Queensland, Australia, aiming to position the region as a global leader in sustainable mining practices. It emphasizes the importance of tracking the origin and sustainability of critical minerals to meet international market demands, regulatory requirements, and environmental goals. Key focus areas include developing a national framework, implementing digital credentials like the Guarantee of Origin, aligning with global standards, enhancing data infrastructure, promoting circular economy practices, and ensuring First Nations participation. The roadmap proposes a phased approach to achieve maturity in these areas, leveraging pilot programs, stakeholder engagement, and international partnerships to build a scalable and interoperable system.

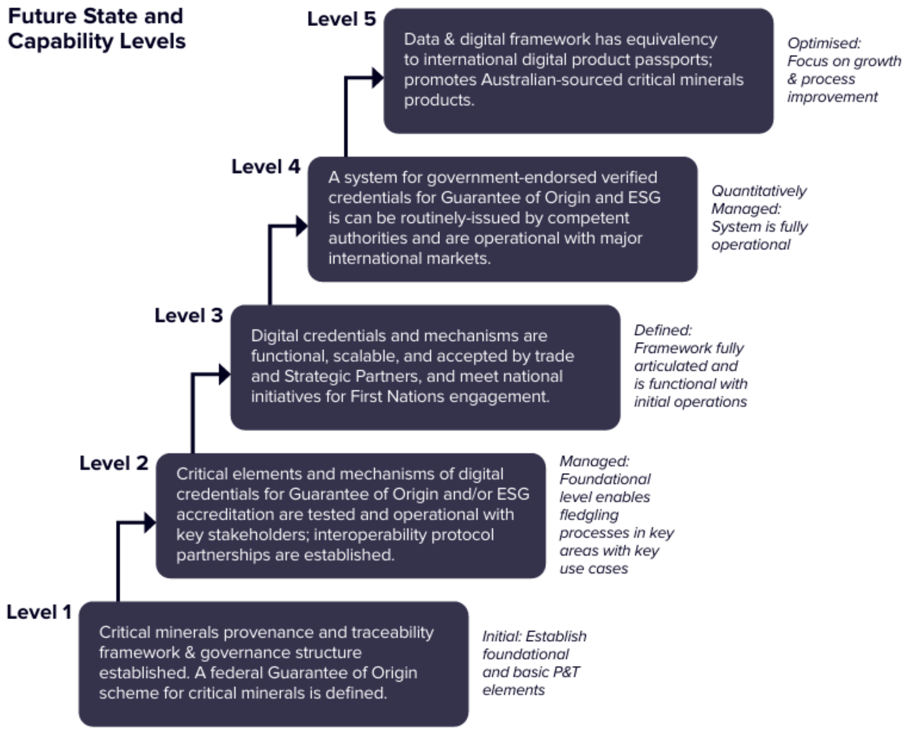

Figure 2: High-level Future State for critical minerals provenance and traceability in Australia (FrontierSI 2024).

3.2.4. G7 roadmap - 2025

G7 countries published a roadmap in October 2025 to strengthen mineral supply chain resilience, reliability, traceability, and transparency.

"Traceability and transparency systems are necessary to demonstrate and verify high-standard production and responsible and reliable supply chains. Traceability is a key tool for the

development of measures to level the global playing field and encourage market-oriented investments. To mitigate the potential for fragmentation and inefficiency as a result of the proliferation of traceability initiatives, we underline the importance of interoperable digital infrastructure across initiatives, and implementing systems based on successful existing models with technical neutrality. Both partner countries and international organizations have taken action to enhance the responsibility and transparency of supply chains, including through multilateral fora such as the IEA, OECD, UNECE, as well as through international standardizing bodies and through other initiatives developed by private sector organizations. To ensure a resilient and diverse supply, and in line with domestic legislation, governments may require economic operators to provide information on their dependency."

Accordingly, the G7 calls for the following strengthening requirements for traceability and transparency within strategic supply chains, including defense, developing a global framework for the interoperability of digital credentials and digital product passport aligned with the UNTP protocol and improve traceability for critical minerals supply chains for off-exchange trading aligned with practices carried out through mineral and metal commodity exchanges and other platforms.

To achieve these goals, G7 members will advance actions to:

- Assess the performance of Sustainability Metals Premia, engaging with relevant private sector-led initiatives as appropriate such as the LME sustainable metals premium market.
- Publish the results of pilot studies that test and demonstrate the feasibility of data collection requirements, identify gaps in data needs, and provide recommendations for the interoperability of digital credentials between G7 members and partners.
- Propose a plan for the G7 to increase transparency, traceability, resilience and reliability to diversify and reduce dependence on unreliable sourcing throughout specific critical mineral supply chains in consultation with the private sector, including to establish a data governance framework pertaining to digital traceability tools.
- Undertake member-specific initiatives to increase user uptake of traceability tools and systems.

4. Traceability in the landscape of EU regulation

The End of "Plausible Deniability": *Between the* ***Battery Regulation's*** *"Digital Battery Passport" (effective 2027) and the* ***CSDDD's*** *mandate for supply chain oversight, firms can no longer claim ignorance of upstream impacts. Traceability is now the required "system of controls" to prove compliance.*

This chapter identifies the position of traceability in different EU regulations: EU Battery Regulation, Critical Raw Materials Act, and Corporate Sustainability Due Diligence Directive.

4.1. EU Battery Regulation

The European Battery Regulation (EU) 2023/1542 (EBR), enacted in 2023, introduces comprehensive requirements for sustainable and safe battery production. Its scope spans the entire product lifecycle and addresses the performance standards, the end-of-life solutions, and the recycling (European Union, 2023). Traceability is one of the objectives of this regulation.

"Ensuring traceability of a battery throughout the whole supply chain helps to make market surveillance simpler and more efficient and provides transparency to consumers. An efficient traceability system facilitates the market surveillance authorities' task of tracing economic operators who have placed on the market, made available on the market, or put into service non-compliant batteries. Economic operators should therefore be required to keep information on their transactions involving batteries for a certain period, including in electronic form".

This Regulation should specify how the traceability of traders' obligations laid down in Regulation (EU) 2022/2065 of the European Parliament and of the Council is to be applied to online platforms allowing consumers to conclude distance contracts with producers offering batteries, including batteries that are incorporated in appliances, light means of transport or other vehicles, and to consumers located in the Union in relation to the registers of producers established pursuant to this Regulation. For the purposes of this Regulation, any producer offering batteries, including those incorporated in appliances, light means of transport or other vehicles, by means of distance contracts directly to consumers located in a Member State, whether established in a Member State or a third country, should be considered to be a trader as defined in Regulation (EU) 2022/2065. Pursuant to that Regulation, providers of online platforms, falling within the scope of Section 4 of Chapter III thereof and who allow consumers to conclude distance contracts with producers, should obtain from those producers information on the register of producers where they are registered as well as their registration number and a self-certification committing to comply with the extended producer responsibility requirements laid down in this Regulation. The implementation of the rules on the traceability of traders for the sale of batteries online are subject to the enforcement rules laid down in Regulation (EU) 2022/2065.

Economic operator management systems "*establish and operate a system of controls and transparency regarding the supply chain, including a chain of custody or traceability system, identifying upstream actors in the supply chain;"*

In particular, the CHAPTER VII, covering Articles 47 through 53, establishes a due diligence framework, representing a transformative development for the battery industry. This framework ensures the effective management of supply chains for critical raw materials, such as cobalt, nickel, lithium and natural graphite, and of chemical compounds based on them (EBR, 2023; Mattea, 2023). From 18 August 2027 (Council of the EU, 2025), economic operators placing batteries on the market or putting them into service shall comply with the due diligence obligations set out in the Regulation by implementing specific battery due diligence policies to to ensure responsible sourcing and sustainable, circular management of supply chains EBR, 2023).

4.2. EU Critical Raw Materials Act (CRMA)

CRMA is not an act that addresses directly traceability purposes. In fact, the word traceability is not mentioned in the final text of the CRMA. However, CRMA recognizes and encourages certification schemes that meet criteria fixed in Annex IV of CRMA.

