Critical Mineral Supply Chain Resilience

Industry-Academia Workshop

Report provided by the Industrial Resilience Research Group, the Institute for Manufacturing

UNIVERSITY OF CAMBRIDGE
Department of Engineering

IfM Industrial Resilience Research Group

This report presents the key findings from the Critical Mineral Supply Chain Resilience workshop conducted independently by the Industrial Resilience Research Group, the Institute for Manufacturing, the University of Cambridge in partnership with IIT Bombay and the UK's Science Innovation Network. The report findings are based on the authors' interpretation of the insights and data shared by the subject matter experts during the workshop. Any mention of firm names or commercial products does not constitute an endorsement by the authors and their affiliated institutions. The copyright of all materials in this publication rests with the respective content authors.

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1. Introduction

Critical Minerals (CMs) have emerged as pivotal resources underpinning modern economies that play an important role in our everyday lives. They form the foundation of our digital age, fuel our devices, form the backbone of our green energy infrastructure, drive the development of numerous technological advancements, and have come to shape global geopolitics. CMs are broadly defined as minerals essential to a nation's economy or security, with supply risks due to scarcity, concentration of mining and production, or geopolitical factors. Consequently, the criticality of these minerals varies from one country to another based on specific economic dependencies, industrial priorities, and strategic interests.

As global demand for CMs surges—driven by rapid technological innovation and sustainability goals—the need for transparent and resilient supply chains has become paramount. The UK and India sit at the crux of these dynamic shifts, with both countries sharing the same quest for scientific, technological and climate-compatible economic growth. The supply chains for CMs are complex and geographically dispersed, spanning from resource identification and extraction to processing, refining and integration into end products. This intricate network, characterised by geographic concentration and fragmentation across supply chain stages, highlights the strategic and logistical challenges of securing and managing these critical resources.

To navigate these challenges, collaboration between the UK, India and international partners is essential to ensure reliable access to these vital materials. Given the UK's leadership in advanced innovation and India's recent opening of its mining sector for critical mineral extraction, alongside its rapidly growing technology landscape, there is substantial potential for synergistic collaboration between the two nations. Together, they have the potential to develop a blueprint of CM sustainability and resilience, facilitating a paradigm shift in international cooperation.

Both nations are currently well-positioned to work together to enhance the resilience of global CM supply chains as recently announced by the UK-India Technology Security Initiative (TSI), leveraging the expertise of both nations, relevant databases, advanced analytics—including big data and generative AI—and circular economy practices to map material flows and foster sustainability. It is within this context that a transformative vision takes shape: the 'UK-India Virtual Critical Minerals Supply Chain Observatory'.

1. UK-India Virtual Critical Minerals Supply Chain Observatory

This visionary project is led by the University of Cambridge IfM's Industrial Resilience Group, in collaboration with IIT Bombay, focusing on material chemistry for recycling; ISSER Pune, focusing on industrial policy; and Google Cloud as the technology partner.

The key objectives of the Observatory are:

- **Data Exploration & Research**: Construct CM supply chain database, pinpointing risks and availabilities, recycling and deficits within the UK and India.
- **Supply Chain Fortification Recommendations**: Providing recommendations on how to strengthen global CM supply chains and mitigate disruptions to the UK and India based on exploration and research.
- **Piloting Innovations to Secure Stable Supply Chains**: Fostering innovations from both countries and piloting innovative technologies such as big data analytics, Generative AI (Gen AI), and remote sensing to enable real-time supply chain analysis.
- **Bilateral Trade and Investment**: Analyse current blockers in the trade and investment environment in CMs between the UK and India. Work to promote seamless trade and allow Indian and British innovations and solutions to be applied seamlessly in each other's markets.
- **Capacity Augmentation & Knowledge Dissemination**: Amplify CM capabilities in terms of extraction, refining and circularity through collaborative workshops and knowledge exchange.

Figure 1 Objectives of the Observatory

The benefits to UK stakeholders are:

- **Establishing the UK as a Trusted Partner for India**: Building a strong partnership with India early on aligns the UK with India's growing CMs sector, where demand is set to rise significantly. By offering UK innovations to support India's supply chain, the UK can position itself as a trusted partner in India's critical mineral strategy, helping to build a resilient supply chain framework.

- **Enhanced Commercial Opportunities for UK plc**: Gaining deeper insights into India's industrial landscape allows UK stakeholders to adapt and scale innovations for the Indian market. The UK can trial emerging technologies, such as big data analytics, Gen AI and remote sensing, at a lower cost and risk, leveraging India's openness to frugal innovation.

- **Broader Global Supply Chain Insight**: Understanding India's critical mineral supply chain—its consumption patterns, resource flows, and potential bottlenecks—will provide the UK with essential insights into global supply dynamics. This intelligence enables the UK to secure reliable supplies for its own critical sectors, including renewable energy, electronics, and defence.

- **Access to Indian Talent and Innovation**: Collaborating on data infrastructure with India through initiatives like the UK-India CMs Observatory will connect the UK with India's robust talent pool and innovative approaches, particularly in research, data analytics, and logistics. This partnership brings new capabilities, ideas, and efficiencies to UK operations.

- **Strengthened Trade and Investment Avenues**: As India opens its mining sector to private entities, stronger UK-India ties will diversify UK trade and investment, reducing dependency on single-source suppliers and mitigating geopolitical risks. A secure and consistent critical mineral supply with India's partnership will reinforce UK capabilities and resilience in critical mineral resources.

The benefits to Indian stakeholders are:

- **Enhanced Data Infrastructure and Access to UK Expertise**: Establishing a robust data infrastructure through the UK-India CMs Supply Chain Observatory will significantly boost India's capabilities in research, data analysis, and logistics. Access to UK expertise fosters cross-sector innovation, driving growth and resilience across India's industrial landscape.

- **Improved Insights for Policymakers and Industry**: With deeper insights into the CMs landscape, including patterns of consumption, shortages, disruptions, and resource flows in India and globally, Indian policymakers and industries can make well-informed decisions to strengthen supply chain resilience.

- **Boosted Innovation, Trade, and Investment**: Strengthening ties with the UK, opens opportunities for Indian stakeholders to engage with UK companies, access capital, and network with pioneering startups. This collaboration can drive advancements in mining and recycling technologies and secure a consistent supply of CMs.

