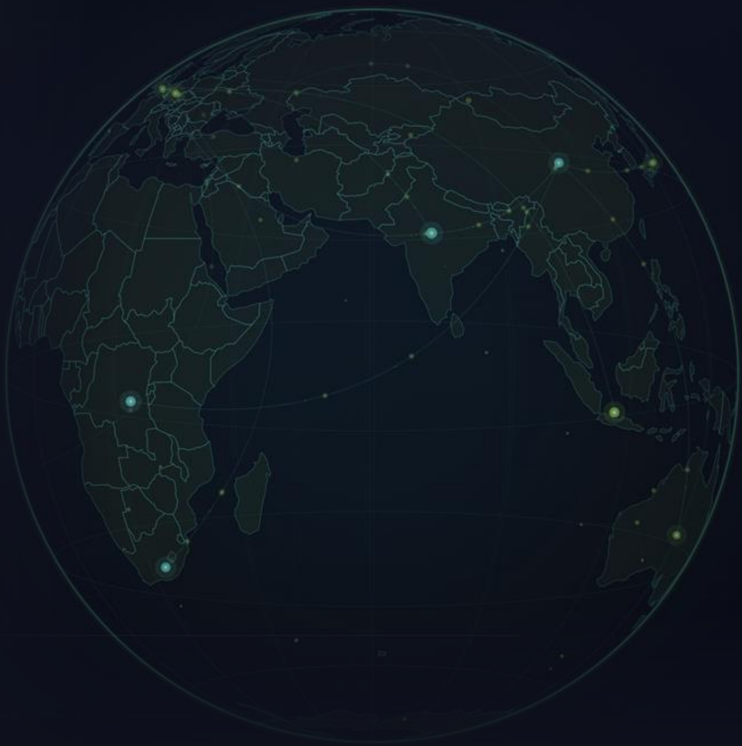

DATA QUALITY AND STANDARDS

For Resilient Critical Minerals Supply Chains

A Report of the UK-India Workshop: New Delhi, 19–20 January 2026

UNIVERSITY OF CAMBRIDGE
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Contents

Foreword (UK)

Flaws and inconsistencies in information adversely affect market transparency, efficiency and resilience. For critical minerals, the quality of data and the nature of standards pose fundamental challenges in global markets. This report documents insights and recommendations on these issues raised by experts from industry, research communities and national authorities from India and the UK in technical discussions convened in January 2026 under the Technology Security Initiative launched by the Prime Ministers of India and the UK in October 2025.

The Bureau of Indian Standards, the British Standards Institution, the Geological Survey of India, and the British Geological Survey worked closely together with the support of the British High Commission to enable well-informed deliberations to take place over two days. The Institute for Manufacturing at Cambridge University in the UK acted as rapporteur and has compiled this independent report. Its comprehensive scope, analysis and recommendations offer welcome and timely food for thought for stakeholders across all sectors in this enormously complex and important field.

Simon Strickland
International Economic Policy
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Foreword (India)

The India-UK Workshop on “Data Quality and Standards for Resilient Critical Minerals Supply Chains” was held in New Delhi on 19–20 January 2026 under the Technology Security Initiative, bringing together government officials, geological surveys, industry, and academic experts from both countries to examine gaps in data quality, classification and standards affecting critical minerals supply chains.

It was highlighted during the workshop, the importance of associated critical minerals and the ongoing reforms to facilitate their recovery form an integral part of India’s efforts under the National Critical Mineral Mission (NCMM). The deliberations covered key issues, including the identification of associated critical minerals, reforms for their inclusion in mining leases, the recovery potential from mine dumps and tailings, and the harmonisation of HS codes to improve the quality of trade data.

The workshop provided a productive platform for knowledge exchange, and its outcomes are expected to support enduring cooperation between India and the United Kingdom in this important area.

This report provides a comprehensive account of the workshop proceedings and the key discussions held during the two-day event. It will support continued collaboration between India and the United Kingdom and contribute to resilient, transparent, and sustainable critical mineral supply chains.

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New Delhi

Executive Summary

Strategic Context

Critical minerals underpin the global transition to net zero emissions, enable digital transformation, and constitute essential inputs for national security. Lithium, cobalt, rare earth elements, graphite, and numerous other materials are irreplaceable in battery technologies, permanent magnets, semiconductors, and advanced alloys. A single electric vehicle battery requires approximately 8 kilograms of lithium, 14 kilograms of cobalt, 35 kilograms of nickel, and 20 kilograms of graphite. Offshore wind turbines depend on rare earth permanent magnets. Solar photovoltaics require tellurium, indium, and gallium. Defence applications demand specialty metals with no viable substitutes.

Yet the supply chains delivering these materials remain concentrated, opaque, and vulnerable. China controls approximately 60 per cent of global rare earth production, 80 per cent of processing capacity, and 90 per cent of permanent magnet manufacturing. Processing capacity for lithium, cobalt, nickel, and graphite shows similar concentration. Democratic nations have outsourced not merely extraction, but the technical knowledge, industrial capacity, skilled workforce, and equipment manufacturing required for critical minerals processing.

On 19–20 January 2026, the United Kingdom and India convened senior officials, technical experts, industry leaders, and academic specialists in New Delhi to address fundamental weaknesses in critical minerals data quality and standards. Over two days of intensive discussion, participants examined production reporting gaps, classification system failures, standards deficits, and implementation barriers across nine substantive sessions. Analysis presented at this bilateral workshop reveals three interconnected crises that threaten supply chain resilience, market functioning, and policy effectiveness.

Three Critical Failures

The Invisibility Crisis

Substantial volumes of critical minerals production remain undocumented, creating systematic information gaps that undermine policymaking and investment decisions. Many critical minerals occur as by-products of major metals extraction, including cobalt from copper and nickel operations, rare earths from iron ore and bauxite, and gallium and germanium from zinc processing. Mining operations optimise extraction for primary metals where revenue and profitability lie.

Associated critical minerals, even when present in economically significant quantities, may represent less than five per cent of operation revenue.

Corporate reporting frameworks, designed around financial materiality thresholds, do not require disclosure of immaterial by-products. The result: strategically vital materials remain invisible in company reports, production statistics, and market data. Analysis of international databases reveals discrepancies exceeding 30 per cent for some materials, reflecting differences in reporting standards and data collection methods. The Myanmar rare earth case study demonstrates how hidden supply can materially distort global markets, mislead policymakers, and undermine investment decisions.

Current frameworks prioritise financial materiality over strategic significance. Materials essential for national security and clean energy remain absent from corporate reporting because they fail to meet traditional financial thresholds. Battery black mass, recovered material containing valuable lithium, cobalt, and nickel, is frequently classified as waste rather than as a commodity, enabling illegal exports and distorting trade statistics.

The Classification Crisis

International trade classification systems lag decades behind market realities, preventing accurate tracking of critical minerals in global commerce. The Harmonised System (HS), administered by the World Customs Organization, provides the foundation for trade statistics, customs duties, and regulatory monitoring. The system works adequately for traditional commodities but fails comprehensively for critical minerals.

Lithium carbonate, lithium hydroxide, and lithium chloride, chemically distinct compounds with different applications, processing requirements, and market values, often share generic residual codes. Individual rare earth elements, despite radically different properties, scarcity, and strategic importance, are aggregated under catch-all categories. This classification failure creates cascading problems: trade statistics provide incomplete pictures of material flows, customs authorities struggle to assess appropriate duties, regulators cannot effectively monitor strategic materials movements, and illicit trade exploits classification ambiguities.

Resource classification and reporting frameworks show similar fragmentation. The JORC Code (Australasia), NI 43-101 (Canada), SAMREC (South Africa), and various national frameworks employ different terminology, confidence thresholds, and classification criteria. This imposes costs on internationally operating companies, prevents like-for-like project comparisons, and undermines the transparency that resource estimates should provide.

The Standards Deficit

Whilst mature industrial sectors benefit from hundreds of technical standards developed over decades, critical minerals standards remain fragmented and incomplete. Although progress has been made (ISO/TC 298 (Rare Earth) has developed 15 standards and ISO/TC 79 (Titanium) 116 standards), significant gaps persist for commercially critical products. This fragmentation creates barriers to trade, undermines quality assurance, prevents transparent price discovery, and constrains market development. Iron and steel are supported by comprehensive standards infrastructure addressing all commercial applications. Critical minerals lack equivalent maturity, particularly for battery-grade materials and recycled products.

Lithium carbonate, fundamental to battery manufacturing, has no universally recognised purity standard. Different battery manufacturers specify different purity thresholds (ranging from 99.0% to 99.9%), particle size distributions, and trace element limits. Indian lithium processors report receiving contradictory specifications from different customers, preventing economies of scale and complicating quality assurance. Rare earth oxides are traded using bespoke specifications that vary by customer, application, and geographic market.

This standards deficit extends beyond product specifications. Validated analytical methods, certified reference materials, and proficiency testing schemes (the measurement infrastructure underpinning credible standards) remain inadequate or absent for many critical minerals products. Recycling standards for battery black mass, tailings characterisation methods, and traceability frameworks are underdeveloped or non-existent.

Workshop discussions revealed important nuance in how the standards landscape is perceived and navigated by practitioners. Whilst gaps in international standards are widely acknowledged, there is also evidence of fatigue among some stakeholders given the proliferation of different standards in this field. Efforts to address remaining gaps may therefore need to be balanced with efforts to consolidate existing standards offerings, and future standardisation efforts should aim to be proportionate to criticality and risk-based in their prioritisation.

Awareness of the merits of different governance models for standards development was found to be low among many participants. The legitimacy and global applicability of a standard is significantly shaped by who develops it: whether a small number of companies from a limited range of countries, or a broader coalition including governments, academic institutions, community groups, and civil society. Participation costs and barriers to entry are material considerations; standards processes that require payment to participate may systematically exclude actors from lower-income countries and smaller enterprises, limiting both the quality and the reach of the resulting standards. International standards developed through genuinely inclusive processes carry particular value given both the need for global collaboration to address critical minerals challenges and the requirements of the WTO Technical Barriers to Trade Agreement to use international standards as the basis for regulation.

Realism about the potential of standards is warranted. Standards are not a panacea for deep market failures or entrenched geopolitical competition. However, where a genuine desire to collaborate exists among stakeholders, standards can serve as an important enabler: facilitating the creation of new markets, enabling technical engagement where political engagement is constrained, supporting innovation, building international communities of practice, and facilitating knowledge sharing for collective action.

Key Evidence from Workshop Analysis

Detailed examination across nine substantive sessions revealed systematic weaknesses requiring urgent policy intervention:

Undocumented Production and By-Product Invisibility. Workshop analysis confirmed that many critical minerals associated with copper, zinc, and bauxite operations remain underreported. Corporate reporting frameworks prioritise financial materiality, and materials representing less than five per cent of revenue need not be disclosed separately. From a company perspective, reporting imposes administrative burden without benefit. From a government perspective, lack of disclosure prevents effective policymaking. India's recent legislative reforms demonstrate that policy change improves transparency. Streamlined declaration procedures and clear taxation frameworks have brought previously hidden production into official statistics, increasing economic recovery of associated minerals whilst improving supply chain visibility.