A recognized certification scheme shall meet the following criteria:

a) It is open under transparent, fair, and non-discriminatory terms to all economic operators willing and able to comply with the scheme's requirements and subject to multi-stakeholder governance.
b) Verification and monitoring of compliance is objective, based on international, Union or national standards, requirements and procedures and carried out independently from the relevant economic operator.
c) It includes sufficient requirements and procedures to ensure the competence and independence of the verifiers responsible.
d) It includes requirements to ensure an audit report is established at the site level.

The requirements set by the commission for the certification shall include:

- requirements ensuring environmentally sustainable practices, including requirements ensuring environmental management and impact mitigation in the following environmental risk categories.
- requirements ensuring socially responsible practices, including respect for human rights and labour rights including the community life of indigenous peoples.
- requirements ensuring business integrity and transparency which includes instructions to apply sound management of financial, environmental and social matters as well as anti-corruption and anti-bribery policies.

4.3. Corporate Sustainability Due Diligence Directive (CSDDD)

MaDiTraCe project deliverable analysed the interaction of this regulation and traceability (Fernandez et al 2025): "A shift toward a harmonized European approach to due diligence legislation has been observed, covering both cross-sectoral and sector-specific policies, with continued expansion anticipated in the coming years (Franken & Schütte, 2022). A key development in this regard is the Corporate Sustainability Due Diligence Directive (EU) 2023/2859 (CSDDD), which entered into force in July 2024. The directive introduces mandatory due diligence requirements outlined in Articles 7 to 16 (CSDDD, 2024). This legislation represents a fundamental advance in the EU regulatory landscape, raising the standards of corporate responsibility in various sectors (Ciacchi, 2024). With the enactment of this legislation, the EU aims to address the multiple challenges of responsible sourcing within global supply chains. Member States must transpose the directive into national law by 26 July 2026, and from 26 July 2027, these obligations will apply to companies following a phased implementation based on company size and turnover, its full application date being set on 26 July 2029 (CSDDD, 2024). These measures are expected to reshape business practices, catalyze significant changes, and set a new benchmark for sustainability (Farooki et al., 2024). It should be noted that the Omnibus Directive (European Commission, 2024) introduced simplifications to the scope and implementation of the CSDDD. These adjustments reduced the number of companies falling under the directive by raising the employee and turnover thresholds, narrowed the scope of systematic due diligence primarily to direct business partners, and extended the review period for risk assessments from annual to every five years. They also postponed the timeline for climate-related obligations and overall application deadlines, giving companies more time to prepare. In addition, the Omnibus removed the draft's EU-wide civil liability regime and streamlined stakeholder engagement obligations, while capping the information large firms can request from SMEs to avoid excessive reporting burdens."

CSDDD identifies traceability technical solutions as follows: "*Digital tools and technologies, such as those used for tracking, surveillance or tracing raw materials, goods and products throughout value chains, for instance satellites, drones, radars, or platform-based solutions, could support and reduce the cost of data gathering for value chain management, including the identification and assessment of adverse impacts, prevention and mitigation, and monitoring of the effectiveness of due diligence measures. In order to help companies fulfil their due diligence obligations along their value chain, the use of such tools and technologies should be encouraged and promoted. To that end, the Commission should issue guidelines with useful information and references to appropriate resources. When using digital tools and technologies, companies should take into account and appropriately address possible risks associated therewith and put in place mechanisms to verify the appropriateness of the information obtained.*" (European Union, 2024, Recital 46a)

4.4. Summary

Regulation	Place of traceability
EU Battery regulation	Fixes a required digital product passport for battery production. The traceability system would be at the heart of the regulation and ensure the reliability of the passport and hence, the proper application of the regulation.
CRM Act	No big place, regulation for raw material supply diversification in Europe. Fixes the conditions for critical raw materials certification schemes in Europe. Those certification schemes require traceability systems and differentiate between certified and non-certified CRM sources.
CSDDD	Traceability is encouraged. Those solutions would help companies address data gaps and risk assessment. For digital tools, companies should take into account mechanisms of verification.

5. Traceability models in raw materials & Chain of Custody

Logic over Interface: *A tool is only as "governance-ready" as the* ***ISO 22095 model*** *it supports. Architects must decide if their system is built for the high-fidelity* ***"Identity Preserved"*** *model (required for high-risk minerals) or the more flexible* ***"Mass Balance"*** *model (common in complex refining).*

According to Haikkonen et al (2022); the Chain of Custody concept broadly relates to the process of evidence documentation. The term is also used in legal proceedings, where CoC is used to authenticate the evidence presented to a court, by documenting the continuity of possession of the evidence from the crime scene to the court (Badiye et al, 2023). Similarly, in mineral supply chains, CoC documents the series of custodians in charge of a mineral 'from the mine through the downstream chain of custody to the end consumer', also documenting their claims of conformity with responsible sourcing standards (Initiative for Responsible Mining Assurance, 2020). The International Social and Environmental Accreditation and Labelling Alliance differentiates between four different conceptual approaches to CoC, articulating exactly how responsibly sourced material should be handled along the supply chain (International Social and Environmental Accreditation and Labelling Alliance, 2016):

The different models of CoC are defined by ISO 22095 norm as the following (International Organization for Standardization, 2020):

Chain of Custody: process by which inputs and outputs and associated information are transferred, monitored, and controlled as they move through each step in the relevant supply chain. A **Chain of Custody system** is a set of measures designed to implement a Chain of Custody, including documentation of these measures. A **Chain of Custody model is the** approach taken to control inputs and outputs and associated information in a particular Chain of Custody system.

<u>Identity Preserved model</u>

Chain of Custody model in which the materials or products originate from a single source and their specified characteristics are maintained throughout the supply chain.

Example: Only raw materials from certified and proven origin of mines are accepted. For one specific raw material, different origins (i.e. mines) are not allowed to be mixed. In a battery with lithium, nickel, cobalt and manganese, all the lithium comes from the same unique lithium certified mine, refined in the same refinery plant and same for the other commodities.

<u>Segregated model</u>

Chain of Custody model in which specified characteristics of a material or product are maintained from the initial input to the final output.

Example: Raw materials can be mixed if they are all individually from certified mines are accepted, and they are mixed. In a battery, all the lithium comes from certified origins, but they are mixed.

Controlled Blending model/mass balance model

Chain of Custody model that are easier to implement, the materials or products with a set of specified characteristics are mixed according to certain criterias. At the end, allocation of the characteristics is done on the product according to the proportion of different material origins.

Example: In a battery, lithium with certified and non-certified origins are mixed. The final product presents the % in mass of certified lithium. In the precedent models, uncertified material was not allowed to be mixed with certified ones.

Book and Claim model or certificate trading

A model in which the administrative record flow is not necessarily connected to the physical flow of material or product throughout the supply chain.

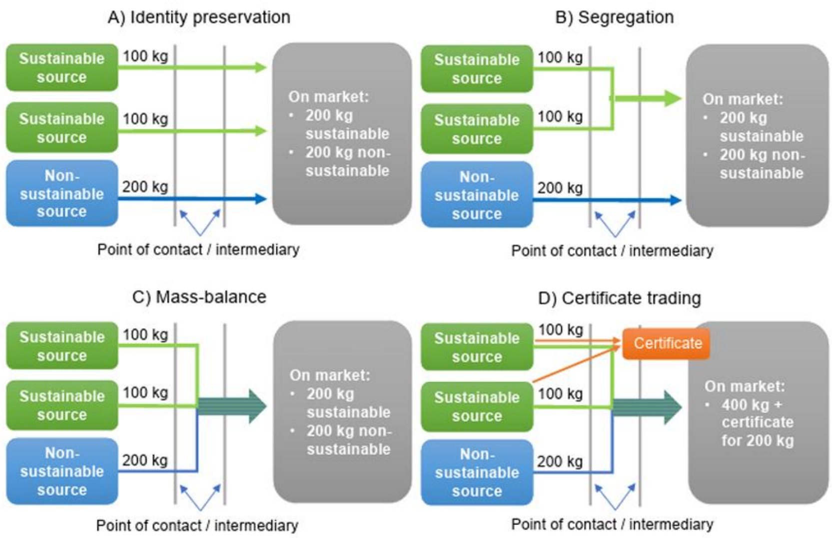

Figure 3: Illustration of the different Chain of Custody model which are different blending of sustainable and non-sustainable products under different chain of custody approaches. From Kaikkonen et al (2022).