- **Advancement in Circularity**: Gaining a clearer picture of material flows will support the development of circular economy policies in India, fostering an

effective recycling ecosystem and promoting sustainable practices across the CMs supply chain.

- **Skill Development and Knowledge Transfer**: Collaboration with the UK will facilitate the transfer of specialised skills and knowledge in advanced mining, processing, and supply chain management practices. This partnership provides Indian professionals with access to advanced knowledge in sustainable mining technologies, digital infrastructure, and circular economy strategies, fostering skill development that strengthens India's capabilities in critical mineral management.

The Observatory Programme

Figure 2 highlights the key activities within the Observatory Programme from February 2024 till March 2025.

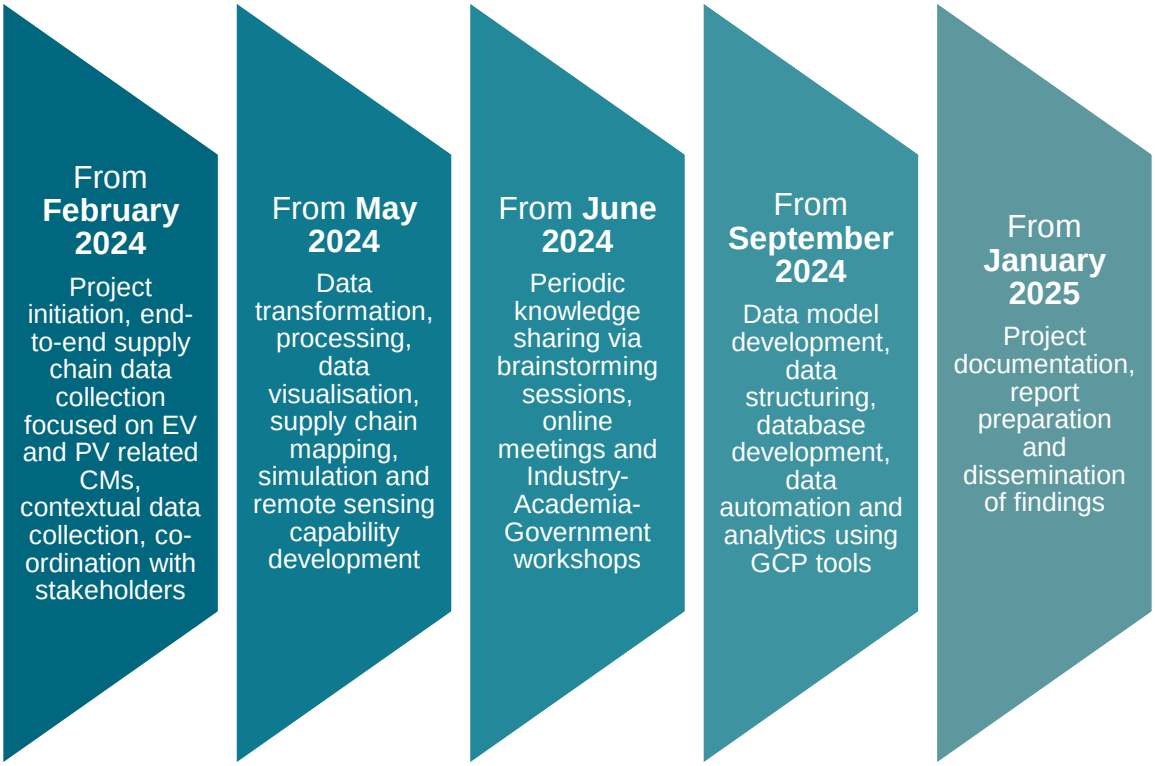

Figure 2 Key Activities of the Observatory Programme

2. Dissemination Workshop

The industry-academia workshop took place on the 23rd and 24th of September 2024 at the Institute for Manufacturing in Cambridge, UK, bringing together 100+ delegates from academic and industrial communities across the UK and India. This workshop was part of the "*Capacity Augmentation and Knowledge Dissemination*" work package (see Figure 1). It aimed to:

1. Encourage UK and Indian industries, academics, and policymakers to work together on sustainable and resilient supply chain solutions.
2. Explore the main challenges and opportunities within critical mineral supply chains and provide actionable recommendations for industrial development.
3. Share the latest technological tools and methods for ensuring transparency and security in the critical mineral supply chain.
4. Provide specific recommendations for enhancing bilateral trade, investment, and industrial development through improved critical mineral supply chain management.
5. Address the socioeconomic and environmental impacts of critical mineral supply chain management.
6. Work towards forming a UK-India Critical Minerals Advisory Group.

Workshop Agenda

2024 Industry-Academia Workshop on Critical Mineral Supply Chain Resilience

Day 1

Date: Monday, September 23rd, 2024

Location: Institute for Manufacturing, University of Cambridge, Cambridge, UK

Special Focus: Soft Launch of the UK-India Critical Mineral Supply Chain Observatory Project

Part I: 09:00 – 10:00 am

Opening Remarks

09:00 – 09:05	Dr Mukesh Kumar, Head of Industrial Resilience Research Group, University of Cambridge
09:05 – 09:15	Professor Dame Ann Dowling, Deputy Vice Chancellor, University of Cambridge
09:15 – 09:25	Professor Tim Minshall, Head of the Institute for Manufacturing, University of Cambridge
09:25 – 09:30	Mr Oliver Richards, Head of Critical Minerals and Mining (International), Department for Business and Trade
09:30 – 09:35	

	Mr Sarvjeet Soodan, Counsellor (Press & Politico-Military Affairs), High Commission of India
09:35 – 09:45	Mr Joshua Bamford, Head of Tech and Innovation, Foreign, Commonwealth and Development Office

Part 2: 10:00 – 11:00 am

UK-India Critical Mineral Supply Chain Observatory

09:45 – 10:30	Observatory Introduction & Demonstrator
	Dr Mukesh Kumar, Head of Industrial Resilience Research Group at the University of Cambridge
	Mr Kiran Srirama, Chief Architect / Field CTO, Google Cloud
10:30 – 11:00	*Network Break*

