Mining, Biodiversity, and Social Conflict in the Renewable Energy Transition: Key Challenges and Research Gaps

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Abstract

Global biodiversity is increasingly threatened by climate change and land-use pressures, including mining. Achieving Net Zero emissions by 2050 requires transitioning from fossil fuel extraction to sourcing the minerals for renewable energy production. While overall material use may decline in a low-carbon economy, the intensity, location, and ecological footprint of extraction are expected to shift. Understanding how evolving mineral demands affect biodiversity is critical to mitigating ecological impacts and social conflicts and meeting the 2030 Global Biodiversity Framework targets. This Review synthesises biodiversity-focused research on the extraction of all minerals required for the renewable energy transition. While ‘critical minerals’ dominate policy discourse, materials such as concrete and steel account for the largest share of demand by volume and are often neglected in research and policy analysis. Moving forward, we take a comprehensive approach, examining the full range of minerals for renewable energy technologies (e.g. lithium, nickel, cobalt) and infrastructure (e.g. iron, aggregates, limestone), and outline the pathways and mechanisms through which mining affects biodiversity from site to global scales. We also explore how these impacts intersect with environmental justice conflicts. Drawing on cases from the Environmental Justice Atlas, we examine triggers, concerns, and outcomes of conflicts related to energy transition minerals. Despite expanding research, critical gaps remain in biodiversity and social risk assessments, comprehensive mineral demand projections, and spatial data on mining for construction materials. Closing the gaps and adopting a comprehensive understanding of mineral requirements and associated risks is essential for decarbonization strategies that are effective, socially and environmentally responsible.

[H1] Introduction

In response to dual biodiversity and climate crises, countries have committed to limiting global warming under the Paris Agreement and to halting and reversing biodiversity loss under the Kunming-Montreal Global Biodiversity Framework (GBF). Climate change not only has wide-ranging impacts on the environment, water resources, food security, human health, and social and economic stability, but disrupts multiple ecological processes at different levels of biological organisation[1], contributing to the biodiversity crisis and putting many species at heightened risk of extinction[2]. To mitigate climate change-related threats and achieve the Paris Agreement's goals, rapid expansion of renewable energy production is underway. However, mining activities associated with the renewable energy transition further exacerbate challenges to biodiversity, and can harm human wellbeing. Comprehensive material projections and risk assessments are crucial for avoiding and mitigating mineral disruptions and socioecological impacts, but current efforts focus almost exclusively on 'critical minerals' and ignore other essential minerals — primarily construction materials.

Although the transition to renewable energy is expected to require less mining overall than the current fossil fuel-dominated energy system[3], a sixfold increase in demand for energy transition-related minerals is projected between 2020 and 2040 under the global Net Zero emissions pathway[4]. The scale and speed of renewable energy development hinges partly on the supply of raw materials, placing the mining sector at the forefront of the transition. However, mineral extraction also poses serious threats to biodiversity[5], including altering both abiotic[6-8] and biotic conditions[9,10]; impacting biodiversity throughout the lifecycle of mine operations; causing or intensifying declines in threatened species[11,12] and ecosystem services[13]; and encroaching into protected areas and other areas important to future biodiversity persistence[14]. According to the International Union for Conservation of Nature's (IUCN) Red List of Threatened Species, 13,581 species are threatened by mining and quarrying activities globally, of which almost half are categorized as threatened with extinction and 9 are already extinct[15].

Biodiversity is also central to the well-being, cultural identity, spiritual life, and survival of local communities, especially those with close connections to land such as Indigenous Peoples, small-scale farmers and fishers, and rural communities[16]. The loss and degradation of species, habitats, and landscapes by mining can cause environmental conflicts[17] by limiting access to essential resources, eroding cultural heritage, or disrupting the supply of ecosystem services such as food, water, or resilience to natural disturbances[13,18]. The major shift in minerals and mining locations required by the renewable energy transition makes novel biodiversity threats likely, which could intensify environmental conflicts and socio-ecological pressures, ultimately undermining efforts to meet the GBF's goals and targets.

A range of minerals is needed for the energy transition, from rare earth elements such as neodymium, dysprosium and terbium used in wind turbine magnets, to bulk materials such as aggregates, cement, and steel for the foundations of those same turbines. Discussions surrounding mining for the energy transition often focus on 'critical minerals', such as lithium and cobalt that are economically important but are subject to supply risks, whereas concrete and steel are the predominant materials needed by volume[4,19,20]. Despite their central role in renewable energy infrastructure, construction materials are often overlooked in environmental risk assessments of mining for the energy transition[21,22]. This oversight renders existing assessments and reviews incomplete, and risks underestimating biodiversity impacts and broader socioecological consequences of mining for the renewable energy transition.

Although previous studies have examined the biodiversity impacts of mineral extraction for energy transition[23,24], in this Review we draw together research on the biodiversity impacts of mining across the full range of minerals required for the renewable energy transition for the first time, and also explore their links to environmental conflict. We first introduce the full spectrum of raw materials required for the renewable energy transition, and clarify key definitions and implications for biodiversity impact assessments. We then summarize the effects of mining on biodiversity, drawing on a rapid evidence review that builds upon previous analysis[5] and examines the pathways and spatial scales through which mining threatens biodiversity (Supplementary Information). We also provide a global overview of environmental conflicts linked to minerals needed for renewable energy, exploring the intersections between mining, biodiversity loss, and environmental conflicts. Finally, we explore key research and conservation priorities for a just and biodiversity-conscious renewable energy transition.