6. Traceability tools in the market

6.1. Digital traceability

In the market, there are many companies providing commercial solutions for minerals and metals traceability. Overall the DiliCHANCE project identified several tools relevant for traceability in mineral supply chains. The following table focuses on companies presenting public cases studies or explicit mentions to use cases with products containing metals or mineral commodities. The tools were selected based on their demonstrated use in mineral and metal supply chains, prioritizing solutions with publicly available case studies and clear traceability functionalities. Emphasis was placed on tools enabling chain-of-custody tracking, upstream actor identification, and integration of due diligence or ESG data. The selection captures both blockchain-based systems and digital product passports, reflecting the main technological approaches and their growing convergence. In the field of IT solutions for traceability, we can distinguish between two types of solutions that are slightly different: blockchain traceability systems and digital passports. In some cases companies provide both solutions and interconnection between both systems.

- Blockchain Traceability Systems

The purpose is to track the movement and history of products or assets across a supply chain. Those systems record every transaction or change of hands on a blockchain, creating an immutable, transparent ledger.

Key feature: Focuses on provenance, i.e., where something came from and who handled it.

- Digital Passports

The purpose is to store and verify the identity, authenticity, and attributes of a product or individual. Digital passports use digital records (often on blockchain or secure databases) to provide a unique, tamper-proof identity for an item or person.

Key feature: Focuses on identity and credentials—proving what something or someone is, not just its history.

The level of accessibility to case studies of these different tools is unfortunately very diverse. This table is also not exhaustive of all the tools existing on the market.

Table 1: digital traceability tools or companies with case studies with minerals and metals.

Tool or company	Minerals applications	Case study / application (real-world use)	Method & comment	Link
Minespider	Batteries, OEMs and metals	Pilots in automotive and critical minerals supply chains	Blockchain-based traceability, carbon emissions tracking, product passport	https://www.minespider.com/ https://www.minespider.com/press/minespider-and-rare-earth-ventures-to-boost-traceability-in-australias-critical-minerals-supply-chains
Spherity	Batteries and lithium.	MaDiTraCe project (EU research integration)	Digital product or material passport.	https://www.spherity.com/
Circulor	Battery materials, vehicles	Volvo lithium supply chain (SQM, IRMA-certified lithium)	Battery passport, blockchain technology	https://circulor.com/ https://circulor.com/articles/working-with-sqm-and-volvo-cars-circulor-makes-available-digital-proof-of-sqm-s-irma-75-lithium-to-downstream-customers
Circularise	Permanent magnets, OEM, battery	Industrial partnerships (limited public case detail)	Blockchain-based technology	https://www.circularise.com/
SourceMap	Metals, electronics	Fairphone supply chain mapping	Supply chain mapping and visualization, transaction traceability	https://www.fairphone.com/en/impact/source-map-transparency/
TilKal	Manganese, mining sector	Eramet manganese traceability (EraTrace	Blockchain-based technology and carbon footprint	https://www.tilkal.com/post/digital-product-ppassport-eratrace-by-eramet-tilkal
iTraceIT	Precious metals, diamonds, luxury sector	Industry use in luxury supply chains	Traceability system powered by blockchain, enriched by compliance intelligence, and built for multi-industry scalability	https://itraceit.io/

Catena-X	Automobile, OEM	Industry-wide ecosystem deployment	Data ecosystem for sovereign data exchange, enabling companies and service providers to collaborate securely and seamlessly. Includes traceability and digital passport	https://catena-x.net/ecosystem/overview/
Ressource Matters	Cobalt from DRC	Public cobalt supply chain map	Not a traceability tool by itself but a supply chain map of cobalt. Open access.	https://supplychains.resourcematters.org/
Re-Source	Metals, battery	Glencore partnership	Digital product passport, traceability, proof of responsible sourcing. Partnership with Glencore	https://re-source.tech/
Predell	Nickel	Eramet nickel case study	Blockchain, digital product passport.	https://www.predell.com/en/home/

6.2. Material fingerprinting and material tagging

The determination of a material provenance or origin can be checked, verified, or determined based on fingerprinting science. Those techniques are also used in the field of geo-forensic science.

According to BATTRACE project, final report: Geo-based fingerprinting, in the present context, is the process of determining the origin of a given sample (ore, concentrate, material/product) by analyzing its properties or characteristics. One must differentiate between "natural" fingerprinting, for which these properties are intrinsic to the material (e.g., geochemistry, mineralogy), and artificial fingerprinting, whereby the material is artificially altered (e.g., addition of particles or taggants with unique properties to a shipment, laser inscription and marking of gemstones) in order to certify its origin and ensure traceability. The natural properties of ores and minerals include a range of geochemical and mineral properties, such as bulk chemistry, mineralogy, and textures, as well as in situ properties, including mineral properties such as minor and trace elements, or stable and radiogenic isotopes in specific minerals. These ore properties are linked to the geological setting and geological history of the deposits in which these ores are found. Some of these properties may be site-specific to a deposit or mining district and can therefore be used for traceability. By comparing these fingerprints with a database or reference samples, one can then certify the origin of the sample analyzed. The final comparison of these features between the control and reference sample is achieved by applying, often multivariate, statistical methods.

For example the company Oritain , a forensic origin verification service provider, explains how its tools are used to scientifically verify product origin independent of supply chain documentation: 'Origin Fingerprints' can be derived from analyzing the chemical compositions of plants, animals, and raw materials. For biomass, these compositions are driven by specific factors unique to each location, including soil composition, precipitation, temperature, and altitude. Material fingerprint science is being applied to trace other products such as cotton, food, wine, coffee, cacao, and timber.

Based on those concepts, there are several companies providing commercial services around material fingerprint science. There are also industries that also have a traceability system combining material fingerprints and digital solutions. Those companies are more advanced in the food, clothes and timber sectors, where we detect maturity for material fingerprints. In the field of minerals and metals, the main tools already in the market are oriented towards luxury industry (diamonds, gold, gemstones).

The entities listed in Table 2 are commercial service providers offering material fingerprinting or tagging solutions (rather than standalone software tools), typically delivered as laboratory-based verification or integrated traceability services; where publicly available, specific case studies are indicated, otherwise the entries reflect the primary mineral or commodity focus of the service.

Table 2: Tools or companies providing services around material fingerprint applied to minerals or metals.

Tool or company	Cases studies (if availaible)	Method & comment	Link
SourceCertain (Australia)	Diamonds, gold	Trace element detection. Contracted service provider to SCS Global Services, an international leader in third-party certification, validation and verification. Source Certain provides the company's provenance verification technology for SCS's Global Services Certification Standard for Sustainable Diamonds (SCS-007).	https://www.sourcecertain.com/
Gubelin-Provenance proof (Switzerland)	Jewellery, gemstones	Material tagging and blockchain. Work with Haelixa.	https://www.gubelin.com/cms/en/news/provenance-proof-blockchain/
Haelixa	Gemstones and precious metals	Artificial tagging based on DNA tagging	https://haelixa.com/customer-story/provenance-proof-partners-with-haelixa-to-track-emerald-origin/

Argor Heraeus	Gold	Geoforensic science, digital twin and distributed ledger technology	https://www.argor-heraeus.com/en/about/news/traceable-gold-lines/
Metalor	Gold	Geoforensic passport, internal check iOS application	https://metalor.com/a-one-slide-presentation-of-metalor-sourcing-traceability-and-security-ecosystem/
AI Analysis		Isotopes. Cooperation with Oritain	https://www.ai-analysis.com/
Imprint Analytics	Rocks	Proof of origin of marble	https://imprint-analytics.at/products-tested/materials
Lyncée	Minerals	Isotopes and trace elements	https://lyncee.io/en/lyncee-tracabilite-born-strategic-partnership-between-trace-and-brgm

7. Discussion/Conclusion

This deep dive has demonstrated that traceability applied to minerals is best understood as a governance infrastructure, rather than a standalone technical solution: traceability constitutes the foundation upon which corporate legitimacy for a risk-based due diligence approach is built. The implications for both developers and decision-makers are therefore significant.

