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Harnessing Blockchain Technology for 3T Value Addition in the African Great Lakes Region: Advancing Traceability and Ethical Supply Chains

Aleksandra Cholewa-Domanagic
Ph.D. Candidate

Academic affiliation: Doctoral School of the University of Szczecin

Professional affiliation: Luma Holding Ltd.

Member of the Board at Rwandan, DRC and Tanzanian trading companies

Member – The European Partnership for Responsible Minerals

Member – The Alumni Committee at International Women in Mining

Member – The Advisory Board of Afriquia Foundation

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🔍 Research Focus: Traceability & Blockchain in Critical Mineral Supply Chains

The dissertation addresses the persistent lack of practical, evidence-based frameworks in the governance of responsible mineral sourcing. While technological solutions like blockchain and digital certification are gaining traction, little empirical work has explored how these tools are actually implemented, verified, and governed in complex, high-risk supply chains.

✍️ Key Hypotheses Under Evaluation:

1. Blockchain strengthens stakeholder engagement in the supply chain.
2. It enhances compliance with conflict minerals reporting standards.
3. Successful deployment requires external and internal organisational support.
4. It improves the credibility and efficiency of due diligence processes.

🧠 Scientific Foundations:

- Traceability technologies (blockchain, certification systems),
- ESG regulation (CSRD, CSDDD, CRMA),
- Business ethics and due diligence,
- Supply chain management and organisational governance,
- Management science methodologies for system design, stakeholder trust-building, and quality evaluation.



Blockchain as a Strategic Fit for the Mining & Mineral Supply Chain

🔗 From Finance to Traceability: Blockchain's Expanding Impact

Blockchain technology is increasingly adopted beyond banking and financial services. As Iansiti & Lakhani (2017) emphasize, blockchain is not merely disruptive—it is foundational, capable of building new systems of economic and social interaction. Its ability to decentralize trust, automate verification, and ensure data integrity makes it especially relevant for industries with high risk, high complexity, and fragmented value chains.

🚚 Supply Chain Integration: From Logistics to Minerals

Over the past decade, logistics management has undergone a transformation with blockchain's integration. It now enables:

- Real-time tracking of shipments, payments, and contractual milestones
- Secure sharing of data across multiple actors with customizable access levels
- Immutable digital records for compliance, certification, and due diligence

This decentralized infrastructure allows every authorized participant in the supply chain to access verified data at every stage of the product journey.

🔍 Why Mining is a Natural Use Case

The mining and minerals sector is complex, multi-actor, and data-intensive. It involves:

- Mining companies, government authorities, local communities, logistics providers, traders, and international buyers
- High-value transactions under regulatory pressure
- Reputational and operational risk from weak governance and conflict areas



African potential

African mining is a major socioeconomic driver on the continent. Africa produce more than 60 different metals and and minerals, hosts about 30 percent of the world's total mineral reserves , but is yet to fully unlock its potential for minerals extraction and processing. Lack of industrialization and advanced processing is often given as one of the reasons of so called “resources cursed” observed in Africa.

Implementation of new technologies run with simultaneous digitalization of traceability processes could be a gamechanger for the continent.

Blockchain aligns with the African raw materials sector's needs by:

- Enhancing transparency and accountability for origin verification
- Preventing fraud, speculation, and theft through immutable transaction history
- Implementing smart contracts for faster and verifiable trade agreements
- Improving environmental and social disclosure, which is increasingly expected by consumers and regulator



CAHRA & The OECD DD Minerals Guidance

Trade and investment in natural mineral resources hold great potential for generating income, growth, and prosperity, sustaining livelihoods, and fostering local development. However, a significant share of mineral resources are located in conflict-affected and high-risk areas, where they may contribute, directly or indirectly, to armed conflict, including terrorist financing, human rights violations, and hinder economic and social development

Those areas are known under the CAHRA name – Conflict-Affected High Risk Areas

“Conflict minerals,” currently include the metals: tantalum, tin, tungsten and gold, which are the extracts of the minerals cassiterite, columbite-tantalite and wolframite, respectively.

Downstream companies often refer to the extracts of these minerals as 3T.



The OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas clarifies how companies can identify and better manage risks throughout the entire mineral supply chain, from miners, local exporters, and mineral processors to the manufacturing and brand-name companies that use these minerals in their products.

For the last 12 years, several DD tools were implemented in the CAHRA region, but none of them was providing clear information on the origin of minerals simultaneously to all stakeholders in the supply chain.



