The Role of Traceability in Critical Mineral Supply Chains

International Energy Agency

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Abstract

As global demand for critical minerals grows, it will be important to anticipate and address the potential harms the mining and metals sector can have on societies, communities and the environment. Overlooking these risks can ultimately disrupt supply for clean energy technologies. Traceability systems can, when used as part of a wider risk-based due diligence process, help meet emerging policy goals by providing ways to integrate data on origin, evolution, and ownership of minerals. Some traceability approaches can also provide a platform for embedding data on environmental, social and governance issues. To work effectively, however, traceability systems must be carefully designed – balancing standardisation and context, maintaining data quality, and adapting to varying supply chain complexities. They also require strong collaboration among companies, governments and civil society, backed by cost-sharing, reliable verification and secure data-sharing protocols. Above all, traceability should serve clear objectives rather than become an end in itself: policy makers and practitioners should adopt a measured approach, progressively deploying mechanisms where necessary while allowing for inclusive participation and access to markets and investment. This report includes a practical eight-step roadmap, from setting policy objectives to building trust mechanisms, which can help ensure traceability systems are fit for purpose and aligned with the realities of global supply chains.

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Executive summary

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 on energy security, and ensuring sustainable and responsible supply chains are supported by strong due diligence processes. Many jurisdictions are already introducing regulations with specific origin and environmental, social and governance requirements that indirectly or directly require supply chain transparency as part of broader supply chain due diligence requirements. If implemented carefully, traceability systems can enable the collection of data on product origin, geographic path, the sequence of entities that held ownership or control over the product and its physical evolution. To the extent that information of this nature can be integrated into traceability systems alongside accurate and reliable data on environmental, social and governance performance, this can enable companies to demonstrate compliance with regulatory requirements while providing governments with tools to monitor regulatory adherence and progress toward sustainability or security-related targets.

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. A robust traceability system must include an assessment of the appropriate technical infrastructure, including choosing appropriate tools and a strategy suitable for the nature of the supply chain, weighing the costs and benefits of different technologies and ensuring interoperability across the supply chain. Standardising the types of data collected and methods used is also important since comparability can help track the results of efforts to address adverse impacts in the supply chain. Policymakers and practitioners, however, should still be careful to avoid standardisation coming at the expense of nuanced information, or scoring of sustainability performance being interpreted too definitively due to the often qualitative or subjective underpinnings of such data. Supporting effective risk identification and management as part of the due diligence process should remain the central tenet. Collaboration between supply chain participants, including appropriate cost-sharing and data-sharing practices, is essential, supported by robust data privacy and security protocols that protect business confidentiality while enabling effective information sharing. Lastly, the governance of traceability systems and the strength of verification mechanisms matter, as these systems can only be as reliable as the data they receive.

Traceability systems must also be tailored to mineral supply chains and risks. Characteristics such as the geographical location of operations, technical complexity of processing, and the number of companies operating in the supply chain can all create unique sourcing challenges that impact the level of visibility that is most effective. For example, the blending of synthetic and natural graphite during the processing stage may obscure full end-to-end traceability. High levels of artisanal and small-scale mining in the cobalt supply chain may require traceability systems to adapt to remain inclusive, for example, by using solutions better suited to low connectivity environments and cognisant of barriers to access in terms of incentives, costs and levels of formality.

Above all, traceability should not be seen as the goal in and of itself – traceability systems should aim to support clear objectives. Any approach that directly requires traceability should be measured, allowing for an increase in pace and stringency to maintain smooth market functioning. Aligning implementation timelines and requirements with industry readiness would foster inclusive engagement with source countries, preventing blanket disengagement. Avoiding being prescriptive on end-to-end traceability and considering technical alternatives for fostering supply chain transparency as necessary can help ensure efforts to promote traceability are fit for policy objectives. Governments play an important role in increasing mineral traceability by promoting it as a tool where it is appropriate and effective by utilising the eight steps we have identified in our Roadmap:

- **Step 1:** Determine the policy objectives that traceability should help achieve and understand the supply chain context.
- **Step 2:** Taking account of policy objectives, choose which products to focus on.
- **Step 3:** Determine what information operators should collect and share.
- **Step 4:** Considering the supply chain context, choose which operators to focus on.
- **Step 5:** Promote the development and use of interoperability protocols.
- **Step 6:** Establish trust mechanisms.
- **Step 7:** Create incentives for increasing traceability, including economic incentives (such as funding arrangements and tax credits) as well as regulatory requirements.
- **Step 8:** Engage with stakeholders in foreign jurisdictions to ensure there is supply chain collaboration and to promote data-sharing.

Chapter 1. Introduction

The need for a responsible and sustainable supply of critical minerals

The energy transition will require the rapid scale-up of clean energy technologies, which is expected to boost demand for many minerals and metals, including lithium, nickel, cobalt, graphite, copper, aluminium and rare earth elements. In the IEA's Stated Policies Scenario, mineral demand for clean energy technologies doubles between 2025 and 2030. In more ambitious climate scenarios, such as the IEA's Net Zero Emissions by 2050 Scenario, which sees the world limit its temperature increase to 1.5°C, a swifter transition implies a nearly tripling of mineral demand by 2030. This would mean the development of about 150 average-sized new mines, processing facilities and refineries.

While there is a mixed picture for future supply-demand balances – with some minerals facing significant supply gaps and others not – all mineral supply chains face significant environmental, social and governance (ESG) risks. These risks cut across areas covered by the OECD Guidelines on Multinational Enterprises for Responsible Business Conduct (RBC), spanning corruption, environment, human rights, labour and taxation, sometimes in the context of armed conflict or a precarious security situation, in addition to other international instruments like the United Nations Guiding Principles on Business and Human Rights and the ILO Tripartite Declaration of Principles concerning Multinational Enterprises and Social Policy.

Failure to prevent, mitigate and address these risks or the adverse sustainability impacts they can result in, can hinder the supply of minerals needed for the clean energy transition. Aside from compromising sustainable development, falling short in this regard can limit market access, create legal barriers, spur litigation, discourage investment, cause reputational harm, increase the likelihood of opposition from local communities, Indigenous Peoples or other stakeholders, or disrupt operations and increase costs due to interference by vested interests. Taken together, if not addressed, these risks can physically prevent mines and processing facilities from operating. This is especially the case for minerals in conflict-affected and high-risk areas, where some of the most abundant reserves of critical minerals lie. Ultimately, critical mineral supply chains cannot be truly secure, reliable and resilient unless they are also sustainable and responsible. To achieve this, companies need to carry out due diligence to identify adverse impacts, prevent and mitigate them, track results and communicate on how adverse impacts have been addressed. In this context, traceability can be an important tool to gain visibility over their own operations, supply chains and other business relationships.

The potential for traceability systems to support key policy objectives

Traceability refers to the ability to determine a product's origin, geographical path, chain of custody and physical evolution over time. This can allow for information about mineral inputs to be attached to end-products, including the location of the mine of origin for each mineral input and detailed information about each transformation that occurred as the mineral moved through the supply chain from refining to the end-product, with all origin and processing information preserved, even in cases of blending and trading. Data on ESG metrics – such as GHG emissions, environmental footprints, beneficial ownership, compliance with national laws and international conventions, information on systems to protect human rights and corruption risks – can also be attached to traceability systems.

Accurate data on ESG factors plays a crucial role in encouraging responsible and sustainable supply chains. Thorough, accurate and transparent data can enable companies and end users to make informed decisions and can support policy makers in identifying trends and tailoring policy decisions, as well as help them implement policy incentives to drive companies towards improved sustainability performance. To the extent that traceability can enhance the availability of such data for different stakeholders, it can contribute to creating an enabling environment for more responsible and sustainable practices.

Traceability systems can also help gather the necessary information to support a risk-based approach to identifying and addressing adverse impacts in line with OECD Guidelines for Multinational Enterprises on Responsible Business Conduct and other internationally agreed standards, in addition to meeting product specifications and other requirements. Companies are already using traceability systems to collect information on the origin and chain of custody of minerals, which is often a starting point for due diligence on the conditions of extraction, trade and processing of mineral resources.

A traceability system that offers sustainability information to end users could offer transparency to the market, enabling product differentiation. This could allow actors such as governments or consumers to more easily and accurately make purchasing decisions based on the performance of competing products against different metrics. It could also facilitate market access in jurisdictions with regulatory restrictions on material performance and origin. Finally, it could potentially support higher prices for products with good performance throughout the supply chain if the right market mechanisms existed to support such a price differentiation.

If used correctly and under the right conditions, traceability can, therefore, serve as a tool to support key policy objectives of countries with respect to critical mineral supply chains. These can include the development of sustainable and responsible supply chains and the promotion of diversification, serving to ensure the reliability and security of supply. An effective traceability system can also help reduce overall cost and complexity, addressing inefficiencies and fragmentation in the current market landscape. In addition to these, traceability is relevant to product safety, supply chain dependencies, national security and trade sanctions.

Regulators and operators have already sought to implement traceability systems that can allow for the tracking of materials throughout the critical mineral value chain. These systems range from direct requirements, like the European Union's battery passport, to indirect incentives through due diligence legislation. The specific approach taken varies based on the policy objectives – from consumer disclosure and sustainability compliance to supply chain security and risk management. While these efforts have proliferated, widespread implementation continues to face challenges due to conflicting compliance requirements, practical limitations and varying technical capabilities across the supply chain.

Policy makers using, or considering using, traceability as a tool to enhance the resilience of mineral supply chains should ensure that the efficiencies and flexibilities of existing markets are maintained. For instance, rather than universally mandating full and immediate end-to-end traceability across all mineral supply chains, a more measured approach could allow for an increase in pace and stringency to maintain smooth market functioning. Aligning implementation timelines with industry needs and readiness would foster inclusive engagement with source countries, preventing blanket disengagement and ensuring that market access is not being denied to emerging market economies. This approach would also allow time for assessing tracing needs, capacity building and the smooth adoption of new systems. In pursuit of more responsible mineral supply chains, traceability is foremost a tool to help identify where companies should prioritise due diligence efforts. It should enable companies to begin mitigating risks and remedying adverse impacts, starting a process to improve supply chains rather than marking the end of a compliance exercise.

In this regard, policy makers must also ensure that the emphasis on traceability does not crowd out resources and attention away from carrying out the full due diligence process; companies should identify, prevent, mitigate and account for how they address actual and potential adverse impacts associated with mineral supply chains. Considering finite resources, feasibility constraints and the importance of avoiding needless market disruptions, there must be a careful consideration of how and under what conditions traceability systems can and should be used.

Key conditions for traceability systems

We have identified four key components of an effective mineral traceability system:

- **Appropriate technical infrastructure** must carefully weigh the advantages and disadvantages of different record-keeping systems and work to ensure standardisation and interoperability across different companies' traceability systems. The infrastructure should also consider the balance between the high costs of setting up, maintaining and scaling certain technical infrastructure and the ability for it to help meet policy objectives.
- The collection and transmission of **relevant, accurate and verifiable data** are essential. At a minimum, traceability systems need to collect and transmit data on the product origin and geographical path, the chain of custody, and the physical evolution over time. Data on ESG performance and risk can be attached to traceability systems, with some types of information more easily quantifiable and transmittable across supply chains than others.
- There should be **supply chain collaboration**, with contributions, financial or otherwise, from across the supply chain and clearly defined roles and buy-in for each actor. Collaborating with competitors or suppliers, including as part of sustainability initiatives, should remain subject to competition and anti-trust law. The **governance of traceability systems and the reliability of data**, including the use of verification and assurance, should be carefully considered. Data standardisation specifications can help ensure data reliability by establishing consistent requirements for what information should be collected and documented. Additional forms of verification may also be needed to ensure traceability information is reliable. The governance frameworks of traceability systems should be credible to maintain stakeholder trust in the information systems and the way information is passed on across supply chains.

Numerous challenges remain in ensuring these conditions, which can hinder the successful uptake or use of traceability systems in mineral supply chains if left unaddressed.

Taking these challenges into account, we have identified eight key steps that policy makers can take to establish the essential conditions for traceability systems to support policy objectives:

- **Step 1:** Determine the policy objectives and understand the supply chain context.
- **Step 2:** Taking into account the policy objectives, choose which products to focus on. Upstream countries may choose to focus on minerals produced in their territory. Midstream and downstream countries may instead focus on minerals imported into their territory.
- **Step 3:** Determine what information needs to be collected and shared by operators. To ensure optimal traceability, information should, at a minimum, be collected on the following elements: origin, geographical path, chain of custody and physical evolution. ESG data can also be attached to these elements to provide a picture of the product's sustainability performance.
- **Step 4:** Considering the supply chain profile, choose which economic operators to focus on. Upstream countries may prefer to focus on mining operators, while midstream and downstream countries may choose to focus on operators further down the supply chain (including smelters and refiners).
- **Step 5:** Promote the development and use of interoperability protocols. These protocols should, at a minimum, allow for the collection of information on a product's origin, path, physical evolution and chain of custody. Protocols should allow operators to decide which technology or software to use to collect and exchange information and not mandate the use of a specific technology or software. They should also contain adequate protections for sharing commercially sensitive information.
- **Step 6:** Establish trust mechanisms. Governments have a role to play in ensuring that information collected and shared along the supply chain is truthful and accurate. Governments can issue verifiable credentials (including Authorised Economic Operator status) to enhance the truthfulness and accuracy of traceability data.
- **Step 7:** Create incentives for increasing traceability. Countries have various tools at their disposal to encourage operators to trace their products and develop traceability systems. These tools include economic incentives, such as funding arrangements and tax credits, as well as regulatory requirements, such as market access restrictions.
- **Step 8:** Engage with stakeholders in foreign jurisdictions. Supply chain collaboration is necessary for achieving traceability. Given the cross-border nature of mineral supply chains, operators in a given country will often need to collaborate with actors located in foreign jurisdictions. Countries should engage with stakeholders in foreign jurisdictions to promote data-sharing along the supply chain and reduce barriers to traceability.

About this report

This report was prepared under the guidance of a dedicated Task Force of the IEA Working Party on Critical Minerals. The report also benefited from consultations and inputs from other delegates to the Working Party, as well as conversations with civil society – including organisations representing Indigenous Peoples – industry associations and industry representatives. While directed primarily at governments, the report is also intended to benefit other stakeholders who are interested in understanding how they can use traceability or contribute to its scale-up in a way that supports sustainable and responsible critical mineral supply chains amid an evolving regulatory landscape.

The report begins by defining the concept of traceability and examining how traceability relates to other key concepts, such as due diligence, transparency, chain of custody and supply chain mapping (Chapter 2). It then explores how traceability can be used by companies to support compliance with regulatory expectations (Chapter 3). Chapter 4 outlines the components of an effective traceability system, including the technical infrastructure, standardisation of the data collected, supply chain collaboration, and governance and verification mechanisms. Chapter 5 provides a mineral-by-mineral analysis of the challenges of deploying traceability for six key energy transition minerals, namely copper, lithium, nickel, graphite, cobalt and rare earth elements, as well as the lessons learned from traceability initiatives in other mineral supply chains and industries. Lastly, Chapter 6 outlines a roadmap for policy makers looking to increase mineral traceability.

Chapter 2. What is traceability?

Defining traceability

Currently, there exists no single common international definition of the term "traceability". Various definitions of this term have been proposed, both broadly and specifically for certain sectors (see Box 2.1). While these definitions differ in some respects, they possess certain common threads:

- Traceability is generally understood as the *capacity to trace.* In other words, it is the capacity of a particular entity (whether a public body, non-governmental organisation or commercial enterprise) to trace certain information about a particular product.
- The capacity to "trace" a product is normally understood as including the ability to track four specific types of information: (1) the product's origin (i.e. the location where the product was originally mined, manufactured or produced); (2) the product's geographical path (i.e. the various locations where the product underwent some form of transformation or through which it transited); (3) the product's chain of custody (i.e. the sequence of entities that held ownership or control over the product throughout the supply chain); and (4) the product's physical evolution (i.e. the product's different stages of processing and transformation).
- Traceability is usually understood as encompassing the capacity to *verify* the four outlined elements. Put differently, the entity "tracing" the product must be able to establish the information with a certain degree of confidence, which is usually done by compiling the relevant documents and records.

Based on these common elements, **traceability can be understood as the capacity to determine where a particular product originates, where it has travelled, who has handled it, and what modifications it has undergone**. If an entity is able to establish these four elements for a particular product with a certain degree of confidence, the product can be said to be "traceable".[1]

Beyond the four outlined elements, traceability can also be used to pass on certain information on a product's ESG performance. When tracing a product, ESG data can be attached to the four elements to provide a more complete picture of the product's sustainability performance. For example, when tracing a mineral product incorporated into a battery, information on GHG emissions can be attached along

[1] The term "provenance" is also used when discussing traceability. Provence is defined as the product's complete historical record of ownership, custody or location from mining to processing to its present state, with a focus on authentication or verification of the product.

the supply chain – thus providing a sense of the battery's environmental performance compared to other batteries available on the market (see "Beyond product origin, chain of custody and physical evolution: The role of sustainability data"). Although traceability can be used to obtain ESG data, establishing the four mentioned elements is the minimum requirement for achieving traceability. Without these four elements, the product cannot be said to be truly "traceable", even if some ESG data are attached along the supply chain.

Box 2.1. Definitions of traceability

The most commonly 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". Similarly, 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".

The relationship between traceability and other concepts

There are various interrelated concepts that are used to describe the collection and disclosure of information along the supply chain, such as “due diligence”, “supply chain transparency”, “product transparency”, “chain of custody” and “supply chain mapping”. These concepts can work together with traceability to allow for a complete understanding of a product’s movement along the supply chain, as well as the associated ESG performance of products and the identification of risks.