For tool developers, the shift from a technical solution to an infrastructural role requires a fundamental rethinking of system design. First, traceability systems must evolve from isolated data silos to interoperable architectures, enabling seamless data exchange across the supply chain through APIs and common data standards (e.g., emerging frameworks such as digital battery passports). Second, the emphasis must move from visualization to verification. Rather than providing descriptive representations of supply chains, systems must incorporate robust "trust layers"—including third-party validation, geospatial monitoring, or sensor-based inputs—capable of withstanding regulatory scrutiny and audit processes. Finally, traceability infrastructures should integrate remedy and accountability mechanisms. This includes embedding grievance systems and automated risk-flagging functionalities, allowing the system not only to identify issues but also to trigger investigation and corrective action, thereby shifting from passive transparency to active governance.

For corporate decision-makers, the adoption of such infrastructure redefines the nature of responsibility. Enhanced visibility into upstream supply chains—often extending to Tier 3 or Tier 4 suppliers—translates directly into increased risk ownership, limiting the ability to claim lack of awareness regarding adverse impacts. This necessitates parallel investments in internal capacities for risk assessment, legal compliance, and response mechanisms. Moreover, traceability as governance enables a strategic shift from supplier substitution to supplier engagement and improvement. In highly concentrated mineral markets, companies can leverage traceability data to establish performance benchmarks and exert influence over upstream actors, using procurement relationships to drive environmental and social improvements. Finally, the effectiveness of this infrastructure is contingent upon data integrity. Inaccurate or unverifiable data introduces significant legal and reputational risks, including exposure to allegations of greenwashing. As such, companies must invest not only in traceability systems but also in assurance processes that ensure alignment between digital records and on-the-ground realities.

Across institutional definitions reviewed in this article — from ISO, OECD-IEA, EU institutions, national geological surveys, and responsible sourcing initiatives — traceability consistently refers to the capacity to document, preserve and verify information on the origin, custody, transformation, and circulation of mineral materials. Yet none of these definitions assign intrinsic normative value to traceability itself. Traceability produces *knowledge*; responsibility depends on how that knowledge is used.

The analysis of recent institutional reports and regulatory frameworks confirms that traceability has become a central policy instrument for securing critical mineral supply chains in the context of the energy transition. In EU legislation (Battery Regulation, CRMA, CSDDD) and G7 policy documents, traceability is mobilized to support due diligence, certification schemes, market surveillance, and risk management. These instruments reflect a shared assumption: that sustainability and responsibility can be achieved through greater transparency, interoperability of data, and auditable supply chain information, while allowing continued growth in mineral production and trade for all industries.

However, this deep dive document also reveals a fundamental limitation: traceability is only meaningful when embedded in a responsible supply chain framework. Several of the traceability systems and tools described — including blockchain-based platforms, digital product passports and geoforensic fingerprinting — can identify provenance, document custody or verify origin. Yet if these systems merely confirm that minerals originate from operations associated with poor environmental performance, labour violations or weak governance, traceability alone does not improve outcomes. Without predefined standards, thresholds and consequences, tracing “irresponsible” supply chains risks normalizing or even legalizing them rather than transforming them.

The discussion of Chain of Custody models further illustrates this point. Identity preserved and segregated models align most closely with strong responsibility claims, but they remain costly and difficult to scale across complex, multi-commodity mineral value chains. More flexible approaches — such as mass balance or book-and-claim models — improve feasibility and inclusiveness but weaken the physical link between material flows and sustainability attributes. These trade-offs are not merely technical; they reflect policy choices about how much responsibility is required, where it should be enforced, and who bears the cost.

Technological diversity, as mapped in this article, constitutes both strength and limitation. Digital traceability systems enable interoperability, reporting and regulatory alignment, while material fingerprinting and artificial taggants provide scientific verification of origin in specific contexts. However, none of these tools can guarantee end-to-end traceability across all minerals, processing stages, and geographies. Their effectiveness depends on governance arrangements, verification mechanisms, data quality, and integration with due diligence obligations — elements that remain unevenly developed across jurisdictions.

Moreover, the deep dive highlights structural asymmetries in how traceability is deployed. Regulatory requirements and market expectations are largely defined by importing regions and downstream industries, while compliance costs, data provision and operational adjustments fall disproportionately on upstream producers, including artisanal and small-scale mining actors. Without complementary measures — such as capacity-building, infrastructure investment, digitalization, and pathways for formalization — traceability systems may exclude certain actors or regions, undermining their stated sustainability objectives.

In conclusion, this article argues that traceability applied to minerals should be regarded as a necessary but insufficient condition for responsible sourcing. Traceability can support due diligence, certification, and regulatory enforcement by making supply chains visible and auditable. It cannot, however, substitute for clear definitions of acceptable practice, enforceable standards, remediation mechanisms, and political decisions about market access. The central policy challenge is therefore not only to expand traceability systems, but to ensure that what is traced is meaningfully linked to responsibility, accountability, and improvement. Without this linkage, traceability risks becoming an end in itself — technically sophisticated, highly regulated, yet disconnected from the responsible supply chain outcomes it is meant to support.

8. Annex: Tool Test Reports

8.1. SPHERITY (VERA)

8.1.1. Short summary

VERA is a Digital Product Passport (DPP) solution developed by Spherity that enables companies to create, manage, and share verifiable product information across supply chains. The tool is based on decentralized identity technologies and uses verifiable credentials to ensure data integrity, traceability, and interoperability. VERA allows product-related data—such as origin, composition, sustainability attributes, and regulatory documentation—to be linked to individual products and accessed through digital interfaces such as QR codes or APIs.

The tool is designed to support emerging EU regulatory requirements, including the Battery Regulation and the Ecodesign for Sustainable Products Regulation (ESPR). While VERA provides a technically robust infrastructure for data exchange and verification, it primarily functions as an information carrier rather than a comprehensive due diligence or risk management tool.

The authors of this deep article and tool test must declare that collaborated with Spherity in the framework of MaDiTraCe project.

Enable secure product data sharing across supply chains

Ensure data integrity, traceability and interoperability

Support compliance with emerging policy regulations such as Battery Regulation

Scalability for large industrial networks

No third-party verification directly in the tool but connected to Auditors/certifiers verifed credential system / **No** support of due diligence anticipation functions

8.1.2. Purpose of the tool

VERA targets manufacturers, upstream suppliers, and downstream actors operating in compliance-driven sectors that face increasing requirements for product-level transparency. Its primary purpose is to enable companies to document and communicate product information in a secure and standardized manner, thereby supporting regulatory compliance, traceability, and data sharing across complex value chains.

Within a due diligence context, VERA supports transparency and documentation requirements by making product-related data accessible and verifiable. However, it does not itself assess risks, contextualize impacts, or support decision-making on mitigation measures. As such, the tool is best understood as a technical enabler that complements, rather than substitutes, broader human rights and environmental due diligence (HREDD) processes.

8.1.3. Experiences

User experience was based on public examples of product passports in Spherity website. Publicly available examples of Digital Product Passports illustrate how environmental, social, and supply chain information is displayed, but these examples appear to be synthetic or mock-up case studies.

The DPP interface presents high-level compliance statements and aggregated indicators. For battery examples, Spherity DPP example provides information about material content, technical characteristics, circularity, LCA and carbon footprint and includes the possibility to download due diligence report. However, current battery examples are examples with synthetic data.

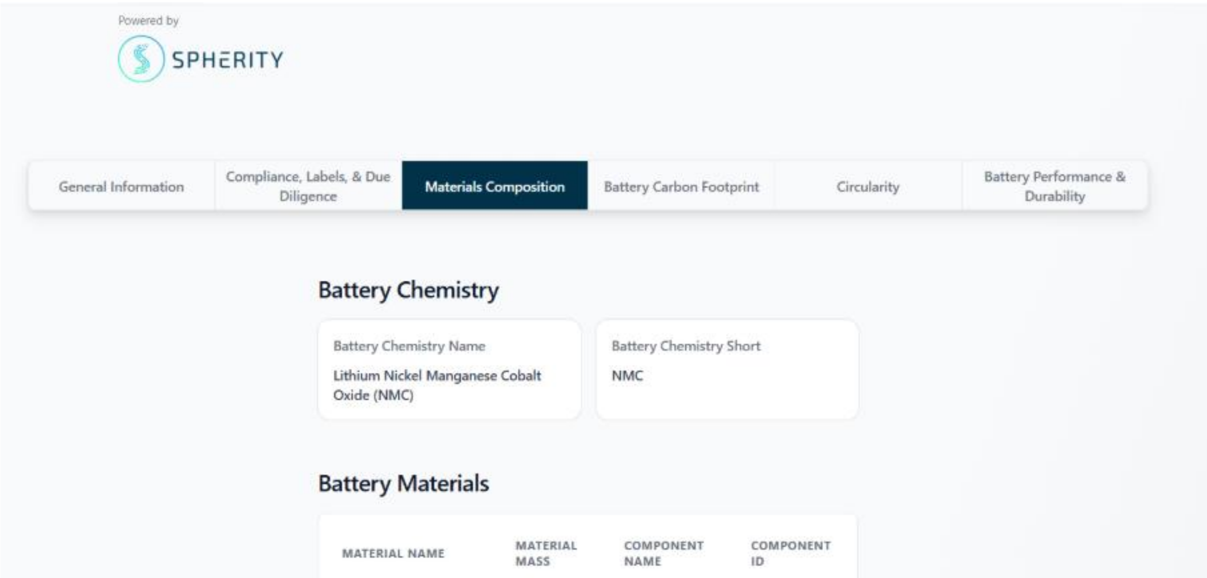

Figure 1: screenshot of a battery DPP example from Spherity available in their website.