Data Infrastructure and Classification Gaps. Incompatible resource classification systems impose costs on companies operating across jurisdictions. The United Nations Framework Classification for Resources (UNFC) provides a potential solution through three-dimensional classification based on geological confidence, technical-economic feasibility, and socio environmental economic viability. Further information on UNFC is available at unece.org. UNFC functions as a bridge between national systems without requiring abandonment of established frameworks. India's National Geoscience Data Repository (NGDR) demonstrates transformative potential. Decades of geological surveys, exploration reports, and resource assessments, previously scattered across paper archives, have been systematically digitised, standardised, and made accessible through a unified platform. This enables private sector exploration, academic research using artificial intelligence, and evidence-based government planning.

Midstream Processing Constraints and Opacity. The midstream, which comprises processing and refining operations converting concentrates into battery-grade chemicals, represents the most constrained segment. China controls 60-90 per cent of global capacity for most critical minerals. This dominance reflects decades of industrial policy, technical development, and integrated supply chain construction. Midstream operations suffer from acute data deficits. Production statistics aggregate diverse products under generic categories. Processing yields, intermediate products, and material flows remain proprietary. Indian processing companies report facing contradictory customer specifications, with one battery manufacturer requiring lithium carbonate with less than 10 ppm calcium whilst another accepts 50 ppm. This fragmentation prevents economies of scale, increases complexity, and creates quality assurance challenges.

Circular Economy Barriers and Secondary Resources. Tailings, urban deposits, and recycled materials represent significant untapped value but remain poorly characterised and often classified as waste. Battery black mass from lithium-ion battery recycling contains valuable lithium, cobalt, nickel, and manganese yet lacks agreed characterisation methods or quality specifications. Trading occurs through bespoke contracts rather than transparent markets. Misclassification as waste enables illegal exports and undermines circular economy objectives. Applying resource classification frameworks to secondary resources, treating tailings as deposits requiring geological survey methods and urban infrastructure as anthropogenic ores, could unlock substantial value whilst addressing environmental legacies.

ESG as Dominant Risk Factor. Environmental, social, and governance considerations have evolved from peripheral concerns to dominant factors responsible for substantial shares of project failures. Community opposition, water conflicts, inadequate closure planning, and biodiversity impacts can derail projects at any development stage. Analysis presented at the workshop emphasised that ESG issues kill more projects than technical or geological challenges. Traditional feasibility studies focusing on technical and economic factors provide incomplete risk assessment. Integration of ESG considerations at early stages enables realistic project evaluation and investment decisions. The distinction between sustainability (the long-term objective) and ESG (the measurement and reporting framework) requires clearer articulation.

The Strategic Opportunity

These failures are not inevitable. Policy interventions, institutional reforms, and technical innovations can address systematic weaknesses. India has demonstrated that legislative change improves transparency, with amendments removing barriers to associated minerals reporting showing early evidence of improved compliance. The National Geoscience Data Repository shows how legacy data becomes strategic infrastructure through systematic modernisation. European standardisation work demonstrates the economic value of harmonised frameworks for facilitating trade and reducing compliance burdens.

The UK and India possess complementary capabilities that, combined through structured bilateral cooperation, can generate solutions with global application. The United Kingdom contributes world-leading expertise in geological surveying through the British Geological Survey, deep financial markets experience in commodity trading and price discovery, strong participation in international standards development through the British Standards Institution, and sophisticated regulatory frameworks for mine permitting and environmental assessment.

India brings substantial mineral endowments including rare earths, lithium, and graphite deposits; rapidly expanding processing capacity with companies developing lithium refining, rare earth separation, and battery material manufacturing; a mature national standards institution in the Bureau of Indian Standards operating through extensive sectoral networks; demonstrated reform capacity through legislative amendments and data infrastructure modernisation; and growing demand driven by clean energy ambitions and industrial transformation.

Joint development of technical standards, harmonised data frameworks, coordinated international advocacy, and shared research programmes can achieve outcomes neither country could deliver independently. Bilateral cooperation provides a vehicle for piloting approaches, sharing lessons, and building technical capacity before scaling solutions through multilateral channels.

Both the UK and India are engaged in initiatives to encourage the development of standards based markets for critical minerals. Further collaboration in defining what such markets should look like, and in identifying the standards work needed to deliver them, represents a natural and productive area for future UK-India cooperation. This shared ambition provides a strong foundation upon which to build a sustained and substantive bilateral partnership.

Policy Recommendations

This report identifies thirteen priority areas for action across five domains. These are offered as recommendations for consideration by relevant authorities, industry bodies, and international organisations, rather than as prescriptive requirements. They balance near term actions with longer term ambitions.

Data Quality and Harmonisation

National authorities could usefully explore establishing bilateral data-sharing frameworks enabling exchange of production statistics, processing capacity data, and trade information between UK and Indian agencies, covering geological survey data, mine production, processing throughput, and trade flows with appropriate commercial confidentiality protections.

Relevant authorities could promote adoption of the United Nations Framework Classification for Resources as a common reference point for resource reporting, including encouraging mining companies and geological surveys to adopt UNFC, developing training programmes for competent persons, and funding research to adapt UNFC for secondary resources.

The UK and India could coordinate advocacy through the World Customs Organization for revision of Harmonised System codes to create specific critical minerals categories, with priority focus on lithium compounds, individual rare earth elements, battery materials, and high-value recyclables.

It may be worth exploring strategic materiality thresholds that could require companies to report production and processing of designated critical minerals regardless of financial materiality, implemented through corporate reporting regulations, stock exchange listing requirements, or operating permit conditions.

Standards Development and Implementation

BSI and BIS could usefully explore establishing bilateral technical working groups for priority critical minerals, initially focusing on lithium compounds, rare earth oxides, and battery materials, building on and complementing existing ISO TC work rather than duplicating it.

National metrology institutes could be supported in developing certified reference materials, validated analytical methods, and proficiency testing schemes for critical minerals products.

Standards development supporting circular economy objectives could usefully be accelerated, including characterisation methods for tailings, quality specifications for recycled materials, design-for-recyclability guidelines, and traceability frameworks.

Capacity Building and Knowledge Exchange

Professional exchange programmes could be established, including competent persons secondments, laboratory personnel exchanges between national metrology institutes, standards officials participating in counterpart technical committees, and research fellowships.

Coordinated positions and active participation in ISO technical committees (TC 298 Rare Earth, TC 333 Lithium), IEC committees on battery technologies, CEN working groups, and WCO technical committees could be supported.

Research and Innovation

Bilateral research funding could usefully address by-product recovery technologies, processing methods for complex ores, urban mining characterisation, and isotopic/chemical tracing for supply chain verification.

Research programmes could include pre-normative standardisation work, ensuring research outputs feed directly into standards development and reducing time lags between scientific advances and market adoption.

International Leadership and Engagement

Coordinated positions could be presented at G7, G20, and WTO forums addressing critical minerals data transparency requirements, trade classification reform, international alignment on product specifications, and practical harmonised ESG standards. The UK and India could also explore engagement through the Data Pillar of the Supply Chains Mission of the Global Clean Power Alliance (GCPA).

Capacity building support could be provided enabling developing countries to participate in critical minerals standards development through training, committee participation funding, and technical assistance.

Implementation

This report proposes establishing a formal UK-India Critical Minerals Partnership with clear governance structures, dedicated resources, and measurable deliverables. The partnership should operate through three governance levels: a Ministerial Steering Committee meeting annually to provide strategic direction and approve work programmes; a Senior Officials Group meeting quarterly to oversee implementation and resolve issues; and Technical Working Groups focused on specific minerals, standards topics, and implementation challenges.

Implementation will proceed in three phases. Quick wins (0-12 months) include establishing governance structures, signing data-sharing framework agreements, launching initial technical working groups, submitting HS code revision proposals, and initiating professional exchange programmes. Building blocks (1-3 years) include publishing interim specifications for priority materials, establishing certified reference material programmes, launching joint research programmes, developing traceability frameworks, and implementing strategic materiality reporting in both jurisdictions. Strategic transformation (3-5 years) includes achieving international adoption of jointly developed standards through ISO/IEC, scaling successful circular economy pilots internationally, and establishing the UK-India partnership as a recognised model for critical minerals cooperation.

Conclusion

Critical minerals supply chains constitute critical infrastructure for the 21st century economy. Current failures in data quality and standardisation create vulnerabilities that threaten both economic prosperity and national security. The UK-India partnership provides a vehicle for addressing these failures whilst demonstrating models that can be scaled internationally.

This report sets out the evidence base, policy framework, and implementation pathway for transformative bilateral cooperation, drawing on intensive technical discussions from the 19-20 January 2026 workshop in New Delhi. The recommendations reflect technical consensus on data quality challenges, standards deficits, and implementation barriers, providing a foundation for sustained bilateral action.

Success requires political commitment from both governments, adequate financial resourcing, active industry engagement, and sustained attention over multi-year timescales. The strategic and economic benefits (enhanced supply chain resilience, improved market transparency, international leadership on critical minerals governance, and practical demonstration of effective bilateral cooperation) justify this investment. This report provides the foundation for sustained UK-India collaboration on critical minerals data quality and standards.

Part I

The Strategic Challenge

Chapter 1
Introduction and Context

1.1 Background

Critical minerals have emerged as a defining strategic priority for modern economies. These materials, including lithium, cobalt, rare earth elements, graphite, and numerous others, are essential inputs for clean energy technologies, digital infrastructure, advanced manufacturing, and defence applications. The global transition to net zero emissions and the accelerating pace of digitalisation have created unprecedented demand for these minerals whilst simultaneously exposing significant vulnerabilities in international supply chains.

On 19–20 January 2026, senior officials and technical experts from the United Kingdom and India convened in New Delhi for a landmark workshop on critical minerals data quality and standards. Hosted by the Bureau of Indian Standards (BIS), the workshop brought together policymakers, industry leaders, geological survey specialists, academic researchers, and standards professionals to address fundamental challenges in critical minerals markets.

This workshop was conceived in recognition of three interconnected realities. First, critical minerals supply chains are global, complex, and opaque. Second, data quality and standardisation are foundational to supply chain resilience, yet remain underdeveloped. Third, bilateral cooperation between major economies such as the UK and India can catalyse broader international action on these issues.

1.2 Strategic Rationale

The UK and India share complementary strengths and strategic interests in critical minerals. The UK possesses world-leading expertise in geological surveying, mine permitting, financial markets, and ESG frameworks. India has substantial mineral endowments, rapidly expanding processing capacity, a strong tradition of standards development through BIS, and growing demand driven by its clean energy ambitions and industrial transformation.

Both nations recognise that securing resilient critical mineral supply chains requires high-quality data, internationally recognised standards, transparent markets, and collaborative approaches beyond resource ownership or processing capacity alone. The workshop was designed as the foundation for sustained bilateral cooperation.