Subject of the research LuNa Smelter Ltd.

LuNa Smelter Ltd. is a pioneering operation, located in Rwanda, that embodies ethical practices and advanced technological capabilities. It plays a vital role in the global tin supply chain, combining modern facilities with a strong commitment to environmental, social, and governance (ESG) principles. LuNa represents an exceptional example of sustainable and impactful investment in the mining sector.

Proud member of:



Operational Excellence: LuNa Smelter is a high-quality, RMAP-conformant smelting facility in Rwanda, a region renowned for stability and ethical mineral sourcing. It sets the benchmark for responsible sourcing and transparency.



Strategic Importance of Tin: Tin, critical for digital transformation and sustainable energy solutions, is key to electronics, renewable energy, and EVs. LuNa provides ethically sourced, high-demand tin aligned with global sustainability goals.



Innovation & R&D – Tantalum production: LuNa is investing in R&D for tantalum alloy production to maximise critical element recovery and enhance product offerings, reinforcing its commitment to responsible resource use.



Favourable Investment Environment: Rwanda's supportive regulations make LuNa an ideal investment for securing critical resources, growing ethical supply chains, and enhancing sustainability-focused portfolios.



Leadership in ESG: For over six years, LuNa has been building a strong reputation for high-quality production, rigorous ESG standards, and traceability, positioning itself as a global leader in sustainable mining.



Growth Potential: As the only industrial-scale smelter in the region, LuNa plans to increase cassiterite processing capacity from 230 to 320 tonnes/month, boosting Rwanda's contribution to the global tin market.



Local Impact: LuNa employs over 130 Rwandans trained by Luma Holding and produces 99.96% pure tin, high-Sn dross, tantalum concentrate, and high tantalum slag. Its ISO-certified lab ensures accurate analysis of 3T and lithium samples.



Market Value in Ethical Sourcing: Ethical sourcing impacts company valuations – violations can lead to significant shareholder losses. LuNa's compliance with international standards mitigates these risks, ensuring premium-quality output and ethical practices to responsible resource.



Future Expansion: Plans include a new furnace to double production capacity, aligning with Rwanda's mining sector growth, driving economic progress, and creating long-term value.

Closing the Traceability Gap in 3T Mineral Supply Chains

Context: Why It Matters

- Global demand for tin, tantalum, and tungsten (3Ts) is surging—fueled by the energy transition and digital innovation.
- These minerals are often sourced from high-risk regions with weak governance, informal extraction, or links to conflict.

Regulatory Pressure is Rising

- The EU is enforcing mandatory due diligence and traceability:
 - CSDDD: Identify and mitigate ESG risks.
 - Conflict Minerals Regulation: Applies directly to 3Ts.
 - Battery Regulation & CSRD: Require full traceability and disclosure.
- Traceability is now a compliance obligation, not just a best practice.

The Opportunity: Blockchain for 3T Chains - Blockchain can enable:

- End-to-end visibility
- Secure, tamper-proof records
- Trust between upstream and downstream actors
- Alignment with regulatory frameworks and investor expectations

The Trust Challenge


Despite growing regulatory expectations, sellers often struggle to provide reliable traceability across multi-tiered, global supply chains. Consumers, on the other hand, expect full transparency—especially regarding:

- Human rights risks (e.g. child labour, forced labour)
- Environmental impact
- Fair benefit-sharing with local communities

Blockchain offers a path forward by providing objective, tamper-resistant records that increase both consumer trust and compliance readiness.

Implementation actors – midstream processors (smelters and refiners) located in the African Great Lakes Region, audited against the Responsible Minerals Assurance Process by the US Responsible Minerals Initiative


RMI Blockchain Guidance – Strengthening Traceability Standards

 **Why RMI Issued the Guidance**
As blockchain-based traceability programs rapidly emerged in mineral and metal supply chains, the Responsible Minerals Initiative (RMI) identified key gaps:

- Fragmented adoption by isolated supply chain actors
- Lack of shared terminology, conceptual clarity, and consistent data models

To address this, RMI published its Blockchain Guidelines:

- 1st Edition in 2018
- 2nd Edition in 2020 (after pilot implementations and multi-stakeholder consultations)

 **Objectives of the RMI Blockchain Guidance**

- Promote a common understanding of blockchain-related terms and use cases
- Establish consensus on core data attributes required at each supply chain stage
- Emphasize the need for interoperability across systems and platforms
- Examine governance impacts of blockchain implementation in producing countries
- Support blockchain’s role as an enhancer of due diligence—not a replacement