Due diligence

Under the OECD Guidelines for Multinational Enterprises on Responsible Business Conduct (“OECD Guidelines”), due diligence is the process enterprises should carry out to identify, prevent, mitigate, and account for how they address adverse impacts in their own operations, their supply chain and other business relationships. These actual or potential adverse impacts, referred to as “responsible business conduct risks”, encompass issues related to human rights, labour rights, environmental concerns and governance. Traceability can support due diligence but is not always necessary, nor is it sufficient, for due diligence to be carried out.

The 2023 OECD Ministerial Declaration on Promoting and Enabling Responsible Business Conduct in the Global Economy emphasises the role the OECD Guidelines play as leading government-backed standards on responsible business conduct alongside the OECD’s practical and actionable guidance on risk-based due diligence. This includes the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas (henceforth referred to as the “OECD Minerals Guidance”), which expects companies to “establish a system of controls and transparency over the mineral supply chain” as part of its Step 1 regarding due diligence management systems. This can entail “a chain of custody or a traceability system or the identification of upstream actors in the supply chain”. Similarly, the cross-sectorial OECD Due Diligence Guidance for Responsible Business Conduct outlines several ways for companies to improve their visibility of the parts of their supply chains with which they do not have a contractual relationship, including traceability or a chain of custody scheme, in addition to the disclosure of information related to suppliers or country of origin and joint assessments.

According to the OECD Minerals Guidance, the measures that a company takes to conduct due diligence should be commensurate with the severity and likelihood of adverse impacts – which tend to be higher in conflict-affected or high-risk areas. The OECD Minerals Guidance includes a list of red flags related to mineral origin and transit, suppliers and unusual circumstances, which should trigger enhanced due diligence whereby the company will need to collect more detailed information on business relationships than in lower-risk contexts (See Box 2.2 for more detail). Measures put in place as a result of enhanced due diligence, however, should be careful to avoid imposing disproportionately high costs on upstream actors to meet the demands for information of downstream customers. Efforts by upstream actors should be properly valued by downstream actors.

In the context of responsible business conduct, traceability is not equivalent to due diligence. Instead, traceability is one approach for achieving the level of transparency necessary to identify, prevent, mitigate and account for how companies address actual and potential adverse impacts in their own operations, their supply chains and other business relationships.

Even with advanced technologies, traceability on its own cannot guarantee responsible production and trade. A product may be completely traceable while still having been produced in problematic circumstances. For example, a company may be able to trace the provenance of a mineral product to a particular mine but may not have any information on the conditions in which that product was produced. Additionally, even if traceability solutions can provide technical features to help users identify risks in their supply chain (for example by overlaying publicly available data on child labour in certain mining areas), that is only an entry point to fully identifying and addressing such risks or making improvements for more sustainable production and trade. It is, therefore, essential to act on information, including that derived through traceability systems, and carry out due diligence processes to identify and address the potential and actual adverse impacts.

Due diligence and traceability are linked through a two-way relationship. On the one hand, traceability information (such as the origin and type of the material, the transportation route and the suppliers' beneficial ownership)[2] may help companies refine their risk assessment, improve risk prioritisation and enhance the effectiveness of risk mitigation strategies. On the other hand, the results of risk assessments undertaken as part of a company's overall due diligence process can determine the most appropriate type of transparency system. For instance, full traceability typically is used for higher-risk supply chains, while chain of custody systems are often used for medium- to lower-risk supply chains. While traceability may therefore be more relevant in high-risk environments, the nature of such settings may also make it more challenging to implement.

To maximise the value of both processes, companies should use the data generated by traceability or other supply chain transparency systems to inform

[2] Beneficial ownership refers to the natural person or persons who ultimately own, control or benefit from a legal entity or arrangement, even if the asset or entity is legally owned by someone else.

their due diligence processes outlined in the steps of the OECD Minerals Guidance. This involves continuously monitoring changes to suppliers' risk profiles and adapting transparency systems when appropriate while ensuring that traceability data are validated and integrated into broader due diligence efforts.

Box 2.2. Systems of control and transparency for due diligence in practice

The OECD Minerals Guidance expects companies to establish a "system of controls and transparency" for their mineral supply chains as part of its requirements on due diligence management systems. This system of transparency can span supply chain mapping, chain of custody or different types of traceability depending on the company's position in the supply chain and the risk profile of the supply chain.

While the responsibility to undertake supply chain due diligence applies to all companies along the supply chain, due diligence takes different forms depending on the position of the company in the supply chain. The Guidance distinguishes between the upstream segment (miners, traders, smelters and refiners) and downstream companies (exchanges, metal traders, component manufacturers, original equipment manufacturers and retail companies).

In cases where enhanced due diligence is warranted because of the identification of risks, upstream companies are expected to introduce a chain of custody and/or traceability system to collect due diligence information, such as on the origin and type of the material, the transportation routes and the suppliers' beneficial ownership. The scope and level of detail of the information such a system should help collect will vary depending on the risk profile of the supply chain – recognising that the extraction and processing of minerals inherently may create or amplify risks. Some supply chains might warrant a more detailed, intensively structured traceability or chain of custody system, for example due to the risk of fraudulent misrepresentation of the origin of minerals, while a paper-trail chain of custody system could be considered sufficient in other cases.

The OECD Minerals Guidance expects downstream companies to introduce supply chain transparency systems that allow for the identification of appropriate control points in the supply chain, typically smelters and refiners. These are key points of transformation where traceability or chain of custody information might be aggregated (or obscured) but where the highest volumes of materials are handled by a small number of companies. Smelters and refiners also have good visibility of the upstream part of the supply chain, and in this supply chain stage, relatively few companies process or handle most of the mineral inputs, which they pass further down to buyers. For red-flagged supply chains, the transparency system should produce due diligence information related to the identification of all countries of origin and the transport and transit of the minerals in the supply chains for each smelter or refiner. That information should then be shared with companies further downstream.

Identifying smelters and refiners may not be a straightforward task for downstream companies, as they may be several tiers removed from them. For example, an average vehicle has an estimated 30 000 component parts and uses approximately 50 raw materials. Electronics companies have reported similar numbers, with some estimating over 100 tier-one suppliers for their products and 7 000 business relationships across the full value chain. Some companies have reported that supply chains could span up to ten tiers. The OECD Minerals Guidance therefore encourages downstream companies to use a progressive approach to gradually identify smelters and refiners in their supply chains and ensure that these are carrying out appropriate due diligence on the upstream parts of their supply chains.

Chain of custody

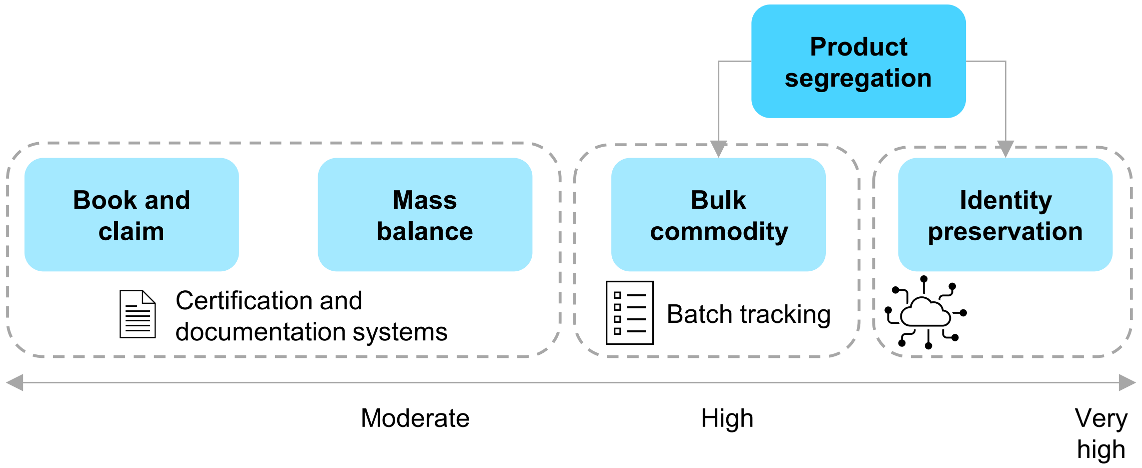
Chain of custody refers to the sequence of entities that have at one point handled the product or material inputs in question, including miners, transporters, exporters, processors and manufacturers.[3] Establishing chain of custody usually necessitates a system that records documents and information on the entities that handled the product. In some cases, a chain of custody system may also record information on the product's origin, geographical path and physical evolution.

Chain of custody differs from traceability in that it represents a *means* to achieve traceability. By establishing a system that tracks and verifies the sequence of entities that held ownership or control over a particular product, this can allow an operator to trace the product in question. To achieve full traceability, the chain of custody system should track and verify information regarding the sequence of entities that held ownership or control over the product, the product's origin, the product's path, and the product's physical evolution. A chain of custody system that only records part of this information will only provide partial traceability.

As with traceability, chain of custody can form part of a company's supply chain transparency system. However, chain of custody is not equivalent to, nor sufficient for, carrying out due diligence in line with the OECD Minerals Guidance.

[3] In some cases, a processor may handle a product without taking legal ownership over that product. Instead, the processor simply provides a service to the product's legal owner. Even if the processor does not have ownership of the product, a proper chain of custody system should still record that the processor handled the product along the supply chain.

Figure 2.1. Spectrum of visibility for chain of custody models



OECD/IEA. CC BY 4.0.

There are several existing chain of custody models that can support the implementation of traceability and provide a range of information on a product's origin, path and evolution (Figure 2.1). Guided by chain of custody standards (see Box 2.3), these models provide varying levels of ability to confidently determine the origin, path and evolution of the minerals within a product, with identity preservation offering the most visibility and book and claim offering the least. The three main types of chain of custody models are as follows:

- **Product segregation:** Materials that can be traced are physically separated from those that cannot and are segregated at each stage of the value chain, ensuring no mixing occurs between traceable and non-traceable materials. Identifying the origin of a final product or product component is possible but may not be specific.
- **Identity preservation:** This approach allows for the complete, unique tracing of products down the supply chain, from the production site and batch to the last point of transformation or labelling of a product. There is no product mixing.
- **Bulk commodity:** This allows for the mixing of different traced materials in the supply chain, meaning that it may not be possible to identify exactly which molecule came from which source.
- **Mass balance:** The volume of a traced product entering the supply chain is exactly equal to the equivalent volume leaving the supply chain. Mass balance allows for the mixing of certified and uncertified products at any stage of the production process, provided that quantities are controlled. There are three levels of mass balance: batch level, site level and group level.

- **Book and claim:** This model does not seek traceability at each stage of the supply chain. Instead, products are certified at the beginning of the supply chain by an independent body and can be bought as booked credits by market participants. Safeguards ensure that the credits booked do not exceed actual sales volumes and that claimed credits accurately correspond to the physical volumes sold to end markets.

Box 2.3. Performance, due diligence and chain of custody standards in mining

Chain of custody standards provide the framework for documenting material transfers in supply chains and verifying claims regarding mineral origin. These standards specify requirements for different models and provide guidance on whether and when a link in the physical chain of custody may be broken – such as when an audited material is physically held by an outsourced contractor.

Many ISO standards touch on traceability requirements. ISO 22095:2020 is a key framework that defines four key chain of custody models (identity preservation, segregation, mass balance, and book and claim). For specific minerals, ISO 23664:2021 provides requirements for traceability during the processing of rare earth elements, explicitly employing a mass balance model. Additionally, ISO Technical Committee (TC) 298 (rare earth elements) and TC 333 (lithium) are collaborating to develop a joint standard for traceability during processing. Other standards like ISO 9001:2015 and ISO/IEC 17025:2017 include traceability components but are more focused on quality management and laboratory processes, respectively. Nevertheless, despite the existence of the ISO/TC 82 Mining Technical Committee, there is no comprehensive ISO standard specifically designed for mineral traceability, making ISO 22095:2020 the primary reference point for supply chain actors seeking to implement traceability systems. However, these standards can be used complementarily to build robust traceability schemes, with ISO 22095:2020 providing the foundational framework while others contribute specific technical requirements.

In the minerals sector, several organisations have developed standards specific to minerals, including the Solar Stewardship Initiative's Supply Chain Traceability Standard, The Copper Mark's Chain of Custody Standard and Initiative for Responsible Mining Assurance's Chain of Custody Standard for Responsible Mined Materials. SAE International is also developing a global standard for tracing minerals used for electric vehicle batteries, aiming to achieve sustainability from upstream production to recycling.

Overview of Chain of Custody Standards in Mining

	The Copper Mark	Solar Stewardship Initiative	Initiative for Responsible Mining Assurance
Launched	2022	2024 (draft)	2024
Scope	Copper supply chain: mines, smelters, traders, refiners, fabricators, manufacturers, end users	Silicon in the solar PV supply chain	Mining supply chains
Model	Segregation or mass balance	Segregated	Identity preserved, segregated, controlled blending, mass balance, book and claim
Time requirements	Material accounting period: maximum 12 months	Material accounting period: maximum 12 months	Six months for recycled materials, annual for general accounting
Verification	Independent verification through their own assurance process	Third-party certification required for Solar Stewardship Initiative manufacturer members	Annual third-party verification
Key requirements	Management systems, material accounting	Management systems, material accounting, supplier certification, segregation controls, transfer documentation	Material flow documentation, conversion factor tracking, inventory balancing, conformance ratings
Outsourced contractors	Considered high-risk if materials are mixed	Considered high-risk if materials are mixed	Considered high-risk if materials are mixed

The robustness of chain of custody standards lies in the ability of the assessed supply chain to maintain material traceability even through complex supply chains with multiple actors and processing steps. This requires sophisticated systems for documentation and verification, along with clear-cut conditions for when the chain of custody is broken and when the mineral can no longer be considered certified under the standards.

In addition to the robustness of their standards, standard-setting bodies need to possess neutrality and a proper governance structure to be credible. While achieving widespread market adoption presents a significant challenge, particularly given the requirement for certification across entire supply chains, successful implementation is both possible and valuable. Early adopters and industry leaders have demonstrated that robust traceability systems can be established incrementally, creating positive momentum for broader adoption. As more companies recognise the business value of verified sustainable sourcing, participation in certification programmes continues to grow, gradually building the critical mass needed for effective chain of custody systems.

Performance standards, supply chain due diligence standards and chain of custody standards serve different but complementary roles in responsible mining and mineral sourcing. Performance standards assess site-specific ESG practices, due diligence standards verify impact mitigation systems, and chain of custody standards focus on tracking materials and ensuring supply chain transparency. These chain of custody standards typically require companies to disclose information about material transfers, processing steps and the chain of custody model used (such as mass balance or segregation), while some may also require public reporting of audit results and corrective actions.

Some chain of custody standards, such as those by the Initiative for Responsible Mining Assurance and The Copper Mark, go beyond traceability by integrating performance requirements that ensure responsible practices at the mine or processor of origin. The reliability of this information is crucial, with growing attention on these initiatives' governance systems, oversight models, and approaches to information and external accountability (see "Governance and verification", Chapter 4). While these comprehensive requirements can be demanding, they represent necessary steps towards creating truly sustainable and transparent supply chains. The growing success of various certification schemes demonstrates that with proper support and phased implementation approaches, companies across the supply chain can successfully adopt and benefit from these standards.

Supply chain mapping

Supply chain mapping refers to the process of documenting and recording information regarding a particular operator's supply chain in order to create a representation of that operator's supply chain network. A supply chain map will normally include information regarding the different entities involved at various tiers in the operator's supply chain (such as raw material producers, traders, processors, manufacturers, suppliers, transporters and distributors), including the geographical locations of these entities. Supply chain mapping provides a snapshot of the operator's entire supply network at a specific point in time, showing all players involved in producing and delivering a particular category of products.

Supply chain mapping differs from traceability in that it does not typically provide information on the flow of individual products through the supply chain. With traceability, an operator will be able to track how a specific product (or batch of products) has moved through the supply chain network. By contrast, supply chain mapping simply provides a bird's eye view of the different entities involved in a particular supply chain, without necessarily providing information on how a particular product has moved through the network of entities.

Supply chain mapping can be useful for multiple purposes. In particular, it can be used to identify control points in mineral supply chains where the largest amount of material is handled by the smallest number of entities (such as smelters and refiners), at which the OECD Minerals Guidance recommends due diligence assessments and audits. Supply chain mapping can also be used to evaluate the need for enhanced due diligence and to prioritise know-your-counterparty processes or checks as part of the due diligence process.

Product transparency

Product transparency (or product disclosure) relates to disclosing certain information to the public or to relevant stakeholders. It does not necessarily equate to, or automatically translate into, product transparency. A product may be traceable, but traceability information regarding that product may not necessarily be disclosed either publicly or down the supply chain. A company may set up an internal traceability system for its own commercial purposes without communicating the full information recorded under this system to its customers or to the public – for example, for business confidentiality reasons. Similarly, a company may be highly transparent when passing on traceability information to its business relationships but may choose not to disclose any traceability information to the public.

Even though product traceability does not always translate to product transparency, product traceability can help companies achieve greater product transparency. When a company sets up a traceability system, it can then choose to disclose traceability data collected by that system to its customers or to the public. If the company chooses to publicly disclose traceability information, this can help customers make informed purchasing decisions and help build trust in the company's sustainability claims.

Chapter 3. Policies, regulations and market requirements on traceability

Legislative and regulatory measures are increasingly driving the uptake of traceability systems and supply chain transparency measures globally. Since 2010, regulations requiring supply chain due diligence have encouraged new industry efforts to map targeted mineral supply chains and use information on the country and mine of origin to mitigate risks and ensure responsible business conduct throughout the supply chain. Mineral due diligence measures have expanded in number and scope since then. In parallel, new mineral sourcing regulations have emerged pursuing a variety of different policy objectives, spanning from responsible business conduct to environmental sustainability, security of supply, industrial competitiveness, decarbonisation and consumer awareness. The degree of traceability that is required in response to these measures ultimately depends on how the provided data are intended to be used and for what purpose.