1.3 Workshop Objectives and Intended Outcomes

The purpose of this two-day workshop was to use expert dialogue and knowledge exchange to support market data quality and standards for critical minerals. The minerals of interest are largely by-products of major "host" commodities of wider interest to both the UK and India.

Core Objectives

The workshop was structured around four core objectives:

1. To examine the current state of data quality across critical minerals value chains, identifying gaps in production reporting, classification systems, and market transparency.
2. To assess the international landscape of standards for critical minerals, including technical specifications, measurement methods, ESG frameworks, and reporting requirements.
3. To identify opportunities for UK-India collaboration on data harmonisation, standards development, capacity building, and research cooperation.
4. To develop practical policy recommendations that can be implemented bilaterally and advanced through multilateral channels.

Intended Outcomes

The workshop was designed to deliver four specific outcomes:

1. Recognised steps to improve market data quality and understanding of standards.
2. Exploration of opportunities for enhanced expert engagement in work setting technical standards for specified critical minerals and minimum criteria for the sustainability of their supply chains.
3. Support for progress towards credible, sustainable and responsible standards-based markets.
4. Improved prospects of reducing standards-related frictions in international minerals trade so as to enhance market efficiency.

1.4 Workshop Structure

The two-day programme comprised nine substantive sessions organised thematically. Day 1 focused on data quality challenges, examining undocumented production, classification systems, by-product reporting, and resource assessment. Day 2 addressed standards development, including the international standards landscape, technical specifications, ESG frameworks, and factors affecting implementation. Each session featured presentations by subject-matter experts followed by structured discussion.

1.5 Structure of This Report

This report is structured to provide policymakers with a comprehensive record of the workshop proceedings and a clear basis for policy action. Following this introduction, Chapter 2 provides profiles of key speakers and their institutional affiliations. Part I (Chapters 3-4) examines the strategic challenge posed by critical minerals dependencies and the data quality imperative. Part II (Chapters 5-8) analyses three critical failures: the invisibility crisis, classification crisis, and standards deficit, along with midstream chokepoints. Part III (Chapter 9) explores the UK-India opportunity for bilateral cooperation through complementary capabilities. Part IV (Chapter 10) presents detailed policy recommendations across five domains. Part V (Chapters 11-13) outlines the implementation framework including governance structures, timelines, and resource requirements. Chapter 14 provides conclusions. Annexes include the workshop programme and acknowledgements.

Chapter 2

Speaker Profiles

The workshop benefited from contributions by distinguished experts representing government, industry, academia, and international organisations. This chapter provides profiles of key speakers, highlighting their expertise and institutional affiliations. These profiles demonstrate the breadth and depth of technical knowledge brought to bear on critical minerals challenges.

2.1 Government, Survey and Standards Representatives

2.1.1 Bureau of Indian Standards (BIS)

BIS is the national standards body, established by the Bureau of Indian Standards Act 1986. As host of the workshop, BIS provided essential support and senior representation. BIS officials outlined the standards development process in India, the role of technical committees, and priorities for critical minerals standardisation. BIS operates through a network of sectoral divisional councils and has established over 20,000 Indian Standards across diverse sectors including metallurgy, chemicals, electronics, and environmental protection. The institution plays a central role in India's industrial quality infrastructure, providing product certification, laboratory accreditation, and participation in international standards development through ISO and IEC membership.

2.1.2 British Geological Survey (BGS)

BGS is the premier provider of geoscience expertise in the United Kingdom and a component organisation of UK Research and Innovation. Established in 1835, BGS maintains world-leading capabilities in geological surveying, resource assessment, and geoscience data management. BGS representatives contributed expertise on geological data infrastructure, resource classification systems (particularly the United Nations Framework Classification for Resources), international collaboration on critical minerals intelligence, and best practices for geological survey modernisation. BGS operates the UK national geological data repository and provides authoritative advice to government on resource security, sustainable development, and environmental protection.

2.1.3 Geological Survey of India (GSI)

GSI, established in 1851, is one of the oldest geological survey organisations globally and serves as India's premier geoscientific organisation. GSI operates under the Ministry of Mines and maintains responsibility for geological mapping, mineral resource assessment, geophysical and geochemical surveys, and provision of geoscience information to government, industry, and research institutions. GSI speakers presented the National Geoscience Data Repository (NGDR), a transformative initiative to digitise and standardise decades of geological information accumulated through systematic mapping, exploration programmes, and research activities.

The NGDR provides a unified digital platform for exploration data, making previously fragmented information accessible for modern analysis. This initiative brings transparency and accessibility to geological resources, enabling private sector exploration companies to access historical data for prospect identification, academic researchers to apply artificial intelligence and machine learning to geological datasets, and government planners to make evidence-based decisions about mineral development priorities.

2.2 Industry Representatives

2.2.1 Mining and Processing Sector

Industry representatives from major mining corporations and processing facilities provided essential operational perspectives on data collection, reporting burdens, and practical implementation of standards. Mining sector participants included companies operating polymetallic deposits containing copper, zinc, lead, and associated critical minerals including cobalt, gallium, germanium, and indium. These operators discussed the economics of by-product recovery, practical constraints on documenting associated minerals, reporting incentives under reformed Indian legislation, and challenges in coordinating across extraction, processing, and marketing functions.

Indian mineral processing companies highlighted specific challenges in navigating fragmented customer specifications for lithium compounds, nickel sulphate, cobalt chemicals, and rare earth products. Processing operators reported receiving contradictory specifications from different customers for nominally identical products, with purity thresholds varying by factors of five, particle size requirements spanning different measurement methods, and trace element limits reflecting different analytical capabilities rather than genuine application requirements.

2.2.2 Trading and Financial Services

Representatives from mineral trading houses and price reporting agencies contributed expertise on market transparency, price discovery mechanisms, and the role of standardised specifications in facilitating trade. Trading house participants operate in markets for lithium, cobalt, rare earth elements, and other critical minerals, managing physical delivery, price risk, and logistics across international borders. These speakers emphasised how the absence of widely recognised benchmarks for critical mineral products creates inefficiencies in price discovery, limits arbitrage opportunities, increases transaction costs, and constrains market development.

Price reporting agencies discussed challenges in establishing credible benchmark prices when product specifications vary, transaction volumes are thin, and market participants guard commercial confidentiality. The importance of transparent pricing mechanisms for lithium carbonate, cobalt sulphate, and rare earth oxides was highlighted as essential for investment decision-making, risk management through derivatives markets, and long-term supply contracting.

2.3 Academic and Research Institutions

Speakers from leading universities and research institutions provided insights on resource assessment methodologies, circularity in mineral value chains, pre-normative research for standards development, and the interface between academic knowledge and industrial implementation. Academic contributions highlighted several emerging research areas with direct policy relevance.

The concept of urban deposits as future mineral resources received substantial attention. Urban infrastructure, end-of-life vehicles, discarded electronics, and decommissioned renewable energy installations contain significant quantities of critical minerals. Unlike geological deposits, anthropogenic accumulations have known locations, accessibility advantages, and potentially lower extraction costs. However, they lack standardised characterisation methods, resource classification frameworks, and economic assessment models.

Isotopic and chemical fingerprinting for supply chain verification represents another active research frontier. Natural isotopic variations in lithium, rare earth elements, and other materials can identify geographic origins and potentially distinguish primary from recycled sources. Chemical impurity profiles reflect ore geology and processing routes. Academic researchers discussed applications including verifying claims about recycled content, tracing materials through complex supply chains, and detecting fraudulent origin claims.

2.4 Standards Development Organisations

2.4.1 British Standards Institution (BSI)

BSI is the United Kingdom's national standards body and one of the world's leading standards organisations, with over a century of experience in standards development, testing, and certification. As the UK's representative in ISO and CEN, BSI plays a central role in shaping international and European standards, including those relevant to critical minerals. BSI participants contributed expertise on the international standards architecture, the UK's engagement in ISO technical committees including ISO/TC 298 (Rare Earth) and ISO/TC 333 (Lithium), and the processes through which national positions are developed and advanced in international forums. BSI's involvement underscores the importance of active national participation in standards development and the value of engaging a broad range of stakeholders, including industry, academia, government, and civil society, in shaping standards that command widespread legitimacy and adoption.

2.4.2 European Committee for Standardisation (CEN)

CEN representatives outlined the European approach to harmonised standards, including the relationship between European standards and the EU single market, processes for standards development combining voluntary participation with regulatory mandates, and current work programmes on critical raw materials. CEN operates as a regional standards body serving 34 member countries, developing European Standards (ENs) that can be adopted as national standards by member states.

Presentations demonstrated how regional standardisation supports economic integration whilst maintaining global relevance through systematic coordination with ISO. The voluntary nature of standards (they provide consensual market solutions rather than regulatory requirements) was emphasised, alongside their role as enablers of trade, innovation, and market transparency.

2.4.3 International Organization for Standardization (ISO)

ISO experts contributed perspectives on the global standards architecture, emphasising the importance of international alignment to avoid fragmentation and trade barriers. ISO operates through national standards bodies, with 169 member countries participating in technical committee work, voting on draft standards, and adopting international standards as national standards. Discussion covered technical committees relevant to critical minerals including ISO/TC 298 for Rare Earth, and ISO/TC 333 for Lithium, as well as various committees addressing analytical methods, sampling, and terminology.

The standards development process relies on consensus-based decision-making, with draft standards circulating through multiple review stages before publication. The critical role of standards in enabling international trade, supporting innovation, and building trust across supply chains was underscored.

2.5 Sustainability and ESG Specialists

Specialists in environmental, social, and governance (ESG) frameworks provided critical context on sustainability reporting requirements, the Business Responsibility and Sustainability Reporting (BRSR) framework in India, the evolution of ESG from voluntary guidance to mandatory disclosure in multiple jurisdictions, and the integration of ESG considerations into investment decision-making and project financing.

Contributors highlighted how ESG considerations have become dominant risk factors in project development and investment decisions. Analysis of recent project failures reveals that community opposition, water conflicts, biodiversity impacts, and inadequate closure planning now cause more project cancellations than technical or geological challenges.

The importance of separating sustainability (the long-term objective of maintaining environmental and social viability) from ESG (the measurement and reporting framework for assessing progress) was emphasised. The concept of bankable sustainability received particular attention, whereby for projects to attract financing, ESG considerations must integrate with financial analysis rather than being treated as separate evaluations.

2.6 Detailed Workshop Sessions and Speakers

The workshop was structured across two days with distinct thematic focus. Day 1 examined data quality challenges whilst Day 2 addressed standards development and implementation. Each session paired expert speakers from UK and Indian institutions to provide complementary perspectives on critical challenges. Dr Simon Strickland (UK Cabinet Office) moderated Day 1 sessions. Professor Mukesh Kumar (University of Cambridge) served as rapporteur, synthesising discussions and identifying key themes for policy recommendations.