RMI BLOCKCHAIN CHARACTERISTICS REVIEW		
No	Characteristic	RMI Proposal
1	Ledger structure	Decentralized – absence of a single place where data is aggregated or controlled
2	Interoperability	Solutions to support interoperability are understood as the ability of two or more systems applications to transact with one another and to mutually use the information that has been exchanged. If possible, adopt ISO/TC 307 (Standard on blockchain and distributed ledger technologies)
3	Partners involved	Solution to ensure all supply chain actors entering data are trusted actors and meet requirements defied for participation. Unique identifier to be established for each participant.
4	Solution access	Solution should be accessible to large, medium, and small actors to enter accurate data and should be capable of working in the field where technology access is limited. Critical – not to exclude ASM participation
5	Areas of relevance to apply global standards to	Data exchange Interoperability and DLT Chain of custody Restrictions for hazardous substances Supply chain due diligence Responsible business conduct Responsible mining practices
6	Access to data	Self-sovereign – no actor on the platform should be able to access supply chain data they do not own, or have not been provided access to by the owning actor
7	Consensus mechanism	Should have adequate considerations on how to protect the application against attacks
8	Reconciliation procedure	To exist based on the same consensus mechanism
9	Account	To record individual transactions with option of integrity test based on a mass balance approach
10	Type of data	1.Supply chain Actor – data related to the identity of the supply chain actor. 2.Transaction – Data specific to one transaction and necessary to establish provenance. 3.Context - Data related to the conditions in the supply chain and / or performance of the actor

Examples of conflict minerals and cobalt blockchain based traceability tools providers			
Company	Claim		
MINESPIDER	End-to-end traceability of conflict minerals Battery Product Passports Supply chain mapping Carbon emission tracking Built on Ethereum	Extractive Industry Automotive Industry Tech downstream	Tin traceability project at Minsur (Peru), Luna Smelter (Rwanda), Woodcross Resources (Uganda)
Circulor	End-to-end traceability for industrial supply chains Carbon emission & ESG data tracking Digital Twin / Digital Product Passports Built on Hyperledger	Extractive Industry Agriculture & Forestry Recycling	Tracing CO2 emission in Mercedes Cobalt Supply Chains. End-to-end traceability project – cooperation with Kumi Consulting and Volvo (cobalt tracking)
Peer Ledger	Supply chain tracking Built on Hyperledger	Minerals & Metals Tech Manufacturing Automotive Pharmaceutical	The Gold Bar Integrity Programme – developed for London Bullion Market Association (LBMA) and the World Gold Council (WGC) for the implementation of an international system of gold bar integrity, a chain of custody, and provenance
RCS Global	Audit, mapping and tracking of supply chains. Build on Hyperledger	Extractive industry Electronics Industry	Blockchain project –responsible sourcing network with IBM, Ford, LG Chem
			Pilot with Tesla – tracing responsibly produced cobalt from the mine to the electric vehicle