Measures encouraging traceability on the rise

Due diligence legislation initially drove supply chain transparency and responsible business conduct but did not mandate specific traceability or supply chain transparency requirements. Instead, it created incentives for the adoption of these practices as a possible tool for gathering and verifying supply chain information. Examples of this include Section 1502 of the US Dodd-Frank Act, which required companies to report on tin, tantalum, tungsten and gold (3TG) from the Democratic Republic of the Congo and adjacent countries, and the European Union's Conflict Minerals Regulation, which required importers of 3TG to carry out risk-based due diligence in line with the OECD Minerals Guidance. This includes the expectation for companies to establish a system of controls and transparency, spanning supply chain mapping, chain of custody or traceability (see "Due diligence", Chapter 2). Regional governmental mechanisms, such as the International Conference on the Great Lakes Region (ICGLR), have developed certification systems to support these requirements. The Regional Certification Mechanism of the ICGLR provides a framework for member states to implement harmonised controls on 3TG minerals through: (1) mine site inspection and validation systems (blue/green/yellow/red flag status); (2) chain of custody tracking from the mine to export; (3) third-party audits of exporters; and (4) due diligence requirements. Each member state implements this through national legislation that designates responsible agencies and specific procedures. The Democratic Republic of the Congo, Rwanda and Tanzania have enacted regulations accordingly.

Table 3.1. Regulations on critical mineral traceability

Title of policy	Country/ Region	Measure(s)	Level of proof required
Directly encouraging traceability			
The Regional Certification Mechanism for minerals 2012	Rwanda	• Implements the International Conference on the Great Lakes Region (ICGLR) Regional Certification Mechanism in Rwanda, establishing a system of designated trading centres and specific requirements for mineral tracking databases and documentation.	Proof of transaction
Traceability Procedures Manual for Tradable Mining Products 2014, 2024	Democratic Republic of the Congo	• Implements the ICGLR Regional Certification Mechanism in the Democratic Republic of the Congo, establishing traceability procedures through site validation, chain of custody documentation and sample analysis, with the Center for Expertise, Evaluation and Certification of Precious and Semi-Precious Mineral Substances as the focal point for implementation, certification and national database management. with specific requirements for chain of custody documentation and database management.	Proof of transaction
Mining (Designated Minerals Certification) Regulations 2019	Tanzania	• Implements the ICGLR Regional Certification Mechanism in Tanzania, establishing specific procedures for certification and documentation through the Mining Commission as the competent authority.	Proof of transaction
Batteries Regulation 2023	European Union	• Sets minimum requirements for traceability, including specific standards, requirements for due diligence reporting and guidelines for handling sensitive data, maintained through digital product passport solutions like the Battery Passport. • Requires supply chain documentation and chain of custody records through electronic verification systems and the disclosure of information about social and environmental risks in raw material sourcing.	Proof of transaction
Sec. 857(a), National Defense Authorization Act 2023	United States	• From June 2025, contractors of the Department of Defense are required to show the provenance of rare earth elements from mining to refining. • The Department of Defense will update the Defense Federal Acquisition Regulation Supplement to implement the requirements.	Proof of transaction

Title of policy	Country/ Region	Measure(s)	Level of proof required
Final Rules on the clean vehicle provisions of the Inflation Reduction Act 2024	United States	• Requires verification of non-Foreign Entity of Concern status throughout the supply chain through a serial number or other identification system to physically track compliant batteries to specific new clean vehicles. • Under the Traced Qualifying Value Test, manufacturers must conduct detailed supply chain tracing to determine the actual value-added percentage for extraction, processing and recycling. The actual percentage is used to determine the qualifying value for the applicable critical mineral. • A compliant-battery ledger tracking system requires verification of the locations of the extraction, manufacturing, processing and recycling facilities.	Proof of transaction
Interim Provisions on the Traceability Management of Power Battery Recycling in New Energy Vehicles 2018	China (People's Republic of)	• Requires a battery code for the traceability management platform, through which the entire life cycle of EV batteries can be traced, including the production time, manufacturing enterprise, installation, use, maintenance, retirement and recycling.	Proof of origin
SIMBARA 2023	Indonesia	• Establishes an inter-agency government monitoring platform for nickel and tin. • Requires government agencies to share and validate data on the covered minerals.	Proof of origin
Colombia's Mining Traceability and Transaction Control System 2024	Colombia	• Establishes a mineral traceability platform run by the National Mining Agency to track minerals from extraction to final sale, with integration with the unified registry of mineral traders. • Requires physical mine visits and inspections, direct verification of extraction sites and the on-site verification of minerals.	Proof of origin
Rare Earth Management Regulation 2024	China (People's Republic of)	• Requires enterprises involved in rare earth mining, smelting separation, metal smelting, comprehensive utilisation and export to establish product flow records and enter information into a rare earth product tracing system. (Applies generally to rare earth products, with specific mention of magnets in the context of recycling).	Proof of origin
Indirectly encouraging traceability as part of wider due diligence expectations			
Corporate Duty of Vigilance Law 2021	France	• French companies with more than 5 000 employees in France, or with headquarters in France and more than 10 000 employees abroad, must develop and implement a plan to audit their subcontractors based on sustainability factors. The law lists human rights, environmental impact, health and safety aspects, and corruption as urgent issues to address.	Proof of intention

Title of policy	Country/ Region	Measure(s)	Level of proof required
Supply Chain Act 2021	Germany	• Requires companies to implement and document due diligence procedures to identify and address human rights and environmental risks throughout their supply chains, with obligations extending from their direct operations to indirect suppliers.	Proof of intention
Corporate Sustainability Reporting Directive 2022	European Union	• Requires assurance on the sustainability information that companies report and provides for the digital taxonomy of sustainability information.	Proof of intention
Fighting Against Forced Labour and Child Labour in Supply Chains Act 2023	Canada	• Requires entities to report annually on their supply chain structures and activities and mandates disclosure of the parts of their business and supply chains that carry the risk of forced or child labour. • Requires public reporting on due diligence processes and steps taken to manage risks.	Proof of intention
Corporate Sustainability Due Diligence Directive 2024	European Union	• Requires European Union-based companies to identify and, where necessary, prevent, end or mitigate the adverse impacts of their activities on human rights (such as child labour and the exploitation of workers) and on the environment throughout their supply chains, including raw materials.	Proof of intention
Uyghur Forced Labor Prevention Act 2021	United States	• Importers that request exceptions to the act's presumption are required to submit supply chain documentation to Customs and Border Protection. Such documents must show the roles of each entity and trace the supply chain from raw materials to the imported good, demonstrating that the supply chain is outside of Xinjiang and unconnected to the listed entities, or that the imports are free of forced labour.	Proof of transaction
Critical Raw Materials Act 2024	European Union	• Aims to improve supply chain transparency of minerals defined as strategic or critical to ensure security of supply to the European Union. • Requires the European Commission to monitor the supply chains of national authorities and large companies using strategic minerals in their manufacturing processes, focusing on disruption risks. This includes undertaking a mineral supply chain mapping until the point of extraction based on information made available by suppliers or the public domain, though it does not require traceability as such.	Proof of transaction

Notes: This analysis examines regulatory requirements for mineral traceability through three distinct levels of verification. The first level, proof of intention, relies on basic documentation like codes of conduct and supplier statements, potentially verified by third parties. The second level, proof of transaction, involves chain of custody systems that track minerals from the mine to the final product, incorporating features like automated ID registration, blockchain logging and inspection methods. The highest level, proof of origin, employs quality assurance and control measures, including quantitative and statistically representative analyses that can definitively determine a material's origins through scientific testing. This framework is used to assess various mineral regulations and their required levels of traceability compliance.

Sources: IEA (2025), Critical Minerals Policy Tracker. Framework is based on Nordic Innovation (2024), Mineral to Metal Traceability: A Proof-Of-Concept Study of Rare Earth Elements in the Nordic Region.

Measures encouraging traceability are on the rise. The evolution of mineral traceability regulations reveals significant differences in approach: while major consumer markets like the European Union and the United States have developed sophisticated frameworks, these primarily affect downstream companies through market requirements. Resource-rich countries like Colombia and the Democratic Republic of the Congo have also established their own national frameworks, but all in all, the limited direct regulation of upstream and midstream operators, combined with data collection challenges in producing regions, creates potential gaps in the implementation of traceability.

These implementation challenges are further complicated by the varying infrastructure requirements of different traceability approaches. A traceability system almost always involves the use of private infrastructure, but it may also involve the use of public infrastructure. A company that decides to create a traceability system on a purely voluntary basis (without being mandated to do so by law) likely will not have to use any government-controlled infrastructure as part of its traceability system. However, when the traceability system is put in place as a result of legal obligations, the company may be required to record some traceability data on a government-operated database or registry.

For example, since 2023, Colombian mining producers and traders have been required to use an approved service provider to record mineral-related commercial transactions along the value chain on a government platform. Similarly, since July 2024, Indonesia’s Mineral and Coal Information System (called SIMBARA) now includes nickel and tin, thus enabling government authorities to track the movement of these minerals between mines and processing facilities. Indonesia plans to further expand this system by including copper, gold, bauxite, manganese and other minerals by 2025.

Given these diverse approaches to infrastructure requirements, current regulations can be categorised by the stringency and scope of their traceability requirements. Few mandate comprehensive traceability or chain of custody systems, and even fewer require information as robust as scientific verification of material origins. Many incorporate the risk-based approach inherent to OECD standards, which span different types of traceability systems according to the risk of adverse impacts along a company's supply chains. The EU Batteries Regulation stands out for establishing precedent-setting standards on data disclosure and the handling of sensitive information. Meanwhile, the dual role of the People’s Republic of China (hereafter, “China”) as both the world’s largest producer and consumer of critical minerals is reflected in its Battery ID system and Rare Earth Management Regulation, although emerging data security laws, including in China, may present challenges to interoperability with international due diligence and traceability systems.

Strengthening co-operation on due diligence overall may help mitigate some of the challenges presented by data security regulations. For example, the China Chamber of Commerce of Metals, Minerals & Chemicals Importers & Exporters (CCCMC), an industry group overseen by China's Ministry of Commerce, introduced the Chinese Due Diligence Guidelines for Responsible Mineral Supply Chains and has developed an audit programme to help Chinese companies comply with the London Metal Exchange's responsible sourcing requirements. To assess such audit programmes, the London Metal Exchange uses the OECD's Alignment Assessment Methodology, which is also used by the European Commission for its due diligence regulations. This common benchmark can help support consistency in due diligence approaches, including for supply chain transparency issues like traceability, even though some transboundary barriers to information flow may be more intractable than others. The CCCMC's role as a convener of Chinese industry on these issues can also play a role in helping build capacity and fostering communication around due diligence implementation challenges, including those related to traceability.

Indirect regulatory mechanisms have emerged as significant drivers of traceability adoption, albeit with complex market implications. The US approach illustrates two distinct policy levers: market incentives through the Inflation Reduction Act's tax credits and import restrictions through the Uyghur Forced Labor Prevention Act (UFLPA). Implementation of the act – particularly in the solar sector, where the supply chain has often been linked to forced labour in the Xinjiang Uyghur Autonomous region – demonstrates how focused enforcement can drive industry-wide standardisation of traceability practices even without explicit regulatory requirements.

However, stringent traceability requirements can have unintended consequences: operators with fewer resources, particularly artisanal miners and small-scale processors, often lack the technical capacity and financial resources to implement sophisticated traceability systems. This regulatory burden risks pushing these actors into informal or markets with low levels of transparency, potentially undermining both the social development goals of traceability programmes and the integrity of mineral supply chains. The challenge is particularly acute in regions where informal mining already represents a significant portion of production. While empirical studies on the overall impacts of UFLPA are scarce, the Act's shift in the burden of proof to importers to rebut a presumption of forced labour has placed significant burdens on them. Indications are that it has led to significant delays of large volumes of imports, even where there may be no connection to forced labour.

At the international level, Colombia's call for an international agreement at the United Nations Biodiversity Conference of the Parties (COP16) signalled a growing recognition of the need for global co-ordination on mineral traceability.

This aligns with recommendations from the UN Secretary General's Panel on Critical Energy Transition Minerals for establishing a global traceability, transparency and accountability framework along the entire mineral value chain.

The trend towards identifying the provenance of minerals across regulatory frameworks highlights the growing role of traceability systems in global supply chain governance. However, regulators have demonstrated pragmatic flexibility when market realities demand it. For example, the "impracticable-to-trace battery materials" rule in the US Internal Revenue Service's rules on clean vehicle credits exemplifies this balanced approach. It temporarily exempts certain highly commingled low-value battery minerals from Foreign Entity of Concern restrictions when tracing would be infeasible, while still requiring manufacturers to document their traceability capabilities. This targeted flexibility, particularly for materials like graphite in anode materials and minerals in electrolyte components, illustrates that traceability requirements must balance ambitious transparency goals with constraints on practical implementation. Such nuanced enforcement helps maintain market functionality while gradually building towards more comprehensive traceability.

Table 3.2. Public funding for minerals traceability

Country/Region	Title	Description
Canada	Grants to support the Critical Minerals Traceability Project	• CAD 675 000 (Canadian dollars) in grants to enhance the transparency of Canadian supply chains and create value.
European Union	Material and Digital Traceability for the Certification of Critical Raw Materials	• EUR 11 million funding from the European Commission for a project to develop and integrate technological solutions for traceability and certification into a Digital Product Passport, reinforcing the transparency, traceability, and sustainability of complex supply chains of critical raw materials, including cobalt, lithium, natural graphite and rare earth elements.
Finland	BATTRACE project: Sustainable Processing and Traceability of Battery Metals, Minerals and Materials	• EUR 5.8 million from Business Finland and other industry partners for the Geological Survey of Finland and VTT Technical Research Centre of Finland. The Geographical Survey of Finland aims to develop traceability methods to verify the origin of metals based on the mineralogical and geochemical composition of the ore deposit. The VTT Technical Research Centre of Finland aims to improve and optimise metals recovery.

Country/Region	Title	Description
United Kingdom and Canada	Canada-UK Critical Minerals: Sustainability and Circularity funding competition	• Up to GBP 3.5 million from Innovate UK and up to CAD 3 million from the National Research Council of Canada Industrial Research Assistance Program to fund innovation projects, including innovations in ESG for critical minerals like traceability of critical minerals and digitisation of systems.
United States	Global Trace Protocol Project	• USD 4 million in funding from 2020 to 2024 for pilot tracing projects to increase the downstream tracing of goods made by child labour and forced labour. One project is directed towards cobalt in the Democratic Republic of the Congo.

Source: IEA (2025), Critical Minerals Policy Tracker.

Recycled content regulations and traceability

Recent regulations are increasingly setting specific requirements for recycled content in batteries and other clean energy technologies, creating new challenges for implementing any type of traceability. The EU Batteries Regulation, for instance, not only mandates progressive recycling targets but also requires verification of recycled content claims – a requirement that existing traceability systems are not yet fully equipped to handle.

The regulatory landscape becomes particularly complex when addressing manufacturing scrap versus post-consumer materials. While manufacturing scrap currently dominates battery mineral recycling and benefits from relatively straightforward industrial documentation, regulatory frameworks will need to evolve as post-consumer materials become more prevalent after 2030. The European Critical Raw Minerals Act and the EU Batteries Regulation exemplify this challenge, requiring member states to increase collection rates while simultaneously verifying recycled content levels.

Previous IEA analysis in Recycling of Critical Minerals points to cross-border regulatory inconsistencies that may further complicate traceability requirements. For example, the varying classification of battery waste and black mass as hazardous or non-hazardous materials across jurisdictions creates significant verification challenges. Without explicit classification under existing frameworks, companies face uncertainty in documenting and verifying the origin of recycled content when materials cross borders.

Compliance with these regulations may require new traceability approaches. While digital solutions like battery passports offer promising verification frameworks, their effectiveness depends on standardised measurement protocols and independent verification processes that can operate across jurisdictions. The challenge for regulators lies in developing frameworks that can verify recycled content claims while remaining practical for implementation across global supply chains.

Regulatory and enforcement limitations

The stringency and structure of traceability requirements vary significantly based on regulatory goals, national priorities and enforcement capabilities. When regulations demand detailed product-specific supply chain information, they typically require sophisticated traceability solutions with robust technical documentation. In contrast, regulations focused on broader supply chain risks often allow for more flexible approaches, such as supply chain mapping or due diligence frameworks.

Government-administered traceability systems reflect these varying priorities and capabilities. The People Republic of China's (hereafter "China") Rare Earth Management Regulations, which entered into force in October 2024, exemplify a comprehensive approach combining government oversight with enterprise-level implementation. Similar systems exist in other producing countries: Indonesia's SIMBARA platform for nickel and tin and Colombia's combined digital-physical chain of custody system represent evolving approaches to strengthening mineral traceability.

However, regulatory fragmentation and data protection laws can undermine global traceability goals. While the European Critical Raw Minerals Act and EU Batteries Regulation allow member states to establish their own penalty frameworks, this flexibility risks creating inconsistent enforcement. More fundamentally, national data protection laws can directly impede cross-border traceability efforts. For example, while China has developed promising initiatives like the China Battery ID system for life cycle tracking and responsible sourcing, implementation challenges persist, including difficulties in mapping material provenance to the mine level. Nevertheless, this system could offer opportunities for creating interoperability between Chinese and international traceability requirements, potentially bridging some regulatory gaps.

The combination of China's Anti-Foreign Sanctions Law and Data Security Law could also create obstacles for foreign companies implementing global traceability systems. Requirements on data localisation and restrictions on data transfers could hinder compliance with regulations in other jurisdictions that demand detailed supply chain documentation. The Anti-Foreign Sanctions Law allows China to take countermeasures against entities complying with foreign sanctions, potentially discouraging robust traceability implementation that might reveal sanctionable activities. These laws also restrict foreign companies' ability to conduct thorough supply chain audits within China, a critical component of many traceability efforts. Similar challenges emerge from data sovereignty requirements in other jurisdictions, where the type and granularity of data collected along the value chain can trigger various national privacy protections, complicating the efforts of companies with international operations to use a common approach to traceability. These challenges make a compelling case for enhancing co-operation on due diligence to promote shared approaches to traceability as part of a broader responsible sourcing agenda in which different regions' interests may converge in many ways. A concrete example of this type of co-ordination is the Inclusive Platform for Due Diligence Policy Coordination convened by the OECD following the Ministerial Declaration on Promoting and Enabling Responsible Business Conduct in the Global Economy.