2.6.1 Day 1: Data Quality Challenges (19 January 2026)

Session	Speakers	Focus Areas
Opening & Strategic Context	*Opening:* Mr Sanjiv Maini, Mr Sanjay Pant (BIS); Sri Sandeep Vasant Kadam, Mohammed Sadiq (Ministry of Mines)* *Introduction:* Dr Simon Strickland (UK Cabinet Office)	Rationale for UK-India cooperation on critical minerals data quality and standards; strategic importance for supply chain resilience
Documented and Undocumented Production	Dr Kathryn Goodenough (British Geological Survey)	Scale of undocumented production; gaps in evidence base; BGS global data quality perspectives; recycling and circular economy data challenges; India's legislative reforms
Disparate Classification and Reporting Systems	Dr PK Singh (Geological Survey of India) Mr Harikrishnan Tulsidas (UNECE)	Diversity in classification systems; India's National Geoscience Data Repository (NGDR); United Nations Framework Classification for Resources (UNFC); JORC, NI 43-101, SAMREC codes; application to secondary resources
Factors Modifying Resources and Reserves	Professor Frances Wall OBE (University of Exeter) Dr R. Ratheesh (C-MET)	Uncertainty sources in defining resources and reserves; geological and sampling methodologies; ESG/sustainability impacts on reserve characterisation; technical feasibility; Indian processing capacity
By-Product Status and Market Reporting	Dr Gavin Mudd (British Geological Survey) Professor Jay Wadhawan (University of Hull) Dr Abhilash (CSIR-NML Jamshedpur)	Host vs by-product minerals relationship; data quality variations; by-product economics; analytical chemistry perspectives; processing technologies; financial vs strategic materiality

Table 2.1: Day 1 Workshop Sessions: Data Quality Challenges

2.6.2 Day 2: Standards and Implementation (20 January 2026)

Session	Speakers	Focus Areas
International Landscape of Minerals Standards	Mr Richard Lee Smith (British Standards Institution) Mr Dinesh Chand Sharma (SESEI)	How international standards support critical minerals industry; UK and international standards development processes; ISO/IEC structures; European approach to critical raw materials; CEN work programmes; voluntary vs mandatory standards
Technical Standards: Existing, In Progress, Anticipated	Dr Rudra Samajdar (National Physical Laboratory, UK) Mr Manodip Bag (Bureau of Indian Standards)	Current global work programmes; achievements and gaps; metrology infrastructure (certified reference materials, analytical validation, proficiency testing); ISO/TC 298 (Rare Earth) and ISO/TC 333 (Lithium); battery materials and recycled products standards
ESG and Sustainability Standards	Professor Sarah Gordon (Satarla, Imperial College London) Dr Rajiv Ranjan (Bureau of Indian Standards)	Existing ESG and sustainability standards landscape; consolidation and simplification potential; evolution from voluntary to mandatory disclosure; India's BRSR framework; ESG as dominant risk factor; water management and community relations
Standards Uptake and Implementation	Dr James McKenzie (Hirst Magnetics) Mr Danny McNiece (Pensana) Mr Aditya Menon (Vedanta)	Factors affecting industry use of standards; encouraging participation in standards development; customer requirements vs regulatory mandates; market incentives; developing-country participation; capacity building needs

Table 2.2: Day 2 Workshop Sessions: Standards and Implementation

Chapter 3

Critical Minerals and National Resilience

The global economy stands at an inflection point. Achieving net zero emissions by 2050 requires unprecedented deployment of clean energy technologies, including solar panels, wind turbines, electric vehicles, and energy storage systems. These technologies are mineral-intensive in ways that fundamentally differ from fossil fuel infrastructure. A single electric vehicle battery contains approximately 8 kilograms of lithium, 14 kilograms of cobalt, 35 kilograms of nickel, and 20 kilograms of graphite.[1] An offshore wind turbine requires approximately 600 kilograms of rare earth permanent magnets containing neodymium, praseodymium, dysprosium, and terbium. Solar photovoltaics depend on tellurium, indium, gallium, and silicon.

International Energy Agency projections indicate that achieving climate goals will require lithium demand to increase by over 40 times current levels by 2040, graphite by 25 times, cobalt by 21 times, and nickel by 20-40 times.[2] This demand growth exceeds anything experienced in traditional commodity markets. The scale and speed of required expansion poses unprecedented challenges for exploration, development, processing, and supply chain construction.

Simultaneously, digitalisation drives demand for semiconductors, data infrastructure, and advanced electronics, all dependent on critical minerals. Defence applications require specialty metals including titanium for aerospace structures, tantalum for capacitors, tungsten for armour-piercing ammunition, and rare earths for guidance systems and communications equipment. Many of these materials have no viable substitutes. The materials underpinning modern civilisation have shifted from oil and steel to lithium, rare earths, and advanced materials.

Yet supply chains delivering these materials remain concentrated, opaque, and vulnerable. China controls approximately 60 per cent of global rare earth production, 80 per cent of processing capacity, and 90 per cent of permanent magnet manufacturing.[3] Processing capacity for lithium, cobalt, nickel, and graphite shows similar concentration. This dominance reflects deliberate industrial policy sustained over decades, including subsidised capital, controlled domestic prices providing cost advantages, integrated supply chain construction, and strategic tolerance for environmental externalities that other jurisdictions internalise.

[1] https://www.nature.com/articles/d41586-021-02222-1
[2] https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions
[3] https://www.bakerinstitute.org/research/chinese-behemoths-what-chinas-rare-earths-dominance-means-us

Democratic nations have outsourced not merely extraction, but the technical knowledge, industrial capacity, skilled workforce, specialised equipment manufacturing, and quality control systems required for critical minerals processing. Rebuilding these capabilities cannot be achieved quickly. Processing facilities require 5-10 years to plan, permit, construct, and ramp to commercial production. Workforce development demands sustained training programmes. Equipment manufacturing requires resurrection of defunct industries.

This concentration creates multiple vulnerabilities. Supply disruptions, whether from trade restrictions, geopolitical tensions, or operational incidents, can cascade through global supply chains. Price volatility reflects both genuine supply-demand dynamics and strategic manipulation. Technology transfer requirements and export controls can limit access to advanced processing techniques. The strategic challenge extends beyond resource security to encompass industrial capacity, technical knowledge, and supply chain resilience.

Chapter 4

The Data Quality Imperative

Effective policy requires reliable data. Governments cannot plan strategic stockpiles without accurate production statistics. Investors cannot assess supply risks without transparent market information. Companies cannot develop resilient supply chains without understanding material flows. Regulators cannot monitor trade without classification systems that reflect commercial reality. Research institutions cannot model future scenarios without historical data.

Current data quality fails these requirements comprehensively. Production statistics for critical minerals suffer from systematic gaps, inconsistent definitions, delayed reporting, and incompatible collection methodologies. Many materials classified as by-products of major metals extraction remain entirely absent from official statistics. Trade data employs classification systems designed decades ago for traditional commodities, rendering modern critical minerals products effectively invisible in customs statistics.

This data deficit has strategic consequences. Policymakers operate with incomplete information about global production, processing capacity, and trade flows. Markets function inefficiently due to opacity, with price discovery constrained by limited transaction transparency. Investment decisions rest on unreliable foundations, increasing costs of capital and deterring project development. The problem transcends individual jurisdictions and requires international cooperation to address.

Analysis of data quality reveals multiple specific failures. International production databases compiled by the United States Geological Survey, British Geological Survey, and specialist services show discrepancies exceeding 30 per cent for some materials. These divergences reflect not merely reporting lags but fundamental differences in what is measured and how it is categorised. When authoritative sources publish contradictory figures, users lose confidence in all sources.

Resource and reserve estimates, which should provide transparency about future supply potential, suffer from incompatible classification systems. The JORC Code (Australia), NI 43-101 (Canada), SAMREC (South Africa), and various European and Asian national systems employ different terminology, confidence thresholds, and classification criteria. Projects reported under one system cannot be directly compared with projects using another. This fragmentation undermines the transparency that resource reporting should provide.

Midstream processing data proves particularly opaque. Production statistics for refined products often aggregate diverse grades and specifications under generic categories. Processing yields, intermediate products, and material flows remain proprietary information. This opacity prevents accurate modelling of supply chains, limits assessment of processing bottlenecks, and constrains understanding of where value is created and captured.

Secondary materials and recycling flows suffer from near-complete data absence. Battery recycling, electronic waste processing, and industrial scrap recovery operate with minimal reporting requirements. Materials flow analysis attempting to track critical minerals through use and end-of-life management rely on estimates rather than measured data. This gap becomes increasingly problematic as circular economy objectives gain prominence and secondary materials represent growing shares of supply.

Part II

Three Critical Failures

Chapter 5

The Invisibility Crisis: What Cannot Be Seen Cannot Be Managed

5.1 The By-Product Problem

Many critical minerals occur not as primary ores but as by-products of major metals extraction. This geological reality creates systematic reporting failures with strategic consequences. Cobalt occurs primarily in copper and nickel deposits. Gallium, germanium, and indium associate with zinc ores. Rare earths appear as accessory minerals in iron ore and bauxite deposits. Tellurium is recovered from copper refining slimes. Platinum group metals occur together in stratiform complexes where only a subset may be economically significant.

Mining operations optimise extraction and processing for primary metals (copper, zinc, nickel, aluminium) where the bulk of revenue and profitability lie. Associated critical minerals, even when present in economically significant quantities, may represent less than five per cent of operation revenue. Typically, by-products receive attention only when recovered volumes justify the capital investment in separation and purification facilities, processing costs can be covered, and markets exist for the resulting products.

Corporate reporting frameworks, designed around financial materiality thresholds, do not require separate disclosure of immaterial by-products. Under International Financial Reporting Standards and similar national frameworks, items representing less than five per cent of revenue (commonly) or ten per cent (in some jurisdictions) need not be disclosed separately in financial statements. From a company perspective, detailed reporting of each by-product imposes administrative burden (separate accounting, potential disclosure of commercially sensitive information, additional audit requirements) without corresponding benefits to shareholders.

From a government and strategic planning perspective, lack of disclosure creates critical information gaps. Strategically vital materials remain invisible in corporate reports, production statistics compiled from corporate disclosures, trade data derived from customs declarations using inadequate classification codes, and market intelligence assembled from publicly available information. The result: policymakers lack fundamental data about production volumes, processing locations, material flows, and supply chain structure for materials essential to national security and economic transformation.

5.2 The Myanmar Case Study

The rare earth sector provides stark illustration of how undocumented production creates strategic vulnerabilities and market dysfunction. From 2012 to 2015, official Chinese production statistics remained relatively stable whilst global market prices for heavy rare earth oxides fell dramatically. Prices for dysprosium oxide, essential for permanent magnets in wind turbines and electric vehicles, fell from approximately £2,500 per kilogram to £400 per kilogram. Terbium oxide showed similar declines.