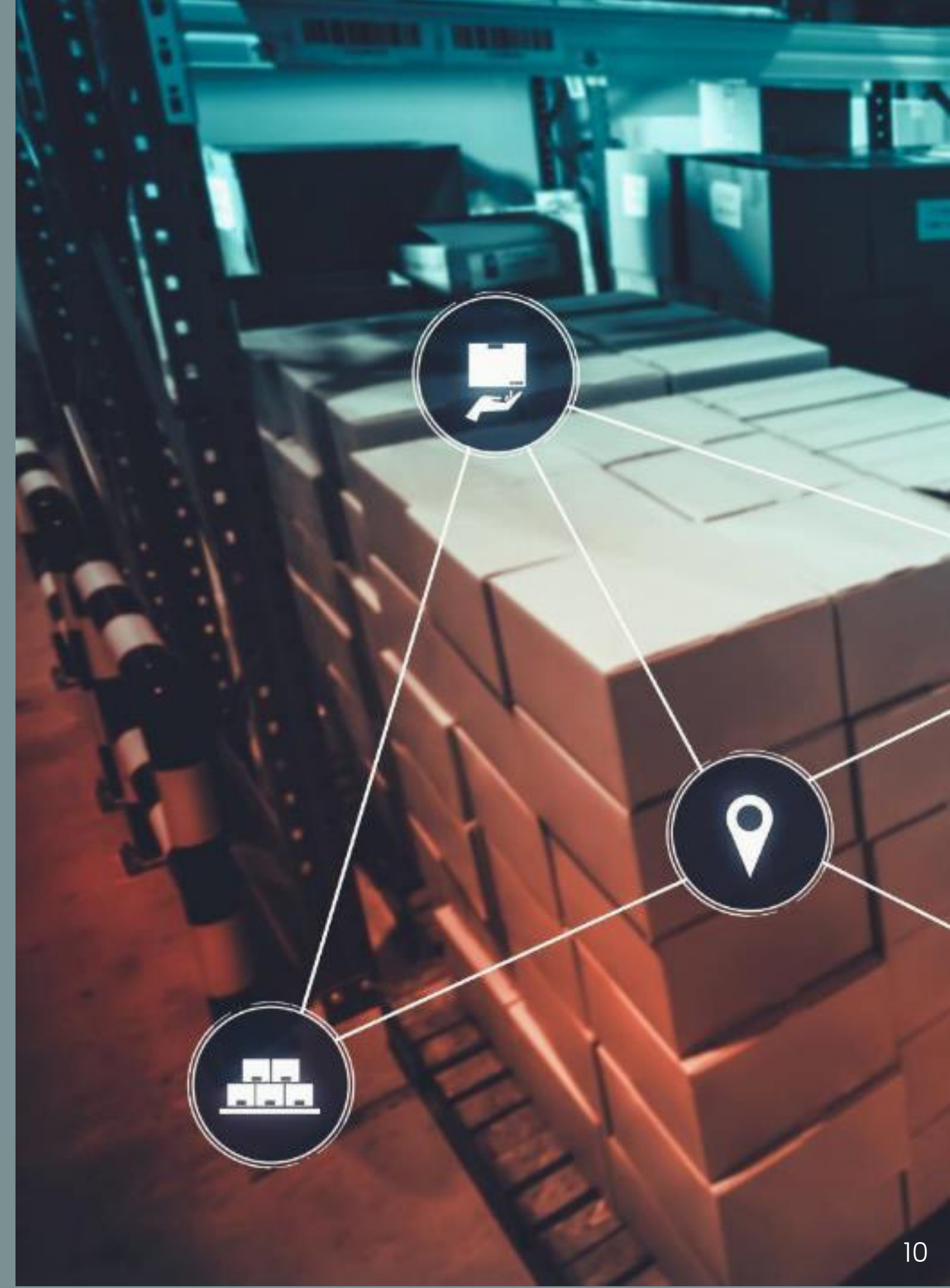
Of the above-listed companies, Minespider has developed the most substantial track record in the tin metal space. The company is present both in East Africa and South America, providing traceability tools and services to several actors in the tin supply chain.

Originally built on Ethereum, Minespider's solution evolved to own, public-permissioned blockchain. Minespider blockchain transactions are conducted with the PoA consensus mechanism. The Minespider's solution was dedicated to upstream members of the supply chain and downstream end-users willing to perform a supply chain mapping exercise.

Minespider is a raw material supply chain infrastructure that consists of several components which operate in concert to make the entire system work:

- The Minespider Protocol
- The Minespider Smart Contract
- The Minespider DApp
- The Minespider Certification
- The SILQ Utility Token

The Minespider Protocol is built around a method of secure storing and transmitting raw material provenance data in the form of segmented digital certificates. These certificates link data collected from different supply chain participants to unique identifiers and QR-Codes. These identifiers are attached to physical material shipments, enabling traceability and tracking throughout the supply chain.



Data Management and Privacy

The data management and transfer's security and privacy are achieved through a three-layer database system.

Each member of the supply chain decides if data that are being generated at his level are put into public, transparent or private data layer.

Supply chain actors' data are available to users in entity certificates, also divided into the three data layers system.

Entity certificates contain essential information about the actor, from legal incorporation documents and certificates through company data such as ESG reports, pictures, and other data per the actor's choice. Transactions are mirrored in product passport certificates generated for each stage of the supply chain, from the ore/concentrate at the mining site, reception certificate through transport routes or at the entrance to the smelter/refinery, then on the metal and further downstream.

Public Data Layer

Available to anyone after scanning the product passport, this layer contains data that supply chain actors choose to make public.