[H1] Broadening views on energy transition minerals

The shift from a fossil fuel-dominated energy system to one based on renewables is transforming the landscape of global mineral extraction. Whereas the current energy system depends on high-volume, continuous material extraction, renewable energy systems are expected to require a lower overall volume. However, the renewable energy sector is driving high-intensity, geographically concentrated material extraction, and is a major driver of global demand[4,25,26]. The World Bank identifies 17 metals — aluminium, chromium, cobalt, copper, graphite, indium, iron, lead, lithium, manganese, molybdenum, neodymium, nickel, silver, titanium, vanadium, and zinc — whose demand will continue to rise owing to their use in solar, wind, and hydropower technologies[27]. For example, solar panels require aluminium and copper for module frames and wiring, and silicon, silver, cadmium, and gallium for various solar cell technologies, while wind turbines rely on large quantities of aluminium, copper, zinc, iron, cadmium, molybdenum and rare earth elements such as dysprosium, and neodymium for permanent magnets[4,25,26]. Hydropower turbines use copper, manganese, chromium, zinc, aluminium, and nickel[4], and energy storage systems — particularly lithium-ion batteries — require lithium, nickel, cobalt, manganese, graphite, and copper[4,26].

The International Energy Agency (IEA) has assessed the material requirements for a range of energy transition scenarios, including a Sustainable Development (Net Zero by 2050) scenario, which outlines the material demand required to achieve the Paris Agreement goals, and a Stated Policies scenario that reflects the projected trajectory of the energy system based on today's policies[4]. In the Sustainable Development scenario, the demand for minerals required for renewable energy technologies is projected to rise substantially by 2040: lithium demand is expected to increase more than 40-fold, while demand for cobalt, nickel, and graphite is anticipated to increase 20–25-fold relative to 2020 levels[4]. The demand for rare earth elements is projected to rise seven-fold, and demand for neodymium — a key component in wind turbine magnets — is expected to triple [4].

Discourse on the material demands of the energy transition has largely centred on a select group of 'critical minerals' defined primarily by their geological scarcity and supply security risks (Box 1). Although some assessments (including that of the Joint Research Centre (JRC) of the European Commission) also estimate the demand of concrete and steel required for wind and solar power projects to achieve Net Zero targets[20,25], construction materials for renewable energy infrastructure have a substantial demand by volume and have been overlooked as the supply of underlying resources (aggregates, limestone, and iron) is generally assumed to be abundant and secure. For example, steel constitutes approximately 34% of the material inputs in solar panels and 24-25% in wind turbines (including foundations), while concrete (produced from both aggregates and cement) dominates material inputs in hydropower dams, comprises up to 70-72% of the materials in wind turbines (including foundations), and constitutes 31% of the materials in solar panel infrastructure[25].

Projections for 'critical minerals' are abundant, but a notable gap exists in forecasts for the demand of construction materials within the renewable energy sector[28]. The extent of this gap can be illustrated by estimating the potential increase in demand for concrete and steel required for solar, wind and hydro projects using the IEA's renewable energy scenarios (Supplementary Information, Fig. 1). Concrete and steel are projected to account for 65-70% and 24-29% of the total material demand from 2025 to 2030, respectively, across both scenarios (Fig. 1a-b). These demands represent approximately 0.4 to 0.8% of global concrete production and 3% of steel production annually, based on the demand required to meet 2025 targets relative to annual global concrete[29] and steel[30] production reported.

Although renewable energy infrastructure occupies a limited share of the global market for aggregate and other bulk materials —such as iron, copper, aluminium and cement — these bulk materials represent the vast majority of minerals demanded by the renewable energy transition. For example, renewable energy infrastructure is estimated to require between 130 million (STEPS) and 250 million (SDS) tonnes of concrete in 2025 alone (Fig, 1a-b, Supplementary Information). . This forecasting gap has consistently been overlooked in assessments of material demand and coupled environmental footprint assessments of the renewable energy transition (an exception is a European Union analysis[28]). As a result, current assessments underestimate the true scale of resource use and biodiversity impacts, obscuring the broader ecological consequences and risks associated with meeting climate targets.

[H1] Mining impacts on biodiversity

Mining exerts multifaceted impacts on biodiversity across spatial scales through direct and indirect pathways[5] (Fig. 2a, Supplementary Figs 1, 2). These impacts vary depending on extraction methods, mineral types, socioecological contexts, and the varied nature of ecological responses they elicit. The transition from a fossil fuel-based energy system to renewable energy sources and the consequent increase in demand for various minerals[31] is expected to alter both the magnitude and geographic distribution of mining-related impacts on biodiversity[23,24]. Understanding how the extraction of all minerals essential for the renewable energy transition impacts biodiversity is crucial for anticipating and managing emerging threats, and for supporting comprehensive biodiversity risk assessments in the context of a Net Zero future.

In the past 6 years, research on mining–biodiversity interactions has expanded rapidly (Supplementary Fig. 1a–b) alongside growing recognition of mining's ecological impacts in high-level national and international biodiversity conservation policies[32], including resolutions of the UN Environmental Assembly, underscoring the need to address biodiversity loss from mineral extraction[33]. This section outlines how mining affects biodiversity by exploring the pathways, mechanisms and spatial scales of its impacts, before examining the specific patterns and types of impacts associated with mining for minerals essential to the renewable energy transition.