8.1.4. Strength and uniqueness

VERA's main strength lies in its use of decentralized identity and verifiable credentials to enable secure, tamper-resistant data exchange without reliance on centralized databases. This architecture supports interoperability across emerging European data ecosystems such as Gaia-X and sector-specific initiatives. The tool is well aligned with forthcoming EU regulatory frameworks and provides structured templates for Digital Product Passports across multiple industries. Its modular design and API-based integration capabilities make it suitable for large enterprises seeking to embed traceability into existing digital infrastructures. VERA is particularly strong as a technical backbone for standardized data sharing and regulatory reporting.

8.1.5. Weaknesses or limitations

VERA tool functions primarily as a data disclosure and transmission infrastructure, enabling the presentation of product-related information, but it does not support core due diligence activities such as risk identification, prioritisation, mitigation planning, or remediation tracking. For that, VERA must be complementary to other due diligence tools. In practice, this complementarity relies on linking VERA-generated data with risk analysis tools, third-party audits, and internal due diligence processes to translate transparency into actionable risk management.

While the use of verifiable credentials strengthens data integrity, it focuses on the authenticity of information rather than on its substantive accuracy, completeness, or contextual relevance. As a result, formally valid data may be interpreted as reliable indicators of responsible practices without sufficient scrutiny of underlying risks. For that, the work done by Spherity in MaDiTraCe project (Sahinel et al 2025) is to connect Spherity DPP solution to material tagging verification and certifications.

In addition, as a general remark for digital tools, effective use of the tool presupposes a relatively high level of digital capacity and governance maturity across supply chain actors. This may limit inclusiveness, particularly for SMEs and upstream suppliers in low-capacity or high-risk contexts. However, the integration of Spherity solutions in the framework of big data systems such as Catena-X is an advantage.

8.1.6. Sources used

Official website: https://www.spherity.com/digital-product-passport VERA documentation and learning materials: https://learn.dpp.spherity.com Spherity technical blog and background materials

Battery example https://vera-staging.dpp.spherity.dev/?did=did:web:api-vera.susi.spherity.dev:did-registry:acme-battery-passport-906039c4e2bb5308

Sahinel et al (2025). Architecture definition for PoC implementation. https://www.maditrace.eu/content/D3.4-Architecture-definition-for-PoC-implementation-Intermediate-Report.pdf

8.2. Tilkal

8.2.1. Short summary

Tilkal is a digital supply chain traceability platform that uses distributed ledger technology (blockchain) combined with data analytics to provide end-to-end visibility across multi-tier supply chains. The tool enables companies to collect, store and share supply chain information among multiple actors while preserving data integrity and access control. Tilkal positions itself as a solution for managing traceability, compliance monitoring and sustainability-related information through digital product passports and structured data exchange. It is presented as applicable across several sectors, including food, cosmetics and mining, and aims to support companies in documenting material flows and associated sustainability indicators.

Blockchain-based traceability

Enable the record on material provenance

Ensure regulatory compliance / Specialized in minerals/ Lack of large-scale feasibility proof

No third-party verification directly in the tool, access to external audit certification

8.2.2. Purpose of the tool

Tilkal targets medium to large companies operating complex, multi-actor supply chains that face increasing regulatory and market driven traceability requirements. In a due diligence context, the tool primarily supports the identification and documentation of supply chain structures, chain of custody information and selected environmental and social indicators. By creating digital product passports and shared records, the platform aims to facilitate information exchange between suppliers, buyers and other partners, thereby supporting compliance verification and internal monitoring.

From a risk based due diligence (for human rights and the environment); Tilkal functions mainly as an enabling infrastructure rather than a comprehensive due diligence system. It can support risk-based due diligence indirectly by improving data availability and traceability, but it does not in itself define risk thresholds, mitigation strategies or remediation processes. The extent to which it meaningfully contributes to due diligence therefore depends on how companies design their data inputs, governance rules and verification mechanisms around the tool.

8.2.3. Experiences

The assessment is based on desk research only and available Eramet case study information. Available materials suggest that the platform is designed with a relatively intuitive user interface, allowing users to visualize supply chain structures and associated data. Demonstration materials indicate that blockchain functions are abstracted through a graphical interface, reducing the need for technical expertise from end users.

Tilkal appears to provide dashboards and visualizations that aggregate key performance indicators related to traceability, material origin and CO2 footprint, which may support internal communication and decision-making. However, because no hands-on testing was possible, it was not feasible to assess the actual onboarding process, learning curve, data input burden or day to day operational effort.

As open demo access is not accessible the user experience is limited. According to the official communication, the tool and Eramet-Tilkal case study provides:

1. Digital Product Passport (DPP): Access complete traceability for every order

- Track raw material consumption, suppliers' country, carbon emissions, and reception dates
- Discover the full Traceability map, from sourcing to final production
- View Ecovadis medals of suppliers
- Monitor each step of production, from casting to transport
- Download the Digital Product Passport for record-keeping or as proof of your sourcing for your customers

2. Carbon Calculator: Gain visibility on CO_2 emissions from cradle to gate

Filter by year, product category, or delivery site to track the total CO_2 equivalent emission of the selected scope. The cradle-to-gate calculation methodology has been verified by DNV, an internationally renowned third party, ensuring reliable data.

3. CSR KPIs & Commitments: Verify ESG compliance at different levels

- Company-wide sustainability efforts
- Business unit-specific decarbonization roadmap (Manganese Alloys)
- Site-specific insights on social and environmental indicators
- Access and download ISO Certifications

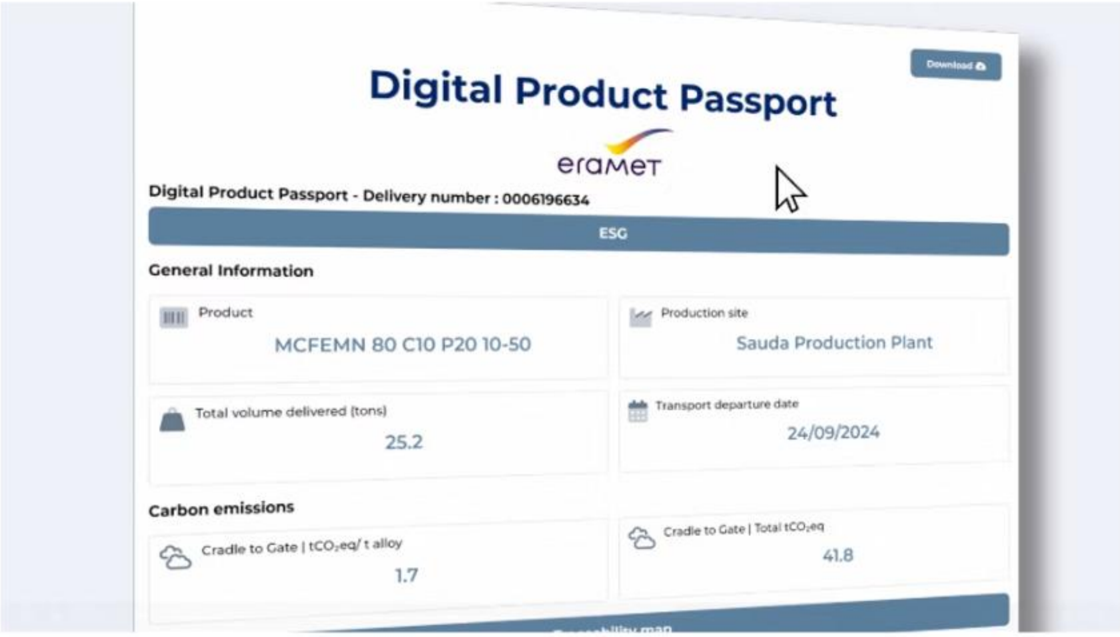

Figure : screenshot of the public demo of Digital Product Passport from Tilkal in partnership with Eramet.