Part 3: 11:00 – 14:50 pm

Building Resilient Supply Chains in a Changing World

11:00 – 11:20	Role of GMDC in Critical Mineral Supply Chain Resilience
	Mr Roopwant Singh, IAS, Managing Director, GMDC
11:20 – 11:40	Shaping the UK-India Joint Policy on Critical Mineral Supply Chains: Data-Driven Decisions, Innovation, Sustainability, and Trade Facilitation
	Prof S Sivaram, Honorary Professor Emeritus and INSA Emeritus Scientist, Indian Institute of Science Education and Research (IISER)
11:40 – 12:00	India's Evolving Demand and Supply Gap in Critical Minerals
	Dr Debashish Bhattacharjee, Chairman, CII Advanced Materials Mission
12:00 – 12:20	Technological Barriers and Innovation Opportunities in the Mining and Mineral Processing Area
	Dr Deependra Singh, Chairman and Managing Director, IREL Limited
12:20 – 13:30	*Lunch*
13:30 – 13:50	Geopolitics of Critical Minerals and its Implications on Supply Chains
	Professor Michael Lewis, Professor of Operations and Supply Management, University of Bath
13:50 – 14:10	Strategic Role of the UK Critical Minerals Intelligence Centre (CMIC) in Enhancing Global Critical Mineral Resilience and Supply Chain Security
	Dr Gavin Mudd, Director, UK Critical Minerals Intelligence Centre
14:10 – 14:30	Opportunities and Challenges in Rare Earth Elements Refining

Ms Pallavi Gill, Executive Director (Rare Earth Division), RCMPA Polishing Technologies Private Limited

Part 4: 14:30 – 16:30 pm

Technological Innovations

14:30 – 14:50	Game-Changing Material Chemistry: Transforming the Critical Mineral Supply Chain through Refining and Recycling for Resilience Prof. Murugavel Ramaswamy, Chair Professor and JC Bose National Fellow, Department of Chemistry, IIT Bombay
14:50 – 15:10	Dependency of Indian Economy on Critical Minerals Prof Rajat Moona, Director, IIT Gandhinagar
15:10 – 15:30	*Networking Break*
15:30 – 15:50	How R&D can Contribute to Managing the Demand for Critical Minerals in Both Countries, With a Special Focus on Electronics and Semiconductor Sectors Dr R. Ratheesh, Director, C-MET (Centre for Materials for Electronics Technology)
15:50 – 16:10	Mining Tech for Critical Minerals Speaker: Mr Dheeraj Kumar, Deputy Director, TEXMiN, IIT(ISM) Dhanbad
16:10 – 16:30	The Role of Indian Innovation Clusters in the Critical Minerals Sector Speaker: Dr Mrutyunjay Suar, Director, Bhubaneswar City Knowledge Innovation Cluster Foundation

Part 5: 16:30 – 18:00 pm

Sustainability and Circular Economy

16:30 – 16:50	Understanding Critical Materials Lifecycles Dr Claire Barlow, Emeritus Faculty, University of Cambridge
16:50 – 17:10	Exploring Responsible Mining and Ethical Value Chains Ms Sarah Makumbe, Sustainability Certifications Manager, Anglo American
17:10 – 17:30	Unlocking Investment and Sustainable Business Models in Critical Mineral Recycling: Opportunities, Innovations, and Future Directions Mr Sachin Maheshwari, Head of Corporate Development, Lohum

17:30 – 17:50	Operation Challenges in Critical Minerals Recycling and Circular Supply Chain Mr Abhinav Mathur, Adviser to Board, Attero Recycling Private Limited
17:50 – 18:00	Closing Remarks and Participants' Photo

19:00 – 21:00 pm

Dinner Reception at Magdalene College

Day 2

Date: Tuesday, September 24th, 2024

Location: West Meeting Room 1, West Hub, University of Cambridge, Cambridge, UK

Special Focus: Establishment of the UK-India Critical Mineral Supply Chain Advisory Group

Part I: 09:00 – 11:30 am

Roundtable Discussions

09:00 – 09:10	Introduction Dr Mukesh Kumar, Head of Industrial Resilience Research Group, University of Cambridge
09:10 – 10:00	Roundtable Discussions (Led by: Dr Diana Khripko) i. Key takeaways ii. Activities India and UK should initiate to address those challenges iii. Contributions to the proposed activities
10:00 – 10:30	*Network Break*
10:30 – 11:30	Continued Roundtable Discussions (Led by: Dr Diana Khripko)

Part 2: 11:30 – 12:30 pm

Keynote Presentations

11:30 – 11:50	Mr Anupam Jalote, Chief Executive Officer, International Centre of Excellence in Mining

11:50 – 12:10	Mr Charanjeet Singh, Strategic Opportunities Manager, Centre for Process Innovation (CPI)
12:10 – 12:30	Mr Sudipto Sen, Chief Executive Officer, Asterix Innovations Private Limited
12:30 – 13:30	*Lunch Break at Institute for Manufacturing*

Part 3: 13:30 – 15:00 pm

UK-India Critical Mineral Supply Chain Advisory Group

13:30 – 15:00	Roundtable Discussions (Led by: Mr Joshua Bamford)
	Establishment of Advisory Group

Methodology

The workshop on Day 1 began with an in-depth exploration of key trends and drivers influencing the CM supply chain, as well as the market perspective. Special attention was given to the requirements of supply chain players from the UK and India. This was followed by a presentation of various innovations around technologies and solutions helping the transition to a sustainable and circular CM supply chain.

On Day 2 the discussion focused on capturing key insights and takeaways on potential activities and collaboration between the stakeholders of both regions to address the trends, drivers and market requirements. The UK-India Critical Mineral Supply Chain Advisory Group was identified as one of the key enablers and therefore its objectives and potential set-up were discussed by a select number of experts from both countries.