[H2] Causal pathways linking to biodiversity loss

Mining affects biodiversity through two primary pathways: direct impacts from mineral extraction activities, and indirect impacts from related industries and external stakeholders[5] (Fig. 2, Supplementary Fig. 1-2). To date, most research has focused on quantifying and predicting the direct impacts of mineral extraction (Supplementary Figs. 1–2). However, attention to indirect effects is growing, particularly effects related to the expansion of access infrastructure, such as roads, which can facilitate additional external pressures on biodiversity by enabling agricultural expansion or illegal hunting. Considering both pathways is crucial for assessing the ecological consequences of future mining.

[H3] Direct impacts from mining activities

Mining projects profoundly alter natural environments throughout their lifecycle. (Fig. 2). Exploration, extraction, processing, waste disposal, and closure typically involve major physical disruptions, including geomorphological and landscape transformations[34,35], vegetation clearance[36], removal of overburden (soils and seedbank loss)[37], and the use of physical and chemical treatments that cause pollution[38]. These activities modify abiotic conditions (such as microclimate, water and air quality, and soil structure)[39,40] and biotic conditions (such as ecological connectivity and species interactions)[41-43]. Impacts tend to be most intense near the core mining site but often extend across the broader landscape, which can also experience habitat loss and degradation through the propagation of impacts (such as pollution and erosion)[44,45] and disturbances (such as noise and traffic)[46,47]. Moreover, impacts from multiple active mining operations within the same region can accumulate, contributing to regional biodiversity loss.

[H3] Indirect impacts associated with mining

Indirect impacts can be broadly grouped into two categories: those arising from supporting industries and those from external stakeholders accessing previously undisturbed landscapes owing to mining expansion (Fig. 2). Supporting industries develop infrastructure necessary for mining operations, such as roads, powerlines, water infrastructure, settlements, and supply chains, which often extend beyond the extraction sites. These developments drive habitat fragmentation, increased human activity, and broader land-use change[48-50]. By contrast, impacts from external stakeholders emerge when mining enables access to undisturbed landscapes by other land-use sectors, including agriculture, forestry, and hunting. Impacts are particularly detrimental when mining indirectly enables human access to ecologically sensitive areas[51,52], intensifying environmental degradation. Further, mining-driven urbanisation and associated population growth[53,54] can create feedback loops in which increased infrastructure needs and resource demand to stimulate further mining, compounding direct and indirect impacts on biodiversity. For example, large-scale mining operations in the Amazon and Sub-Saharan Africa have attracted a surge of workers and related industries, driving the rapid growth of settlements around mines[55,56] and boosting demand for housing, roads, and other infrastructure that rely on locally sourced construction materials[57,58].

[H2] Spatial scales and mechanisms linking mining activities to biodiversity loss

Mining affects biodiversity through multiple mechanisms across spatial scales, from local disturbances and pollution to landscape fragmentation, regional cumulative effects (Fig. 2), and global consequences such as species extinction[5]. Research remains focused on direct mining impacts at site and landscape scales, whereas global-level impacts and cumulative effects have received limited attention (Supplementary Figs. 1–2). Nonetheless, in the past six years, broader scale impacts have been increasingly studied, including through landscape, regional, and global analyses, accompanied by a relative decline in site-level assessments (Fig. 2b).

[H3] Site-scale

Extraction activities vary substantially in method and scale, encompassing underground, open-pit, strip mining, hard rock quarrying, and dredging in river, coastal and marine ecosystems, ranging from small-scale artisanal to large-scale industrial operations. Despite this variation, extraction often impacts biodiversity through a combination of common mechanisms, primarily through habitat loss and degradation via physical disturbances and pollution (Fig. 2-3).

Mining is a major source of pollutants that are generated through waste disposal, tailings, use of toxic substances such as cyanide and mercury in mineral processing, and sediment runoff from geomorphological and soil disturbances that include vegetation clearance, topsoil removal, blasting, and excavation[41]. Similarly, sand and gravel extraction in rivers and coastal areas modifies local geomorphology, destroys benthic habitats and increases turbidity and sedimentation [59,60]. Airborne pollutants, including cadmium vapour, sulphur dioxide, nitrogen oxides, carbon dioxide, and particulate matter, have also been widely reported[61,62]. These stressors are associated with reduced species fitness, reproductive suppression and increased mortality, particularly among small-range or specialist taxa such as invertebrates, fish, amphibians, and reptiles, and monitoring data have revealed shifts in community composition[41,63,64].

Interestingly though, site-level research has predominantly focused on the management and mitigation of biodiversity impacts associated with mining activities, with particular emphasis on restoration, rehabilitation, and more recently on offsetting efforts following disturbance[65-67] (Supplementary Table 2 and Supplementary Fig. 2b) [68,6970].

[H3] Landscape to regional scale

Mining's impacts on biodiversity extend beyond the extraction site and can contribute to large-scale habitat loss and degradation[48-50], particularly through combined effects of multiple mines[9,71]and other indirect processes. At the landscape and regional scale, conservation can be affected by mining activities occurring within protected areas or impacting threatened species. Increasingly, mining poses risks to areas protected or otherwise prioritised for conservation[72-74], raising concerns about the adequacy of current conservation strategies amid expanding mining and related pressures. Mining also drives land-use change, including deforestation, by replacing natural habitat with mining-related land use (Supplementary Fig. 2). Pollution and the degradation of ecosystem services and functions as a result of mining also occur at these broader scales (Supplementary Table 2 and Supplementary Fig. 2b).