The effectiveness of traceability systems thus depends not only on technical capabilities but also on navigating and resolving these regulatory tensions. While government-administered platforms can enhance domestic oversight, their value for international supply chain verification requires compatibility with private sector initiatives and cross-border information-sharing frameworks. Consequently, regulations focused on due diligence often avoid prescribing specific traceability methods, instead allowing companies flexibility in establishing appropriate transparency measures that align with international standards while navigating complex national requirements.

Chapter 4. Components of an effective mineral traceability system: A toolkit

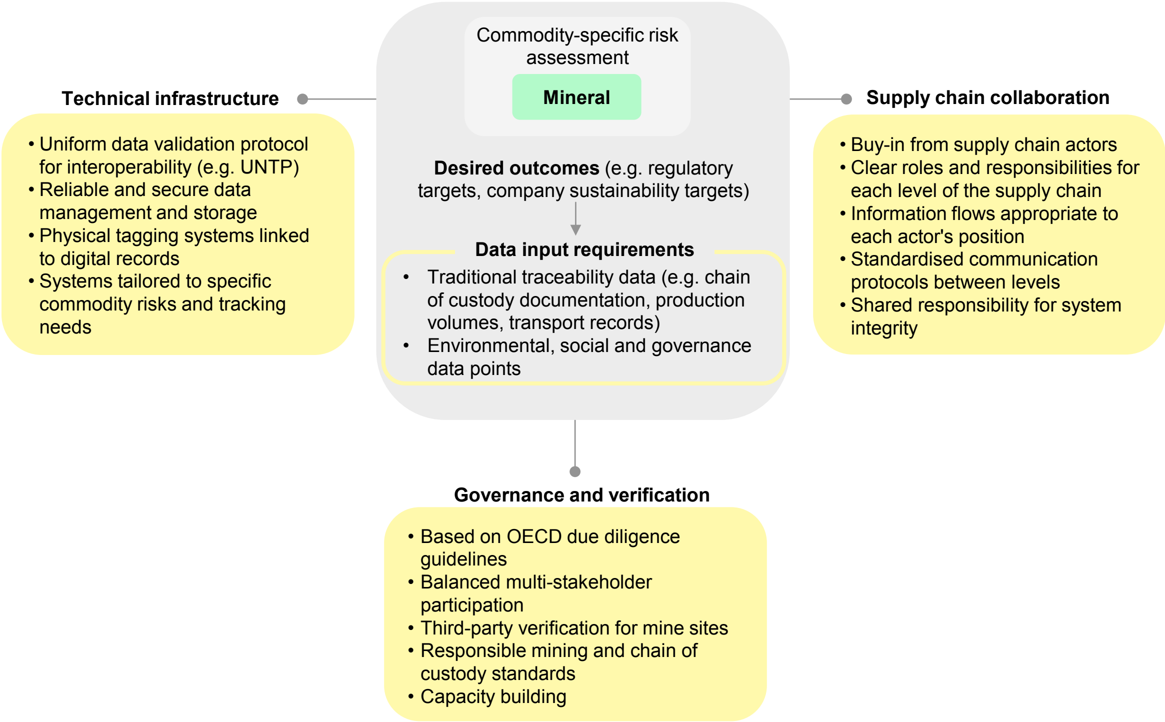
To achieve traceability, it is usually necessary to have a traceability system with defined processes and definitions that have been agreed upon by all actors in the product's supply chain. This ensures that the actors have the same understanding of the various pieces of information that must be traced and a shared approach to recording and communicating that information. These systems should be continuously improved, gradually expanded and refined as they are implemented, adapted to different circumstances and complemented by other supply chain transparency approaches.

There is no single model for traceability systems, as they vary in terms of the information that must be recorded, and the technology used to track and communicate this information. These characteristics depend on the system's objectives. The system can also be voluntary or mandatory. Companies may choose to set up a voluntary system even without a legal obligation for various reasons, such as to understand the origin of the products it purchases or to claim that its products are sourced or produced in a sustainable manner (noting that traceability alone may not be sufficient to allow the company to make such a claim). At the same time, traceability systems can also be put into place to comply with legal obligations (see Chapter 3).

A critical mineral traceability system must be thoughtfully designed to balance added value, robustness and practicality while maintaining credibility at a proportionate cost. Success depends on trust, widespread buy-in and alignment with regulatory requirements, all supported through four core criteria: technical infrastructure, well-defined and standardised data collection, supply chain collaboration, and governance and verification.

This section examines how these components interact to deliver credible and practical tracing outcomes while meeting regulatory requirements and sustainability goals (see Figure 4.1). Systems also need to be tailored to commodity-specific supply chains and risks (see Chapter 5).

Figure 4.1. Conceptualising a critical mineral traceability system



Technical infrastructure

A traceability system needs robust technical infrastructure, including reliable data management, secure storage and physical tagging mechanisms to link digital records with actual materials. To ensure standardised data handling across the system, it should align with established and mutually agreed upon protocols for data exchange, such as the UN Transparency Protocol, which provides specifications on how information should be collected, validated and shared. The infrastructure must be flexible enough to work across diverse operating environments, from high-tech facilities to remote mining locations with limited connectivity. This technical foundation builds trust by ensuring data integrity and accessibility for all participants regardless of their operational context.

Tools and strategies

There are several tools and strategies that traceability systems can use to collect and transmit data across the supply chain. These have traditionally relied on paper-based methods to provide a means of recording relevant information, such as on the mine of origin, the journey through the supply chain, and ESG performance and risks. Common documents include mine origin certificates to verify the source of raw materials, transportation documentation to track the movement of goods, export and import records to ensure compliance with trade regulations, and factory receipts to confirm processing and assembly stages.

Digital track-and-trace systems have emerged as a widely adopted means of storing and transmitting data across the supply chain. These systems enable companies to track relevant information, such as product origin, volumes, and compliance credentials. Such data can be compiled into a comprehensive digital history for each product, often taking the form of documents that detail each step of a product's journey – from the mine to the processing facility – while capturing relevant information or metrics. The resulting digital archives can be recalled or queried as needed, allowing businesses and regulators to verify compliance with ESG standards or sourcing requirements.

Material tagging and fingerprinting are methods that can be utilised for traceability by linking physical products directly to their digital record. Material tagging involves attaching identifiable labels – such as radio-frequency identification (RFID) tags, Global Positioning System (GPS) tracking, QR codes, or barcodes – to items, allowing companies to monitor the movement of goods in real time across the supply chain. On the other hand, fingerprinting uses inherent physical properties, such as unique isotopic or molecular signatures, to create distinct identifiers that can be used to trace materials along the supply chain. However, fingerprinting does have limitations in tracing materials throughout the entire supply chain, as smelting and concentration processes alter the physical characteristics of a material.

Blockchain has gained popularity in recent years as it creates a decentralised digital "ledger" that allows for the digital recording of transactions. Rather than being a tracking mechanism in and of itself, blockchain serves as a theoretically secure repository where various tracked data can be stored. Each actor along the supply chain adds a "block" that captures various data inputs, theoretically ensuring that data remain immutable as the product moves through the supply chain as long as the system is set up properly.

Blockchain is often described as tamperproof because it relies on cryptographic mechanisms and decentralised consensus protocols to validate transactions. However, its immutability is only guaranteed under a certain set of conditions, including having a robust network of independent nodes and properly implemented protocols. If a single or colluding group holds the most computational power or validation authority, it can alter the ledger. Importantly, blockchain is also only as good as the data that is inputted into the technology – it cannot provide certainty on the quality of the data entered.

Other advanced technologies utilised in traceability systems are now finding their way into critical mineral supply chains, having emerged from use in other industries. For example, artificial intelligence and machine learning analyse large datasets to detect patterns or flag risks and can be used for fraud detection and proactive risk management. Smart contracts can automatically execute, control or document events and actions in accordance with the terms of a contract, making them useful for tracking transaction details or verifying trades and deliveries.

Table 4.1. Traceability technologies

Purpose	Technology	Application	Benefits	Drawbacks	Example(s) of use
Digital record system	Blockchain	Digital ledger for tracking transactions across the supply chain	Records are difficult to tamper with, can allow for enhanced data integrity	High energy consumption, costly infrastructure, potential interoperability issues	Used by various mining and metals companies
Physical tracking system	RFID and GPS tracking	Real-time tracking of physical assets	Enables live tracking, can improve logistics and enhance security	Limited to physical assets, may be difficult to capture detailed ESG data, ill-adapted for artisanal and small-scale mining	Often used in logistics and transportation
	QR codes and tracking	Scannable codes for product information	Low cost, easy to implement	Less secure, can be prone to damage	Often used in manufacturing or consumer-facing products
	Geochemical tracing through DNA tagging or chemical markers	Physical tracking of materials	Allows identification of material origin, resilient to tampering	Higher cost, requires specialised equipment, limited ability to trace back to the first step of the value chain	Could be used in mineral supply chains for verifying origin
Advanced analytical tools	Artificial intelligence and machine learning	Data analysis for risk detection and fraud protection	Can identify patterns, particularly useful in large datasets, can support proactive risk management	Requires extensive data, energy and infrastructure to implement, can be costly to implement	Used by companies for fraud detection and supply chain risk assessment
	Smart contracts	Automated, secure transactions	Reduces paperwork, improves transaction accuracy, increases efficiency	Complex to set up, requires compatible blockchain infrastructure	Applied in minerals trading to ensure contract terms are met and automatically verified

Choosing the appropriate technical infrastructure

When designing an effective traceability system, it is important to weigh the advantages and disadvantages of using a purely paper-based system versus a technology-based one, as well as to consider the costs and opportunities they can provide.

Advantages and disadvantages

Paper-based systems are often straightforward to implement as they require minimal upfront investment in specialised infrastructure and less technical knowledge to set up and maintain. As a result, implementation may be easier for certain actors, such as artisanal and small-scale miners or those located in regions without consistent or reliable access to technological infrastructure. However, paper-based systems can have drawbacks: they can place burdens on individual actors due to inefficiencies and a lack of real-time data, which may make it harder or less efficient to track certain information.

Technology-based systems, on the other hand, can bring significant benefits. When implemented effectively, they can streamline data collection, offer real-time updates and provide higher levels of accuracy and reliability. By automating processes, they can reduce manual workloads and improve the ability to trace materials across global supply chains. However, despite these advantages, they can also present their own challenges. Some may have higher initial costs and require ongoing maintenance, technical expertise and robust infrastructure (see "Cost and opportunities"). Additionally, governance concerns can arise if a few for-profit companies dominate the market, particularly if only a few companies hold computational power or validation authority (see "Governance and verification"). Energy use and environmental considerations must also be accounted for (see Box 4.1).

Cost and opportunities

Similar to other elements of supply chain due diligence, costs related to traceability systems tend to be concentrated upstream. The cost of adopting a traceability system varies based on the technology used and the complexity and specific requirements of a company's supply chain. For companies with minimal or non-existent data infrastructure within their operations or across their supply chains, significant upfront investments would be needed in physical and human capital, including training and raising awareness among employees and companies across the supply chain. The costs related to training and engagement may be ongoing, particularly if the buy-in of suppliers is difficult to obtain. Companies with existing chain of custody systems, even if they are paper-based or non-standardised, may find it easier or less costly to adopt a traceability system.

Implementing technology-based systems, especially those that rely on blockchain or other data-intensive platforms, involves other considerable upfront capital and operational costs. For example, blockchain-based systems require considerable computing power, with costs rising as the volume of tracked data grows. These systems can also require regular maintenance and skilled technical support, possibly requiring the hiring of additional staff and increasing operational expenses. In addition, ongoing support from dedicated technical staff could be needed to ensure the accuracy and implementation of a common data language or norms, as well as to verify data inputs provided by suppliers. Additional human resources could be needed depending on the complexity of the supply chain, especially for supply chains involving regular supplier changes and short-term or spot trading. Costs relating to the human efforts and resources needed for ongoing risk monitoring, assessment and third-party verification must also be factored in.

Despite these high implementation and maintenance costs, digital systems may lead to long-term cost savings by improving existing data management systems and operational efficiencies. By automating and integrating data collection and reporting processes, these systems – if set up properly and with the appropriate safeguards – could help reduce the risk of errors, delays and compliance breaches, all of which can be costly to address. Over time, companies may achieve more consistent data quality, lower administrative costs, and improved resource allocation.

Traceability systems may also yield long-term savings if they contribute to making overall due diligence more effective by anticipating and preventing risks. When implemented properly, digital traceability systems can improve a company's ability to identify, demonstrate and verify sustainable sourcing as well as its ESG performance. This can help companies strengthen their resilience against disruptions, thereby reducing costly delays. It can further enable companies to identify supply chain risks earlier, mitigating legal costs or those related to public perception.

Improved data reliability, management, and verifiable ESG performance can deliver significant value to companies by enhancing their overall reputation and facilitating market access, particularly in certain regulatory environments, as discussed in Chapter 3. Additionally, these improvements could help companies secure access to financing.

Box 4.1. Environmental cost of technological solutions

While technology can increase the efficiency of traceability, it can also require substantial computing power, which can have significant environmental impacts. One of the technologies with the highest energy-intensity being used for traceability is blockchain. Its environmental impact results mainly from the energy-intensive consensus mechanism used to validate transactions and maintain network security, with different blockchain protocols serving different purposes and having varying levels of environmental impact. For example, utilising a "Proof of Stake" or "Proof of Authority" algorithm requires substantially less energy than the commonly used "Proof of Work" algorithm. In the context of traceability, block validation is the most energy-intensive process, whereas tracing the blocks, once set up, is not.

While no estimates exist of the environmental impact of blockchain technology, the energy footprint of the "Proof of Work" blockchain for Bitcoin is estimated to be 120 Twh in 2023. More broadly, the carbon emissions from datacentres globally could reach 450 million tonnes by 2027, or 1.2% of the world's total.

Given that traceability is being used as a tool to support the creation and upkeep of sustainable and responsible critical mineral supply chains, it is crucial to ensure that any technology-based solutions do not introduce their own environmental costs. Selection criteria for traceability systems should consider environmental implications, including energy efficiency, the potential to utilise renewable energy sources and incentives to minimise environmental impact. Where possible, choosing low-impact or low-emission solutions can help align technology-based traceability systems with sustainability goals.

Interoperability across the supply chain

To ensure useful data exchange across the supply chain, traceability systems need to consider interoperability between different systems. Without interoperability, fragmentation can hinder widescale adoption across the supply chain, increase costs and create inefficiencies. Various stakeholders are working to support interoperability among the different technology-based traceability systems utilised by actors in critical mineral supply chains, such as the UN Transparency Protocol. This standard aims to provide a standardised technical toolkit that enables different systems to "talk" to each other, facilitating the exchange of data through digital product passports and conformity credentials (see Box 4.2). Other initiatives, such as British Columbia's Energy and Mines Digital Trust pilot, are exploring how digital credentials can be used to share trustworthy, verified data on the sustainability of mining operations.

Box 4.2. United Nations Transparency Protocol for technical interoperability

The United Nations Transparency Protocol (UNTP) is a standardised framework developed under the United Nations Economic Commission for Europe to address challenges in supply chain transparency and sustainability reporting. The UNTP aims to provide an interoperability toolkit that enables businesses to share verifiable sustainability information globally by utilising digital product passports, traceability events and digital product conformity credentials. It works with existing product identifiers and incorporating privacy and security tools. The protocol supports both human-readable and machine-readable formats, aiming to combat greenwashing, meet increasing regulatory requirements and manage the complexity of various ESG standards through a semantic mapping architecture.

The UNTP launched a pilot for its Critical Raw Materials extension in January 2025, focusing on interoperability for traceability systems in upstream mining and refining. An extension is a customisation that adapts the core protocol to meet the specific needs of any industry sector or regulated market while maintaining interoperability. The broader implementation of this extension is planned across multiple industries and jurisdictions, complementing existing initiatives such as the European Union's Digital Product Passport. The pilots are scheduled in Australia, Canada and the Democratic Republic of the Congo and aim to adapt the general UNTP framework to address the particular traceability and sustainability reporting needs of the critical raw materials industry, including specific data fields, event types and conformity credentials relevant to mining, processing and trading critical raw materials.

Standardised data collection

For traceability systems to be effective, they must enable supply chains to transmit accurate, reliable and trustworthy data along their length. At a minimum, effective mineral traceability requires data on a product's origin, geographical path, chain of custody and physical evolution. Beyond this, traceability systems can also include other product attributes, such as product safety information, chemical makeup and assay results, among others.

Data on a product's ESG performance, including due diligence risk information or how suppliers have responded to risks, can be included in traceability systems. This supplementary information can be gathered from publicly available data scans (e.g. *ex ante* risk information) or through active inputs from actors along the supply chain to demonstrate how risks are being managed.

These features can help assess performance and compliance with international standards, though traceability systems alone are not sufficient for meeting international due diligence expectations. While they provide a platform for gathering and transmitting data, they do not inherently identify risks in an exhaustive fashion or ensure that the identified risks are addressed or remedied. Beyond simply tracking material flows and chain of custody, data collected through traceability systems must also lead to efforts to mitigate potential and actual sustainability risks.

To ensure comparability, data standardisation specifications play an important role in ensuring data reliability by establishing consistent requirements for what information must be collected and documented. For example, the DIN DKE SPEC 99100 standards, developed by German standardisation bodies and industry experts for the EU Battery Passport system, provide detailed guidance on which battery-related data points should be recorded – from technical specifications and material composition to carbon footprint calculations and social responsibility documentation. Unlike technical infrastructure requirements that define how data should be stored and transmitted digitally, this specification focuses on standardising what data needs to be collected and in what format. By creating a common framework for data collection and verification, such standards help prevent inconsistencies and errors that could undermine traceability systems.

