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Corresponding author: Saleem H. Ali; Email: saleem@udel.edu

Critical minerals policies need clearer interface with scientifically credible targets

Thomas Nolan Hale[1], Saleem H. Ali[2,3], Patrice Christman[4], Raimund Bleischwitz[5], Kamila Svobodova[6], Eeva Primmer[7], Vera Lucia Pires Moutinho[8] and Joanna Kulczycka[9]

[1]Geography and Spatial Sciences, University of Delaware College of Earth Ocean and Environment, Newark, DE, USA; [2]Geography and Spatial Sciences, University of Delaware, Newark, DE, USA; [3]The University of Queensland, St Lucia, QLD, Australia; [4]Institute for Sustainable Resources, University College London, London, UK; [5]Helmholtz Association of German Research Centres, Berlin, Germany; [6]Department of Geography, Czech University of Life Sciences Prague, Praha-Suchdol, Czech Republic; [7]Natural Resources, SYKE, Helsinki, Finland; [8]Lisbon Polytechnic Institute Interdisciplinary Centre for Educational Studies, Lisbon, Portugal and [9]Polish Academy of Sciences, Warsaw, Poland

The EU's Critical Raw Materials Act is a vital legislative step but needs better interface with environmental and social data on impacts and benefits.

Abstract

Nontechnical Summary: The need for critical minerals for various technologies for commercial and defense use has led to a range of national policy interventions. However, many of these new laws to encourage mining, or protect local industries have not considered as scientific data on mineral reserves or the economic viability of setting specific targets. The EU's Critical Raw Materials Act is a pivotal case in point that illustrates this challenge. We present a review of the range of laws and policies that have been set forth worldwide.

Technical Summary: Growing international conflict between countries that have large mineral production and processing capacity and those which are in demand of critical raw materials for new technologies has led to a proliferation of policies that promote resource nationalism or 'friend-shoring'. We analyzed over 400 critical raw material policies to date that have been documented by the International Energy Agency's policy tracking tool and present the findings of the six most active jurisdictions. The EU's Critical Raw Materials Act which came into force in May 2024 stands out as the most significant legislative step taken thus far but needs better interface with environmental and social data on impacts and benefits. By analyzing the challenges faced by lithium mining projects across a range of technologies and geographic locations in Europe, we suggest the use of data generated from life cycle analyses, economic geological calculations, and ecosystem service valuation in improving the implementation of such policies and also mitigate social conflicts.

Social Media Summary: There are now more than 400 critical raw material policies worldwide, but they need to be predicated in economic and geological data to be effective.

On April 26, 2024, The United Nations Secretary General appointed a special panel to focus on 'Critical Energy Transition Minerals'. This action further alerted the world to the need for policy action to ensure we do not end up with a material supply bottleneck to meet energy transition targets for decarbonization. The recommendation of this panel's report were published in September 2024 and are currently pending implementation with the United Nations Conference on Trade and Development (UNCTAD) and the United Nations Environment Programme (UNEP). The International Energy Agency launched a "Policy Tracker" for Critical Raw Materials (CRM) in November 2022 to consider ways of harmonizing actions more effectively. Since its launch, the tool has tracked up to 82 countries with over 585 different policies broken down into three primary categories: (a) ensuring supply reliability and resilience; (b) promoting exploration, production, and innovation; and (c) encouraging sustainable and responsible practices (IEA, 2025). Country data for each category varies, with Sustainable and Responsible Practices being the largest at 82 documented countries and Exploration, Production, and Innovation (EPI) being the lowest at 33 countries.