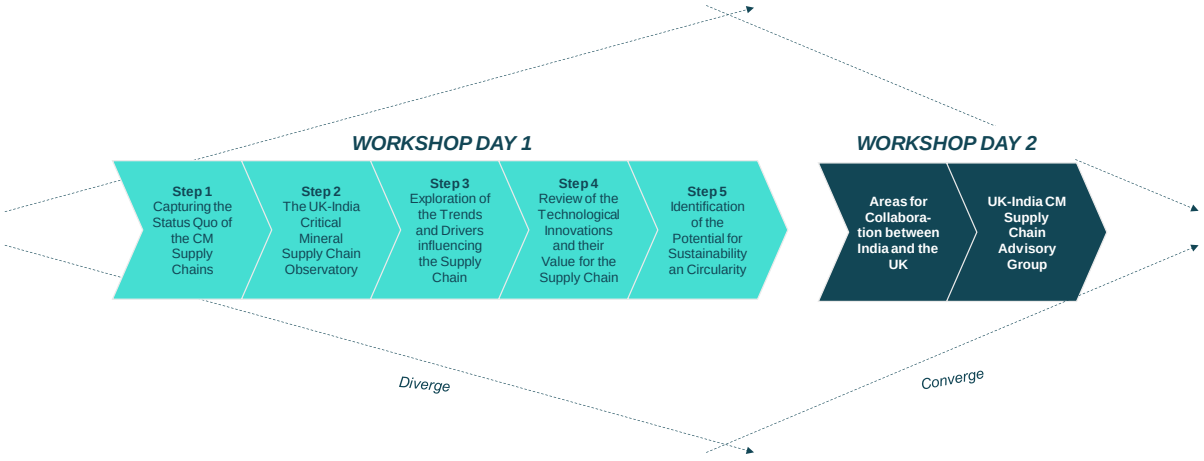

Figure 3 Workshop Methodology

3. Global Trends and Drivers

The expert talks during the workshop highlighted multiple trends and drivers that are significantly shaping CMs supply chains, both in the short and long term. These trends and drivers are interconnected and underscore the complexities of CM supply chains and the need for coordinated strategies to ensure long-term sustainability and resilience.

End Consumer Markets

The growth of end-consumer markets drives demand for CMs, highlighting the importance of resilient and sustainable supply chains to ensure reliable and consistent production. For example, as industries such as energy, automotive, semiconductors, aerospace and defence, and consumer electronics rapidly expand, the associated rising demand for CM places increasing pressure on global supply chains, leading to potential shortages and heightened market volatility. Rapid urbanisation further strains supply chains as expanding cities require more CM for infrastructure development and integration of advanced technologies.

The widening gap between the surging demand for these minerals and their current availability exacerbates this issue. The demand fluctuations can cause significant instability in the pricing and availability of essential minerals. And, cyclical over- or undersupply of CM drives price fluctuations, causing sharp increases or decreases in market value, which can render some mines economically unviable and lead to temporary closures or reduced production. These effects in turn threaten the stability and growth of the end-user industries depending on relevant CMs.

Electric Mobility relies heavily on CMs such as lithium, cobalt, graphite, manganese and nickel for batteries.

The Energy Sector and Energy Transition requires CM such as copper, cobalt, nickel, lithium, graphite, silicon, tellurium, indium and RRE are essential for producing solar panels (PV), wind turbines, and battery energy storage systems.

The Semiconductor Industry depends on various rare materials like gallium, indium germanium, palladium.

Aerospace and Defence consume CMs through the use of a wide range of key technologies related to computing, satellites, telecommunications and advanced defence, making CMs a matter of national security.

Consumer Electronics such as smartphones, laptops, and other electronics depend on RRE, cobalt, lithium, neodymium, nickel, etc.

Global Dynamics and Supply Security

Many deposits of CM are concentrated in specific regions and often located in remote, hard-to-access areas, making the extraction and transportation of these resources challenging. This geographic concentration also renders supply chains highly vulnerable to geopolitical instability and unexpected disruptions, such as black swan events. Supply security could be expanded from resource concentration to include the

supply chain concentration on different stages of the critical mineral supply chains, e.g., only limited countries have mineral processing capabilities. Consequently, nations that control substantial portions of these resources and processing capabilities have the power to shape global supply chains, potentially creating monopolies and enabling market manipulation. Strategies employed by these countries range from significant investments in regional production capacities to imposing trade restrictions and export bans.

Securing a steady supply of CMs is therefore becoming a strategic priority for countries to ensure the continuity of essential industries like technology and defence. Furthermore, to mitigate these risks, some technology companies[1] are seeking long-term supply agreements to secure a stable flow of CMs, safeguarding against supply disruptions caused by political instability or rising demand.

Urgency of Climate Change

National net-zero strategies are fundamentally dependent on a stable and secure supply of CMs, as they are essential components for the technologies that will enable the transition to a low-carbon economy. Moreover, as countries compete to meet their net-zero targets, securing access to CMs becomes a matter of both economic and strategic importance. Nations will need to implement policies that support responsible sourcing, foster international cooperation, and invest in domestic supply chains to reduce reliance on foreign sources. Such interconnection makes the alignment of mineral supply chains with climate strategies an urgent priority for policymakers worldwide.

The extraction and processing of CMs are carbon-intensive activities due to the high proportion of fossil fuels in the energy mix used. These processes also often lead to other significant environmental impacts, such as deforestation and water and soil pollution, necessitating cleaner, more sustainable supply chain practices. Further, managing waste from the extraction, processing and use of CMs is a growing concern, driving the urgent need to enhance recycling efforts and mitigate environmental impacts.

[1] E.g. Tesla and Volkswagen securing long-term supply agreements directly with Indonesian producers.

4. Areas for Collaboration between India and the UK

During the workshop, participants identified and discussed various challenges, requirements and needs that stakeholders in CM supply chains face and for which India and the UK could jointly develop solutions. The individual ideas were summarised in clusters and then prioritised in an individual voting process, resulting in a list of seven areas for collaboration. The full list of challenges and barriers including the voting results can be found in Appendix III. These key priority collaboration areas are explained below.

1. **Establishing greater visibility and availability of Technology Readiness Level (TRL) 5+[2] Technologies for stakeholders across the supply chain**

The innovative technologies and solutions, which have moved beyond the laboratory validation (i.e., TRL 5+), demonstrate crucial potential for improving productivity, resource efficiency and sustainability in CM supply chains. However, the expert consultation highlighted that many stakeholders are often unaware of or unable to access these technologies due to barriers like fragmented communication between research institutions and industry, an unmet need for testbed or pilot-scale facilities to help validate, demonstrate, and compare new technologies, insufficient funding for scaling innovations and a lack of platforms for sharing breakthroughs. This disconnect hinders the timely adoption of technologies needed to address supply chain bottlenecks, environmental concerns, and the growing demand for strategic minerals. Thus, there is a need to improve the technology transfer processes up-, mid- and downstream of the supply chain.