ISO standards also play a significant role in facilitating data standardisation. They provide globally recognised guidelines for data management and exchange, supporting the development of common data structures, definitions and processes to ensure seamless information flow across the supply chain. Similarly, the Battery Passport Technical Guidance, developed under the Global Battery Alliance, aims to tackle this concern by providing a detailed framework for defining consistent data fields, reporting standards and verification mechanisms.

Key challenges in how traceability systems manage and transmit data include ensuring data quality, consistency and verifiability (see "Governance and verification"). Inconsistent, incomplete or false data can hinder efforts to implement effective traceability systems that can support sustainable and responsible critical mineral supply chains. Although technology-based traceability systems can improve data integrity and trustworthiness, precautions must be taken to ensure that records remain tamperproof (see "Technical infrastructure") and that the data entered into systems are accurate from the outset (see "Governance and verification"). As proxies, ESG metrics can provide indications on business performance, but their meaningfulness depends on how well they represent actual performance, which may vary widely. For example, OECD research finds that high scores for the environmental component of ESG metrics are not correlated with factors such as reduced GHG emissions and emission intensity or increased use of and investment in renewable energy.

These challenges highlight why standards on responsible business conduct call for on-the-ground risk assessments and extensive direct engagement with suppliers. While traceability systems may include features to transmit risk or other due diligence information, even the most advanced technology cannot close certain data gaps that require alternative methods of risk assessment. In contexts such as artisanal and small-scale mining operations, where data are often inaccessible or non-existent, or when dealing with smuggling and other integrity risks, alternative methods are essential. These situations require dedicated attention from individuals assigned with clear due diligence responsibilities within their respective companies or organisations.

Beyond product origin, chain of custody and physical evolution: The role of sustainability data

The data most relevant to sustainable and responsible supply chains generally fall into three categories: environmental data, such as on GHG emissions, impacts on biodiversity and water use; social data, such as compliance with domestic and international labour and human rights standards; and governance data, including regulatory compliance, payments such as revenue flows from companies to governments and data that can be used to identify governance and corruption risks, including data on regulatory compliance, payments to governments and beneficial ownership. These intersect with the risk scope of the OECD Guidelines for Multinational Enterprises on Responsible Business Conduct. Other types of ESG data may be more suitable for collection through traceability systems, whereas some may require different approaches.

Environmental data

Environmental data are theoretically more straightforward to collect and utilise than social and governance data. Data on GHG emissions, water usage, and energy consumption can be quantified using sensors and technological tracking systems, enabling easier integration into digital track-and-trace tools or blockchain technologies. Many companies already track this type of data to improve resource efficiency and demonstrate compliance with environmental regulations and reporting requirements. Many of the recent key regulatory pushes encouraging the uptake of traceability in clean energy technology supply chains, such as the EU Battery Passport, focus largely on environmental data, such as GHG emissions.

However, challenges remain in collecting environmental data. GHG data can be enormously complex to collect and calculate, biodiversity impacts from land use or water and soil contamination change require multi-year assessments with correct baselines and an assessment of health impacts on nearby populations. Additionally, environmental data must be interpreted within the appropriate local geographical context to accurately assess risk levels. For example, water usage data can indicate vastly different risk levels depending on local water scarcity, while biodiversity impacts need to be evaluated against specific local ecosystem characteristics and species presence rather than relying on simple metrics like forest cover. These challenges will require context-specific solutions, improvements in data collection efforts across the industry and the standardisation of methodology and verification.

Social data

Social data, especially related to human rights, can be more complicated to quantify, track and verify than environmental metrics, regardless of whether a traceability system is used. Traceability systems can provide valuable data on product origins, trade flows and processing locations, which contribute to assessing social risk and performance and serve as a foundation for supply chain transparency and due diligence. However, as with any data-gathering exercise, this information alone cannot determine compliance with social standards. Issues such as forced labour, fair wages, working conditions and adherence to free, prior and informed consent (FPIC) principles require robust risk assessment and ongoing due diligence, beyond tracing.

Governance data

Governance data encompass a wide range of critical aspects, from internal corporate systems and processes to broader interactions with public institutions and other companies. These include issues like corruption, fraud, regulatory compliance, illicit financial flows, tax evasion and money laundering – factors that often serve as leading indicators of broader sustainability challenges. Indeed, weak public and corporate governance typically correlates strongly with increased environmental harm and human rights violations, making it a fundamental, rather than merely technical, consideration in sustainability assessments.

Some aspects of governance data may be easily captured through technology-based traceability systems, while others require additional verification approaches. For example, some traceability platforms can record operational data, such as contracts management, transactional records and post-trade processes like financing and logistics, providing valuable insights into practices and potential risk areas related to governance.

More complex governance issues, such as corruption, fraud, regulatory breaches and illicit financial flows, benefit from combining traceability data with specialised verification and monitoring. Emerging technologies, such as artificial intelligence, can help flag data inconsistencies that may indicate governance issues and, when combined with appropriate oversight and verification, strengthen overall governance monitoring systems. Creative approaches to data collection and analysis, such as integrating multiple data sources and leveraging new technologies, continue to enhance the role of traceability in governance assessment.

Supply chain collaboration

Equally important in an effective traceability system is collaboration along the supply chain, including appropriate cost-sharing and interoperability across different companies' traceability systems. In line with due diligence expectations, each participant – from miners to exporters, processors, traders, manufacturers and retailers – has specific roles and responsibilities, and traceability systems should reflect this to enable proper generation and sharing of information.

For example, miners and exporters might focus on documenting the origin, government payments, taxes and fees and conditions of extraction or initial sustainability claims. Processors verify these claims, collect import documentation and related fee information, and make this information available to downstream purchasers, while retailers consolidate the information for consumer-facing transparency. This creates a chain of responsibility where each tier communicates effectively with the next, maintaining the integrity of information throughout the supply chain.

Upstream companies

For traceability systems covering the upstream part of the supply chain and aiming to embed risk information, the mode of production and trade – with related risks of adverse impacts – can be an important factor to consider. While ASM has more often been associated with serious human rights abuses, lack of health and safety measures and extortion by security forces, large-scale mining has also been linked to corruption and environmental and labour abuses. Given the mostly informal nature of the ASM sector, traceability systems should be adapted to ASM characteristics and rolled out progressively to incentivise participation and overcome the structural barriers ASM faces. Traceability systems targeting the large-scale mining sector could be oriented towards detecting potential anomalies related to expected versus actual production at the production stage, the purity and quantity of materials, the corresponding taxes and royalties at the export stage, and chain of custody information.

Commodity traders play a pivotal role in mineral supply chains, purchasing, transporting, storing, blending and selling ores, concentrates and secondary materials from diverse sources. These traders range from small informal operators to large multinational companies. In some cases, they also operate their own mines and refineries, adding to the complexity of their operations. As intermediaries, traders connect multiple actors across geographically dispersed supply chain stages, blending and handling minerals from diverse origins to meet client requirements for location, mineral grade and timing.

This creates significant challenges for due diligence and traceability, as the blending of materials and reliance on upstream documentation can obscure the true origin of minerals, making it harder to identify risks. Some efforts have been made to apply and interpret due diligence expectations in the context of commodity trading, including the Commodity Trading Sector Guidance on Implementing the UN Guiding Principles on Business and Human Rights. Additional challenges include managing commercially sensitive information and implementing traceability systems for spot market purchases versus longer-term agreements. The fast-paced nature of trading and the potential for supply chain opacity may justify greater traceability efforts, including detailed identification of origin, transit routes, and blending or mixing processes, to ensure responsible sourcing.

Downstream companies

Downstream corporations and original equipment manufacturers can help drive market signals for enhanced accountability, traceability, and ESG practices throughout the supply chain. Sector-wide, industry-wide and multi-stakeholder sustainability initiatives can play an important role in identifying upstream suppliers and providing other due diligence information for both upstream and downstream companies. For example, they can provide templates for supplier identification letters and due diligence disclosure information, as well as facilitate the sharing of information on supplier identification, supply chain structures and risk profiles.

Scale and purpose can be important considerations, too. While most companies operating between the mining and refining stages typically set up internal material tracking systems from the mine of origin to the processing facilities, there are already examples of traceability systems with a wider geographic or supply chain coverage for due diligence purposes (see “Lessons learned from traceability initiatives”, Chapter 5).

Cross-cutting collaboration

Industry associations and sustainability initiatives can help support collaboration. Spanning a range of functions related to due diligence, certification and supply chain transparency, sustainability initiatives tend to fall into two categories: facilitation and verification. In this context, facilitation initiatives are better suited to delivering traceability, whereas verification initiatives are suited to checking the results generated by traceability and the broader due diligence process it supports. Both types of sustainability initiatives can play a role in transmitting data.

Challenges

In practice, there are significant challenges to collaboration. Commercial confidentiality concerns are not always well defined. This risks the issue being used as a pretext for opacity or, alternatively, being overlooked. Some sustainability initiatives are positioning themselves as trusted repositories of data shared through traceability and as facilitators to direct this information to those who need it. Neutral third parties have also been proposed to support information flow, but these concepts have yet to be piloted in a meaningful way. In some contexts, enterprises have raised competition law concerns with respect to collaboration amongst companies through sustainability initiatives. According to the MNE Guidelines, "While enterprises and the collaborative initiatives in which they are involved should take proactive steps to understand competition law issues in their jurisdiction and avoid activities which could represent a breach of competition law, credible responsible business conduct initiatives are not inherently in tension with the purposes of competition law and typically collaboration in such initiatives will not be in breach of such laws."

At a minimum, even accounting for commercial sensitivities, traceability should enable smelters, refiners and companies further upstream to identify mines of origin. The information obtained from traceability should allow downstream companies to understand countries of origin so that they can carry out red flag assessments in line with the OECD Minerals Guidance.

To the extent that sustainability initiatives serve a data repository function, collaboration between them, including across borders could play an important role in facilitating traceability. However, in the context of initiatives operating at different segments of the supply chain, upstream schemes that manage confidential or commercially sensitive data on supply chains can be unwilling or unable to share information with downstream schemes (see also "Regulatory and enforcement limitations", Chapter 3). Cross-recognition between sustainability initiatives can help, but initiative owners should take care not to dilute expectations or make the due diligence process perfunctory. In this regard, it is worth recalling that companies retain individual responsibility for their due diligence and that all joint work should consider the circumstances specific to each company.

Collaboration between initiatives and governments can help maintain shared expectations and build trusted platforms for data to flow. Anchoring such collaboration in the overall due diligence process and keeping it focused on mitigating risks to people, the planet and society in mineral supply chains can help foster trust and maintain alignment.

Governance and verification

Traceability systems are only as reliable as the data they receive. Ensuring robust data inputs is, therefore, as critical as implementing secure methods for information exchange. If inaccurate or fraudulent data are introduced, the system will simply replicate those errors across the supply chain.

Appropriate safeguards need to be put in place to prevent data reliability issues. For example, reconciling physical tracking data while accounting for conversion and loss factors can help detect inconsistencies and red flags in volumes and financial transactions within traceability systems. Furthermore, advanced technologies for traceability may provide additional data points for reconciliation, despite trade-offs related to costs and uptake.

Another key component of an effective traceability system is its capability to account for corruption and conflicts of interest, which can threaten the reliability and integrity of the data and systems. Strengthening oversight, implementing multiple verification levels and using independent audits can all help counter any potential fraudulent documentation of claims about origin, composition or producer. This may be particularly important at certain stages of the supply chain, such as processing, that may be susceptible to false claims about recycled content, the mixing of raw materials from unverified sources or different modes of production.

Different traceability systems may pose different risks – for example, in traceability schemes employing bagging and tagging systems, tags obtained through bribery may be misused to validate production from non-validated mine sites. To combat these risks, effective traceability systems can benefit from multiple layers of verification and assurance to enhance data reliability. When government-issued documentation is used, additional oversight, such as monitoring the rule of law, corruption red flags and allegations of fraud in the minerals sector, can help ensure that information is accurate and trustworthy. In some cases, this may prompt companies to require additional levels of verification at certain stages of the supply chain for suppliers located in high-risk geographies.

The verification challenge becomes even more critical when traceability systems incorporate ESG data. Fraudulent audit results or compliance certificates – secured through business-to-business corruption or bribes to inspectors – can infiltrate a system and compromise its reliability. Sustainability initiatives can, therefore, play an important role in facilitating traceability information or providing third-party verification of traceability systems, in addition to other parts of the due diligence process. Depending on the scope of the sustainability initiative, facilitation and verification initiatives may both feature traceability in some way. Facilitation initiatives are more likely to deliver traceability, whereas verification initiatives are more suited to checking the results generated by traceability and the broader due diligence process it supports.

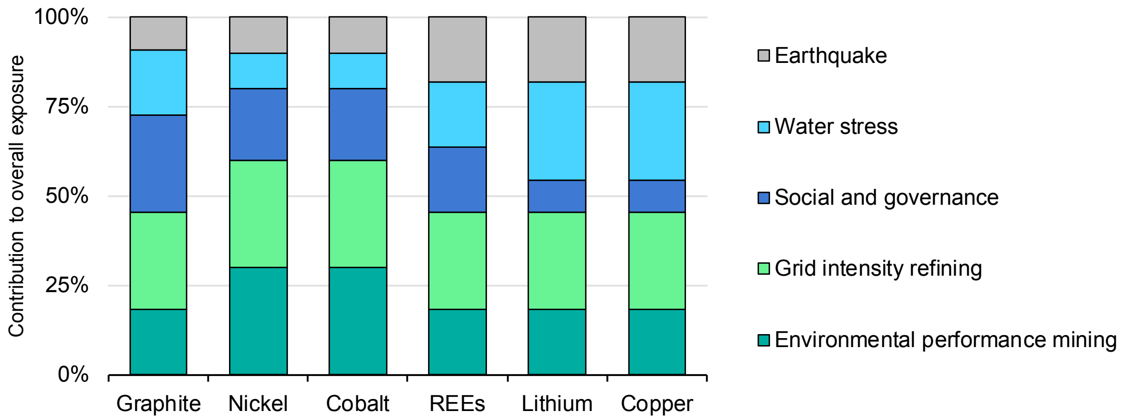
The effectiveness of verification initiatives varies depending on the quality and independence of their assessment and assurance processes, the robustness of their assessment methodologies and the extent to which they hold participating companies accountable for underperformance. Their credibility, therefore, hinges on factors such as governance structure and approaches to the management of conflicts of interest and information disclosure – in addition to other criteria laid out in the principles for Good Governance in the OECD Due Diligence Guidance for Responsible Business Conduct and ISEAL Credibility Principles.

These credibility criteria are also applicable to the way traceability systems are designed and operated. The governance framework is particularly crucial for maintaining stakeholder trust in the information held by traceability systems and how it is carried across supply chains. Including relevant stakeholders like civil society representatives and, where applicable, Indigenous Peoples in the design and operations of traceability systems ensures systems are credible, legitimate and adapted to local contexts of production and trade, particularly in high-risk areas.

Chapter 5. Considerations for energy transition minerals

Supply chains for different minerals have certain common attributes. However, there are important differences that require careful consideration when looking at how traceability systems can be implemented. These characteristics include the geographical location of operations, the technical complexity of processing and the number of companies operating in the supply chain, as well as the degree of concentration within those supply chains. There may also be unique sourcing challenges and ESG performance and risks. Some minerals, such as copper, nickel and cobalt, are co-produced. This can pose additional specific challenges to traceability, as differentiating and tracking each material's origin, production path, and ESG characteristics may require more complex data management and greater collaboration across the supply chain, especially if co-produced materials are blended or mixed at various stages. These factors may impact the level of visibility required, the degree of traceability system that is justifiable and the type of technology that is best suited.

Figure 5.1. IEA's assessment of exposure to environmental, social and governance performance for energy transition minerals



Notes: REEs = rare earth elements. Environmental performance of mining refers to the weighted average environmental performance score of today's mined production, based on selected indicators in Yale's Environmental Performance Index. Grid intensity refining is the weighted average grid carbon intensity of the regions refining minerals today. Social and governance refer to the weighted average corruption, human rights and conflict scores of today's mined production, based on relevant indicators in the V-Dem database. Water stress is the share of mining production located in areas with high or extremely high water stress and arid conditions. Earthquake refers to the share of mining production located in areas with high earthquake risk.
Source: Based on IEA (2024), Global Critical Minerals Outlook 2024.

Full traceability for every mineral would require significant cost and effort to implement. According to the OECD Minerals Guidance, the measures that a company takes to conduct due diligence should be commensurate with the severity and likelihood of the adverse impact, which tends to be higher in conflict-affected or high-risk areas. Therefore, it may be useful to evaluate the complexities and risks associated with each individual supply chain to provide valuable insights into the costs and benefits of traceability systems in different critical mineral supply chains. This section considers "key energy transition minerals" (also referred to as "focus minerals") – copper, lithium, nickel, cobalt, graphite and rare earth elements – as they are the minerals most critical to clean energy technologies due to their high intensity of use.