Private Data Layer

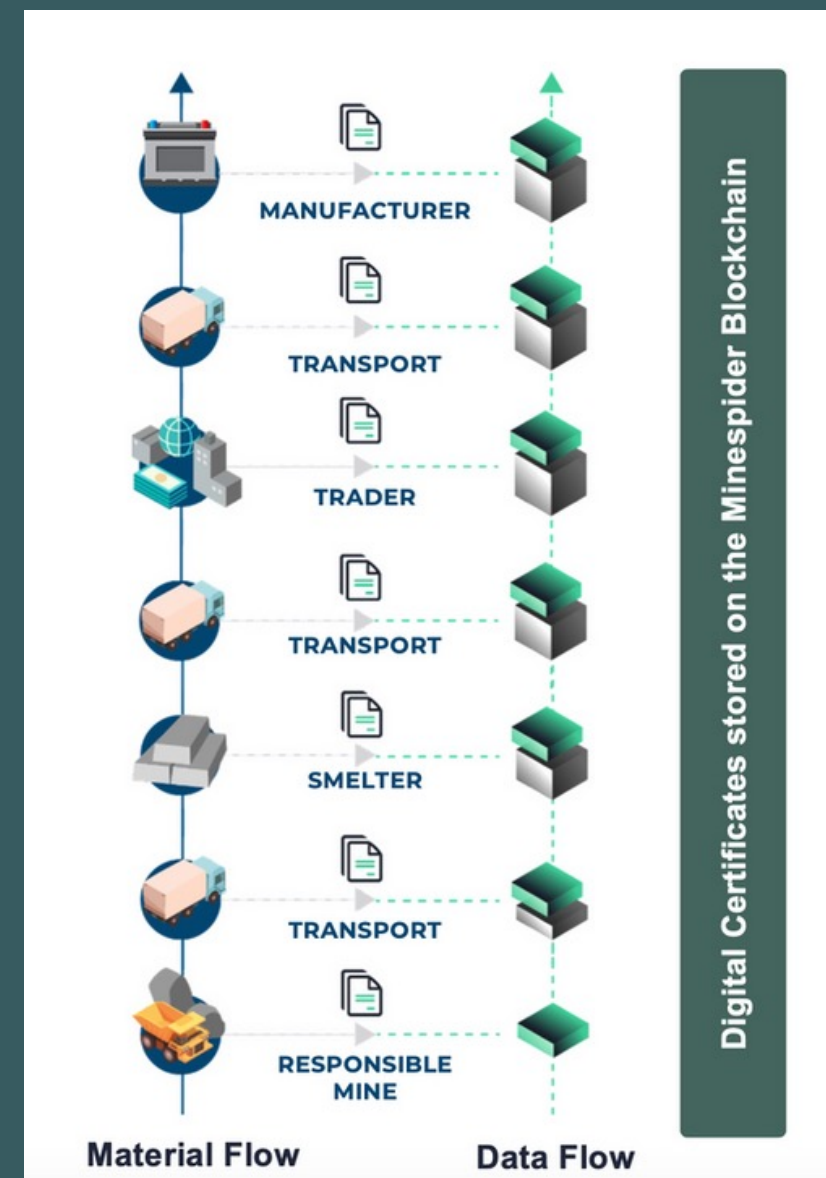
Available only to two directly engaged supply chain members, this layer contains sensitive or confidential data.

Transparent Data Layer

Available only to participants within the same supply chain, this layer contains data shared among trusted actors.

Encrypted Certificates

Data is stored as encrypted self-sovereign data packet certificates, under the complete control of the data owner.



LuNa Smelter Tin & Tantalum Digital Product Passport

In 2020, subject of the research – LuNa Smelter Ltd. implemented a blockchain infrastructure that was specifically designed for the minerals' industry.

Implementation:

1. At the UPSTREAM SUPPLIERS for the data management and transfer
2. For the DOWNSTREAM CLIENTS in the form of tin metal digital product passport