2. **Collaborate on supply chain mapping to improve visibility**

The need for CM supply chain mapping and visibility has become increasingly urgent for the UK and India as global demand for these minerals, essential for industries like automotive, renewable energy, electronics, and defence, continues to rise. Supply chain mapping helps to understand supply chain structure and interdependencies and trace the origins and flow of minerals, ensuring transparency across the supply chain activities from extraction to end-of-life recycling, which is crucial for mitigating risks such as resource scarcity, geopolitical tensions, and unethical mining practices. Enhanced visibility also enables better forecasting of supply disruptions, supports sustainability efforts, and ensures regulatory compliance. By understanding and monitoring the end-to-end supply chain, industries, including SMEs, multinational corporations, and governments can develop more resilient, sustainable, and ethical sourcing strategies for CM.

3. **Joint innovation and R&D on new technologies and solutions across the entire CM lifecycle**

[2] TRL stands for Technology Readiness Level and describes an evaluation approach to assess the maturity of a technology.

The participants emphasised the need for research and development of new innovative solutions and technologies that can help solve various technological, system integration, environmental and societal problems that arise in different lifecycle phases of CMs. For example, non-destructive technologies such as geophysical, geological and remote sensing are needed worldwide for mining and resource exploration.

Innovative technologies are also needed to improve the processing of minerals to reduce the generation of waste and improve processing schedules. Billions of tonnes of waste containing CM remains need to be converted into usable deposits. Given the value and role of many CMs in a sustainable and just transition and the resulting increase in demand for them, the recovery of high-quality grades of materials necessitates R&D on effective recycling solutions and secondary recovery technologies.

Another important environmental and social issue is the regeneration of mines. Proven concepts and solutions for the rehabilitation of damaged areas are needed to restore ecosystems and reduce environmental damage. Such approaches include, for example, reforestation, soil remediation and the conversion of former mining areas for new uses such as agriculture or renewable energy generation. Mine rehabilitation not only helps to restore the environment but also offers economic and social benefits for local communities affected by mining.

4. Development of mechanisms to prevent shocks on supply chains and enhance security

The geographic concentration of deposits, as well as various supply chain stages of certain CMs, poses various risks and uncertainties to supply chains due to geopolitical tensions, trade policies, market monopolies, environmental concerns, etc. To mitigate these risks, countries, as well as the private sector, must implement measures to diversify their sources of CMs and reduce reliance on any single region.

The experts have identified a need to re-direct material flows away from current dominant regions and develop a multifaceted approach which combines resource exploration (e.g., diversification of mining and processing locations, recycling, deep sea mining and urban mining), investment in alternative suppliers, innovation in extraction technologies, innovation in substitution and resource efficiency, and international collaboration, to establish strategic alliances and trade partnerships.

5. Design industry-driven academic programmes

Companies and organisations across the supply chain are facing shortages of skilled labour, which is hindering resilient operations and technological innovation as well as sustainable and future-oriented growth. One, but not the only, important factor influencing the interest of youth in the sector is the social perception of the mining industry.

"The greatest need was reported to be at the technician level, where the industry is already anticipating multi-generational workforce gaps, and many pointed out that there are very few mining programs at higher education institutions."[3]

[3] Gill, P. RCMPA Polishing Technologies PVT. Ltd.

Nonetheless, emerging technologies such as AI, ML and IoT have the potential to support the creation of new value and market opportunities for supply chain players. The transfer and adoption of these technologies require the development of completely new skills that go beyond traditional technical skills.

Clear mechanisms therefore need to be put in place for industry and higher education institutions to work together to develop programmes that target the skills gap and create a workforce pipeline. Lessons can be learnt from existing case studies, e.g. the MSc programme on supply chains from Rolls Royce.

6. Establishing a Funding Landscape to support Stakeholder Collaboration

Funding availability is crucial to facilitating inter-stakeholder interactions that drive technology development. For instance, TRL 5+ technologies, such as emerging technologies for the extraction of nickel (Ni) and cobalt (Co) from chromite ore overburden or rare earth elements (REE) from coal ash, need dedicated funding to progress from pilot stages to commercial viability. Recycling initiatives will benefit from financial support for the coordination and fostering of collaboration between governments, industries, and research institutions.

Establishing new mining sites, especially in regions that are underdeveloped or less explored, presents both technical and financial challenges. Capital shortfalls can delay or prevent the development of promising new sources of CMs, and technical obstacles such as environmental concerns and complex extraction processes further complicate these efforts. Public-private partnerships and international funding mechanisms are essential to overcoming these challenges. Investment in feasibility studies, infrastructure and revenue models can help mitigate risks, ensuring that new mining sites can meet growing demand.

7. Develop effective policy frameworks and models for harmonisation of standards

Enhancing collaboration between the Indian and UK partners of the CM supply chain will require an effective policy framework that helps reduce the complexity of the regulatory landscape, addresses the barriers such as permitting and, in some instances, fills the policy vacuum. Industry representatives emphasised the current complexity of the application processes due to a wide range of trade codes (e.g., HS codes) across different countries. Therefore, to achieve greater efficiency and a higher degree of international collaboration, alignment and harmonisation of trade codes are needed. This process would start by establishing a standardised model template that comprises guidelines on standardised data collection, reporting and analysis methods as well as standards on material basis and composition.

Ways to Strengthen the India-UK Collaboration

During the workshop, experts discussed numerous ideas on how to strengthen the collaboration between organisations in India and the UK. They highlighted the need for formalised models. The ideas for such models were:

1. An India-UK critical mineral collaborative initiative that sets up an Innovation Hub to support:

- Technology R&D,
- Innovation and entrepreneurship,
- International collaboration,
- Commercialisation of TRL 5+ technologies,
- Capacity building,
- Academic programme,
- Access to funding.

2. An India-UK critical mineral advisory panel that can provide a multi-stakeholder platform allocating funding and enabling collaboration, prioritisation and focus of activities.

3. A national Graduate Certificate programme that provides training on selected technology solutions; preparation is needed to make available to stakeholders a structured compendium.