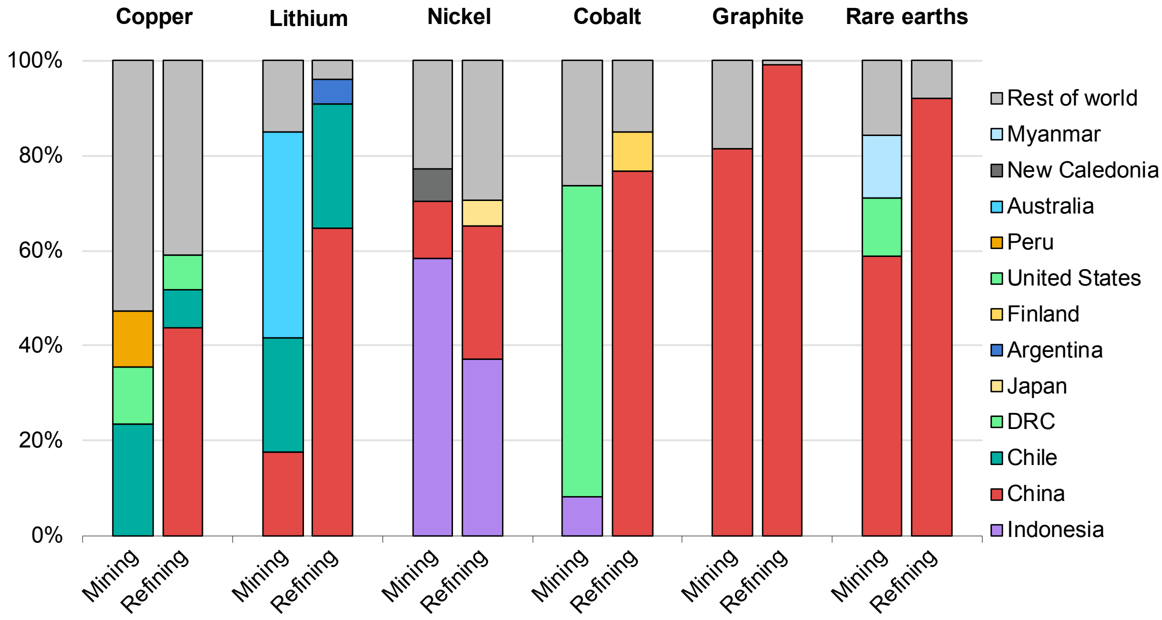
Table 5.1. Summary of considerations for the traceability of different minerals

Mineral	Sourcing challenges	Processing complexities
Copper	Complex and global supply chain.	Often blended during smelting and refining.
Lithium	Sourced mainly from two types of deposits; impacts and risks between the two are significantly different.	Extensive processing with conversion from brine or spodumene to lithium hydroxide or lithium carbonate.
Nickel	Production of nickel sulphate used in batteries is largely concentrated in markets where there may be low visibility over adverse impacts.	Combination into different products depending on the end-use, with various intermediaries produced that require further processing for battery-grade nickel.
Graphite	Battery-grade graphite production largely concentrated in markets where there may be low visibility over adverse impacts.	Battery-grade graphite requires high purity, which requires additional complex processing. Synthetic and natural graphite are often blended.
Cobalt	Concentrated upstream supply. ASM accounts for an average 5-15% share of the global total.	Often produced as a by-product of copper or nickel. Mixing of sources from various mines, including large-scale mining and ASM.
Rare earth elements	Midstream production largely concentrated in markets where there may be low visibility over adverse impacts.	Different rare earth elements are often extracted together and require complex separation processes.

Copper

Copper is among the most complex energy minerals in terms of supply chain logistics. While copper is mainly used in infrastructure, such as for construction and electricity networks, which accounted for 25% and 20% of global demand in 2023, respectively, it also sees demand from numerous applications such as industrial machinery and equipment and the transportation sector. The production of copper is also among the least concentrated of all the minerals (see Figure 5.2), with mining occurring in over 60 countries, and the largest countries – Chile, China and Peru – accounting for less than half of global production.

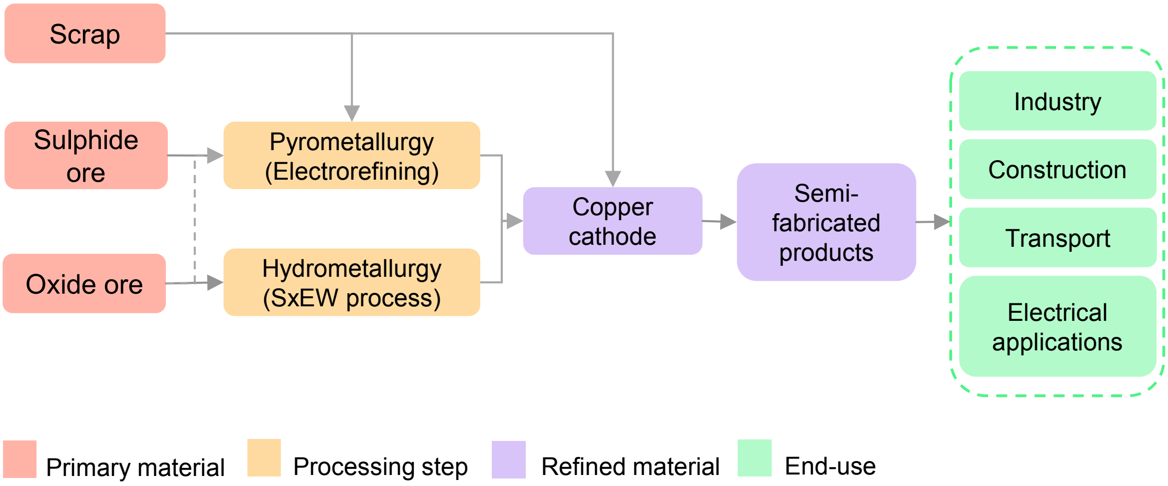
Figure 5.2. Geographical concentration of mining and refining for critical minerals, 2023



Notes: DRC = Democratic Republic of the Congo. Graphite extraction is for natural flake graphite. Rare earths are magnet rare earths only.

Refining is more concentrated, with China accounting for 45% of global copper refining. However, over 55 other countries also produced at least some copper in 2023. In the process of producing final refined copper, the metal is often blended during both the smelting and refining stages, requiring careful consideration of ways to differentiate products down to the batch level when integrating traceability systems into the supply chain. Although copper is less geographically concentrated compared to other energy transition minerals, reducing its geopolitical risks, the diversity of end-uses and the technical process of refining it into a final product increase the complexity of traceability in the copper supply chain (Figure 5.3).

Figure 5.3. Copper supply chain



Note: SxEW = solvent extraction-electrowinning.

Copper faces ESG risks that include the high emissions intensity of the grid in refining locations, the energy-, water- and waste-intensive nature of the mining phase, which will become increasingly significant as lower-grade copper deposits are mined, and the high water stress faced by copper production operations in drought-prone regions. Failure to secure a social licence to operate and conduct adequate free, prior and informed consent processes can lead to opposition from local communities and disrupted 0.1% of global copper's initial mine production targets in 2023. Over the last 5 years, weather-related incidents disrupted an average of 0.4% of global copper's initial mine production targets.

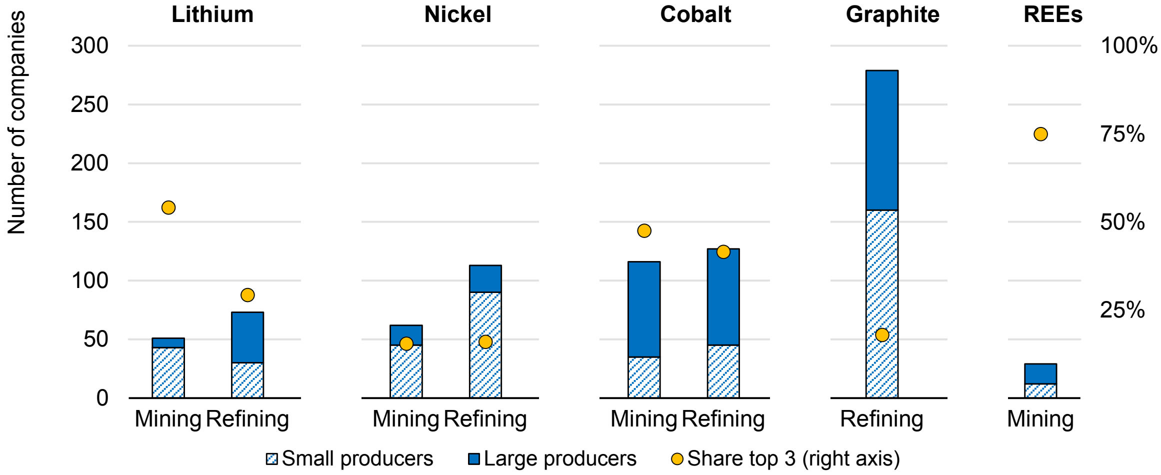
In certain countries, copper ASM comprises a significant part of national production. In Peru, it is estimated to employ 100 000 people working in almost complete informality. The material enters legal supply chains through certain copper concentrators or "invoicers" (licence-holders with no actual mining operations). In 1960, Chile created ENAMI, a state-owned enterprise that to this day buys ASM copper and gold, carries out smelting, and provides credit and capacity building to miners.

Lithium

While lithium is used in a variety of applications such as ceramics or lubricants, as well as in small volumes in pharmaceuticals, batteries have become the predominant end-use for lithium over the last 10 years. As lithium is a key component in battery chemistries, electric vehicle batteries are expected to account for over 80% of lithium demand across all of the IEA's *World Energy Outlook* scenarios by 2030, potentially simplifying the supply chain in the future.

Primarily, lithium is sourced from brines in Latin America (Argentina and Chile) and hard rock in Australia, which together accounted for over 70% of production in 2023. Within those countries, there is a high concentration among the top three lithium-producing operators (Figure 5.4), who accounted for just over 50% of production in 2024. Despite this, the rest of the world's production is spread out among a large number of smaller producers, who account for 85% of companies. Although a high level of concentration among top producers could allow for easier traceability in lithium supply chains, the rest of production, being carried out by small producers, could increase the complexity and cost of traceability systems.

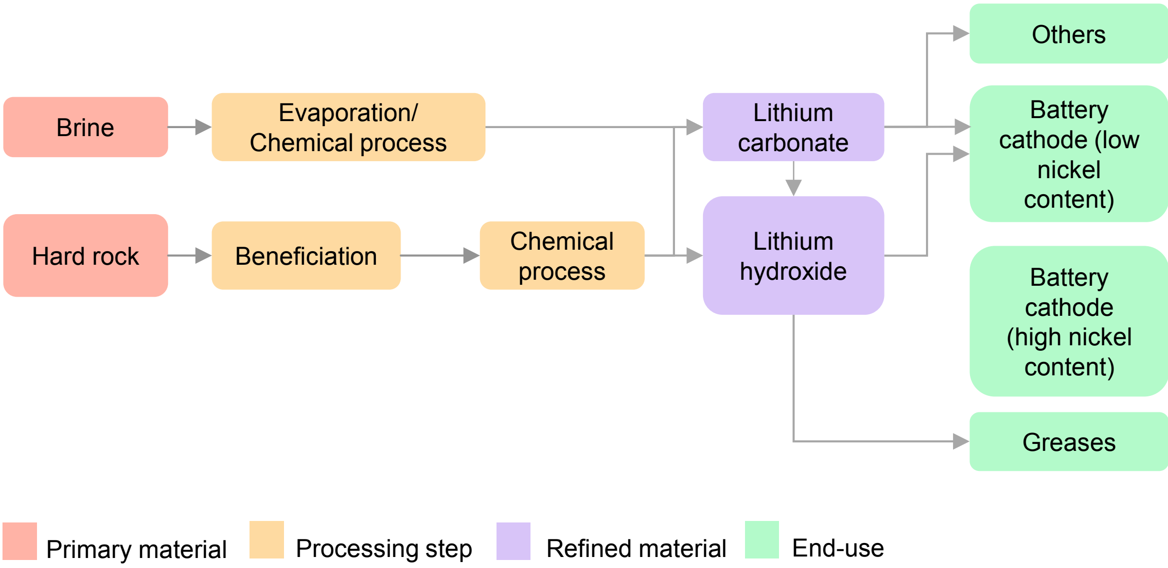
Figure 5.4. Concentration of production among companies in mineral supply chains, 2023



Notes: Small producers are defined as those with less than the average amount of production per company. Nickel and cobalt consider the number of owners, whereas lithium, REEs and graphite consider the number of operators. For some minerals, data only cover a percentage of total production: nickel mining, 58%; nickel refining, 95%; and REE mining, 86%.

The refining of brine or hard rock lithium into lithium carbonate or hydroxide requires extensive processing (Figure 5.5). This process largely occurs in China, which accounted for nearly two-thirds of refined production in 2023. Compared to the mining segment, there is less concentration among companies in refining, with the top three accounting for only 30% of production, and a lower number of small producers. Therefore, the complexities of traceability within the lithium supply chain are largely driven by the diverse extraction methods and the large number of small companies in the mining segment, which could potentially increase costs for tracing lithium supply chains.

Figure 5.5. Lithium supply chain



In the lithium supply chain, the largest ESG risks that should be considered when setting up traceability systems for due diligence revolve around its high water demand and the environmental performance of its refining sector (Figure 5.1). Brine extraction, a common method of obtaining lithium, is particularly water-intensive and typically occurs in arid regions where water scarcity is already a significant concern. Insufficient consultation with local communities and the absence of free, prior and informed consent from Indigenous Peoples have led to opposition to extraction projects, such as in Argentina, Portugal and the United States. There have also been governance issues around the acquisition of licences in Chile, the Democratic Republic of the Congo and Namibia.

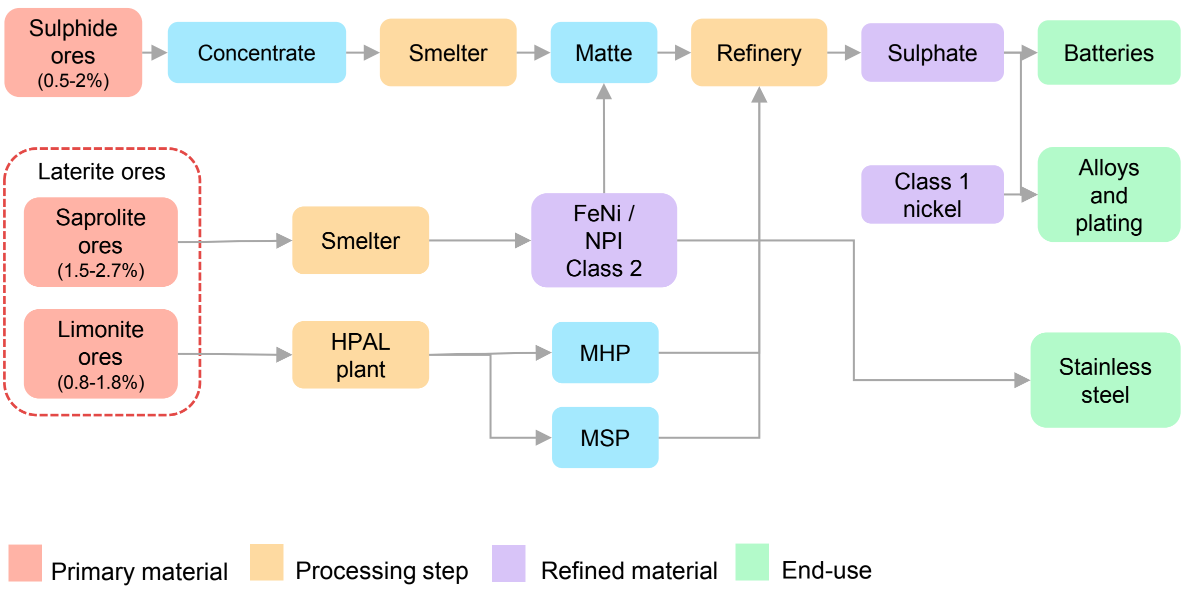
Nickel

Nickel is primarily used in alloys for stainless steel, with 60% of demand coming from this application in 2023. However, it also plays a dominant role in a variety of battery chemistries, making it an important contributor to the energy transition. In climate-driven scenarios, demand for nickel from clean energy technologies is expected to reach around 50% by 2050. Nickel has moderate geographical concentration for both mining and refining, with the top three countries accounting for around 70% for both processes (Figure 5.2). This is expected to further increase towards 2030, as many of the announced projects in the pipeline are in the world's incumbent players. Outside the top three, there are just over 25 other countries that mine or refine nickel in varying quantities.

Despite the level of geographical concentration, the concentration among companies is quite low compared to other minerals, with the top three companies accounting for only around 16% for both mining and refining (Figure 5.4). Small producers account for a large portion of the total number of companies, at about 75% for both segments. Similar to lithium, the relatively high level of geographical concentration of nickel may allow for easier traceability, but this is counterbalanced by the relatively large number of small producers.

Nickel ore comes from various sources – laterite ore is found in Indonesia, New Caledonia the Philippines, and Australia while sulphide ore is found in Australia, Canada, China and the Russian Federation (hereafter, "Russia"). These different types of ore require distinct processing methods to produce battery-grade nickel, making traceability in nickel supply chains complex (Figure 5.6). In recent years, the practice of processing lower-grade nickel into intermediates has emerged, largely taking place in Indonesia. Intermediates are then transformed into battery-grade nickel sulphate in China. Almost 75% of battery-sulphate production takes place in China. Due to the multiple sources of ore and the associated processing pathways, including the intermediate stages, full traceability in nickel supply chains can be highly complex and costly to implement. For certain high-grade nickel with vertical integration – such as production that occurs in Canada – it may be easier and less costly to implement.

Figure 5.6. Nickel supply chain



Notes: HPAL = high-pressure acid leaching; FeNi = ferronickel; NPI = nickel pig iron; MHP = mixed hydroxide precipitate; MSP = mixed sulphide precipitate.

Nickel has high ESG risks. Its low environmental performance in mining can result in high levels of biodiversity risk, while nickel refining is energy- and carbon-intensive, particularly for laterite ore processing in the currently dominant pathways. Refining can also produce high levels of waste, particularly in the emerging processing pathway of high-pressure acid leaching. In Indonesia, a string of corruption cases related to nickel mining and smelting put the spotlight on corruption risks at the licensing stage, as well as the interlinkages between governance and environmental harm. There has also been opposition to projects and operations due to adverse and unmitigated impacts on local communities, particularly Indigenous Peoples, in Indonesia and the Philippines.