Investigation revealed substantial informal rare earth mining and initial processing operations in northern Myanmar, along the Chinese border. Material crossed into China for final processing, then entered global markets. Chinese statistics recorded imports from Myanmar as negligible. Myanmar had no functioning statistical system for rare earth production. The result: substantial supply volumes remained entirely invisible in official statistics whilst materially affecting global markets.

This hidden supply had multiple consequences. Companies planning rare earth mining projects outside China based investment decisions on apparently tight supply-demand balances, only to face competition from unrecorded production. Governments implementing rare earth strategies operated with incomplete understanding of actual global supply. Market participants attempting to hedge price risks found that prices reflected unknown supply variations, making risk management ineffective.

5.3 Financial Versus Strategic Materiality

Current corporate reporting frameworks employ financial materiality as the threshold for disclosure. International accounting standards define materiality in terms of whether omission or misstatement could influence economic decisions of users. Quantitatively, items representing less than approximately five per cent of revenue often qualify as immaterial and need not be disclosed separately.

This creates fundamental misalignment between financial reporting and strategic needs. A cobalt by-product from a copper mine may represent two per cent of revenue (financially immaterial to the mining company) yet constitute strategically essential supply for battery manufacturing and energy storage. From the company perspective, detailed disclosure imposes costs without material benefit to investors. From the government perspective, lack of visibility prevents effective strategic planning.

Several factors compound this misalignment. First, strategic importance and financial materiality correlate imperfectly. Materials critical for national security or clean energy transitions may constitute small shares of individual company revenues. Second, financial reporting focuses on company-level materiality. A material that is immaterial to multiple producers individually may collectively represent significant strategic supply. Third, forward-looking strategic assessments require production data that corporate financial reporting, focused on historical performance, does not necessarily provide.

5.4 India's Legislative Response

India provides concrete demonstration that legislative reform can improve transparency and economic recovery of associated minerals. Historical mining legislation created significant disincentives for reporting and recovering by-products. The Mines and Minerals (Development and Regulation) Act and associated regulations required separate permissions for different minerals, even when co-occurring in the same deposit. Miners reporting associated minerals faced complex administrative procedures, potential taxation disputes over valuation of by-products, and regulatory uncertainty about rights and obligations.

Practical consequences followed predictably. Many mining operations simply discarded associated minerals or left them unreported. Cobalt from copper operations, rare earths from iron ore mines, and numerous other by-products received minimal attention. From a company perspective, navigating administrative complexity, potential tax liabilities, and regulatory uncertainty imposed costs exceeding benefits from recovering small by-product volumes.

Recent legislative amendments addressed these barriers directly. The reformed framework allows miners to declare associated minerals through streamlined procedures without separate permissions for each material. Taxation treatment provides clarity, valuing by-products at realised prices rather than imputed values that could trigger disputes. Administrative procedures consolidate across associated minerals rather than requiring multiple parallel applications.

Early evidence indicates positive effects. Reporting compliance has improved as administrative burden decreased. Economic recovery of associated minerals has increased as regulatory clarity reduced uncertainty. Several mining operations have invested in by-product recovery facilities, bringing previously discarded materials into productive use.

5.5 Policy Implications

Strategic materiality thresholds could usefully require companies to report production and processing of designated critical minerals regardless of financial materiality, implemented through corporate reporting regulations, stock exchange listings, or operating permits.

Legislative frameworks could facilitate by-product reporting and recovery through streamlined declarations, clear taxation, consolidated administration, and regulatory certainty that reduce compliance costs whilst improving transparency.

Independent verification through third-party audits and satellite monitoring can improve data confidence and identify discrepancies. National authorities may consider aligning economic incentives with reporting through tax advantages, priority permits, or preferential procurement.

Chapter 6

The Classification Crisis: Speaking Different Languages

6.1 The Harmonised System Deficit

International trade depends fundamentally on standardised classification. The Harmonised System (HS), administered by the World Customs Organization, provides the foundation for customs duties, trade statistics, rules of origin, and regulatory monitoring. The system assigns six-digit codes to traded products, with additional digits added by countries for more detailed classification. Over 200 countries and economies use HS codes, covering approximately 98 per cent of international merchandise trade.

The system works adequately for traditional commodities. There are specific codes for copper cathodes (7403.11), unwrought aluminium (7601), iron ore pellets (2601.12), and numerous other conventional materials. Critical minerals products fall through the gaps. The HS, while updated every five years, most recently in January 2022, was originally designed in the 1980s for traditional commodities and struggles to accommodate modern critical minerals products due to classification categories that reflect historical trade patterns rather than contemporary battery materials, rare earth products, and advanced minerals.

Lithium carbonate, lithium hydroxide, and lithium chloride, chemically distinct compounds with different applications, processing requirements, specifications, and market values, often share generic residual codes under lithium compounds (2836.91 and 2836.99 depending on jurisdiction). Individual rare earth elements, despite radically different properties, scarcity, and strategic importance, aggregate under catch-all categories (2846.10 for cerium compounds, 2846.90 for other rare earth compounds). Battery black mass, containing valuable lithium, cobalt, and nickel, frequently receives classification as waste (various codes under Heading 38.25 in Chapter 38, which covers residual products and industrial wastes, as defined in the WCO Harmonised System Nomenclature rather than as a commodity.

This classification failure creates cascading problems. Trade statistics compiled from customs declarations provide incomplete pictures of critical minerals flows. A country importing substantial lithium hydroxide for battery manufacturing and lithium carbonate for glass and ceramics cannot distinguish volumes by compound from aggregated statistics. Customs authorities attempting to assess appropriate duties face ambiguity when multiple distinct products share classification codes. Regulators monitoring strategic materials movements cannot accurately track flows when trade classification obscures material identities.

6.1.1 Downstream Technology and Processed Materials

The classification challenge extends significantly into the downstream technology product chain, where the gap between HS code categories and commercial reality is particularly acute. Battery cathode active materials, including lithium nickel manganese cobalt oxide (NMC), lithium iron phosphate (LFP), and lithium cobalt oxide (LCO), are central to the global battery supply chain but lack dedicated HS codes, typically falling under broad chemical compound categories (Chapter 28 or 38) that provide no useful statistical signal. Similarly, cathode precursor materials (pCAM), which are intermediate products of high commercial value in battery manufacturing, are aggregated with other inorganic chemical compounds without distinction.

Permanent magnet alloys and sintered neodymium-iron-boron (NdFeB) magnets, critical components in electric vehicle motors and wind turbine generators, are classified under broad headings for magnets and magnetic articles (HS 8505) that fail to differentiate between commodity ferrite magnets and high-value rare earth permanent magnets. This prevents any meaningful tracking of rare earth consumption embedded in manufactured goods.

For recycled and recovered materials, the classification challenge is compounded by the waste/product boundary problem. Battery black mass, electrode scraps, and hydrometallurgical intermediates from recycling operations may be classified as hazardous waste (Heading 38.25 in Chapter 38), as base metal compounds, or as ores and concentrates depending on jurisdiction and the judgment of customs officials. This inconsistency distorts trade statistics for secondary materials, creates compliance uncertainty for recyclers, and can facilitate misclassification to circumvent waste export controls.

The HS 2022 revision introduced some improvements, including new subheadings for lithium-ion batteries (8507.60) and solar panels, but the pace of revision remains misaligned with the speed of technology development in clean energy. Advocacy for further targeted revision, particularly for battery materials, rare earth compounds, and recycled critical minerals streams, could usefully be coordinated through the WCO's Harmonized System Committee.

6.2 Incompatible Resource Classification Systems

Resource and reserve reporting suffers from fragmentation across incompatible national systems. Mining companies publicly disclosing resources and reserves must follow classification frameworks appropriate to their jurisdiction and stock exchange listing. The JORC Code (Australasian), NI 43-101 (Canadian), SAMREC (South African), and various European and Asian frameworks employ different terminology, confidence requirements, and classification criteria.

These differences are not trivial. JORC and NI 43-101 both classify resources into measured, indicated, and inferred based on geological confidence, but confidence thresholds differ. Reserve definitions under JORC require demonstration of economic extraction, while NI 43-101 employs different economic parameters. SAMREC incorporates considerations absent from other codes. European countries maintain various national systems reflecting different regulatory traditions.

This fragmentation creates multiple problems. Mining companies operating internationally must maintain parallel resource reporting to satisfy different jurisdictions, including separate resource estimates, different classification, and varying disclosure requirements. Investors comparing projects across jurisdictions cannot rely on like-for-like comparisons of resources and reserves. When one project reports reserves under NI 43-101 and another under JORC, direct comparison requires understanding classification differences and making subjective adjustments.

6.3 India's National Geoscience Data Repository

The Geological Survey of India's National Geoscience Data Repository (NGDR) demonstrates how legacy geological data can be transformed into strategic infrastructure through systematic digitisation, standardisation, and accessibility improvements. For over 170 years, GSI has conducted geological mapping, mineral exploration, geophysical surveys, and geochemical sampling across India. This generated vast quantities of data, including geological maps, borehole logs, analytical results, resource estimates, and exploration reports, stored in paper formats, obsolete digital systems, or scattered across regional offices.

The NGDR initiative systematically digitised this legacy data, standardised formats and terminologies, integrated geographic information, and made it accessible through a unified web-based platform. Users can search by location, commodity, data type, or other parameters. Historical exploration reports provide insights into past work that may guide modern programmes. Geochemical data enables machine learning applications identifying exploration targets. Geological maps integrate with satellite imagery and geophysical surveys.

This transformation enables multiple benefits. Private sector exploration companies, particularly international firms less familiar with Indian geology, can access decades of government-funded exploration data to identify prospective areas. This reduces exploration costs, accelerates prospect identification, and improves success rates. Academic researchers can apply artificial intelligence and machine learning to geological datasets, identifying patterns and relationships invisible to human analysis. Government planners can make evidence-based decisions about mineral development priorities, infrastructure planning, and investment attraction.

6.4 The Cost of Incompatibility

Incompatible classification and reporting systems impose tangible costs. Companies spend resources maintaining parallel reporting frameworks to satisfy different national requirements. This administrative burden falls disproportionately on mid-sized companies operating internationally, for whom compliance costs represent higher percentage of budgets.

Regulators struggle to compile accurate statistics when reported data uses inconsistent definitions. Attempting to aggregate production statistics from multiple jurisdictions requires manual reconciliation, introduces errors, and creates delays. Even sophisticated agencies like geological surveys find cross-jurisdictional analysis challenging when basic terminology varies.

Market analysts face substantial uncertainty when international databases provide divergent figures. When USGS, BGS, and commercial data providers publish different production statistics for the same material and period, users lose confidence in all sources. This erosion of data credibility affects investment decisions, policy development, and market functioning.

6.5 Policy Implications

The UK and India could usefully coordinate advocacy through the World Customs Organization for creation of specific HS codes for critical minerals products. Priority categories could include lithium compounds (carbonate, hydroxide, chloride), individual rare earth elements or element groups, battery-grade versus industrial-grade materials, and high-value recyclables including battery black mass.