8.2.4. Strength and uniqueness

A key strength of Tilkal lies in its focus on end-to-end traceability across multitier supply chains using a shared digital infrastructure. The use of blockchain technology aims to ensure data integrity and tamper resistance, which can be relevant for high-risk supply chains where data credibility is critical. The concept of a digital product passport allows structured information sharing across actors and can, in principle, support regulatory compliance and downstream transparency requirements.

Tilkal also differentiates itself by claiming scalability for large industrial networks and by integrating additional data sources, such as satellite imagery, to enrich traceability information. If effectively implemented, such integrations could support enhanced monitoring of geographic and environmental aspects of supply chains. The platform's claimed interoperability through APIs and ERP compatibility is another potential strength, as integration into existing corporate systems is essential for operational uptake.

8.2.5. Weaknesses or limitations

From an analytical perspective, a key limitation of the tool lies in its strong dependence on company-defined governance frameworks. While flexibility in configuring data fields, indicators and access rights can facilitate adoption, it also implies that the robustness of due diligence outcomes is largely determined by internal corporate choices. In the absence of externally anchored minimum requirements, there is a risk that the tool reproduces existing practices rather than challenging insufficient due diligence approaches.

Furthermore, the operation of a shared digital traceability infrastructure may reinforce asymmetries in power and voice within supply chains. Downstream actors are typically better positioned to define reporting expectations, while upstream suppliers—particularly in high-risk or low-capacity contexts—may have limited ability to contextualize data or contest interpretations. This dynamic may constrain the tool's capacity to support reciprocal and inclusive due diligence processes.

Questions also arise regarding accountability and responsibility allocation. Where data are incomplete, outdated or misleading, it remains unclear how responsibility is distributed between users and the platform, particularly in situations of regulatory scrutiny or adverse impacts.

Finally, the linkage between traceability outputs and concrete operational decisions is not inherent. Without explicit integration into procurement, escalation or remediation processes, there is a risk that the tool functions primarily as an information repository rather than as a driver of substantive due diligence action. However, as shown in the published case study Eramet-Tilkal, there is the possibility to download field audits.

8.2.6. Sources used

Public information available on Tilkal's website https://www.tilkal.com/ (product descriptions, articles, guides and customer stories) – Public demo video communicated by Tilkal and Eramet (March 2025) https://www.tilkal.com/resources/videos?lang=fr&utm_ and https://www.tilkal.com/post/digital-product-ppassport-eratrace-by-eramet-tilkal

Public communication material released jointly by Tilkal and partner companies https://www.tilkal.com/post/digital-product-passports-a-foundation-for-trusted-end-to-end-product-data-sharing?utm

8.3. MineSpider

8.3.1. Short summary

MineSpider is a blockchain-based traceability and supply chain transparency platform focused on the mining and raw materials sector. It enables stakeholders to record, verify, and share information about material provenance, responsible sourcing, and due diligence compliance (e.g., OECD guidance and EU regulations). Key features include blockchain-secured Digital Product Passports (DPPs), chain-of-custody tracking, QR code scanning, supplier onboarding, and data exchange tools. The platform is designed to help companies document ethical sourcing and ESG attributes across multi-tier supply chains.

Blockchain-based traceability

Enable the record on material provenance

Ensure regulatory compliance / Specialized in minerals/Battery cases studies

Audit reports available in the tool, audit can upload the report (immutable records)

8.3.2. Purpose of the tool

MineSpider is intended for a wide set of supply chain actors including mines, processors, smelters, traders, OEMs (e.g., automotive and electronics), brands, and auditors, particularly those needing to disclose and verify the origins and compliance of critical minerals.

How it helps due diligence:

- Anchors traceability data on blockchain, which cannot be altered once entered, enhancing the credibility of recorded provenance and records.
- Supports Digital Product Passports that compile key data about origin, certifications, audits, and regulatory compliance across tiers.
- Facilitates **regulatory compliance reporting** (e.g., OECD Due Diligence Guidance & EU Conflict Minerals Regulation, battery regulation) and commercial transparency. The tool helps collect and share structured supply chain data, but this alone does not guarantee ethical sourcing unless paired with robust verification and action.

8.3.3. Experiences

As the tool is not publicly available for direct testing, the following assessment is based on observed characteristics and documented use cases.

In terms of usability, the tool offers web-based dashboards and scanning functionalities that can reduce manual documentation and facilitate data entry. Adoption may be relatively straightforward for companies with already digitised supply chains. However, for organisations with low levels of digitalisation, onboarding can be resource-intensive, requiring significant time, training, and process adjustments.

With regard to integration, effective deployment depends on the participation of all relevant supply chain actors. In the absence of broad supplier engagement, the continuity and reliability of traceability are compromised. Furthermore, integration with existing enterprise resource planning (ERP) and compliance systems often necessitates tailored configurations, increasing implementation costs and potentially slowing adoption.

Available real-world insights suggest that while blockchain-based traceability solutions (e.g., MineSpider in the automotive sector) have been piloted to support transparency and documentation, scaling beyond pilot phases remains challenging. Although such initiatives can improve data availability and oversight, their effectiveness at scale is constrained by coordination requirements, technical complexity, and uneven participation across supply chains.

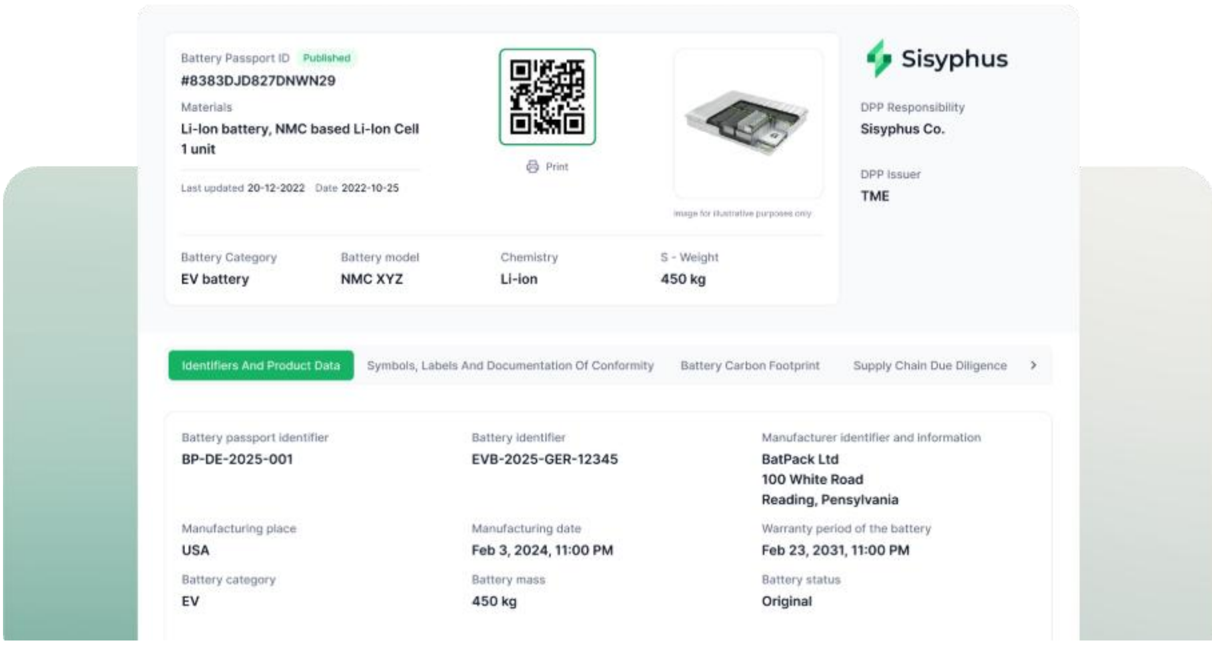

Figure 1: screenshot of digital battery passport proposed by Minespider.