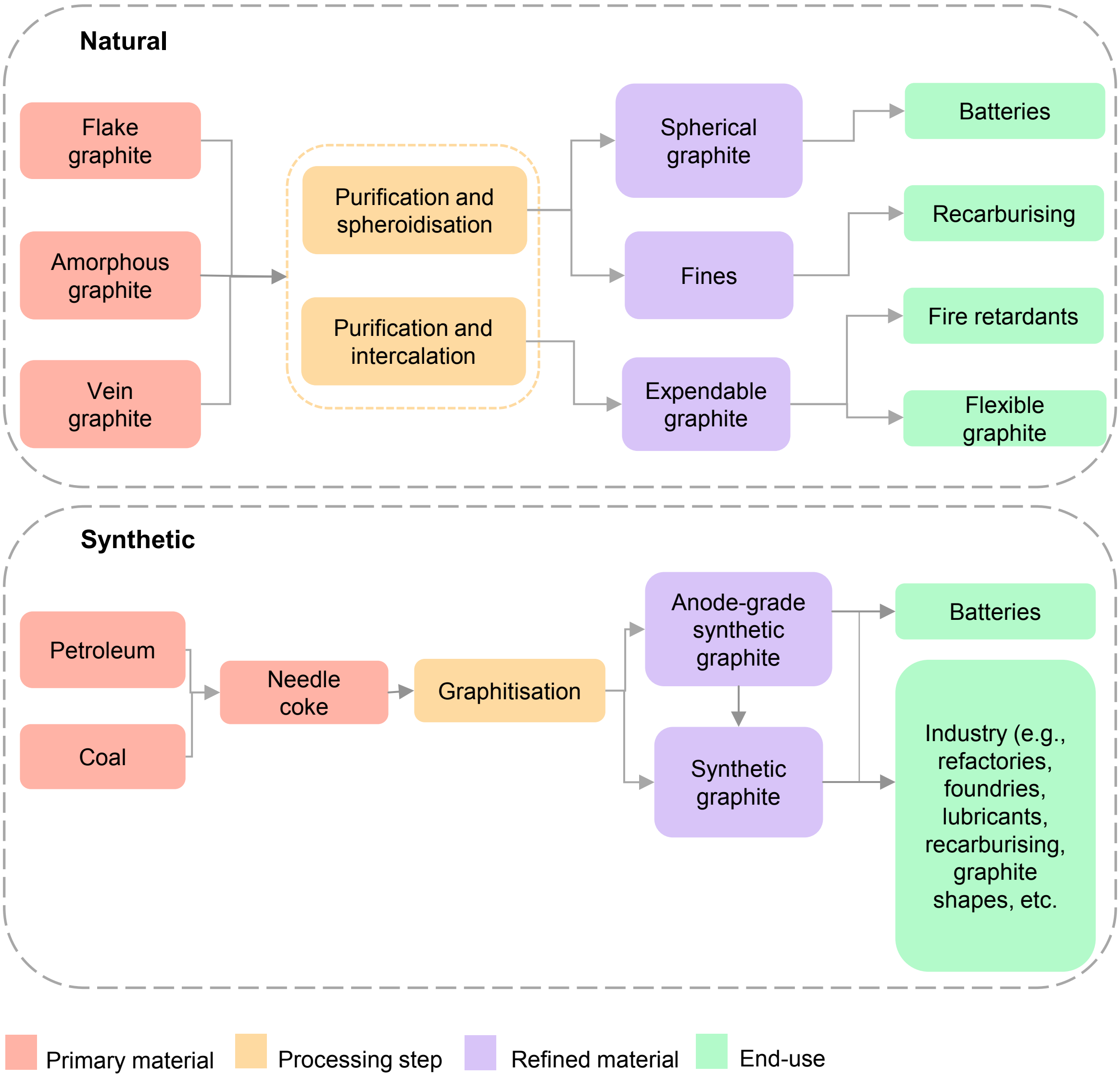
Graphite

Historically, graphite has primarily been used in the metallurgical industry as an input for steel making and as electrodes in electric arc furnaces. However, the battery industry is rapidly emerging as the leading consumer of graphite due to its use in anodes and is expected to account for about half of total demand by 2030.

Battery-grade graphite supply can be sourced from either natural or synthetic graphite, both of which must meet high purity requirements (Figure 5.7). Achieving this involves additional processing, which may include the blending of natural and synthetic graphite. This complex processing may complicate traceability efforts for graphite, particularly in the midstream.

Graphite is the most geographically concentrated mineral, with about 80% of mining and almost 100% of refining occurring in China. It also has the highest number of companies in its supply chain out of any critical mineral, at almost 300, and a low level of concentration among the top three companies, which account for just under 20% of production (Figure 5.4). All of these factors mean that full traceability of the graphite supply chain may be extremely difficult and costly.

Figure 5.7. Battery-grade graphite supply chain



OECD/IEA. CC BY 4.0.

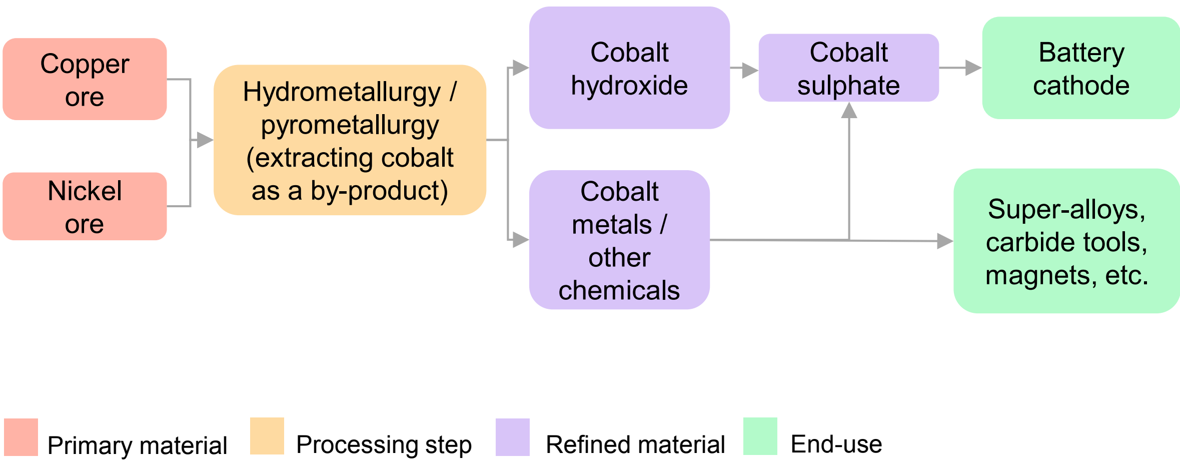
Graphite faces significant ESG challenges. Many graphite refining operations are concentrated in areas with carbon-intensive grids, further increasing emissions levels, and in areas with poor social and governance performance. The specific risks vary depending on whether natural or synthetic graphite is considered. Natural graphite tends to have a lower environmental footprint during production, whereas synthetic graphite, produced from carbon-rich materials such as petroleum coke, generates over four times the carbon emissions of natural graphite anodes.

Cobalt

Cobalt is a key component of batteries, particularly for portable batteries used in electronics, which accounted for the largest share of demand in 2023 at just over 40%. In the future, EV batteries will drive growth in cobalt demand. In the IEA's Net Zero Emissions by 2050 Scenario, demand grows by 4.5 times by 2040, and EV batteries are responsible for the largest share of total cobalt consumption by the end of this decade, with the share rising to 60% by 2040 in a climate-driven scenario.

The mining of cobalt is heavily concentrated in the Democratic Republic of the Congo, which accounts for 65% of the supply. Tracing cobalt to the mine sites poses numerous challenges, including potential interaction between large-scale mining and ASM, both commercially and physically, throughout all segments of the upstream supply chain. ASM in the Democratic Republic of the Congo has accounted for an average of 5-15% over the last decade. Cobalt is also typically mined as a by-product of copper and nickel, potentially complicating efforts to separate and trace it individually throughout the supply chain down to the mine level (Figure 5.8). At the midstream, cobalt refining mostly takes place in China, a market that accounts for almost 80% of refining and smelting operations.

Figure 5.8. Cobalt supply chain



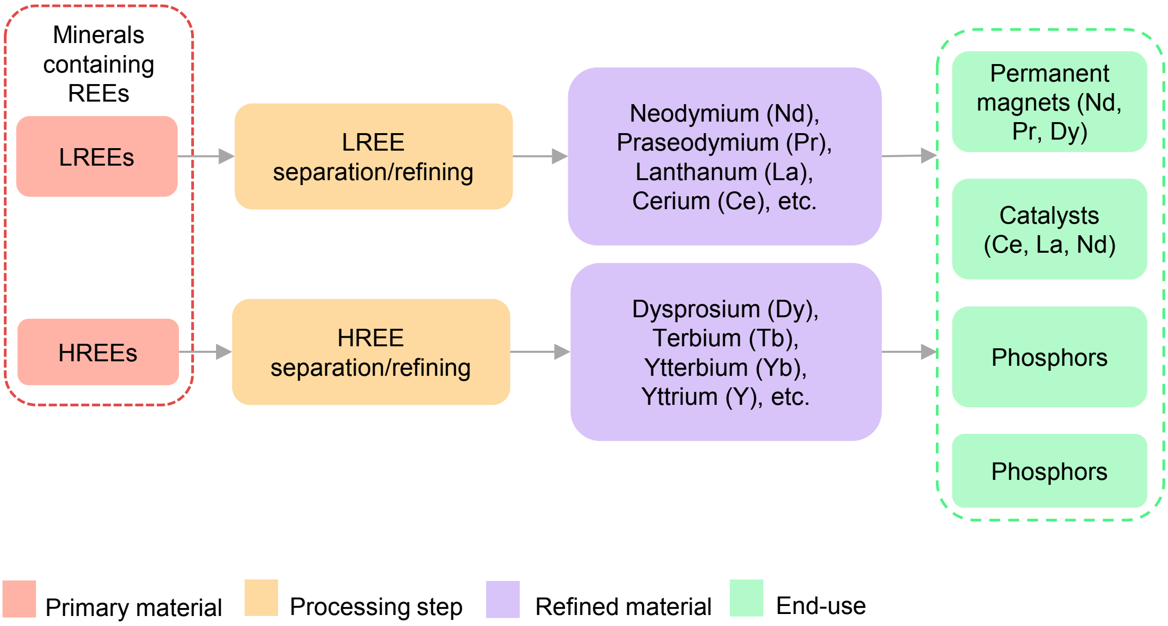
OECD/IEA. CC BY 4.0.

In contrast with other critical minerals, cobalt has relatively higher levels of company concentration in its supply chain (Figure 5.4), with the top three owners in the formalised sector accounting for around 45% of both mining and refining. There are not as many small producers operating in the formalised sector of the supply chain. This makes it easier to achieve a high level of traceability, at least outside the ASM sector, provided there is co-ordination among the major actors in the supply chain. However, much of the high social and governance risk associated with the cobalt supply chain stems from the informal sector, which has historically been linked to human rights abuses. Disengaging from this sector due to the challenges of achieving full traceability does not constitute responsible sourcing and may exacerbate the root causes of child labour. There are also high risks associated with the environmental performance of mining and refining, a key concern that traceability solutions may help address.

Rare earth elements

Rare earth elements are essential for magnets, which play a crucial role in energy technologies, including automotive traction motors and wind turbine motors. The production of rare earth elements is the second most geographically concentrated of all key energy transition minerals – over 85% of the mining occurs in the top three producers, while over 90% of refining takes place in China. Traceability in this supply chain may be difficult, particularly due to the large number of small producers, which account for almost 50% of all companies mining rare earth elements. Traceability to the individual product level is further complicated by supply chain complexities, as different elements are often extracted together and require complex and costly separation processes. China has only two main rare earth element refiners, making it potentially challenging for other companies in the supply chain to exert leverage on responsible sourcing issues.

Figure 5.9. Rare earth elements supply chain



Notes: LREEs = light rare earth elements; HREEs = heavy rare earth elements.

Rare earth elements faces one of the highest weighted average grid intensity scores for refining operations. The supply chain also faces social and governance risks, which may be particularly difficult to trace in cases of illegal mining, such as smuggling from Myanmar, Malaysia and Viet Nam to China. Most rare earth element mining operations in Myanmar occur near the Pang War-Tengchong border crossing with China in Kachin State, which is largely controlled by the Kachin Independence Organisation. Due to the proximity of these critical resources to China, the vast majority is transported across the border for further processing and refining at multiple rare earth element processing facilities throughout China, which often combine raw materials from diverse sources, making traceability difficult.

Lessons learned from traceability initiatives

Mineral supply chains

The implementation of traceability systems has evolved significantly, starting with early efforts focused on supply chains in specific geographical areas or precious metals (see Box 6.1) and expanding to broader applications across critical mineral supply chains. With few exceptions, many early traceability initiatives were set up in response to media reporting or advocacy by civil society organisations. These efforts, often led by individual companies, focused narrowly on selected risks of adverse impacts within specific regions and never went beyond the pilot stage, raising questions about the limits of voluntary mechanisms.

Many early adopters of traceability systems were concentrated in certain countries, such as the Democratic Republic of the Congo for tin, tungsten and tantalum in the 2010s, and cobalt after 2016. Traceability first emerged in 2011 through industry initiatives like the ITSCI Programme, which started implementing traceability jointly with government agents through a sector-wide bagging-and-tagging system of tin, tantalum and tungsten originating from the African Great Lakes region to meet international responsible sourcing regulations for these supply chains.

Other early examples of traceability initiatives emerged in the cobalt sector after 2016, driven by concerns about human rights abuses in the Democratic Republic of the Congo, which supplies around 70% of the world's cobalt. Downstream companies – including some in the clean energy sector – began using traceability systems to improve visibility in their cobalt supply chains, facilitated by service providers. After 2020, the scope of traceability initiatives in minerals expanded even further to encompass other minerals relevant to clean energy technologies. Many private and public traceability initiatives in the 2020s focused on integrating sustainability data, particularly on GHG emissions, with product traceability information.

With the progressive adoption of private sector requirements by key market-makers, such as the London Metal Exchange's Responsible Sourcing programme, as well as regulatory initiatives (see Chapter 3), traceability systems gradually expanded to encompass broader critical mineral supply chains spanning multiple countries. Current consumer and regulatory pressures for mandatory due diligence in critical raw material sourcing largely rely on downstream players for enforcement and reporting, with requirements on upstream and midstream players slowly cascading up the chain through industry initiatives and audits.

The Global Battery Alliance's Battery Passport pilots in 2024 demonstrated both the potential and the challenges of implementing a global system for battery sustainability management, comparison and certification. Working with ten consortia representing 80% of global EV battery manufacturing, the pilots revealed several critical insights. While almost 250 site-level reports were generated covering sustainability data, some companies limited their disclosure due to uncertainties about how commercially sensitive information would be shared, suggesting the need for a robust and transparent data access model. A framework for grouping different stages of battery production helped improve transparency, while areas for greater standardisation were identified to ensure meaningful comparisons between manufacturers. The pilots' scoring methodology also revealed challenges in ensuring comparability, due to variations in the scope of reported data and incomplete verification of results.

Table 5.2. A sample of traceability system implementations by private companies in the mineral value chain before and after 2020

Market players	Cobalt	Nickel	Lithium	Copper	Tantalum
Responsible Sourcing Blockchain Network	○ (blue)				
Volvo, CATL and LG Chem	○ (blue)				
Mercedes-Benz Cars	○ (blue)				
Power Resources Group (PRG) pilot					○ (blue)
Volvo and SQM			○ (orange)		
Automotive Cells Co (JV between Stellantis, TotalEnergies and Mercedes-Benz Group)	○ (orange)	○ (orange)	○ (orange)		
Trafigura	○ (orange)	○ (orange)			
Ørsted, Siemens Gamesa, and Siemens Energy Grid Technologies				○ (orange)	
BHP and Southwire pilot				○ (orange)	

Note: Blue circles indicate implementation before 2020; orange circles indicate implementation after 2020.

Box 6.1. Lessons learned from traceability in the supply chains of precious metals and stones

In 2003, the Kimberley Process Certification Scheme became one of the first processes set up in the mineral supply chain with the aim of preventing "conflict diamonds" in global supply chains. Under the scheme, producing countries certify the conflict-free status of rough diamonds and produce chain of custody documentation. While the scheme has built powerful infrastructure to track the movement of diamonds, it has faced several challenges related to the design and implementation of its chain of custody system, including an overreliance on government controls for certification, which may be undermined by limited capacity, corruption and coercion. There have also been complications with the widespread use of the scheme's mixed origin certificates for shipments containing materials from multiple sources.

In the gold supply chain, initiatives have included the Just Gold project, implemented by the non-governmental organisation IMPACT between 2012 and 2020, which used a mixed-method chain of custody approach to trace artisanal gold from mining sites in the Democratic Republic of the Congo and Côte d'Ivoire through a traceability and due diligence digital data-sharing platform. The government of the Democratic Republic of the Congo developed the Traceability Initiative for Artisanal Gold to certify the origin and chain of custody of artisanal gold using a paper-based system. In Latin America, the Brazilian government's Ouro Alvo project analyses gold's geochemical, morphological and isotopic signatures to verify document-based chain of custody. Non-governmental organisations and multi-stakeholder initiatives in South America have also implemented formalisation initiatives combined with closed-pipe traceability to refiners or jewellers, such as those put in place by the Swiss Better Gold Association and the Alliance for Responsible Mining. Major market actors have also sought to set up traceability initiatives from mine to refiner, such as the Gold Bar Integrity Programme by the London Bullion Market Association and the World Gold Council.