While all policy categories are essential for creating and sustaining a just transition, EPI is the most tangible in the short-term. It provides the capital and legislative authorities to kickstart critical mineral mining, processing, and recycling efforts to establish both domestic and allied markets, which reduce vulnerabilities across the supply chain. IEA breaks EPI into five different

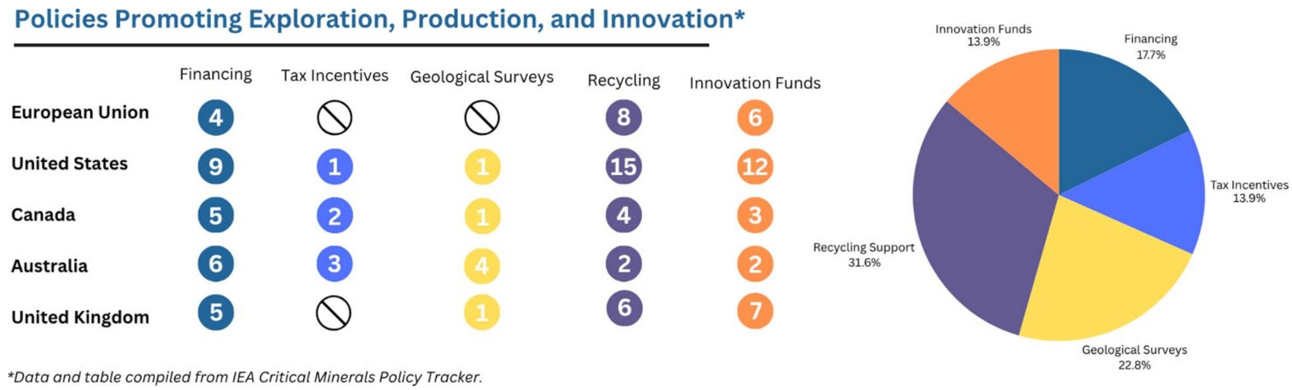

Figure 1. Global critical raw materials policy summary based on analysis of international energy agency policy tracker, March 2025. Numbers refer to specific stand-alone policies documented by international energy agency.

policy areas: (1) financing, (2) tax incentives, (3) geological surveys, (4) recycling support, and (5) innovation funds.

We analyzed the policies using this tracking tool and found that of these promoting EPI policies, 31.6% focused on recycling support with 22.8% being directed to geological surveys for mapping and surveying projects. Innovation funds and Tax incentives were the lowest, each representing 13.9% of total policies, with financing coming in at 17.7%. In 2024, the policy tracker showed tax incentives at only 7.4% of total policies, with innovation and financing policies reaching 58.5% of policies when combined. The policy tracker updates indicate increasing policies on the surveying, mapping, and data collection along with downstream recycling capabilities, with financing, innovation, and tax incentives taking a more equal distribution. With policies focused on innovation and financing, the primary concern right now is creating an attractive allied domestic supply chain landscape and building logistical and technological capabilities. Figure 1 provides an analysis of the five leading entities who have produced the largest number of CRM-related policies.

By number of policies alone, the tracker highlights the United States as a leading player in policy development surrounding CRM supply chains. While this may be true for the number of policies and capital awarded when compared to other countries, it does not suggest tangible outcomes. The new administration in the United States, in coordination with the Department of Government Efficiency, is also in the process of reshaping and cutting back many of these government institutions responsible for handing out government loans around recycling and innovation, including the Loans Programs Office in the Department of Energy. The United States is also moving its critical mineral policy closer in line with defense and national security agreements abroad, such as the Ukraine Minerals Deal and the potential Congolese Minerals Deal. Likewise, none of the facilities, processing capacity, or mine sites have made it to full production yet. There is a growing concern against onshoring CRM supply chains from a social and environmental perspective, further limiting the actual progress of the stated policies. The U.S. Department of Interior's decision last year to deny permits for a series of major CRM projects in Minnesota is a case in point that new current U.S. government is now trying to reactivate.

Two major legislative developments stand out in this context:

- The 2023 U.S. Critical Mineral Independence and the 2024 U.S. Critical Minerals Security Acts and the related U.S. 2024 Defense Industrial Strategy, and the Executive Order of March 20, 2025, whereby the President of the United States announced Immediate Measures to Increase American Mineral Production using wartime powers.
- The EU's Critical Raw Materials Act that came into force in May 2024, which in contrast with the U.S. policy texts, repeatedly refers to environmental and social sustainability in addition to economic and competitiveness considerations.