4. Purchase commitments supported by governmental and bilateral industry funding to provide access to low-cost capital and grants for technology scale-up.

5. Work with the Indian government to help invest in exploration and feasibility studies.

Future Stakeholder Engagement with the Observatory

Potential Engagement Stage/Areas	Organisation Name	Country
Subscription to the Observatory	Gujarat Mineral Development Corporation (GMDC)	India
Recycling Initiatives and CM Hub Development • Develop a regional hub for recycling and circular economy initiatives for critical minerals	Indian Institute of Technology (IIT) Gandhinagar	India
Promotion of the Observatory Utility • Provide feedback from industry partners (exploration, consultancy, etc.) • Access to the observatory	Critical Minerals Association	United Kingdom
Inclusion of Geological, Mining, and Localized Social Data • Provide data for a prospective mining operation	Mkango Resources Ltd	United Kingdom
Beta Users of the Observatory • Provide insights on necessary data analysis types • Assist in program development, including defining and refining data sources	Lohum	India
Compiling a List of Industry Technology Requirements	Institute for Climate and Environmental Management (iCEM),	India

	Gujarat Mineral Development Corporation (GMDC)	
Access to Observatory for Critical Raw Materials (CRMs) • Develop insights for various sectors, including wind energy, nuclear, and food industries	Centre for Process Innovation (CPI)	United Kingdom
Business Operations Prediction • Use observatory data to predict potential business operations and opportunities	Attero	India
Hub for Observatory and Mining Industry Engagement • Conduct company need-based assessments and capacity-building initiatives • Co-founder for technology stack development	Technology Innovation in Exploration and Mining (TEXMiN) Indian Institute of Technology (IIT) Indian School of Mines (ISM)	India
Critical Mineral Repository Identification • Utilize observatory datasets for identifying critical mineral reserves, particularly zircon for hafnium producers	-	-
Academic Support and Research Opportunities • Offer support and guidance; provide MSc and PhD students for supply chain topics • Link students to specific observatory tasks/activities	University of Nottingham	United Kingdom
Risk Assessment for Development Plans • Anticipate risks to mainstream development plans (e.g., potential shortages affecting electric vehicles, electrolysers, and solar technology)	British Petroleum (BP)	United Kingdom

5. The Observatory as a Critical Enabler

The Global Supply Chain Observatory is regarded as **a critical enabler** in addressing the uncertainties and challenges faced by companies and policymakers due to vulnerabilities and potential disruptions in critical mineral supply chains, empowering CM stakeholders to make informed decisions. The **world's largest and most comprehensive digital data infrastructure** on these CM supply chains comprises over 4,000 data points, covering supply and demand market dynamics, key minerals production data, data on contextual environments, and data on supply chain actors. There is also an important opportunity to link to the UK Critical Minerals Intelligence Centre (UKCMIC) as the observatory enables the dynamic analysis of mineral criticality based on big data.

With its comprehensive database, the Observatory addresses the need for greater visibility and transparency across the global value chain and offers invaluable insights to all stakeholders. Such **data and information are needed across all seven areas of collaboration** identified above (Section 5). The use cases and future potential of the observatory are limitless. Currently, the observatory demonstrates the following capabilities:

1. Comprehensive Global Supply Chain Mapping with Big Data Analytics

The observatory provides a bird's-eye view of the global critical mineral (CM) supply chain for cobalt and lithium (integration of other CM data is under development, i.e., graphite, silicon, indium, tellurium in Phase 1). Using advanced Big Data analytics and large language models (LLMs), the observatory integrates data from production volumes, processing locations, and trade flows to geopolitical and climate-related events. This detailed mapping allows stakeholders to visualise supply chain dynamics in near real-time, facilitating proactive decision-making.

2. Advanced Supply Chain Stress Testing and Risk Resilience Analysis

The observatory offers robust stress testing services using simulation models that assess the resilience of CM supply chains against a spectrum of global risks, including geopolitical instability, economic shocks, and extreme climate events. By identifying potential vulnerabilities, the observatory helps organisations develop risk mitigation strategies to maintain supply chain continuity and build long-term resilience.

3. Environmental and Sustainability Assessment

The observatory's environmental impact assessments leverage satellite data and state-of-the-art remote sensing technologies to quantify greenhouse gas (GHG) emissions and monitor biodiversity loss associated with critical mineral extraction and processing. These assessments enable clients to track their environmental footprint, adhere to regulatory requirements, and develop strategies for sustainable sourcing.

4. Enhanced Transparency and Regulatory Compliance

The observatory provides comprehensive supply chain transparency solutions to support compliance with global standards, including Scope 3 emissions reporting and the EU Carbon Border Adjustment Mechanism (EU CBAM). The observatory's data-driven insights could empower governments, NGOs, and industry leaders to create policies that drive sustainable and ethical practices.

5. Digital Sustainability Auditing and Governance

Using cutting-edge digital tools, the observatory's sustainability auditing service offers detailed evaluations of environmental, social, and governance (ESG) practices within supply chains. By incorporating near real-time data and machine learning algorithms, the observatory helps organisations align their operations with global sustainability standards, reducing reputational risks and ensuring long-term competitive advantage.

In summary, the Observatory enhances capacity building and informed decision-making. It fosters collaboration across technology, policy, and business sectors, thereby strengthening the partnership between the UK and India and helping to drive sustainable growth and accelerate the transition to net-zero goals.

Participants perceived this project to be very valuable and indicated that they would like to continue engaging with it in the future. Delegates also proposed a set of ideas on how they can support the further development of the Observatory and post-programme scale-up. **The ways in which they would like to engage further with the Observatory** include:

Support with **enhancing data sources and refining of the data** deployed by the Observatory platform including detailed geological, mining and localised social data for prospective mining operations as well as data on existing and potential new recycling sites.

Link students, PhD and post-doctoral researchers with the industry partners.

Getting involved in beta-testing of the platform to help with the **mapping the potential use cases** of the platform such as use of its data to

- conduct data analysis,
- predict possible business opportunities,
- identify CM repository, e.g. Zircon for Hafnium producers,
- anticipate risks to business development plans i.e. whether CM shortages can derail EV, electrolyser, solar energy scale-up etc.
- access information for Customer Relationship Management (CRM).

and to develop a list of **technology requirements from industry**, as well as provide feedback from the user perspective.