Ecosystems downstream of individual or multiple mining sites are impacted by chemical pollutants and sediment loads released at extraction sites that can travel via surface runoff, groundwater, and river networks, contaminating connected freshwater and coastal ecosystems [75-78]. Similarly, extraction of river sand and gravel beyond replenishment rates can erode riverine ecosystems and disrupt sediment flow[79]. Failures or poor management of tailing storage facilities can lead to the release of large volumes of contaminants into surrounding environments[6], causing extensive habitat destruction and spreading pollutants throughout fluvial systems and into marine ecosystems[80].

Biodiversity loss from mining alters ecosystem functioning and degrades ecosystem services at the landscape scale (Supplementary Fig. 2b). Mining can compromise ecosystem services such as carbon sequestration, soil fertility, water purification, recreational and cultural values, and food security[81,82]. For example, widespread deforestation and soil disruption reduce the landscape's capacity to store carbon[13], the cumulative pressure of mines and other land uses can exacerbate regional water scarcity[83], and habitat degradation can impair food provisioning services such as fisheries in riverine and coastal systems[84,85].

[H3] Global scale

A substantial development in mining and biodiversity research in the past 6 years has been the increase in global scale assessments (Supplementary Fig. 1a–b). These assessments have been facilitated by enhanced access to geospatial information and driven by increased corporate investment (for example, databases compiled by S&P Global), research mapping via high-resolution remote sensing public satellite imagery[86,87], and global monitoring initiatives such as the Marine Sand Watch launched in 2022 by UNEP/GRID-Geneva.

Assessments have focused on the overlap between mining activities and areas of high biodiversity conservation value defined by species richness, endemism[88,89] or conservation designations such as Protected Areas, Key Biodiversity Areas, and Remaining Intact Ecosystems[14,89,90]. For example, 8% of global metal mining operations are estimated to occur within Protected Areas[91], and almost 30% of their waste storage facilities are located within or near protected areas[24], posing risks to river systems and adjacent ecosystems owing to contamination and catastrophic failures[92]. Moreover, examining mining datasets and IUCN Red List species ranges has revealed that approximately 8% of vertebrate species are threatened by mining[93], and 43 threatened mammal species have over 30% of their habitat within 10 km of an active mine[89]. In marine environments, almost half of globally active operators extract aggregates and other sediments each year in Marine Protected Areas, accounting for an average of 14.2% of total annual dredging time[60]. However, substantial challenges remain in quantifying global biodiversity risks, particularly for aggregates and other non-metallic minerals for which spatially explicit global data are still lacking[32].

[H2] Impacts of mining for the renewable energy transition on biodiversity

The impacts on biodiversity from mining for minerals essential to the renewable energy transition are similar to mining's effects on biodiversity broadly. However, increasing demand for specific minerals is affecting the location and intensity of mining operations, which has implications for biodiversity impacts. Additionally, mechanisms such as pollution will differ between extracting and processing minerals for a renewable energy system compared with minerals for a predominantly fossil-fuel-based system.

Research examining minerals needed for renewable energy often does not explicitly contextualise their extraction within the framework of energy transition–driven demand, as many of these minerals are also widely used across other industrial and infrastructure-related sectors. Minerals such as cobalt, lithium, and rare earth elements, whose demand is driven mostly by the renewable energy transition, are the focus of fewer assessments as research attention for their specific role in renewable energy technologies is only beginning to emerge. However, biodiversity assessments that focus explicitly on the energy transition have exclusively focused on the 'critical minerals'[21,22] and metals[23,24], leaving a substantial gap in understanding the use and biodiversity impacts of construction materials in renewable energy infrastructure.

[H3] Mining geographic patterns across energy systems

The geographic footprint of mining differs between minerals used in traditional and renewable energy systems, and shifts in production might alter regional pressures on biodiversity in the future. Mining for energy production currently accounts for approximately 10% of global biodiversity loss, and coal mining is historically responsible for the vast majority of these impacts (95%)[23]. Mining to supply the renewable energy transition is expanding, adding new pressures to regions already affected by coal mining as well as impacting previously unaffected areas. Although the renewable energy transition sector accounted for only 3.5% of mining-related biodiversity impacts in 2014[23], it has grown 3–4% annually since 2010[94]. This shift might not significantly change the global locations of extraction in the short term, but is likely to intensify ecological pressures in existing mining regions, while reducing pressures from coal mining and expanding frontiers into new areas.

Mapping the global distribution of both active mining sites and early-stage exploration efforts for metals needed for renewable energy production and for coal provides early insight into how the transition from fossil fuels to renewable energy technologies is reshaping mining frontiers (Fig. 4). Despite a gradual decline in global coal demand since 2020, coal still supplies about 35% of global energy needs[94]. Further, active coal mining continues in countries such as Indonesia, Australia, China, India, Europe, the US, and many of which contain biodiversity hotspots. Although exploration and early-stage development of coal projects have declined in Europe (Fig. 4), new projects continue in regions such as Indonesia and Australia, largely driven by sustained demand from China. Interestingly, many regions with a legacy of coal mining activity are now experiencing dual pressures from both continued coal extraction and rising demand for transition minerals.