Both policy developments aim to secure the supply of minerals and metals and to drastically reduce dependence on imports. But only the EU legislation includes sustainability goals, stressing the importance of environmental and social impacts and benefits, and the need for related data and scientific knowledge. The United States has tended to focus on the 'national security' dimensions of critical minerals and sees a broader goal of geopolitical dominance in mind. The Europeans have a more utilitarian view of the issue focused on the supply needs of their industries being assured. Given the sharper focus of European policy on supply assurance rather than broader goals of geopolitical dominance of resources, there is more opportunity for environmental and economic efficiency arguments taking traction with EU policy-makers.

This paper focuses on the policy development at EU level, as it stresses (Preamble, paragraph 43: 'Space data and services derived from earth observation can support the efforts towards sustainable critical raw materials value chains by providing a continuous flow of information, which could be useful for activities such as monitoring and management of mining areas, the environmental and socioeconomic impact assessment, or mineral resource exploration'. We analyze the challenges faced by lithium mining projects across a range of technologies and geographic locations in Europe, as these well document the value of data generated from life cycle analyses, economic geological calculations and ecosystem service valuation in improving the implementation of policies and the mitigation of social conflicts.

Although the policy tracker is useful for identifying government programs and legislation, it does not provide any monitoring analysis around the effectiveness or specific financial capital granted for a given policy or changes in political administration which could revise or withdrawal certain agreements and initiatives. There are also no categories broken down for midstream processing or workforce development policies, which are often highlighted as critical bottlenecks in supply chains. Further review of policies at a higher level of detail reveals that the European Union has made the most concerted and legally binding efforts at defining CRM policies. Sharp targets for promoting exploration, production and innovation, sustainable use of minerals and metals through the development of recycling, and the development of certification schemes have been set forth.

1. European leadership and lithium

The European Union Critical Raw Materials Act (CRMA) came into force on May 3, 2024. It seeks to increase and diversify the EU's own supply, strengthen circularity, and support research and innovation on resource efficiency. The new rules are aimed at strengthening Europe's strategic autonomy and list 17 strategic raw materials (SRM) in Annex 1 as well as 34 critical raw materials (CRM) in Annex 2. The Act sets clear benchmarks for domestic capacities along the strategic raw material supply chain and to diversify EU supply by 2030:

- At least 10% of the EU's annual consumption for **e**xtraction,
- At least 40% of the EU's annual consumption for processing,
- At least 15% of the EU's annual consumption for recycling,
- Not more than 65% of the Union's annual consumption of each strategic raw material at any relevant stage of processing from a single third country.

To increase transparency and knowledge about non-fuel, non-agricultural primary and secondary raw materials production, the EC's Raw Materials Information System (RMIS) was created including raw materials factsheets, for both critical and non-critical materials. Criticality allows for exemptions from some environmental regulatory steps or fast-tracking of others as well. The EU also considers criticality of processes and components in its industrial development profile and the salience of strategic environmental assessments has thus become even more salient to ensure we have a systems-wide perspective.

Among CRMs, lithium is especially notable for its urgency of production because of its dominance in battery technologies that are essential for not only electric vehicles but also for a range of stationery storage infrastructure for wind and solar power as well as for smart grids (Brunelli et al., 2024). Here we use lithium as an exemplar of the complexity of conflicts at the science-policy interface that can get exacerbated without effective data communication. Projects in Portugal, the Czech Republic and France cover the full spectrum of technologies for extraction and both greenfield and brownfield sites and hence are described in greater detail.

Alternatives to lithium like sodium continue to face challenges due to cost and performance (Vaalma et al., 2018). Domestic lithium production for the European Union is thus a particular priority. The EU ban on the sale of new combustion engine cars from 2035 is shifting the European car industry towards the electric car and zero emissions. By 2028, S&P Global Market Intelligence expects the EU's lithium demand for passenger battery electric vehicles to exceed 300,000 tons in 2027 (S&P Global, 2023).