Support the development of a hub that collaborates with the Observatory and mining industry partners through engagement and company need-based assessment and capacity building.

Support with knowledge and insights transfer to develop similar platforms for other sectors such as wind power, nuclear industry, food supply chains, etc.

6. Key Takeaways

The key insights from the industry-academia Critical Minerals Resilience workshop were:

- The role of rare earth materials capability in India was identified as one of the key capabilities to shape and secure UK-India CM supply chains, in which organisations like GMDC will play an important role.
- India's ecosystem is more advanced in CM recycling and thus, the investment from India's companies, in particular those focused on recycling, is needed in the UK and should be encouraged through a formalised framework.
- UK companies bring expertise in advanced mining and processing technologies including solutions for efficiency, automation, and sustainability, which can help India to achieve its growth ambitions.
- Both nations could benefit from UK mining companies participating in the exploration of mineral reserves by forming strategic partnerships, investing in joint ventures, and leveraging their technological and operational capabilities to collaborate on large-scale projects in India.
- Advancements in material science and chemistry are crucial for sustainable mining and recycling as they enable the development of innovative methods to extract, process and reuse CMs more efficiently, while minimising environmental harm and enhancing the circular economy.
- Sustainability and circularity offer a key opportunity for both the UK and India, as well as academia and industry. Together they can collaborate on developing and implementing environmentally friendly, innovative technologies and practices for minerals extraction and recycling to boost the transition of both nations towards responsible CM supply chains.
- The importance of supply chain visibility and transparency to enhance resilience…

The Global Supply Chain Observatory integrates all these elements to provide the UK and India with a new digital data infrastructure for end-to-end supply chain visibility, enabling real-time monitoring and evaluation for risk identification, vulnerability assessment, capability enhancement, and the promotion of ESG principles and sustainability. The Observatory fosters international collaboration and supports policy and industry actors in designing effective and growth-oriented strategies for resilient and sustainable CMs supply chains.

7. Outlook

Figure 4 highlights the key activities planned for the second phase of the observatory programme from March 2025 till March 2026.

Figure 4: Activities Planned for Phase 2 of the Observatory Programme

8. Annex

Annex I List of Participants

Name	Organisation
Aaron Vermiglio	University of Liverpool
Abhi Agarwal	University of Cambridge
Dr Abhinav Mathur	Attero Recycling Private Limited
Aditya Thiru	Advanced Propulsion Centre UK
Aimie Keeler	Anglo American
Dr Ajeseun Jimo	Henley Business School
Dr Al-Amin Dabo	University of Northampton
Dr Alok Choudhary	University of Warwick
Andrew Fulton	Mining Association of the UK
Professor Dame Ann Dowling	University of Cambridge
Anupam Jalote	International Centre of Excellence in Mining
Professor Aravind Vijayaraghavan	University of Manchester
Arthur Pena	Echion Technologies LTD
Dr Arthur Poliakov	MINEX Forum
Dr Bang Yong	University of Cambridge
Celine Notin	University of Cambridge
Dr Charanjeet Singh	Centre for Process Innovation (CPI)
Dr Christos Braziotis	University of Nottingham
Dr Claire Barlow	University of Cambridge
Dr David Leal-Ayala	University of Cambridge
Dr Debashish Bhattacharjee	Advanced Materials Initiative of the Confederation of Indian Industries (CII)
Dr Deependra Singh	IREL Limited
Deepesh Jayasekara	University of Cambridge
Dev Malya Sarkar	University of Cambridge
Dr Dheeraj Kumar	TEXMiN, IIT(ISM) Dhanbad
Dr Diana Khripko	University of Cambridge
Dillon Rajakarier	AWR Lloyd
Eddie Li	University of Cambridge
Edward Munyard	RCS Global Group
Dr Elisabetta Mariani	University of Liverpool
Dr Emre Usenmez	University of Cambridge
Enzo Granzella	Critical Minerals Association UK
Felix Manoharan	Google Cloud
Garry Clawson	University of Cambridge
Gaurav Daga	Guidance TamilNadu
Professor Gavin Bridge	Durham University
Dr Gavin Harper	Birmingham Centre for Strategic Elements and Critical Materials
Dr Gavin Mudd	UK Critical Minerals Intelligence Centre
Gowtham Daas Rajendran	Guidance TamilNadu
Dr Hamid Moradlou	University of Warwick
Hariprasad Radhakrishnan	Google Cloud
Professor Helen Rogers	Technische Hochschule Nürnberg

Hilary Perrott	University of Cambridge
Jack Simpson	Deloitte
Jawad Sardar	Richmond Global Consulting Ltd
Jeff Borrman	Bioscope Technology Ltd
Dr Jon Salkeld	BP
Joshua Bamford	British High Commission in India
Juliana Reed	FCDO/DESNZ International Energy Unit
Karen Smith	University of Cambridge
Dr Keri Goodwin	Centre for Process Innovation (CPI)
Kiran Srirama	Google Cloud
Krishna Gampa	Telekom Malaysia UK Ltd
Kruthika Anastasia Bala	Resources Now
Professor Kulwant Pawar	University of Nottingham
Dr Leandro Pugliese de Siqueira	Traton Group
Lucy Goodman	Department for Business and Trade
Dr Maharshi Dhada	University of Cambridge
Margaret Beever	High Speed Sustainable Manufacturing Institute (HSSMI)
Mariel Alem Fonseca	University of Cambridge
Dr Mauro Velasco-Castro	University of Cambridge
Professor Michael Lewis	Bath University
Dr Minhao Zhang	University of Bristol
Mohammad Danish	TEXMiN, IIT(ISM) Dhanbad
Dr Mrinalini Ganapati Walwalkar	Indian Institute of Technology (IIT) Bombay
Dr Mrutyunjay Suar	Bhubaneswar City Knowledge Innovation Cluster
Dr Mukesh Kumar	University of Cambridge
Professor Ramaswamy Murugavel	Indian Institute of Technology (IIT) Bombay
Dr Naoum Tsolakis	University of Cambridge
Dr Nikolai Kazantsev	University of Cambridge
Oliver Richards	Department for Business and Trade
Pallavi Gill	RCMPA Polishing Technologies Private Limited
Dr Rahul Mor	University of Northampton
Professor Rajat Moona	IIT Gandhinagar
Dr Ramya Venkataraman	University College London
Dr Ran Bhamra	Royal Holloway University of London
Dr Ratheesh Ravendran	Centre for Materials for Electronics Technology (C-MET)
Dr Richard Jackson	Decision Analysis Services Ltd
Dr Robert Mitchell	Centre for Process Innovation (CPI)
Professor Roger Maull	University of Exeter
Roopwant Singh IAS	GMDC Limited
Rupi Nandra MBE	Richmond Global Consulting Ltd
Sachin Maheshwari	Lohum
Samsad Reza	University of Northampton
Dr Sanjog Nagarkar	Indian Institute of Technology (IIT) Bombay
Sarah Makumbe	Anglo American
Sarvjeet Soodan	High Commission of India
Dr Sean Arisian	La Trobe University
Dr Shawkat Rahman	Anglia Ruskin University
Stephen Peach	High Speed Sustainable Manufacturing Institute (HSSMI)