8.3.4. Strength and uniqueness

In terms of strengths and distinguishing features, the tool leverages blockchain technology as a data integrity layer, enabling the creation of immutable records that reduce the risk of data tampering once information has been entered. It also supports the development of digital product passports (DPPs), allowing for structured and shareable records that can include information on origin, certifications, audit results, and due diligence-related data.

The system is further designed to incentivise participation across multiple tiers of the supply chain, including upstream actors such as small-scale producers, which may contribute to improved inclusiveness and data coverage. In addition, the tool demonstrates a degree of alignment with emerging regulatory frameworks, including OECD due diligence guidance and relevant EU legislation such as the Battery Regulation, by facilitating the documentation and transmission of sourcing information.

Minespider integrates third-party audits by allowing auditors to upload their reports, certifications, and other credentials directly into the blockchain-based platform. This data is then linked to specific shipments or materials, creating a secure, immutable record that can be accessed and verified by all relevant supply chain actors. For example, a mine can receive a carbon emissions report from an auditor and share it with Minespider, which then attaches this data to the material's digital product passport. This ensures that third-party audit information is part of the passport.

Finally, adoption by established industry actors, including major brands and commodity traders, suggests growing market relevance and increasing interest in traceability-based solutions within complex global supply chains.

8.3.5. Weaknesses or limitations

A central limitation of MineSpider, as with most blockchain-based traceability systems, is that data integrity depends entirely on the quality and honesty of data entered at the source. Blockchain ensures immutability, not accuracy. If origin, volume, ESG, or compliance data are incorrect, incomplete, or intentionally misreported at the point of entry, the system will preserve and legitimize this information.

Another key risk lies in selective or partial traceability. In practice, not all supply-chain actors—particularly upstream, artisanal, or informal producers—are able or willing to participate due to digital, financial, or governance constraints. As a result, traceability may cover only certain segments of the supply chain. Companies may nonetheless highlight the existence of a blockchain-based system as proof of responsible sourcing, while problematic or untraceable segments remain excluded, creating a misleading impression of full transparency.

MineSpider documents and structures due-diligence data but does not replace independent verification or audits. Without robust third-party validation, on-site inspections, and corrective-action mechanisms, the platform risks becoming a compliance documentation tool rather than a driver of real risk mitigation. Over-reliance on the technology may lead to "technological overconfidence", where blockchain records are mistaken for proof of ethical performance. MineSpider tool offers auditors the option to upload audit reports in a secure way.

Finally, implementation requires broad adoption and ongoing governance. Gaps in participation, lack of interoperability with other traceability systems, and the potential for companies to cherry-pick favorable data points all reduce the effectiveness of the tool and increase the risk that it is used primarily for reputational or marketing purposes, rather than as a rigorous due-diligence instrument.

8.4. Sourcemap

8.4.1. Short summary

Sourcemap is a cloud-based supply chain mapping, traceability, and regulatory due-diligence platform used to document and monitor complex global supply chains from raw material sources to finished products. It provides n-tier supplier mapping, chain-of-custody traceability, risk analytics, continuous monitoring, and automated reporting to support compliance with emerging and existing social and environmental supply-chain laws such as the EU Corporate Sustainability Due Diligence Directive (CSDDD), EU Deforestation-free Regulation (EUDR), forced labour regulations, and U.S. forced labour import guidance. It integrates with ERP systems and can reconcile transaction volumes, collect supplier documentation, and generate compliance-ready reports. Users include brands and manufacturers in sectors such as apparel, food & agriculture, automotive, cosmetics, electronics, and more.

Sourcemap also has an open platform called "Open Sourcemap" where some supply chains of some products or companies are mapped. Those supply chain maps could be official from companies or any registered user in the platform can create a supply chain map.

Cloud based plateform

Ensure regulatory compliance

Chain of custody tracking/ Integrate supplier documentation

Can be used across several sectors/ Public access

8.4.2. Purpose of the tool

Target users:

Sourcemap is intended for procurement, compliance, regulatory, and sustainability teams within companies that have complex multi-tier global supply chains and are subject to regulatory due-diligence requirements in Europe, the U.S., and elsewhere. It also serves suppliers who respond to downstream data requests.

How it helps due diligence:

- Provides end-to-end supply chain visibility, enabling companies to discover and map suppliers at every tier.
- Offers chain-of-custody traceability through transaction reconciliation and evidence collection (e.g., invoices, shipment data).
- Supports ongoing risk scoring, monitoring against watchlists, and regulatory risk analytics.

- Automates report generation for regulators and internal stakeholders, aligned with key regulations like CSDDD, EUDR, and forced labour laws.

Overall, Sourcemap helps companies structure and centralize the information needed for compliance, risk identification, and supply chain analysis — but its effectiveness ultimately depends on data quality, supplier participation, and complementary due-diligence practices.

8.4.3. Experiences

This summary is based on available documentation and reported characteristics.

Navigation and onboarding:

Sourcemap provides n-tier mapping interfaces and data portals designed to gather supplier-reported information, supplemented by enterprise integrations via APIs for tools such as SAP and Oracle. Supplier onboarding is supported by an international engagement team to assist with training and ongoing data submissions.

Support & guidance:

The platform includes policy and regulation teams to help customers keep up with evolving laws, expert customer support in major regions, watchlist monitoring, AI-assisted risk analytics, and automated dashboards for compliance.

Learning curve & effort:

Initial implementation can require organizational alignment, integration with existing data systems, and supplier engagement efforts, especially for deep multi-tier mapping and traceability. Continuous updating is necessary as supply chains evolve.

User insights:

Large brands across sectors use Sourcemap to support compliance strategies and risk monitoring, demonstrating practical value in managing and reporting on complex supply chains. In the field of critical raw materials, one of the first examples from SourceMap was the supply chain map of Fairphone4.

Figure 1: screenshot of one of SourceMap results, supply chain mapping.

8.4.4. Strength and uniqueness

Key strengths include:

- Comprehensive multi-tier mapping and traceability: Covers supplier networks from raw materials up to finished products.
- Regulatory alignment: Supports compliance with multiple global supply chain laws (EUDR, CSDDD, forced labour rules).
- Continuous monitoring and analytics: Real-time risk monitoring against global watchlists and automated risk scoring.
- Integrations & automation: Strong ERP and data system integration capabilities, enabling automated workflow and reporting.
- Extensive supplier engagement: Dedicated teams to assist with onboarding and ensuring data flows from suppliers.

These features make Sourcemap a robust choice for companies that need to operationalize supply chain due diligence, reduce manual processes, and align compliance with global regulatory requirements.

8.4.5. Weaknesses or limitations

Sourcemap depends heavily on supplier-provided data and document submissions to build its maps and traceability. If supplier data are incomplete, inaccurate, or delayed, the resulting visibility can be misleading — potentially masking gaps or risks that remain undetected. Although the platform collects documents and performs data reconciliation, independent verification of supplier claims still requires external audits or third-party assurance. Automated checks and AI analyses can help, but they cannot fully replace manual verification — raising the possibility that mapped transparency may not equate to verified ethical performance.

Upfront implementation, training, integration with ERP systems, and ongoing supplier engagement can be resource-intensive, especially for smaller companies or SMEs, potentially limiting adoption and leaving parts of the supply chain unmapped. Complete visibility depends on supplier and sub-supplier engagement. Resistance or non-response from certain suppliers can create blind spots. If these gaps are not transparently communicated, companies risk presenting incomplete traceability as full compliance, which can contribute to greenwashing.

Using Sourcemap's regulatory features and dashboards does not guarantee legal compliance by itself — companies must still exercise meaningful due diligence, corrective actions, and risk mitigation programs. Simply having mapped supply chain data could be misinterpreted as proof of ethical sourcing without further validation and audit.