LuNa implements two types of certificates

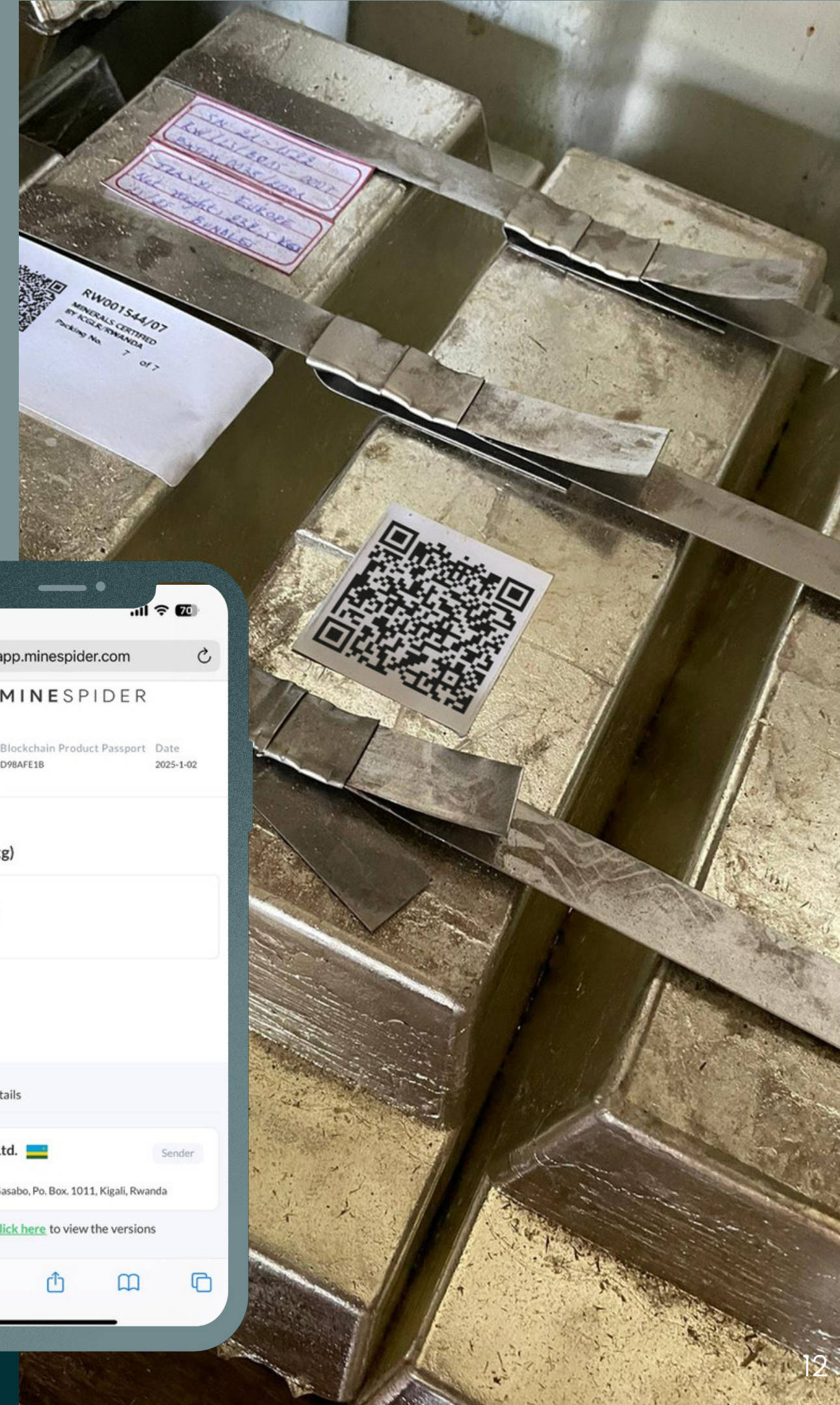
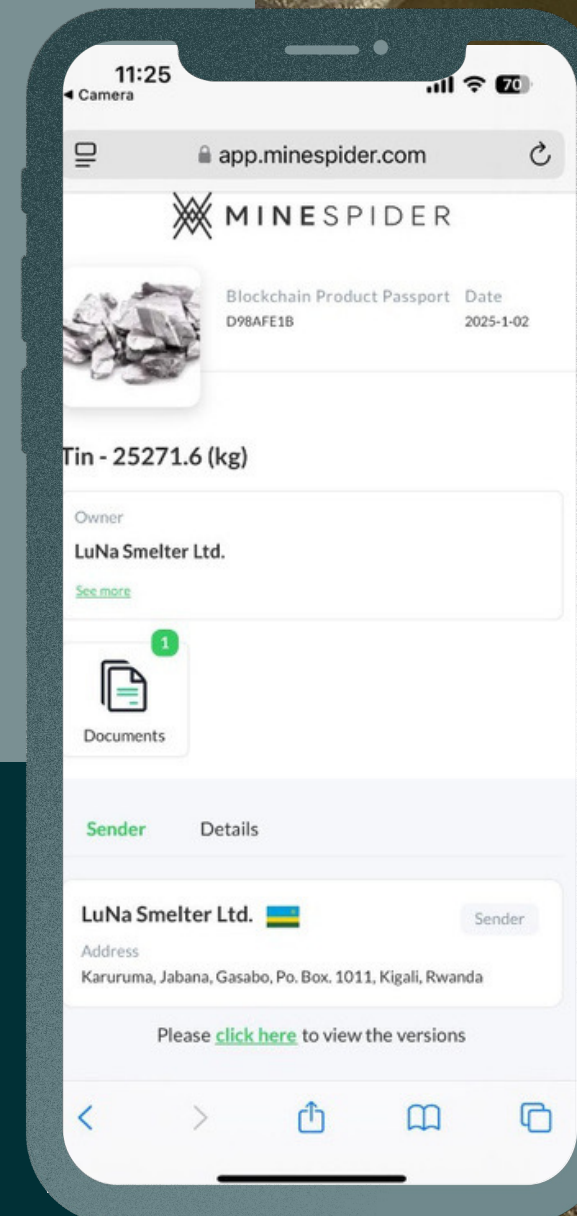
Entity Certificate – contains company-level information.