Sudipto Sen	Asterix Consultancy
Dr Superb Misra	IIT Gandhinagar
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Professor Swaminathan Sivaram	IISER Pune
Thorge Schaum	University of Cambridge
Tim Archer	Natural Resource Consulting Limited
Professor Tim Minshall	University of Cambridge
Dr Venkat Daramalla	Centre for Process Innovation (CPI)
Vikki Jeckell	Alkemy Capital Investments Plc
Wei Nie	University of Cambridge
Dr Yousef Ghorbani	University of Lincoln
Zhong Guan	University of Cambridge

Annex II List of Speakers

Dr Mukesh Kumar, Head of Industrial Resilience Research Group at the University of Cambridge

Professor Dame Ann Dowling, Deputy Vice Chancellor, University of Cambridge

Professor Tim Minshall, Head of the Institute for Manufacturing, University of Cambridge

Mr Kiran Srirama, Chief Architect, Field CTO, Google Cloud

Mr Oliver Richards, Head of Critical Minerals and Mining (International), Department for Business and Trade

Mr Sarvjeet Soodan, Counsellor (Press & Politico-Military Affairs), High Commission of India

Mr Joshua Bamford, Head of Tech and Innovation, Foreign, Commonwealth and Development Office

Mr Roopwant Singh, IAS, Managing Director, GMDC

Dr Debashish Bhattacharjee, Chairman, CII Advanced Materials Mission

Dr Deependra Singh, Chairman and Managing Director, IREL Limited

Professor Michael Lewis, Professor of Operations and Supply Management, University of Bath

Dr Gavin Mudd, Director, UK Critical Minerals Intelligence Centre

Ms Pallavi Gill, Executive Director (Rare Earth Division), RCMPA Polishing Technologies Private Limited

Dr R. Ratheesh, Director, C-MET (Centre for Materials for Electronics Technology)

Dr Mrutyunjay Suar, Director, Bhubaneswar City Knowledge Innovation Cluster Foundation

Dr Claire Barlow, Emeritus Faculty, University of Cambridge

Ms Sarah Makumbe, Sustainability Certifications Manager, Anglo American

Mr Sachin Maheshwari, Head of Corporate Development, Lohum

Professor Murugavel Ramaswamy, Chair Professor and JC Bose National Fellow, Department of Chemistry, IIT Bombay

Dr Dheeraj Kumar, Deputy Director, TEXMiN, IIT(ISM) Dhanbad

Dr Abhinav Mathur, Adviser to Board, Attero Recycling Private Limited

Mr Anupam Jalote, Chief Executive Officer, International Centre of Excellence in Mining

Mr Sudipto Sen, Chief Executive Officer, Asterix Innovations Private Limited

Dr Charanjeet Singh, Strategic Opportunities Manager, Centre for Process Innovation (CPI)

Annex III List of Challenges and Barriers

Challenges and Barriers	Votes
Availability and visibility of new TRL 5t technology for recycling, recovery, value add, etc. Affordable/scalable and sustainable	10
Recycling spoke in UK and a hub in India to ensure that material does not flow to China and is obtained in particular countries available for use by the battery manufacturer. TEXMiN, Attero	9
Industry driven academic programs	8
Critical mineral exploration is a big challenge worldwide	7
Non-destructive technologies combing neophsyical, geological and remote sensing is needed world wide	
Mid-term evaluation	
Technology maturity in clean energy areas is nowhere near very high public investment and business investment is needed to dive with this ambiguity. Sivaram	6
Availability of funding to enable inter-stakeholder interaction, technology development and policy framework	5
Mapping Supply Chain of SMEs and large industrial companies to give visibility at all levels	5
Networking and collaboration	4
Technology transfer and training	
Commercial viability evaluation	
Lack of inter-organisational connectivity. 2041 + KS Pawar	4
Commercial viability of recycling and secondary extraction technologies to alleviate pressure on primary resources and increase circularity (2024-2030)	2
Need mechanism to financially support if prices drop too much	2
Midterm: Innovative technologies are required for better processing of pre and recovering minerals in order to reduce the waste creation and improving the processing plan capability. Billion tonnes of rejects are still lying to be converted to useful deposits	2
Consumer industry development	2

Expedited planning and permitting processes across different jurisdictions for projects at all stages of the supply chain. 2024 Enzo, Grazella	2
Regeneration of mines	1
Action points solutions are to be integrated! Superb Misra	1
Public investment priorities across the value chain	0
Lack of resources mapping for CM/REE and prioritisation	0

Institute for Manufacturing: IfM

The IfM is part of the University of Cambridge's Department of Engineering. With a focus on manufacturing industries, the IfM creates, develops and deploys new insights into management, technology and policy. We strive to be the partner of choice for businesses and policy-makers, as they enhance manufacturing processes, systems and supply chains to deliver sustainable economic growth through productivity and innovation.

Industrial Resilience Research Group:

This multidisciplinary research group focuses on how manufacturing can become more resilient at the factory, supply network and industrial system levels. By investigating the relationship between products, processes and location, we aim to identify and evaluate risk, develop mitigations, and build resilience in a wide range of industrial sectors but with a particular focus on the food and critical mineral sector. We work closely with industry and academic institutions in the UK, US and India.

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