The extraction of metals needed for the energy transition is more geographically widespread than coal mining, as it targets a broader range of minerals (Fig. 4)[95]. Despite this broader distribution, mining for the energy transition remains strongly concentrated in a small number of countries that dominate global production.. Many of these regions do not have active or projected coal mining, such as Northern Europe, Andes, Western Africa, and Central and Southeast Asia (excluding Indonesia and Philippines). Projected activities might particularly affect new frontiers such as Northern America, Western Australia, and Northern Europe, which are emerging as key regions of growth, potentially driven by increasing demand for renewable energy transition metals.

Overall, the shift in mineral demand implies that although many extraction zones might remain stable, the intensity and nature of impacts are likely to change. For example, nickel production increased fourfold from 1985 to 2022, and Indonesia now supplies 50% of the global nickel[95]. Similar trends are evident with cobalt, lithium and rare earth elements.

[H3] Renewable energy transition metals

Biodiversity impacts associated with the extraction of iron, bauxite, copper, and nickel have been the most widely studied across all spatial scales among metals needed for the energy transition (Supplementary Fig. 4a). The deposits of these minerals are frequently located within high-biodiversity tropical ecosystems, rendering their extraction particularly concerning for global conservation efforts[90]. Research on the impacts of iron mining is primarily concentrated in Brazil, India, and Australia (Fig. 5), whereas research on other renewable energy transition metals is more geographically focused: for example, research on copper is concentrated along the Andes in South

America; lithium in the 'Lithium Triangle' of Bolivia, Argentina, and Chile; and cobalt- in the Democratic Republic of Congo; and nickel in Indonesia, the Philippines, and New Caledonia.

Although some biodiversity impacts for renewable energy transition metals mirror impacts caused by the extraction of fossil fuels such as coal (primarily mining activities[9,96,97,98] and associated infrastructure development[48] including habitat loss, landscape alteration, the mobilisation of acid mine drainage, and emissions of particulate matter, sulphur dioxide, or carbon monoxide), other impacts are intensified or distinct (Fig. 2b). For example, increased soil erosion leads to the deposition of heavy-metal enriched sediments in the adjacent terrestrial and aquatic ecosystems(Fig. 2b)[99-101]. Other metals required specifically for the renewable energy transition, such as rare earth elements and lithium from brines, introduce further unique challenges. For example, mining of rare earth elements is associated with the release of radioactive heavy metals such as uranium and thorium, which can accumulate in the surrounding biodiversity[102-104]. Whereas, lithium brine extraction — particularly in the Lithium Triangle — has been shown to alter groundwater hydrology, increase salt accumulation, and release chemical contaminants[105,106], posing serious risks to sensitive wetland ecosystems that provide critical habitat for migratory and endemic bird species, including Chilean, Andean, and James's flamingos [107,108].

However, assessments of biodiversity impacts from renewable energy transition metal mining are limited, and substantial knowledge gaps remain. For example, although over half of the global cobalt supply is sourced from the Democratic Republic of Congo — one of the world's most biodiverse countries — the ecological consequences of large-scale and artisanal-scale cobalt mining operations remain poorly documented.

Deep-sea mining of polymetallic nodules (Supplementary Fig. 4b) — mineral concretions on the ocean floor that contain trace amounts of minerals like nickel, cobalt, copper, titanium, and rare earth elements — is another source of metals required for the renewable energy transition. Much of what is known about deep-sea mining comes from exploratory biodiversity assessments[109-112], experimental sediment plumes and sediment redeposition, and expert opinion[112-114]. These analyses suggest that that deep sea mining could alter benthic macrofaunal diversity and community structure by suppressing the physiological processes (such as feeding, breeding and foraging communication)[115,116] in deep-sea fauna, and increasing mortality due through disrupted larval dispersal and reduced settlement success[117]. Despite growing research, the full extent of these impacts remains poorly understood, particularly when considering trade-offs between terrestrial and potential future deep-sea mining.

[H3] Aggregates and limestone

Research into the impacts of has focused heavily on regions that have high aggregate extraction rates, including Europe, Vietnam, and China (Fig. 5, Supplementary Fig. 4a). However, in Europe, biodiversity impacts are have received less research effort compared to site-level post-mining rehabilitation[118-120] aiming to investigate ecosystem processes such as vegetation succession and the effectiveness of ecological restoration techniques in recovering biodiversity[119,121,122]. At regional scales, the impacts of sand mining on biodiversity loss (e.g., fish, invertebrates, plants) and habitat degradation in freshwater ecosystems are better understood; for example, in the Mekong Delta in Vietnam [75,123], the Yangtze River in China [124], and along the Andes and the northern rainforest of South America[125]. Research on the site and broader-scale biodiversity impacts of quarrying remain scarce, despite most construction minerals being extracted from land-based sources and the expansion of aggregate and limestone quarrying into biodiversity-rich regions, including areas with high levels of endemism, such as the karst systems in Malaysia and Vietnam[126,127]. Moreover, global-scale research on aggregate mining is lacking, likely owing to a lack of global mining datasets for these and other non-metallic minerals[32]; overall, very few studies having assessed the biodiversity and conservation relevance of aggregate mining[8,60,125].