National authorities could actively promote UNFC as the global standard for resource classification, encouraging adoption by mining companies, geological surveys, and regulatory agencies. Following India's NGDR model, it can be recommended that relevant authorities invest in digitising and standardising geological data, making it accessible for exploration, research, and policy planning.

The UK and India could explore establishing formal data-sharing arrangements covering geological survey information, mineral resource assessments, and production statistics. Reciprocal access to geological databases, exchange of technical expertise, and collaborative research programmes can generate mutual benefits.

Chapter 7

The Standards Deficit: Building Markets Requires Common Language

7.1 The Maturity Gap

Technical standards enable markets to function efficiently by providing common language, reducing information asymmetries, facilitating conformity assessment, and creating level playing fields for competition. Buyers and sellers must agree on product specifications. Testing laboratories require validated methods producing comparable results. Quality assurance demands certified reference materials for instrument calibration. International trade depends on mutual recognition that products meeting standards in one jurisdiction satisfy requirements elsewhere.

Mature industrial sectors benefit from comprehensive standards infrastructure developed over decades. Iron and steel are covered by hundreds of technical specifications addressing chemical composition, mechanical properties, dimensional tolerances, surface finish, testing procedures, sampling protocols, and specific applications. These standards, developed through consensus processes involving producers, users, testing laboratories, regulators, and research institutions, provide the common technical language enabling a global industry worth trillions annually.

Critical minerals lack equivalent maturity. Lithium carbonate, fundamental to battery manufacturing and representing a market of tens of billions annually, has no universally recognised purity standard. Different battery manufacturers specify different purity thresholds (ranging from 99.0% to 99.9% depending on cathode chemistry), different particle size distributions, different moisture content limits, and different trace element specifications.

Indian lithium processing companies report receiving contradictory specifications from different customers. One battery manufacturer may require lithium carbonate with less than 10 parts per million (ppm) calcium, whilst another accepts 50 ppm. Magnesium limits vary from 20 ppm to 100 ppm. Particle size distributions specify different measurement methods (laser diffraction versus sieving) with incompatible results. These specification differences prevent economies of scale, as processors must maintain multiple production lines or accept constrained markets.

7.2 The Measurement Problem

Effective standards require robust measurement infrastructure. Claims about purity, composition, particle size, or performance must be verifiable through validated analytical methods traceable to internationally recognised units. This requires certified reference materials (CRMs), samples with precisely known composition used to calibrate instruments and validate test procedures. Without measurement traceability, technical standards lack credibility.

Critical minerals suffer from inadequate metrology infrastructure. Certified reference materials exist for common metals (copper, zinc, aluminium) and their alloys, covering major and trace element compositions. Analytical methods for these materials are well-validated through extensive inter-laboratory studies. Proficiency testing schemes enable laboratories to demonstrate competence and maintain quality control.

CRMs for critical minerals products remain limited or non-existent. Lithium carbonate, despite commercial significance, lacks widely available CRMs covering the range of purity grades, particle size distributions, and matrices encountered commercially. Rare earth oxide CRMs exist for some individual elements but coverage remains incomplete. Battery black mass, an increasingly important recyclable material, has no internationally recognised CRMs despite containing lithium, cobalt, nickel, and manganese in complex matrices.

Without measurement foundation, technical standards lack practical value. A purity specification means little if different laboratories, using different analytical methods, produce divergent results for the same sample. International trade requires confidence that products tested in the exporting country meet specifications when independently tested in the importing country.

7.3 The Neodymium Magnets Challenge

Permanent magnets containing neodymium, praseodymium, dysprosium, and other rare earths illustrate the standards challenge. These magnets are essential for electric vehicle motors, wind turbine generators, and numerous other applications. Yet their manufacture depends on rare earth oxides and metals that lack comprehensive specifications.

Magnet performance depends critically on input material purity and composition. Trace elements at parts-per-million levels can degrade magnetic properties. Oxidation during handling affects performance. Particle size distribution influences sintering behaviour. Each parameter requires precise specification and reliable measurement.

Currently, magnet manufacturers develop proprietary specifications for rare earth inputs, guard these as trade secrets, and source from qualified suppliers through long-term relationships. This approach works for established supply chains but creates barriers for new entrants. A new rare earth processor cannot easily access the market without meeting specifications that are proprietary and unavailable.

7.4 The Recycling Void

Circular economy objectives require standards for recycled materials. Battery black mass, the mixed metal output from battery recycling, contains valuable quantities of lithium, cobalt, nickel, and manganese. Yet it lacks agreed characterisation methods, quality specifications, or trading standards.

This standards void creates multiple problems. Recyclers cannot provide credible assurances about material quality because standardised characterisation methods do not exist. Refiners processing black mass face uncertainty about feed material composition, complicating production planning and process control. Trade occurs through bespoke contracts rather than transparent markets.

Misclassification as waste, rather than as a valuable commodity, facilitates illegal exports and undermines circular economy objectives. When battery black mass is classified as hazardous waste rather than as a recycled material, it becomes subject to waste export restrictions. Yet the absence of clear product standards creates ambiguity about whether specific materials are products or waste.

7.5 International Dimensions of Standards Development

International standards development at the technical level can be politically neutral and often is: the work of drafting analytical methods, specifying purity thresholds, and developing sampling protocols is primarily a technical exercise grounded in science and industrial practice. The voluntary, consensus-based nature of international standards, developed through ISO and IEC technical committees, is designed precisely to enable participation from across the world on an equal footing, regardless of political relationships between member countries.

At the same time, it is worth recognising that the distribution of participation in standards development is not uniform. Countries and organisations that invest in sustained technical engagement (through funding experts, sponsoring secretariat functions, and coordinating positions across domestic stakeholders), are better positioned to shape the content and direction of international standards. A number of national bodies from several countries have made such investments in technical committees relevant to critical minerals, including ISO/TC 298 (Rare Earth) and ISO/TC 333 (Lithium). This reflects the value those countries place on international standards work, and illustrates why participation by a wide range of actors matters for achieving broadly applicable outcomes.

The UK and India, working together, can contribute substantive technical expertise spanning geological surveying, materials science, processing technology, analytical chemistry, and industrial operations. Joint engagement in standards development can strengthen the breadth of perspectives represented in technical committees and contribute to standards that reflect the needs of a wide range of producing, processing, and consuming nations. This collaborative approach is consistent with the open, inclusive model of international standards development that the WTO TBT Agreement supports.

7.6 Standards and Market Development

Markets require standards to function efficiently. Without agreed product specifications, buyers and sellers must negotiate terms bilaterally. Transaction costs rise. Market liquidity suffers. New entrants face barriers to market access. Innovation struggles when products must meet multiple bespoke specifications rather than published standards.

Transparent price benchmarks depend on standardised products. When lithium carbonate lacks universal specifications, price reporting agencies struggle to establish benchmarks. Financial instruments like futures contracts require standardised products for delivery specifications.

Quality assurance becomes challenging without testing standards. A buyer purchasing lithium carbonate needs confidence that material meets specifications. This requires validated testing methods, accredited laboratories, and traceable measurement.

7.7 Policy Implications

Priority critical minerals could benefit from further standards development, building on existing work. Interim specifications and published authority documents can provide near-term guidance whilst comprehensive standards undergo full consensus processes. BSI and BIS could usefully explore jointly developing interim specifications for lithium compounds and rare earth oxides as demonstrator projects, complementing rather than duplicating ongoing ISO Technical Committee work.

It is worth noting the active standards development already under way: ISO/TC 298 (Rare Earth) has published standards on terminology, sampling, and chemical analysis methods; ISO/TC 333 (Lithium) is developing standards for lithium carbonate, lithium hydroxide, and related compounds; and ISO/TC 47 (Chemistry) covers relevant analytical methods. Any new bilateral work could usefully be coordinated with these existing programmes to avoid duplication and maximise international uptake. BSI representatives are well placed to advise on current ISO TC activity and opportunities for UK-India joint engagement.

National metrology institutes could be supported in developing certified reference materials, validating analytical methods, and establishing proficiency testing schemes for critical minerals. Research programmes could usefully include explicit standardisation deliverables, translating findings into draft standards.

Effective participation in international standards bodies requires sustained resourcing, including funding for technical experts, coordination mechanisms, and long-term institutional commitment. The UK and India could explore coordinating positions in ISO/TC 298 (Rare Earth), ISO/TC 333 (Lithium), and related committees, presenting joint proposals where beneficial.

7.8 Workshop Conclusions on the Standardisation Landscape

The workshop generated important conclusions that should inform the design of future standardisation efforts for critical minerals. These conclusions reflect an honest assessment of what standards can and cannot achieve, and of how the current landscape is experienced by practitioners.

The standards landscape is not always well understood by those who operate within it. Greater efforts to raise awareness of existing standards offerings may be as valuable as developing new ones. Workshop discussions revealed that whilst gaps remain, there is also genuine fatigue among some practitioners confronted with a proliferating range of standards across this field. Future standardisation efforts should therefore aim to be proportionate to criticality and risk-based in their prioritisation, and should consider whether consolidation of existing standards might sometimes be more valuable than the development of new ones.

Awareness of the governance implications of different standards development models was found to be low. Yet governance matters enormously: the credibility, legitimacy, and ultimately the adoption of a standard is shaped significantly by who develops it, on what terms, and with whose input. Standards developed by a small number of companies from a narrow group of countries may embed particular technical approaches and competitive advantages. By contrast, standards developed through genuinely inclusive processes (encompassing governments, industry, academic institutions, civil society, and community groups, and ensuring that participation is accessible without prohibitive cost barriers), are more likely to command broad international acceptance and to reflect the full range of stakeholder interests. The WTO Technical Barriers to Trade Agreement requirement to use international standards as the basis for regulation reinforces the importance of ensuring that international standards are developed through appropriately inclusive processes.

Appropriate realism about what standards can achieve is warranted. Standards are not a substitute for addressing fundamental market failures or resolving entrenched geopolitical competition. However, where collaborative intent exists, standards can be a powerful enabling instrument: helping to create markets, facilitating technical engagement where political dialogue is constrained, supporting innovation, building international communities of practice, and enabling the knowledge sharing required for effective collective action on shared challenges.

Both the UK and India are engaged in broader efforts to encourage the development of standards-based markets for critical minerals. Defining more precisely what such markets should look like, and identifying the standards work needed to deliver them, represents a natural area for deepened bilateral collaboration. This shared ambition provides a strong and practical foundation for the sustained partnership recommended in this report.

7.9 Defining the Midstream

Critical minerals value chains comprise three distinct segments. Upstream extraction produces ores and concentrates through mining and initial beneficiation. Downstream manufacturing converts materials into finished products, including batteries, magnets, alloys, and semiconductors. Between them sits the midstream: processing and refining operations that convert concentrates into battery-grade chemicals, high-purity metals, separated rare earth elements, and other intermediate materials.