Product Passport – contains shipment-level information specific to one shipment

For the LuNa CoC system, the entity certificate is developed for every mine site covered by the LuNa chain of custody system.

Data in the certificates are stored in three layers:

1. The public Layer is visible to all users of the blockchain, if they share a supply chain.
2. The transparency Layer contains data that will be visible to all downstream companies in a supply chain that receive the Product Passport
3. The private layer contains data visible only to the sender and recipient of a product passport.



The specific reporting requirements for mines and smelters and identification of the corresponding data within Luna’s digitalised Entity Certificates and Product Passport Certificates.

Type of Certificate	Details Requires	Mine Site Data requirement Area	Smelter Data Requirement Area	Details Required	Type of Certificate
Mine Site Entity Certificate, in which full mine site report is uploaded together with extended KYC form	Mine name Mine owner/operator details Mining license number GPS coordinates (exact location) - Mining permit/authorization documentation	Mine Identification	Smelter Identification	◦Smelter name ◦Smelter location and facility address ◦Details on smelter ownership	Smelter Entity Certificate
Mine Site Entity Certificate	Full ownership structure - Information on all stakeholders involved in mine operations - Details on beneficial ownership	Ownership and Control	Supply Chain Traceability	◦Full list of upstream suppliers (including mines, traders, and intermediaries) ◦Supplier verification records ◦Transport records for received minerals	Metal Product Passport linked to entity certificates relevant for the production of feed for particular metal shipment
Product Passports Certificates for each shipment data – linked to Smelter reception certificates Includes – production records, transport note, reception note confirmed by local regulator	Production records (volume, mineral type) - Daily/weekly/monthly production logs - Transport and export records	Production Data	Material Flow Control	◦Records tracking incoming mineral shipments (volume, weight, source) ◦Batch documentation for each processed shipment	Mine Site Product Passports Certificates received at the Smelter Reception Level
Mine Site Entity Certificates	Number of employees - Details of subcontractors - Confirmation of legal hiring practices - Evidence of adherence to labor rights (e.g., no child labor)	Mine Worker Information	Conflict-Free Status Verification	◦Documentation proving sourced minerals are conflict-free ◦Supplier certifications and risk assessment records ◦Records confirming adherence to the OECD Due Diligence Guidance	Mine Sites Entity Certificates
Mine Site Entity Certificate with photo and video documentation	Records of community consultations - Evidence of environmental management plans - Social impact assessments	Community Engagement	Audit and Compliance Records	◦Results from third-party audits conducted by RCM-accredited auditors ◦Audit findings and corrective action plans (if risks are identified)	Smelter Entity Certificate
Mine Site Entity Certificate with Smelter DD Team assessment included	Evidence confirming that the mine is not financing armed groups - Security assessment of the mine site - Confirmation of local security force engagement (if applicable)	Conflict-Free Status Documentation	Downstream Customer Information	◦List of downstream customers (if applicable) ◦Supply chain documentation for processed metals	Product Passports Certificates (downstream details are contain in the private certificate layer)
Shipment Product Passport Certificate	Detailed records tracking the flow of minerals from the mine site to exporters - Bagging and tagging systems to identify mineral origin	Chain of Custody (CoC) Documentation - Detailed records tracking the flow	Risk Management and Mitigation	◦Documentation of risk assessment procedures ◦Details on risk mitigation strategies and corrective actions	Entity Certificate of the Smelter
Shipment Product Passport Certificate	Invoices for sales transactions - Export license and customs documentation - Records identifying the first purchaser or exporter	Export and Sales Information	Documentation and Reporting	◦Detailed records of each mineral shipment received and processed ◦Records of chain-of-custody data	Mine Site Product Passports Certificated received at the Smelter Reception Level