[H1] The nexus between mining, biodiversity and social conflict

As mining for the renewable energy transition negatively affects natural systems throughout its lifecycle, often causing long-lasting or irreversible damage that extends beyond the mine site, it can also disrupt the intricate relationships between people and biodiversity (Fig. 2-3). Mining impacts directly and indirectly undermine biodiversity and the ecosystem services that human well-being depends on, from provisioning (hunting, fishing, freshwater, medicine) to cultural (damage to landscape and sacred sites) and regulating functions (soil integrity, wetland health)[13,128-130]. Experiencing or anticipating the loss or degradation of biodiversity and associated landscapes can easily spark conflict[131-133] , particularly when the burden of change falls on local or marginalized communities whose access and use of nature is limited by mining activities[134] . Indigenous Peoples and local communities are especially vulnerable to mining impacts as their relationships with land and nature are rooted in cultural, spiritual, and subsistence values [128]. Although mining projects can provide benefits to local communities, such as employment opportunities, infrastructure, agreements, and royalties that support well-being, this section focusses on the biodiversity triggers of conflicts. The impacts of mining on biodiversity and social conflicts have been extensively studied individually, yet research exploring the link between the two remain limited. Understanding their interconnected effects is crucial for minimizing biodiversity impacts, fostering thriving local communities, and promoting just pathways in the renewable energy transition.

Since the 2000s, environmental conflicts have been increasingly documented and studied[132,135-138,139,128] primarily to deepen the understanding environmental justice mobilisations and community resistance across the world[135,140]. While this body of research continues to grow, studies specifically linking mining conflicts with the energy transition is still emerging[17,141]. The Environmental Justice Atlas (EJAtlas; ejatlas.org)[142], is an initiative documenting mining-related conflicts, alongside other initiatives such as Amazon Mining Watch and Global Witness. EJAtlas contains 3,861 recorded cases across terrestrial, freshwater, and marine environments, and is the most comprehensive open-access citizen science platform on environmental conflicts, built through contributions from citizens, academics, NGOs, and activists[131,143,144]. Data from the EJAtlas can be used to identify and further understand reported conflicts linked to mining projects involving minerals critical to the renewable energy transition (Supplementary Information).

[H2] Minerals associated with conflict

Extraction of minerals (713 cases) and fossil fuels (739 cases) are the most prevalent causes of environmental conflicts according to the EJAtlas, and 532 mining-related conflicts are tied to the extraction of minerals needed for the transition towards renewable energy production (Fig. 6). Among these, minerals needed for renewable energy technologies are linked to the largest share of reported conflicts (64.6%), and copper and silver are the most frequently cited (170 and 139 cases, respectively). Minerals used for renewable energy infrastructure are linked to fewer conflicts than minerals for renewable technologies, and aggregates (78 cases) and iron (74 cases) are most common. It is important to highlight that cases are not always directly connected to renewable energy expansion itself, but rather to the upstream extraction of the minerals that make such a transition possible.

[H2] Environmental concerns

Conflicts surrounding the extraction of technology-related minerals are predominantly marked by concerns over surface and groundwater pollution (Supplementary Fig. 6). Pollution of water and soil, along with hazards related to mine tailings, were often central to local resistance. One prominent example is the large-scale lithium extraction in Chile's Salar de Atacama, where over 2 million litres of brine are drawn daily, disrupting ecosystems, depleting water tables, and salinizing freshwater used by local communities[107,145,146]. In addition to substantial biodiversity impacts, this extraction has also sparked social conflicts. Local communities, affected by the loss of water and habitats, have clashed with mining companies, with internal disputes arising within the communities over the trade-offs of extraction and its long-term effects[147,148].

By contrast, infrastructure-related mineral extraction tends to drive conflict owing to concerns regarding biodiversity loss, landscape degradation, soil erosion, and noise pollution, although water pollution remains a shared issue (Supplementary Fig. 6; Box 2). Sand mining for construction and iron extraction has triggered numerous environmental and social conflicts[85]. In Kulon Progo, Yogyakarta, iron sand mining disrupted coastal dune ecosystems, leading to habitat degradation, pollution, saltwater intrusion and erosion, thereby threatening both biodiversity and the ecological functions underpinning coastal resilience and livelihoods[159]. The project also provoked strong resistance from the Coastal Land Farmers Association (PPLP), whose members had cultivated the area for generations. In response to the threat of displacement, they organised protests and blockades, which were met with intimidation, violence and repression, including against supporting academics[159]. The conflict undermined social cohesion and trust, as decision-making was dominated by state and corporate actors with limited transparency or local participation[159].

Although many conflict dynamics are shared across extractive industries, mining for the renewable energy transition introduces new or intensified triggers — particularly related to urgency, territoriality, and governance complexity. These triggers include, for example: fast-tracked permitting and regulatory rollbacks, where efforts to meet climate and supply chain targets lead governments to bypass environmental reviews and weaken community consultation[149]; global demand shocks and price volatility, which fuel land disruption of customary and Indigenous land rights, in which renewable energy transition-linked projects often proceed without Free, Prior and Informed Consent (FPIC)[150], triggering protests and legal challenges, as in parts of the Lithium Triangle. Although not an exhaustive list, these examples illustrate how the race to secure supply of minerals essential for renewable energy production and the associated rapid mining expansion can heighten socio-environmental tensions and introduce distinct pathways to conflict that warrant close attention in transition planning.

[H2] Environmental conflict locations

Mining-related conflicts are observed on all continents (excluding Antarctica), but reported disputes are largely concentrated in key mineral-producing regions of the low and middle-income countries (Fig. 6), reflecting a clear geographic and socio-political bias. Approximately 8% of mining areas encroach on areas of high biodiversity conservation value[24], some of which also lie within Indigenous Peoples' lands, although this percentage might be larger given that half of the world's mines remain unmapped[151]. Indeed, over half of mining projects for the commonly considered energy transition minerals and metals (excluding aggregates) are located on or near the lands of Indigenous Peoples and low-income farmers[152], affecting not only traditional land tenure and ownership, but also landscapes with substantial ecological and cultural integrity.