8.5. Sources used

[1] https://www.sourcemap.com/

[2] https://www.prnewswire.com/news-releases/sourcemap-partners-with-salesforce-to-bring-eudr-compliance-automation-to-net-zero-cloud-302385185.html

[3] https://canvasbusinessmodel.com/products/sourcemap-swot-analysis

[4] https://aisuperior.com/eudr-software/

[5] https://open.sourcemap.com/

[6] https://open.sourcemap.com/maps/61a98acef1ddeb086156a529

8.6. Oritain

8.6.1. Short summary

Oritain is a forensic origin verification and traceability service designed to provide scientifically validated proof of the geographic source of products and raw materials. Rather than relying on paper or digital chain-of-custody records alone, it uses scientific analysis of intrinsic product properties — such as isotopes and trace elements — to create an “Origin Fingerprint” that identifies where a product was produced or grown. This approach is used to support supply chain transparency, authenticity, regulatory compliance (e.g., against forced labour and deforestation risks), and consumer trust across industries such as cotton, leather, timber, coffee, food and dairy, and more including minerals.

Forensic verification through Material finger printing

Chain of custody

Ensure regulatory compliance

Use across several sectors

8.6.2. Purpose of the tool

Oritain’s services are aimed at brands, manufacturers, suppliers, and retailers that need verified evidence of the origin of products or raw materials. This includes companies subject to forced labour import restrictions (e.g., U.S. Uyghur Forced Labor Prevention Act), EU mandatory due-diligence laws, and consumer demand for traceability.

How it helps due diligence:

- Provides scientifically verified origin data for products and materials at any point in the supply chain — from source to finished goods — rather than relying solely on documentation.
- Enables detection of product fraud, contamination, substitution, or misrepresentation (e.g., mixing of materials).
- Supports compliance with regulations by giving robust evidence of origin, accepted by authorities (e.g., US Customs & Border Protection for some commodities).
- Supplements other traceability methods to strengthen risk assessments and decision-making.

8.6.3. Experiences

This is a synthesis based on public information, not direct tool use.

- Onboarding & support:

Oritain offers end-to-end support including sample collection guidance, laboratory analysis, and tailored verification programs, often coordinated through a secure web portal.

- Application breadth:

Originally built on long-standing scientific methods rooted in forensic analysis, Oritain's techniques have been applied in agriculture and textiles (e.g., cotton), and continue to expand into commodities like leather, coffee, timber, and dairy.

- Perceived value:

For brands, scientific origin verification provides evidence-based credibility that can surpass traditional documentation by confirming the product itself matches its claimed origin — a meaningful enhancement where documentation may be incomplete or untrustworthy.

8.6.4. Strength and uniqueness

By analyzing inherent material properties (isotope ratios, trace elements), Oritain's method provides objective origin evidence rather than inferred provenance from documentation.

The Origin Fingerprint is based on nature's own markers, making it resistant to tampering compared with systems that depend on data input or physical tags.

Certain origin verifications (e.g., cotton isotope results) are recognised by authorities like U.S. Customs and Border Protection, strengthening compliance claims.

Oritain's product-centric science can be combined with supply-chain mapping, blockchains, and audits to build a fuller due-diligence picture, as recommended by independent authorities.

From textiles to food and leather, the technology has wide application when intrinsic traceability is needed, particularly where documentation alone is insufficient.

8.6.5. Weaknesses or limitations

Forensic testing relies on laboratory analysis and specialized statistical modelling. This can add cost, time, and logistical requirements (sample collection, shipping, lab processing) compared with simpler digital traceability tools. Its scientific nature can also demand specialised interpretation and can reduce accessibility to SMEs.

Scientific origin verification is not enough to capture labour rights, worker conditions, governance practices, or environmental degradation at origin. These require separate due-diligence actions (audits, inspections).

The accuracy of origin identification depends on comprehensive reference datasets. Gaps or biases in these databases could reduce precision in less studied regions or commodities.

Current case studies put forward by Oritain are more oriented to food, timber and clothes sector and few references to application to mineral sector (only diamonds are mentioned).

8.6.6. Sources used

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[3] https://www.globenewswire.com/fr/news-release/2025/09/23/3154871/0/en/Oritain-Extends-Cutting-Edge-Origin-Verification-to-Leather-for-EUDR-Readiness.html

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9. Glossary

API (Application Programming Interface)
A digital interface that allows different software systems or platforms to exchange information automatically.

Artisanal and Small-Scale Mining (ASM)
Mining activities carried out by individuals or small enterprises using limited technology and financial resources. ASM often operates informally and faces challenges related to regulation, traceability, and market access.

Audit
An independent assessment used to verify whether a company, supplier, or system complies with defined standards, regulations, or due diligence requirements.

Battery Passport

A digital record containing information about a product’s origin, composition, carbon footprint, recycled content, certifications, technical information and supply chain history. Required under EU battery regulations.

Digital Product Passport (DPP)
A digital record containing information about a product’s origin, composition, carbon footprint, recycled content, certifications, and supply chain history.

Blockchain
A decentralized and tamper-resistant digital ledger used to securely record transactions and trace supply chain information.

Book-and-Claim Model
A Chain of Custody model in which sustainability claims are traded independently from the physical material flow. The certified material is not necessarily physically present in the final product.

Carbon Footprint
The total greenhouse gas emissions associated with a product, activity, organization, or supply chain.

Certification Scheme
A system through which independent organizations verify compliance with specific environmental, social, governance, or quality standards.

Chain of Custody (CoC)
The documented process through which materials and related information are tracked, transferred, and controlled throughout a supply chain.

Circular Economy
An economic model aiming to reduce waste and resource consumption through reuse, repair, recycling, and material recovery.

Corporate Sustainability Due Diligence Directive (CSDDD)
European Union legislation requiring companies to identify, prevent, mitigate, and address adverse human rights and environmental impacts across their operations and value chains.

Critical Raw Materials (CRM)
Raw materials considered strategically important for the economy and at risk of supply disruption, particularly for energy, defense, and digital technologies.

Data Integrity
The accuracy, reliability, consistency, and trustworthiness of data throughout its lifecycle.

Decentralized Identity
A digital identity system allowing organizations or individuals to control and verify data without relying on a centralized authority.

Digital Traceability
The use of digital technologies to record, track, and exchange information on materials and products throughout the supply chain.

Due Diligence
A continuous risk-based process through which companies identify, assess, prevent, mitigate, and remediate adverse impacts linked to their operations and supply chains.

Environmental, Social and Governance (ESG)
Criteria used to evaluate a company's environmental performance, social responsibility, and governance practices.

Geoforensic / Material Fingerprinting
Scientific methods using chemical, isotopic, mineralogical, or physical characteristics to determine the geographic origin of materials.

Greenwashing
Misleading claims or communication presenting products, operations, or supply chains as more sustainable or responsible than they actually are.

Grievance Mechanism
A formal process allowing workers, communities, or stakeholders to report concerns, abuses, or adverse impacts linked to company activities.

Human Rights and Environmental Due Diligence (HREDD)
A due diligence approach specifically focused on identifying and addressing risks to human rights and the environment within business operations and supply chains.

Identity Preserved Model
A Chain of Custody model where materials from a single verified source remain physically separated and identifiable throughout the supply chain.

Interoperability
The ability of different systems, databases, or digital platforms to exchange and use information seamlessly.

Mass Balance Model
A Chain of Custody model allowing certified and non-certified materials to be mixed while administratively tracking the proportion of certified content.

OECD Due Diligence Guidance
International guidance developed by the OECD to support responsible business conduct and responsible mineral sourcing.

Provenance
The documented origin and history of a material or product.

Responsible Sourcing
The process of ensuring that raw materials and products are obtained in a manner that respects environmental, social, and ethical standards.

Risk-Based Due Diligence
An approach prioritizing the most severe actual or potential risks and impacts rather than attempting to address all risks equally.

Segregated Model
A Chain of Custody model where certified materials from different certified sources may be mixed together but remain separated from non-certified materials.

Supply Chain Mapping
The identification and visualization of actors, suppliers, locations, and flows across a supply chain.

Traceability
The ability to identify, track, document, and verify the origin, movement, transformation, and custody of materials or products throughout a supply chain.

Verification
Processes used to confirm that information, claims, or data are accurate, reliable, and supported by evidence, often through audits, testing, or scientific analysis.

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*All of the traceability definitions (ISO; ISEAL; Business for Social Responsibility; Codex Alimentarius; EU General Food Law; Responsible Minerals Initiative; BRGM) are presented in the OECD-IEA report *The Role of Traceability in Critical Mineral Supply Chains* in **Box 2.1 ("Definitions of traceability")** in Chapter 2.

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