For many of these pilots and initiatives, market viability proved to be a significant issue, as challenges linked to gold volume and inventory financing are compounded by a market that prefers to avoid certain geographical contexts. As a result, legal artisanal mining supply chains cannot compete with informal or illegal buyers who offer higher prices (as the material is subsequently smuggled without paying taxes) and immediate compensation. As in other mineral supply chains, smaller actors tend to face sizeable constraints, often associated with limited liquidity, small margins and higher costs of doing business. While several forms of downstream contributions support upstream traceability and due diligence (e.g. through membership fees or premiums paid for the minerals), the costs of doing business responsibly remain a competitive disadvantage where responsible business conduct is the exception rather than the norm.

Other industries

Traceability systems are widely used in industries outside the mineral sector. By examining the challenges these industries have faced when implementing traceability systems, along with the solutions they have adopted, the mineral industry can identify good practices and strategies for mitigating similar challenges. At the same time, it is important to note that some of these industries may not be organised in the same way as the mineral sector, and some of the approaches in these other industries may not be readily applicable.

Food supply chains

Traceability systems have a long history in food supply chains. Traceability first emerged in the mid-1930s as a way for agricultural producers to prove the origin of high-value products, such as French champagne. Since the mid-1990s, outbreaks of foodborne diseases and food adulteration scandals have accelerated the adoption of traceability systems in food supply chains. Beyond food safety, other factors are also driving the increased adoption of traceability in global food supply chains. The seafood industry, for example, has been marred by issues of illegal fishing practices and human rights abuses. Traceability systems are increasingly seen as a tool to address these issues.

Although traceability has risen in prominence in the food industry over the past 30 years, some challenges remain. Food supply chains can be highly complex and fragmented, with products crossing multiple borders before reaching consumers. Additionally, implementing a food traceability system can be time-consuming and cost-intensive, particularly for small-scale farmers. Interoperability also remains a significant challenge for full end-to-end food traceability, as different actors along the supply chain often use different information technology systems. This challenge is further aggravated by the multiplicity of standards on food safety and sustainability, which are often inconsistent.

To address some of these issues, stakeholders in the food industry have launched various measures:

- **Industry alignment on interoperability standards:** To increase interoperability, some food industry actors have come together to draft common interoperability standards for traceability. For example, in 2017, two dozen companies came together to create the Global Dialogue on Seafood Traceability. In 2020, after 3 years of dialogue among participants, the foundation released its Standards and Guidelines for Interoperable Seafood Traceability Systems (GDST Standards). The GDST Standards have two main components: (1) standards identifying the minimum data elements that need to be documented and transmitted within compliant seafood supply chains; and (2) standards governing the technical formats and nomenclatures for sharing data among interoperable traceability systems. By increasing interoperability along the seafood supply chain, the GDST Standards have the potential to reduce costs for operators and improve traceability.

- **Financial support for traceability systems:** To support the implementation of food traceability systems, governments across the world are providing financial assistance to food operators. Examples include Australia's Agricultural Traceability Grants and British Columbia's Traceability Adoption Program.
- **Mandatory traceability obligations:** To ensure that food operators adhere to a common minimum set of traceability practices, many countries – including Canada, the European Union, Japan, the United Kingdom and the United States – require operators to comply with certain traceability obligations and set up systems that enable tracing of the origin and destination of food products. In many countries, food operators are required to implement a traceability system based on the "one step back, one step forward" model, which requires them to identify *from whom* and *to whom* a product has been supplied. This is currently the case in Canada, the European Union and the United Kingdom.

These examples from the food industry can offer valuable lessons for mineral supply chains, showing that mineral traceability could be made more effective and less cost-intensive through the introduction of common interoperability standards, financial support from governments and common mandatory traceability obligations.

Deforestation

In recent years, traceability has emerged as a key tool to deliver greater accountability with regard to deforestation taking place in global supply chains. The European Union's Deforestation Regulation (EUDR) is a recent prominent anti-deforestation initiative that relies heavily on traceability as a tool. From December 2025, the EUDR will prohibit operators and traders from placing certain commodities and products – including cattle, cocoa, coffee, oil palm, rubber, soya and wood – on the EU market if they are associated with deforestation or forest degradation. To confirm that the commodities or products are deforestation-free, operators and traders will need to submit a due diligence statement prior to placing them on the EU market, indicating the geographical co-ordinates of all plots of land where they were produced.

The EUDR has faced criticism from some stakeholders. In particular, certain European industry associations have argued that geolocation information could be difficult to obtain, particularly for those commodities produced by smallholder farmers. Some exporting countries consider geolocation information to be confidential under data protection laws, meaning operators and traders may not be able to obtain this information without breaching the exporting country's laws. Other exporting countries, such as Côte d'Ivoire and Indonesia, do not currently have national traceability systems for some of the commodities covered by the EUDR, making it difficult to trace them back to the farm of origin. Meanwhile, the European Feed Manufacturers' Federation has noted that intermediaries are often reluctant to share information about smallholder farms for fear of being passed over by purchasers.

In addition, the obligation to compile geolocation information will likely entail costs for EU operators and traders, as the European Commission itself has recognised. Small and medium-sized enterprises may be particularly affected by these compliance costs. Commodity producers in developing countries may also face increased costs, especially if EU operators and traders shift compliance costs onto upstream producers. Consumers could also be impacted, as operators and traders might offset compliance costs by raising prices. To reduce transaction costs, some operators and traders may decide to simplify their supply chains, such as by sourcing from larger agricultural farms or operating their own farms in exporting countries. This could result in smallholders being excluded from global supply chains.

The European Union has introduced various measures to address some of these challenges:

- The EUDR contains lighter requirements for small and medium-sized enterprises, including simplified due diligence obligations and deferred entry into force, providing more time for small and medium-sized enterprises to adapt to the new regulation. These simplified rules are expected to reduce compliance costs for small and medium-sized enterprises.
- The European Union is engaging with stakeholders globally to facilitate the implementation of the EUDR[1], including with respect to the new geolocation requirements. It has launched various international initiatives to enhance co-operation with stakeholders, ranging from bilateral co-operation mechanisms (such as the European Union's Forest Partnerships) to technical assistance initiatives (such as the EUR 70 million Team Europe Initiative on Deforestation-Free Value Chains and the EUR 25 million Sustainable Cocoa Programme) and multi-stakeholder dialogue platforms (such as the Multi-Stakeholder Platform on Protecting and Restoring the World's Forests, the Joint Task Force on EUDR Implementation with stakeholders from Indonesia and Malaysia, and the Cocoa Talks with

[1] See Article 30 of Regulation (EU) 2023.

stakeholders from Cameroon, Côte d'Ivoire and Ghana). Actions considered under these initiatives include technical assistance and training for stakeholders, the exchange of best practices on traceability, financial support, and access to relevant equipment and technology.

Similar to food traceability, the EUDR offers valuable lessons for the mineral supply chain. Discussions related to the EUDR indicate that traceability may be costly to implement for operators and traders, particularly upfront costs, and that downstream operators may face difficulties obtaining traceability data, such as due to legal barriers or a lack of infrastructure in producing countries. Some of the approaches adopted by the European Union to tackle deforestation could, nonetheless, be considered for making mineral traceability more effective and less cost-intensive, particularly through simplified traceability obligations for small and medium-sized enterprises and international engagement with global stakeholders.

Chapter 6. Roadmap for increasing mineral traceability

While companies play a crucial role in setting up and developing traceability systems, governments have various tools at their disposal to increase mineral traceability and encourage operators to develop effective mineral traceability systems. This section presents a roadmap for countries aiming to support expanded mineral traceability. We have identified eight steps that policy makers can take to incentivise the uptake of traceability among operators in the supply chain.

When developing traceability approaches to encourage responsible sourcing, policy makers should consider the relationship between traceability and the wider due diligence process. Countries pursuing policy objectives outside the scope of responsible business conduct, such as trade sanctions or origin requirements, may require or encourage companies to avoid certain jurisdictions. In such cases, traceability can ensure that mineral products from those jurisdictions are not imported into the country's territory. However, where a country is pursuing ESG or responsible business conduct objectives, its focus should be on incentivising or mandating companies to address risks within supply chains. In this regard, operators can be encouraged to use traceability to support their due diligence efforts. Countries pursuing these objectives should be careful not to encourage operators to avoid risks altogether. They should also provide scope for industry to use alternative methods to traceability where traceability solutions are not absolutely necessary.

Step 1: Determine the policy objectives and understand the supply chain context

Traceability can be used to obtain information on a product's origin, path, chain of custody and physical evolution (see Chapter 4). It can also be used to pass along ESG data, thus helping to provide a picture of the product's ESG performance and supporting a broader due diligence process.

Countries interested in increasing mineral traceability should start by determining which policy objectives they want to achieve. For example, mineral-producing countries may be interested in increasing traceability to enable product differentiation, potentially supporting higher prices for products with strong performance throughout the supply chain. In contrast, midstream and downstream countries may be interested in using traceability data, including information on geographical origin and chain of custody, to inform risk assessments. In some cases, traceability may support compliance with industrial policies that disincentivise sourcing from specific jurisdictions or with sanctions on entities within the supply chain. However, these policy objectives fall outside the scope of responsible business conduct.

In parallel, countries should seek to understand the context in which traceability will be implemented. They should aim to have a solid understanding of their mineral supply chains, including which mineral activities occur within their territories (e.g. mining, processing or transformation), the proportion of mineral products that are imported as opposed to mined or processed domestically, the main countries from which mineral products are sourced and the key domestic industries that consume mineral products.

Step 2: Choose which products to focus on

After determining the policy objectives and understanding the supply chain context, countries should determine which products to focus on.

Deciding which products to focus on will depend on a country's policy objectives and economic profile. As mentioned, traceability can be used by mineral-producing countries to enable product differentiation, which can potentially support higher prices for products with strong performance throughout the supply chain. Mineral-producing countries may therefore find it more logical to concentrate on minerals produced within their territory. For example, a country with a large lithium-producing industry may wish to focus its efforts on increasing traceability for lithium produced within its jurisdiction.

In contrast, countries with large midstream and downstream industries may be more interested in ensuring that minerals imported into their territory comply with certain ESG criteria or do not originate from certain jurisdictions. Accordingly, downstream countries may wish to focus their traceability efforts on the various minerals imported into their territory.

Step 3: Determine which information should be collected and shared

After determining which products to focus on, countries should determine which data they want relevant operators to collect and share. Determining which information is needed will depend to some extent on the country's policy objectives (see Chapter 3 and "Standardised data collection", Chapter 5).

Regardless of a country's policy objectives, if optimal mineral traceability is the goal, operators should, at a minimum, be encouraged to collect and provide information on the following elements: origin, geographical path, chain of custody and physical evolution. Encouraging operators to provide data on each of these elements ensures that stakeholders, including government agencies, will have a clear picture of a mineral's journey. Without one or more of these elements, traceability will only be partial.

Step 4: Choose which operators to focus on

After determining which products and information to focus on, countries should determine which operators need to be involved in collecting and sharing traceability information.

Deciding which operators need to be involved will depend to some extent on the country's economic profile. For example, a country that does not extract minerals may find it more logical to adopt a "downstream approach" to traceability – that is, encouraging downstream operators to obtain traceability data from actors further up the supply chain. In contrast, a country that does extract minerals may prefer to focus on upstream actors and encourage them to pass information further down the supply chain.

Step 5: Promote the development and use of interoperability protocols

Interoperability remains a major challenge for mineral traceability (see "Interoperability across the supply chain", Chapter 4). Different operators use different traceability systems, which are often inconsistent with one another.

To resolve interoperability issues, countries may be tempted to develop government-controlled platforms so that operators can share traceability data among themselves. However, government platforms present their own difficulties. Given the cross-border nature of mineral supply chains, the same operator may need to use multiple national platforms to exchange traceability data. These national platforms may not always be interoperable with the operator's own data collection system. As a result, the operator would need to integrate its data into the national platform, which can be costly and time-consuming for the operator. Developing national platforms may also be costly for governments themselves.

As an alternative to building national platforms, countries can develop interoperability protocols to promote traceability for the products, operators and information they have chosen to focus on. Instead of requiring operators to use a particular platform or software, the protocol should establish clear standards and guidelines on how information is collected, validated and shared. At a minimum, the protocol should allow for the collection of information on a product's origin, path, physical evolution and chain of custody. However, it should not mandate which technology or software operators must use to collect and exchange information. Instead, the protocol should allow operators the flexibility to use any technology or software they prefer, provided they comply with the protocol's standards and guidelines.

The protocol should also contain adequate protections for commercially sensitive information. For traceability to be effective, operators must share information with other actors along the supply chain and with relevant stakeholders, such as government bodies and consumers, as appropriate. While some information, such as details about a product's physical evolution, may not be particularly sensitive for operators, other data may hold economic value and be commercially sensitive. This can act as a barrier to effective traceability. For example, some operators may be reluctant to provide detailed information on GHG emissions, fearing that competitors or customers could use it to reverse-engineer costs and determine the operator's mark-up. To address business confidentiality concerns, the protocol should include standards on data privacy and security. Protecting confidential business information will encourage operators to share more information, thereby enhancing mineral traceability.

After developing the interoperability protocol, countries can promote its use and encourage operators to adopt it. To expedite the process of developing interoperability protocols, countries can start by using the United Nations Transparency Protocol, developed by the United Nations Economic Commission for Europe, and expand upon it to fit their own policy preferences.

Step 6: Establish trust mechanisms

In order for traceability to be effective, information that is collected and shared by operators must be accurate, reliable and trustworthy (see "Standardised data collection" and "Governance and verification", Chapter 4). Traceability systems must include appropriate safeguards to prevent fraud. A traceability system without proper verification mechanisms can lead to inaccurate or falsified data, thus negating the objective behind the creation of a traceability system.

Governments have a role to play in ensuring that information collected and shared by operators is truthful and accurate. As public authorities, governments are typically seen as more trustworthy than private operators. Governments can issue verifiable credentials to enhance trust along the supply chain. For example, they can issue registration credentials, such as business identification numbers, as verifiable credentials to help operators prove their status as legitimate business entities. Governments can also implement Authorised Economic Operator programmes, enabling operators that fulfil certain criteria relevant for traceability – such as compliance with customs and tax legislation, absence of criminal offences related to the economic activity, appropriate record keeping, and financial solvency – to gain official recognition.

Similarly, governments can issue licences and permits as digitally verifiable credentials to certify operators' compliance with relevant regulations and procedures, including mining, environmental and labour regulations, as well as procedures for free, prior and informed consent of Indigenous Peoples where applicable. Governments in mineral-producing countries can issue origin certificates for minerals produced within their territory, thus helping mining operators establish the origin of their minerals when exporting them abroad.

While government-issued credentials can enhance trust along the supply chain, they are not sufficient on their own to ensure that information is truthful and accurate. Traceability systems should include appropriate oversight mechanisms to account for the risk of corruption and conflicts of interest, particularly for documentation issued by governments located in high-risk jurisdictions (see "Governance and data verification", Chapter 4).

Step 7: Create incentives for increasing traceability

To encourage operators to develop traceability systems where appropriate and use the transparency protocols outlined in Step 5, countries should create incentives for operators to trace the relevant products and collect and share the necessary information.

Countries can use various tools to encourage operators to trace products or material inputs. Mineral-producing countries can provide funding to encourage mining operators to develop traceability systems. For example, governments can provide financial support for the development of technological infrastructure in remote mining locations with limited connectivity. Countries can specify in the funding arrangement which products should be covered under the system and which data should be collected. This will enable mining operators to pass the relevant data down the supply chain, allowing them to market their products as more responsible and sustainable.

Midstream and downstream countries can use economic tools to encourage operators to develop traceability systems. For example, if a country wants to encourage midstream and downstream operators to source mineral products from certain jurisdictions rather than others, it can introduce a tax credit for products containing minerals sourced from the designated countries. This approach can incentivise midstream and downstream operators to develop traceability systems for tax credit eligibility. Midstream and downstream operators can also fund operators located in their territory to encourage collaboration with suppliers to trace products further up the supply chain. In addition to economic tools, midstream and downstream countries can use regulatory tools to incentivise operators to develop traceability systems. For example, if a country wants to ensure that imported minerals meet certain ESG criteria, it can require operators to incorporate traceability as part of enhanced due diligence on sources exposed to elevated risks. In some cases, such requirements can have implications for market access (see Chapter 3). When using regulatory tools to incentivise traceability, midstream and downstream countries should be careful not to do so in a way that disrupts market efficiencies and flexibilities. Mandating immediate end-to-end traceability could be particularly disruptive, creating supply chain issues for midstream and downstream countries. Instead, countries should adopt a measured approach that takes into account market realities and maintains smooth market functioning.

Countries should pay particular attention to ensuring that midstream and downstream operators have the capacity to carry out traceability for the relevant mineral products. Traceability regulations and implementation timelines should align with industry readiness, allowing for capacity building and the smooth adoption of new systems.

Step 8: Engage with stakeholders in foreign jurisdictions

Many energy minerals have complex supply chains spanning multiple jurisdictions and involving numerous actors. Operators seeking to trace their products often need to collaborate with actors located in foreign jurisdictions. This is particularly true for downstream operators located in countries with few upstream operations. Without collaboration from actors in foreign jurisdictions, obtaining traceability information may be practically difficult, if not impossible, for operators seeking to trace their products.

However, in some cases, collaboration can be hindered by limited access to digital technology (especially in least-developed countries), the reluctance of midstream operators to pass on information about upstream activities, or data protection laws prohibiting the disclosure of traceability data. To encourage collaboration between operators, countries can engage with stakeholders located in foreign jurisdictions – including regulatory authorities, producer associations, mining operators, civil society organisations and Indigenous Peoples, where applicable – to promote data-sharing along the supply chain and reduce barriers to traceability.

Engagement with foreign actors can take various forms, including bilateral co-operation mechanisms with producing countries, technical assistance initiatives in producing countries, or multi-stakeholder dialogue platforms for relevant commodities. To promote data-sharing along the supply chain and reduce barriers to traceability, countries can use tools such as technical assistance and training for mining operators, the exchange of best practices on traceability, financial support for traceability projects in producing countries, and the transfer of relevant technology and equipment.