Europe's lithium processing capacity is projected to reach 658,000 mt/year by 2028, driven by 21 projects nearing full-scale production (S&P Global, 2023). These projects account for over 5 million mt Lithium (5.3% of global lithium reserves), with about 4.5 million mt located in Germany and the Czech Republic. Australia and Chile account for nearly 60% of global reserves (proven to be extractable economically) with Argentina and China accounting for an additional 18% (United States Geological Survey, 2025). However, China's role in downstream processing of lithium is still considerably higher.

One of Europe's largest lithium deposits lies beneath the village of Cínovec in the Czech Republic, near the Czech-German border. This former tin mining village boasts a mining tradition that dates back to the 13th century. The area is home to historical mining monuments added to the UNESCO World Heritage List in 2019. Cínovec holds around 1.56% of the world's total documented lithium. These estimates follow the Joint Ore Reserves Committee (JORC) measurement assurance, which is an industry-wide body based in Australia that certifies geological reserves data for accuracy. The region predicts that the lithium extraction project could create jobs for 1,000 miners over the anticipated 25-year extraction period. Additionally, a planned gigafactory to produce batteries for electric vehicles would further boost the region's economy and employment prospects.

Portugal is currently the largest producer of lithium in Europe and the ninth largest in the world, with a total of 60,000 tons of lithium reserves (United States Geological Survey, 2025). It is currently the only EU Member State to mine and process lithium and has important lithium reserves, 10% of the European total, but Portugal's lithium resources have been traditionally extracted and used for application in the ceramic and glass industry. Among the newer projects, The Barroso mine, owned by the British company Savannah Resources, is the most advanced mining project on Portuguese soil and is expected to be the largest conventional lithium exploration project in Europe. The Barroso project has the shortest duration (11 years) of all the European projects in preparation. It is expected to produce lithium for approximately 500,000 vehicle batteries per year.

In France, several lithium exploration projects are in progress. France's largest current hard rock lithium project is the EMILI project located at Echassières, in the Allier département (Central France), which is at the prefeasibility stage. The feasibility study is expected in 2026. Mining waste generation is expected to be minimal as the granite's feldspar would be recovered and marketed as a by-product. Residual materials (essentially quartz) would be used to backfill underground voids, thus minimizing the risk of later land subsidence. This region has a history of kaolin mining and some of the extraction could thus occur in brownfield sites rather than greenfield development.

France and Germany are home to several projects aiming to recover lithium from geothermal brines, essentially in the Rhine valley. The AGELI project in France is jointly developed by ERAMET, a French mining and metallurgical company with broad international activities, and Electricité de Strasbourg, an electricity producer operating two geothermal plants (Rittershoffen, for heat production, and Soultz-sous-Forêts, for electricity production) using Li-bearing geothermal brine. These projects would produce heat, for district heating and/or industrial purposes as well as lithium carbonate or hydroxide with a lower environmental footprint. The proprietary "Direct Lithium Extraction" technology that is proposed would require less water usage and area for evaporation ponds that characterize conventional lithium brine projects. Yet all these nuanced comparisons of technology need to be conveyed through accessible data to the policy makers and the public. There is considerable confusion regarding the way technologies around critical minerals because of strident activism against any new projects. Careful delineation of impacts and benefits of various technologies; the opportunities and limits of circular economy approaches, and the prospects for substitutability need to be clearly presented. Industrial ecology methods like life cycle analysis as well as comparative technoeconomic analysis can be effective tools in this regard for a variety of evaluative approaches (Sahu et al., 2025).