One potential explanation for the global imbalances and biased geographical distribution of mining-related conflicts associated with minerals essential to decarbonisation is the theory of ecologically unequal exchange[153]. Ecologically unequal exchange proposes that high-income countries are a net appropriator of embodied labour, resources and environmental impacts from low and middle-income countries, and that economic and historical power imbalances determine the global spatial distribution of the production and consumption of environmentally damaging raw materials. This perspective argues the high-income countries has consumed far in excess of its 'fair share' of raw materials in the context of the finite environmental damage and resource extraction that can be tolerated whilst remaining within planetary boundaries[154], and that this process is ongoing as companies in high-income countries are disproportionately likely to be associated with ecological distribution conflicts in the low and middle-income countries [155]. These patterns are fundamentally intertwined with economic and financial (that is, currency) imbalances[156], that are at least partially explained by the history of colonialism of low and middle-income countries by high-income countries[157].

Although these global dynamics help explain patterns of conflict, some conflicts do not fit this framework. In particular, conflicts involving aggregates and iron — often extracted for domestic infrastructure rather than global supply chains[158] — might reflect internal inequalities, especially between urban and rural areas, rather than international exploitation.

Additionally, growing geopolitical concerns are connected to increased efforts to secure domestic mineral supplies, shifting attention toward local deposits in regions such as Europe and the United States. This push for mineral security has spurred new exploration and development initiatives, leading to the emergence of conflicts around proposed mining projects[159], highlighting that tensions over resource extraction are not exclusively confined to the Global South.

[H3] Research on biodiversity and conflict

The deep relationship between biodiversity loss and social conflict in the context of mining for the renewable energy transition becomes evident when looking at the spatial patterns of biodiversity studies and conflict reports (Fig. 6). The strong overlap between regions experiencing biodiversity impacts and those reporting environmental conflicts suggests that ecological degradation and social tensions often go hand in hand. Geographic differences in the distribution of environmental conflicts also depend on the type of minerals extracted.

In North and South America, biodiversity studies and environmental conflicts overlap to a high degree. Chile, Argentina, and Peru are key exporters of copper and lithium, extraction of which has caused intense pressure on biodiversity and environmental conflicts[148,160,161]. For example, the Tres

Quebradas lithium project in Argentina is advancing within a Ramsar-designated site that protects high Andean wetlands rich in specialist and endemic species. Lithium extraction is ongoing amid opposition from Indigenous communities and regional groups, who demand hydrogeomorphological studies on potential mining impacts[162]. Conflicts related to minerals needed for infrastructure are concentrated in coastal areas of Argentina and Brazil, Central America, and Mexico. Two major environmental conflicts related to iron mining are the Mariana[163] and Brumadinho[164] tailings storage facility failures. These disasters resulted in loss of life and severe environmental degradation, disrupting access to freshwater and fish sources, and led to social uprising and legal action against the mining companies[165,166]. Brazil also faces multiple pressures from aggregate mining including quarrying[8,58], river sand mining, and marine sand dredging, which have led to significant environmental degradation, biodiversity loss and social conflict[167] — including disputes involving Indigenous Peoples[168].

A similar pattern of overlap is evident in South and Southeast Asia, where environmental conflicts were more often linked to infrastructure-related minerals than renewable energy transition metals. India, Bangladesh, and Vietnam are hotspots of reported conflict, as primarily related to river and coastal sand mining (for example, in the Mekong River and Delta, and Ganges River), iron mining[71,169], and limestone quarries expanding into regions rich in endemic species, such as the limestone hills of Malaysia and Vietnam[126,127]. Conflicts associated with the extraction of minerals for renewable energy technologies, though more spatially scattered, were notable in Indonesia and the Philippines, both key global suppliers of nickel and cobalt. For example, nickel mining in Sulawesi has resulted in substantial forest loss, posing threats to 17 endemic primate species, and exposing low-income communities to severe environmental and health risks[97].

In Western and Central Europe, substantial overlap exists between biodiversity studies–primarily on mine restoration–and conflicts associated with minerals required for renewable energy infrastructure [170-173], which could be due to the high number of operating, closed, or abandoned quarries. However, significant knowledge gaps remain regarding the consequences of metal mining across the region. Although Western and Central Europe are not currently major contributors to the supply chains for minerals required to renewable energy technologies[174], rising demand might intensify extraction pressures in countries such as Spain, Finland, Norway, Sweden, and Ireland, where mines overlap substantially with areas important to biodiversity conservation[21].

Mismatches between reported biodiversity impacts and environmental conflicts are also evident. In Australia and Canada, which each have a high density of mining projects and biodiversity studies, relatively few environmental conflicts were reported relating to minerals needed for renewable energy technologies and infrastructure. This could be attributed to stronger governance frameworks and regulatory enforcement, and the implementation of higher social and environmental safeguards that address potential conflicts. However, conflict still occurs, particularly involving Indigenous Peoples. For example, in 2020 Rio Tinto legally destroyed 46,000-year-old Juukan George rock shelters owned by the Puutu Kunti Kurrama and Pinikura Peoples to expand an iron mine, which evidences tensions between mining and Indigenous land rights in Western Australia[175]. Although not exclusively related to biodiversity loss, such conflicts raise concerns about the effectiveness of regulatory frameworks and management plans in protecting nature integral to Indigenous Peoples' livelihood and cultural practices[176].