Traders play an important role across the value chain and are not easily confined to a single segment. In many supply chains, trading companies operate in the midstream purchasing concentrates or intermediate products, arranging processing or tolling, and selling refined outputs to downstream manufacturers. In some corporate structures, trading operations span upstream offtake agreements, midstream logistics and processing arrangements, and downstream supply contracts. Price reporting agencies, which serve the trading community, are also closely integrated with midstream market activity. The inclusion of trading perspectives in the workshop was therefore valuable in illuminating market transparency challenges that span the full value chain.

The midstream represents the most constrained segment of global critical minerals supply chains. Processing capacity for most critical minerals is geographically concentrated, reflecting decades of industrial policy, technical development, and integrated supply chain construction by a small number of dominant producers.

7.10 The Transparency Problem

Midstream processing suffers from acute data deficits compounding the transparency problems identified for upstream mining. Production statistics, when they exist, often aggregate diverse products under generic categories. Lithium carbonate, lithium hydroxide, and lithium chloride appear as undifferentiated “lithium compounds” in many trade databases. Processing yields, the percentage of input concentrate converted to saleable products, remain proprietary information.

This opacity prevents effective market analysis and policy development. Analysts cannot accurately model supply-demand balances without understanding processing capacity, throughput rates, material yields, and product specifications. Investors cannot assess project economics without reliable data on processing costs, capital requirements, and technical performance.

7.11 The Specification Fragmentation

Unlike conventional metals where products like copper cathodes or zinc ingots have globally recognised specifications, critical minerals products suffer from fragmentation. Battery manufacturers employ proprietary cathode chemistries, each requiring specific input material specifications. Permanent magnet producers guard manufacturing processes, translating into bespoke rare earth oxide requirements.

This fragmentation has multiple root causes. Technical requirements genuinely vary across applications. Different cathode chemistries tolerate different impurity levels, permanent magnet performance depends on precise rare earth ratios, and semiconductor requirements tighten as feature sizes decrease. Intellectual property protection leads companies to specify inputs narrowly, preventing competitors from reverse-engineering processes.

7.12 Secondary Resources and Circular Economy

The midstream presents both challenge and opportunity for circular economy development. Tailings from historical mining operations contain recoverable quantities of critical minerals but remain classified as waste rather than resources. Urban deposits, including end-of-life batteries, discarded electronics, and decommissioned infrastructure, constitute high-grade anthropogenic ores that lack standardised characterisation methods.

Battery recycling illustrates the opportunity. Black mass recovered from end-of-life lithium-ion batteries contains valuable lithium, cobalt, nickel, and manganese, often in concentrations exceeding primary ores. Yet the absence of quality standards, testing methods, and trading frameworks forces material through opaque, bespoke transactions.

7.13 ESG as Dominant Risk Factor

Environmental, social, and governance (ESG) considerations have evolved from peripheral concerns to dominant factors responsible for substantial shares of project failures. Community opposition, water conflicts, inadequate closure planning, and biodiversity impacts can derail projects at any development stage. Analysis presented at the workshop emphasised that ESG issues kill more projects than technical or geological challenges.

Traditional feasibility studies focusing on technical and economic factors provide incomplete risk assessment. Integration of ESG considerations at early stages enables realistic project evaluation and investment decisions. The distinction between sustainability (the long-term objective) and ESG (the measurement and reporting framework) requires clearer articulation.

7.14 Bankable Sustainability

The concept of bankable sustainability integrates ESG considerations into financial decision-making from project inception. Rather than treating environmental and social factors as constraints to be minimised, bankable sustainability recognises them as value drivers affecting project viability, risk profile, and returns.

This requires moving beyond box-ticking compliance to genuine integration. ESG assessments should occur at feasibility stage, identifying material risks and mitigation strategies. Financial models should incorporate ESG costs and benefits realistically.

7.15 Policy Implications

National authorities and industry bodies could usefully explore requiring processing facilities producing critical minerals to report capacity, throughput, yields, and product specifications. Strategic materiality thresholds could apply equally to midstream operations. Industry consortia, with support from national authorities where appropriate, could develop harmonised specifications for priority battery chemicals, rare earth products, and other critical materials.

Standards development could usefully prioritise characterisation methods for recycled materials, tailings, and anthropogenic deposits. Resource classification frameworks could be adapted to accommodate secondary materials.

Project permitting frameworks could usefully require ESG assessments at feasibility stage, with detailed mitigation plans and monitoring frameworks. Financial models submitted for regulatory approval could incorporate ESG costs realistically.

Part III

The UK-India Opportunity

Chapter 8

Complementary Capabilities and Strategic Alignment

The generic problems identified in this report: data quality gaps, fragmented classification systems, incomplete standards, and midstream opacity, are not unique to any one country and cannot be resolved unilaterally. Addressing them effectively requires collaboration between countries with different but complementary assets: geological knowledge, institutional experience, processing capability, standards expertise, financial market depth, and reform capacity. The UK and India bring a distinctive combination of such assets, and the potential value to be added by each merits consideration on its own terms.

8.1 What the UK Brings to the Partnership

The United Kingdom's principal contributions to data quality and standards work in this domain lie in institutional expertise and international connectivity rather than in mineral endowment. The British Geological Survey brings world-leading capabilities in geological data management, resource classification (including active engagement with UNFC), and international scientific collaboration, assets directly relevant to the data quality challenges identified. The British Standards Institution brings deep experience of international standards processes through ISO and CEN, sector-specific technical committees, and an established network of relationships with standards bodies globally.

UK financial markets, including commodity trading, price reporting, and derivatives, offer experience of how transparent, standardised markets function in practice, and what market infrastructure is needed to support them. This experience is directly applicable to the question of how standards-based markets for critical minerals could be developed.

British academic institutions bring research capabilities in geological sciences, processing technologies, analytical chemistry, and supply chain analysis that can contribute to the pre-normative research underpinning credible standards. The UK's regulatory experience in environmental assessment and community engagement, though developed in a different context, also offers transferable lessons for ESG standards development.

8.2 What India Brings to the Partnership

India's contributions are equally distinctive. India's substantial mineral endowments, including rare earth, lithium, graphite, and associated deposits, mean that data quality and classification improvements have direct practical value: better data about Indian resources can attract exploration investment and support evidence-based policy. India's rapidly expanding processing sector, encompassing lithium refining, rare earth separation, and battery material manufacturing, gives Indian industry a direct operational stake in the development of product specifications and testing standards.

The Bureau of Indian Standards represents a mature national standards institution with extensive experience in consensus-based development, sectoral technical committees, and ISO/IEC membership. India's demonstrated reform capacity - evidenced by the legislative amendments to minerals reporting and the development of the National Geoscience Data Repository - shows both political willingness and technical capability to address structural problems at scale. India's position as a major and growing consumer of critical minerals for clean energy applications gives it a strategic interest in supply chain transparency that complements the UK's interests.

8.3 The Case for Partnership

Bilateral partnerships succeed when addressing shared challenges through complementary capabilities. The UK and India face common problems, supply chain vulnerabilities, data deficits, and standards gaps - whilst seeking enhanced resilience - improved market transparency, and reduced dependence on concentrated supply chains.

The value added by partnership lies in combining assets that neither country holds alone: geological and processing knowledge with financial and regulatory expertise; a growing consumer market with established commodity market infrastructure; and two national standards bodies with complementary international networks. Joint development of standards, harmonised data frameworks, and coordinated international advocacy can generate outcomes neither country could achieve independently. Approaches developed bilaterally can serve as templates for broader international adoption, increasing their impact beyond the bilateral relationship.

8.4 Historical Context and Trust

UK-India cooperation on critical minerals builds on established institutional relationships and shared interests. Both countries participate in Commonwealth frameworks, maintain strong educational and research links, and collaborate on multiple international forums, providing foundation for deeper cooperation on strategic minerals. Trust develops through successful cooperation on defined objectives with mutual benefit. The workshop in New Delhi demonstrated willingness to engage substantively on technical challenges.

Part IV

Policy Framework and Recommendations

Chapter 9

Strategic Priorities

The following priority areas for action are organised across five domains. They are presented as recommendations for consideration by relevant national authorities, industry bodies, and international organisations, rather than as prescriptive requirements. Short-term actions are those that could plausibly be initiated within 12 months; long-term actions are those requiring sustained effort over one to five years. Outcome indicators and indicative resource implications are included where these can usefully be estimated. The UK and India could also explore possibilities for working together on data challenges and solutions through the Data Pillar of the Supply Chains Mission of the Global Clean Power Alliance (GCPA).

No.	Action Area	Term	Description and Priority Actions	Outcome Indicators	Indicative Resources
Domain 1: Data Quality and Harmonisation					
1	Bilateral Data-Sharing Framework	Short	Exchange production statistics, processing capacity data, and trade information between national authorities. Priority action: conclude MoU between BGS and GSI within 12 months	MoU signed; datasets exchanged within 18 months; discrepancies between national datasets reduced by 20% over 3 years	Staff time from BGS, GSI, statistical agencies; low incremental cost
2	UNFC Adoption and Promotion	Long	Promote UN Framework Classification for Resources as a common reference point for resource reporting, including training and research for secondary resources. Priority: develop joint training materials	Number of companies and surveys adopting UNFC; training participants; secondary resource pilots completed	Joint BGS-GSI programme; est. £200–500k over 3 years
3	Trade Classification Reform	Long	Coordinate advocacy through the WCO for revised HS codes for lithium compounds, rare earth elements, battery cathode materials, and recyclables. Priority: prepare joint technical submission	WCO submission filed by Q3 2026; new codes adopted in HS revision cycle 2027/2028	Technical working group; est. £50–100k for analysis and submission

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No.	Action Area	Term	Description and Priority Actions	Outcome Indicators	Indicative Resources
4	Strategic Materiality Reporting	Long	Explore requirements for companies to report critical minerals production regardless of financial materiality, via regulations, listing rules, or permits. Priority: consult industry on design	Consultation completed; pilot reporting by 10+ companies within 2 years	Regulatory design resource; consultation process; low compliance cost if well-designed
Domain 2: Standards Development					
5	Bilateral Technical Working Groups	Short	Establish joint UK-India working groups for lithium compounds, rare earth oxides, and battery materials, building on existing ISO TC work. Priority: map current ISO TC activity before proposing new work	Interim specifications published for 2+ materials within 18 months; joint submissions to ISO TCs	BSI-BIS joint secretariat; est. £100–200k p.a.
6	Metrology Infrastructure	Long	Support development of certified reference materials and validated test methods through national metrology institutes. Priority: identify top 3 CRM gaps	CRMs available for lithium carbonate, NMC, and rare earth oxides within 3 years; inter-lab proficiency schemes established	Joint NPL(UK)-NPL(India) programme; est. £500k–1M
7	Circular Economy Standards	Long	Develop standards for tailings characterisation, battery black mass, design-for-recyclability, and traceability. Priority: pilot black mass characterisation standard	Black mass characterisation method agreed; 2+ traceability pilots running within 3 years	Joint working group; est. £200–400k
Domain 3: Capacity Building					
8	Professional Exchanges	Short	Structured exchanges of competent persons, laboratory personnel, and standards officials. Priority: launch first cohort within 12 months	20+ exchanges in first two years; qualitative feedback from participants	Funding programme; est. £200k p.a.
9	International Standards Participation	Short	Coordinate positions and support participation in ISO TC 298/333, IEC battery committees, CEN, and WCO. Priority: establish BSI-BIS coordination mechanism	Joint position papers submitted; participation in 3+ TCs within 12 months	Coordination mechanism; travel funding; est. £100k p.a.
Domain 4: Research and Innovation					