Upscaling of the technology at the ASM Sector

Multi-stakeholder Approach

LuNa Smelter is the only company from Rwanda actively engaged with global partners in the European Partnership on Responsible Minerals (EPRM)– a LuNa representative was elected to the Governance Board of this EU organisation and is working jointly on the solutions for the artisanal and small-scale mining (ASM) sector, not only in Africa but on a global scale.



European
Partnership
for Responsible
Minerals

In 2024, LuNa Smelter was awarded the TinLink Project aimed at enhancing local mining practices, particularly in artisanal and small-scale mining (ASM). This initiative is designed to significantly improve the social, environmental, and economic conditions for mine workers and the local mining communities, thereby fostering a more sustainable and prosperous future.



Furter Upscaling of the Minespider Solution in the AGLR:

- 1. Power X – Tantalum Refinery in Rwanda
- 2. Woodcross Resources – Tin Smelter in Uganda
- 3. EPRM Project partners – 80 Upstream Level Mines in Rwanda, Uganda, DRC


EPRM PARTNERS ON A PROJECT:


- Siemens Energy (Germany) – a global leader in energy technology
- Woodcross Resources (Uganda) – leading integrated tin producer in Uganda
- Responsible Trade (US) – boutique consultancy that supports systems and controls that supports market access for minerals and products from conflict affected and high-risk areas
- Minespider AG (Switzerland) – technology company that developed blockchain-powered tool
- International Women in Mining (UK) – global not-for-profit organisation leading change for social sustainability in the extractives and resources sector
- Luma Holding Ltd. (Malta) – European industrial group focused on mid-market investment across the CEE, Balkans, and Africa.


Key Research Findings – Blockchain at LuNa Smelter: Trust, Compliance, and Stakeholder Value


 Central Research Thesis – Confirmed
Blockchain, when properly implemented, enables credible, efficient, and regulatorily aligned traceability in mineral supply chains.


-  H1: Strengthening Stakeholder Relationships:
 - Digital product passports improved transparency.
 - Real-time data sharing with Tier 1 & 2 partners.
 - Embedded into contracts and validated by EPRM.

-  H2: Enhancing Conflict Minerals Reporting:
 - Minespider aligned with OECD, EU 2017/821, Dodd-Frank.
 - Standardized certificates reduced duplication.
 - Multi-sector endorsement of compliance value.

 Result:
LuNa's blockchain infrastructure evolved into a compliance enabler—mitigating legal risk and boosting transparency.

-  H3: Organisational & Ecosystem Support:
 - 400+ hours of training.
 - EPRM & RMI support through TinLink.
 - Low cost (1.65% of DD budget), high ROI.

-  H4: Simplifying Due Diligence:
 - Minespider digitized KYC, audits, lab tests.
 - Streamlined audits and improved reporting consistency.
 - Third-party and public authority verification ensured credibility.

-  AI Integration (Early-Stage):
 - Anomaly detection, real-time comparisons, and error reduction.
 - Enhancing analytics and regulatory accuracy.

Conclusion: Embracing Innovation for Sustainable Supply Chains

This research demonstrates the transformative potential of blockchain technology in addressing the complex challenges of conflict minerals supply chain management. By leveraging the advantages of transparency, traceability, and collaborative governance, blockchain-enabled solutions can drive positive change and contribute to the development of more sustainable and responsible mineral supply chains. As the industry continues to grapple with the evolving regulatory landscape and the need for enhanced due diligence, the insights and recommendations from this study can provide valuable guidance for practitioners, policymakers, and researchers seeking to embrace innovative approaches.





Aleksandra Cholewa-Domanagic

Doctoral School of the University of Szczecin
Ul. Mickiewicza 16
70-383 Szczecin
Poland
<https://szkoladoktorska.usz.edu.pl/>

aleksandra.cholewa-domanagic@phd.usz.edu.pl
Aleksandra.cholewa@gmail.com

Mob. No. +48515773556 / +48602578483