The wars, conflicts, and risks of critical mineral supply chains

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The global shift towards renewable energy, driven by urgent climate concerns and international commitments to decarbonization, is reshaping the architecture of energy systems worldwide. At the core of this transformation lies a skyrocketing demand for so-called energy transition minerals (ETMs)â€”such as lithium, cobalt, copper, and rare earth elementsâ€”essential for the manufacturing of batteries, wind turbines, solar panels, and grid infrastructure. However, the procurement of these minerals often depends upon extraction from geologically concentrated locations, which are not only marked by intensive resource exploitation but also characterized by sociopolitical fragility, weak governance, and elevated risks of conflict.

In this study, we develop a comprehensive framework to quantify and analyze the dual challenges facing the global clean energy supply chain: its metal footprint and conflict footprint. Drawing upon an extensive geospatial database encompassing thousands of mining facilities worldwide and integrating this with an expansive archive of documented conflict events, we map, for the first time, the intersection between resource extraction activities and areas of recent or ongoing social unrest. This spatial overlay enables a nuanced understanding of how mineral demand driven by the clean energy transition may be entangled with, and exacerbated by, local conflict dynamics. To deepen our analysis, we employ a multi-region input-output (MRIO) modeling approach, which allows us to trace the global flows of mineral resources and quantify the transmission of associated conflict risks along complex, multi-tiered supply chains. By leveraging MRIO tables, we link primary extraction sites to intermediate processing facilities, manufacturing hubs, and ultimately to end-use sectors and countries. This methodology enables the disentangling of direct and indirect conflict exposures and illuminates the extent to which international trade in raw and semi-processed minerals transmits conflict risk far beyond national borders. Our results reveal that mining operations for ETMs are frequently situated in landscapes that are not only ecologically sensitive but also prone to episodes of violence, protest, and political instability. Proximity analyses indicate that a significant proportion of mining sites are located within zones that have witnessed at least one conflict incident in recent years. Moreover, our MRIO analysis demonstrates that these conflict exposures are not confined to the mining countries themselves. Rather, the globalization of supply chainsâ€”through transnational flows of minerals and intermediate productsâ€”means that end-user countries and industries in geographically distant locations are often implicated, albeit indirectly, in the perpetuation or exacerbation of social tensions in producer countries.

Disaggregating the metal and conflict footprints by clean energy technology, we observe significant variation by clean technology. For instance, technologies with intensive mineral requirements, such as hydropower and nuclear power (which rely heavily on steel, concrete, and other minerals for infrastructure), exhibit notably higher combined footprints compared to those with less metal-intensive designs. Among the various ETMs, copper surfaces as particularly critical, playing a pivotal role in both electrical transmission infrastructure and clean energy manufacturing as a whole. The importance of copper is further underscored by its ubiquity in supply chains and its frequent linkage to sites with histories of unrest and contestation over resource governance. A striking insight derived from our MRIO modeling is that a substantial share of conflict risks embedded in clean energy supply chains is effectively â€œoutsourcedâ€• via international trade. For certain renewable technologiesâ€”especially wind energy and solar photovoltaicsâ€”the majority of conflict exposure does not occur in end-user nations but is instead concentrated in upstream producer countries. This finding has powerful implications for policy and corporate responsibility, highlighting the ethical

entanglement of consuming nations in the social consequences of mineral extraction worldwide. Scenario analysis under various socio-economic and climate policy pathways suggests that absent significant changes in current practices, both mineral demand and associated conflict risks are set to escalate dramatically over the course of the twenty-first century. Under pathways characterized by aggressive decarbonizationâ€”consistent with limiting temperature rise to well below two degrees Celsiusâ€”resource demand and the associated social resilience challenges could intensify several-fold relative to more gradual transition scenarios.