2. Data and community conflicts

The speed with which the Critical Raw Materials Act has been prepared has resulted in less deliberations on what form of data would be needed to define "sustainability" and also to engage communities who will be impacted by the development (Kivinen et al., 2020). The local level concerns have to do with immediate environmental and health impacts as well as disregarding local communities' social benefits and rights. At the same time, civil society movements call for thorough sustainability transformation and disruptive policies that would address energy and material intensive consumption and economic growth (Berthet et al., 2024). Specific data on environmental and social impact metrics which is comparable across projects and geographies as well as benefits of particular mitigation measures and technologies needs to be articulated up front.

The EU has the potential to build confidence with communities through existing regulatory oversight of projects. For example, the EU's Water Framework Directive, Nature Directives (that allow biodiversity offsetting in protected areas), and Circular Economy policies have the potential to deliver system-level assessment to the public on tradeoffs and benefits of projects. However, there has not been a concerted effort to convey such metrics and data allowing comparison of such wide-ranging policies. This, together with the EU Green Deal putting attention onto environmental and justice goals has criticism and resulted in what human geographers call "the social amplification of risk" (Pidgeon et al., 2003).

For example, the future of the lithium mining project near Cinovec remains uncertain, as permit procedures are stymied by conflict over environmental risk. Even after 3 years since the start of the environmental impact assessment process, Geomet still does not have the necessary permits in hand due to ongoing debacle over broader sharing of data through more regional level assessments. The Ústí Region is demanding an international environmental impact assessment of lithium mining on the German side of the Ore Mountains. Moreover, the feasibility study remains incomplete, and definitive external studies on the estimated investment and operating costs are still pending.

The development of the lithium mining projects in Portugal are also mired in conflict over potential damage to water sources, ecosystems, and landscapes. There is also skepticism about the socio-economic benefits that these projects might bring. Residents worry that the promised economic advantages, such as job creation and infrastructure development, may not materialize. The Barroso mine is in a region classified as global agricultural heritage by the Food and Agricultural Organization (FAO). The region also contains plants and animals which fall under the Priority Species classification under the European Commission's Birds and Habitats Directive.

Moreover, the corruption investigation that led to the fall of prime-minister António Costa's socialist government in November 2023 involved the concession of lithium mining and hydrogen projects in Portugal and it opened a debate on the pressure to sacrifice nature in the name of investment in new technologies and the energy transition. Since then, Portuguese anti-mining groups have urged the government to suspend and review all lithium projects. A new Portuguese government was elected in March 2024, and appointed a mineral science professor, Maria João Pereira, as Secretary of State for Energy.

Assurance on compliance and data verification can also be provided through third-party certification systems that have broad civil society support. Both the IMERYS and ERAMET projects in Franche have agreed to Responsible Mining Standard developed by the Initiative for Responsible Mining Assurance (IRMA), the most comprehensive ESG standard for mining that includes environmental organizations and unions on its certification board. Germany has also managed to mitigate conflict at the Vulcan lithium brine project that started production in May 2024 by focusing on data sharing via a 'Sustainable Materiality Assessment' (Calabrese et al., 2017). Net carbon calculations and the interface with renewable energy generation also helped to build community confidence in the project.

3. Data-driven prioritization

While data might not lead to community consensus on the future of a project, it can be essential evidence for policy-makers when used in a comparative process for prioritization of projects. Life Cycle Analysis (LCA) is a powerful tool in this regard which can compare across projects a range of environmental and social variables and assist with decision-making. For example, mineral sourcing from mines with different extraction techniques, versus extraction of metals from tailings piles, versus recycled metals from a range of waste-streams. Each supply source could be compared in terms of carbon footprint, water usage, energy consumption per unit production, biodiversity impacts and a range of other metrics. The EU also has among the most advanced LCA policies as well as a range of guidelines on Social License to Operate (SLO), which have been developed over the past three decades (Sala et al., 2021).