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No.	Action Area	Term	Description and Priority Actions	Outcome Indicators	Indicative Resources
10	Joint Research Programmes	Long	Collaborative research on by-product recovery, complex ore processing, urban mining, and isotopic tracing, with explicit standardisation deliverables. Priority: issue first joint call	First joint call issued within 18 months; 5+ projects funded; at least 2 draft standards outputs	Matched contributions; est. £5–10M over 3 years
11	Pre-Normative Research	Long	Ensure research programmes include standardisation deliverables feeding into ISO/IEC or national standards	At least 50% of funded projects include standards deliverable; 3+ draft standards contributed	Embedded in research funding criteria; no additional cost
Domain 5: International Leadership					
12	Multilateral Advocacy	Long	Present coordinated positions at G7, G20, WTO, and GCPA on data transparency, trade classification, and standards. Priority: agree joint statement by Q3 2026	Joint statement at major forum within 12 months; GCPA Data Pillar engagement initiated	Foreign ministry coordination; joint policy papers; low incremental cost
13	Developing-Country Engagement	Long	Support participation of developing countries in standards processes through training, committee funding, and technical assistance	10+ developing countries supported; 3+ capacity-building programmes running within 3 years	Training programmes; travel funding; est. £200–500k p.a.

Table 9.1: Priority Action Areas Across Five Domains (Short-term: 0–12 months; Long-term: 1–5 years)

Chapter 10
Conclusion

Critical minerals constitute the foundation of 21st century economic prosperity and national security. The transition to net zero emissions, digital transformation, and advanced manufacturing all depend absolutely on reliable access to these materials. Yet the supply chains delivering critical minerals suffer from fundamental weaknesses in data quality, classification systems, and technical standards.

This report has identified three critical failures that threaten supply chain resilience and market functioning. The invisibility crisis renders strategically vital materials absent from corporate reports, production statistics, and market data. The classification crisis imposes costs and creates confusion through incompatible systems and outdated trade codes. The standards deficit prevents development of transparent, efficient markets.

These failures are not inevitable. India has demonstrated that legislative reform can bring hidden production into official statistics. The National Geoscience Data Repository shows how legacy data can be transformed into strategic infrastructure. European standardisation demonstrates the economic value of harmonised frameworks.

The UK and India possess complementary capabilities that enable effective partnership. British expertise in geological surveying, financial markets, and standards development aligns with Indian mineral endowments, rapidly expanding processing capacity, and institutional infrastructure. Joint development of standards, harmonised data frameworks, and coordinated international advocacy can generate solutions with global application.

This report proposes establishing a formal UK-India Critical Minerals Partnership with clear governance structures, dedicated resources, and measurable deliverables. Implementation should proceed through structured phases: establishing institutional frameworks and demonstrating commitment; delivering practical capabilities and tools; and achieving international adoption of jointly developed approaches.

The thirteen recommendations presented in this report provide the policy framework across five domains: data quality and harmonisation, standards development, capacity building, research and innovation, and international leadership. Success requires sustained political commitment from both governments, adequate funding, active industry engagement, and flexibility to adapt based on experience.

The strategic and economic benefits justify this investment. Enhanced supply chain resilience reduces vulnerability to disruptions. Improved market transparency enables better investment decisions and policy planning. International leadership on critical minerals governance positions both countries advantageously. Demonstrated bilateral cooperation provides a model for broader international action.

Both governments should take this agenda forward through close cooperation. The partnership offers opportunity not merely to address shared challenges but to demonstrate international leadership on an issue of global significance. Success will require sustained effort, but the strategic imperative demands nothing less.

The proposals warrant consideration by policymakers in both nations as they advance this partnership as a cornerstone of critical minerals strategy.

Chapter A

Workshop Programme

UK-India Workshop on Enhancing Critical Minerals Data Quality and Standards

19-20 January 2026
Bureau of Indian Standards Headquarters, New Delhi

Day 1: Data Quality Challenges

Session 1: Introduction and Strategic Rationale

Opening addresses by BIS leadership and UK delegation; overview of workshop objectives; strategic context for UK-India cooperation on critical minerals.

Session 2: Documented and Undocumented Production

Analysis of production data gaps; by-product reporting challenges; case studies including Myanmar rare earths; India's legislative reforms enabling associated minerals declaration.

Session 3: Disparate Classification and Reporting Systems

Harmonised System code limitations for critical minerals; incompatible resource classification frameworks; UNFC as bridge between systems; India's National Geoscience Data Repository.

Session 4: By-Product Status and Market Reporting

Financial versus strategic materiality; economics of by-product recovery; market transparency and price discovery; regulatory approaches to strategic materiality reporting.

Session 5: Resource and Reserve Classification

JORC, NI 43-101, SAMREC and other national codes; UNFC three-dimensional classification; application to secondary resources including tailings and anthropogenic deposits.

Day 2: Standards and Implementation

Session 6: International Standards Landscape

ISO, IEC, CEN structures and processes; voluntary nature of standards; ISO/TC 298 Rare Earth and ISO/TC 333 Lithium; European approach to critical raw materials standardisation.

Session 7: Technical Standards for Critical Minerals

Specifications for lithium compounds, rare earth oxides, battery materials; certified reference materials and analytical method validation; neodymium magnets case study; standards for recycled materials.

Session 8: ESG and Sustainability Standards

ESG as dominant risk factor; India's BRSR framework; water management and community relations; mine closure planning; bankable sustainability integrating ESG into financial decision-making.

Session 9: Standards Uptake and Implementation

Drivers of standards adoption; customer requirements and regulatory mandates; market incentives; capacity building requirements; developing-country participation in standards processes.

Chapter B

Workshop Participants

The workshop brought together 58 participants from government, industry, academia, and international organisations. Representation spanned the critical minerals value chain from geological surveying through processing to end-use applications.

B.0.1 UK and Global Delegation (30 participants)

Standards Bodies: British Standards Institution (R.L. Smith, A. Price); UNECE (H. Tulsidas); SESEI (D.C. Sharma)

Government & Research: British Geological Survey (K. Goodenough, G. Mudd); UK Cabinet Office (S. Strickland); UK FCDO (S. Hookins, D. Weaver); British High Commission India (S. Taylor, S.N. Booth, J. Bamford, B.M. Reghurajan, A. Narayanan); NPL UK (R. Samajdar)

Universities: Cambridge (M. Kumar, D. Jayasekara); Exeter (F. Wall); Hull (J. Wadhawan); Imperial (R. Myers)

Industry: Pensana (D. McNeice); Cornish Lithium (M. Dunn); Hirst Magnetics (J. McKenzie); Rolls Royce (R. Smith, G. Round); Johnson Matthey (D. Satoskar); Advanced Alloys (S. Hall); Minviro (M. Knevett); Satarla (S. Gordon)

B.0.2 Indian Delegation (28 participants)

Standards & Government: Bureau of Indian Standards (S. Maini, M. Bag, R. Ranjan); Geological Survey of India (P.K. Singh, V.K. Palleti); Ministry of Mines (S.V. Kadam, M. Sadiq); NPL India (S. Dhakate)

Universities & Research: IIT/ISM Dhanbad (D. Kumar, D.K. Singh, M. Danish); CSIR-NML Jamshedpur (Abhilash); C-MET (R. Ratheesh)

Industry - Mining & Processing: Hindustan Zinc (S. Dhali, P. Mehta); Hindalco/Aditya Birla (V. Tathavadkar); GMDC (S. Agrawal, D. Srivastava); Indian Rare Earths (B.R. Mishra); Vedanta (A. Menon); Jindal Stainless (A. Goyal); MECL (P. Pandey); Asterix Innovation (S. Sen)

Industry - Battery & Recycling: LOHUM (S. Gopalan); ACE Green Recycling (N. Chadha, S. Gupta); Ola Electric (R. Mekkat)

Chapter C

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The Bureau of Indian Standards for hosting the workshop and providing essential institutional support throughout the process.

The Geological Survey of India and British Geological Survey for technical expertise on resource classification, data infrastructure, and geological intelligence.

Industry representatives from mining, processing, and trading sectors who shared operational perspectives and practical insights essential for grounded policy recommendations.

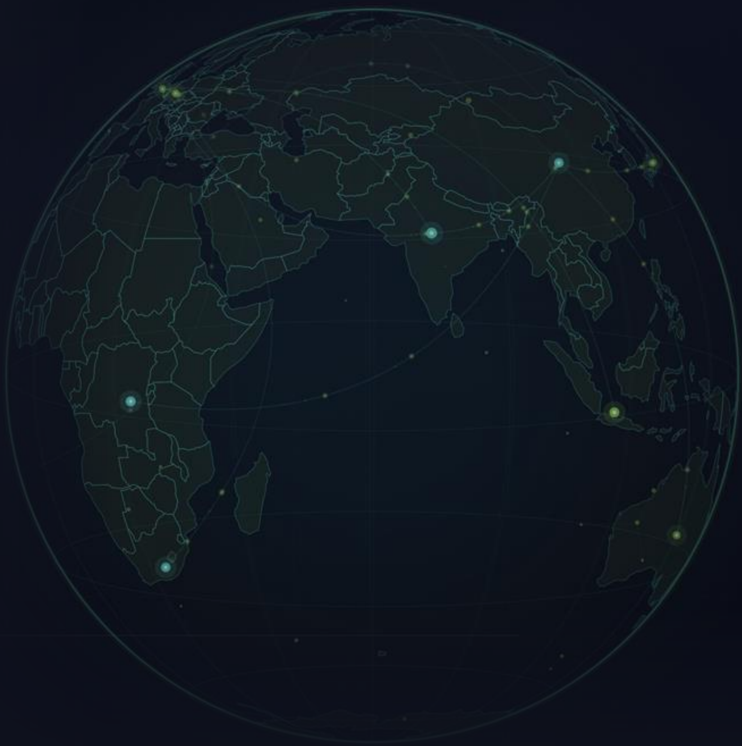
Academic researchers from universities and research institutions who contributed scientific expertise on resource assessment, processing technologies, and analytical methods.

International standards organisations including ISO, IEC, and CEN whose representatives explained global standards architecture and development processes.

ESG and sustainability specialists who highlighted the transformation of environmental and social considerations from peripheral concerns to dominant risk factors.

Officials from both governments who contributed policy expertise, coordinated logistics, and ensured substantive outcomes from technical discussions.

The engagement, expertise, and commitment demonstrated by all participants enabled the productive exchange of views and development of actionable recommendations presented in this report.



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