While securing critical materials from sustainable and resilient primary sources will be essential given the expected increase in demand, the EU highlights circularity by design and opportunities to establish novel product pathways and business models with re-use and recycling as well as less-critical substitutes. The 'Scoreboard' approach that has been used by the EU in this regard also sharpens the focus on data and its consequent impact on ranking and prioritization. According to the scoreboard, current recycling rates for metals are about 1%, and increasing them to the proposed 15% by 2030 in the EU will require strong efforts on streamlining and fastening permission processes, setting up logistics for collection and disassembly, and establishing a new industrial infrastructure for processing and re-use (EU Raw Materials Scoreboard, 2025).

Policies to incentivize collection and re-use are being further developed through eco-design norms and take-back requirements for permanent magnets and EV-batteries as well as quotas for using secondary sources in key products, and tax rebates/subsidies for funding research (Geng et al., 2023). Ideally, this will lead to regional hubs for secondary materials with advanced remanufacturing capacities, enabled by material passports and digital supply chain efforts. Such hubs could well be aligned with advanced extraction processes wherever suitable or be located close to ports relating to international trade, data exchange, training and foresight.

These policies have led to increased government signaling but have yet to create significant change which would reduce pressure on the impending timelines of many national and international climate goals. The primary emphasis on promoting exploration, production, and innovation also showcases limited political knowledge and expertise on the more medium-to-long term and the lack

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of geological and mineral life cycle data necessary for moving the ball forward in a meaningful way which reaches global climate goals.

Data on climate mitigation timelines thus also needs to be presented alongside the impact risks to ensure there is clarity on tradeoffs of delay. Ultimately, such a systems level exercise is will, supported by scenarios and pathways on clean technology underpinned by critical materials; ensure policy-makers recognize that delay in emission mitigation will ultimately lead to more drastic proposals like solar radiation management or construction of massive adaptive structures to ward off sea-level rise, permafrost collapse, and urban climate control.

4. Multilateralism must continue

The diversification of mineral supply through such CRM policies should not diminish the need for continued multilateral engagement with dominant market players in different parts of the world. It would be neither economically nor ecologically efficient to try to disengage completely from existing supply chains. Indeed, laws requiring quotas such as the EU's CRMA could lead to lower grade ores with higher energy and environmental footprints being extracted albeit with more stringent environmental protection regulations and enforcement. For example, Goldman Sachs has estimated that a fully localized battery supply chain for the United States and EU would cost $160 billion by 2030, not to mention the environmental costs of such a drastic move of industrial infrastructure to greenfield sites (Cohen & Svensson, 2023).

Those projects should be prioritized for decoupling from single-material dependencies where there is a clear technological advantage such as the net zero direct lithium extraction from geothermal brines. In other cases, attempts should be made to establish supply security arrangements, e.g., with China through the World Trade Organization or the UN Conference on Trade and Development. A broader international agreement on mineral supply security for the Green Transition has also been suggested and deserves greater attention from all regions producing, processing and consuming critical raw materials (Ali et al, 2022; Saleem H. Ali et al., 2025). Klinger et al. (2024) also highlights the need for a nationally determined contribution framework for energy transition minerals which can improve domestic policies tracked by the IEA around the world and enable greater national and global coordination.

Sharing systems-wide data on impacts and benefits for comparison, organizations such as the International Institute for Applied Systems Analysis (IIASA), the International Energy Agency, the Organization for Economic Co-operation and Development (OECD), and the International Resource Panel deserve greater attention from policy-makers. They can help to establish 'epistemic communities' that build trust in complex environmental decision challenges through development of more realistic scenarios for planning purposes (Haas, 2015). As the UN Secretary General's panel lays forth its plan at the General Assembly meetings, such a science-based approach with credible data must be paramount.

In summary, policies around critical minerals are currently being developed ad hoc for parochial political reasons rather than being anchored in science. Such an approach could lead to rampant extractive project development without considering either environmental or economic efficiency considerations. Ultimately projects may then get stalled due to social conflict or financial constraints. A science-based policy approach that is based on sharing systems-level data on supply and demand from both extraction and circular economy sources as well as analyzing a full range of material options will chart a path for sustainable outcomes.

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