Conversely, regions with substantial environmental conflicts but limited biodiversity research represent crucial gaps where the ecological consequences of mining remain poorly understood. Such regions include Eastern Europe, Central and East Asia, the Middle East, the South Pacific, and much of the African continent. Within these regions, environmental conflicts linked to minerals used in renewable energy were widely reported, especially in the Balkans, Northen Europe, the Eastern Mediterranean, and Greenland. For example, the Middle East hosts the highest share of projects near Indigenous lands (82%)[152] and Africa has the highest proportion of projects located on or near peasant land (77%)[152], yet biodiversity impacts remain understudied in both regions except for in South Africa and Madagascar. These discrepancies suggest that although social and political tensions related to mining are being documented, their ecological consequences remain largely unexamined.

Importantly, the observed patterns in mining-related conflicts are also influenced by structural limitations in the data. The EJAtlas highlights regions with strong civil society and digital connectivity, and conflicts in remote or censored areas might be underrepresented. Therefore, the EJAtlas provides a valuable, though conservative, estimate of mining disruptions, offering insights that reflect available data and advocacy efforts while acknowledging areas where more research is needed.

[H2] Participants and outcomes of conflict

A range of social actors emerge as mobilising groups across mining conflicts, including self-organized local communities, local organizations, farmers, Indigenous Peoples or traditional communities, and local scientists (Supplementary Information). Broad-based mobilizations, uniting diverse groups such as farmers, Indigenous communities, and civil society, tend to achieve substantial, lasting outcomes than isolated groups by increasing pressure on authorities and companies. Their engagement is often driven by the need to protect biodiversity or other vital resources (for example,, food and water security), cultural values, and livelihoods in the face of mining's risks or impacts. For example, in Ecuador, new mining concessions overlap with the Cotacachi-Cayapas Ecological Reserve and Indigenous territories, prompting social movements to demand stronger environmental and social safeguards[177]. In the context of the energy transition, the fast-tracking of projects for ’critical minerals‘ to ensure rapid supply (e.g., excluding public consultation) is already triggering conflicts. In New Zealand, classifying aggregates as critical minerals has raised concerns from the Tāngaro Tuia te Ora and the Endangered Species Foundation, who warn that fast-tracking projects like marine dredging in Bream Bay will harm sensitive ecosystems, while existing, less damaging sources already meet the aggregates demand[178].

Mobilizing groups appear to follow different mobilizing strategies depending on the nature and phase of the mining activity (Supplementary Fig. S7). In large-scale mining operations such as those for metals, resistance frequently emerges during early stages, such as exploration and project approval. These stages mark a major turning points for local communities often involving land-use changes and a substantial influx of workers from other areas, which can disrupt socioecological systems[179]. Foreign firms might also be perceived as less legitimate by local activists and can be more susceptible to social mobilization than local firms[180]. Resolution Copper (United States), Tampakan (Philippines), and Pascua Lama (Chile) are examples of numerous cases linked with energy transition minerals where conflicts over sustainability objectives have emerged during the pre-development phase[152]. Early mobilization by community members can reflect a preventive strategy, attempting to halt or reshape the project before irreversible impacts take hold. Underlying these mobilizations is often a deep mistrust between communities and mining companies, rooted in repeated experiences of environmental degradation, inadequate consultation, and inequitable distribution of benefits[181]. In many low- and middle-income countries, such scepticism is compounded by historical global dynamics—particularly colonial legacies—in which extractive industries were designed to serve foreign interests with minimal regard for local well-being. These histories have shaped lasting perceptions of exploitation and marginalization, contributing to ongoing resistance and critical scrutiny of mining operations today[182].

By contrast, conflicts related to the extraction of construction materials often become visible later on during the construction or operational phases when environmental degradation is perceived (Box 2). These projects might be less likely to trigger conflicts in early stages owing to their relatively scale and the type of mining enterprises, as the sector is dominated by small or medium-sized companies that are typically local or regional[158,183]. However, numerous operations can accumulate across a large region, amplifying their reach and generating substantial cumulative impacts that trigger conflicts[45].

Movements linked to mining conflicts have led to diverse outcomes. Sustained mobilization has achieved outcomes including regulatory enforcement, increased community participation in decision-making, renegotiation of compensation agreements, and the development of new environmental impact assessments (Supplementary Information). Mining operations were temporarily suspended in 21.7% of cases, full suspensions were reported in only 9.3%, and company investment withdrawals were reported in 5.0%. However, activists involved in these movements often faced sizeable challenges, including criminalization and violence, especially in conflicts involving high-value minerals such as copper and silver where economic interests are especially strong. From 2021–2024, 334 incidents of violence or protest linked to mining copper, cobalt, lithium and nickel were reported across the top 10 producing countries overall for these metals[188]. Outcomes for biodiversity, unfortunately, remain mixed. Although some conflicts have succeeded in halting particularly destructive projects, efforts toward environmental rehabilitation or restoration after conflict remain rare, occurring in only 6.8% of documented cases. Few cases have seen ecosystems meaningfully restored, even when mining has ceased. This gap highlights the need for stronger mechanisms to ensure not just the prevention of harm but also the active repair of damaged environments. Moreover, in some cases environmental conflicts can exacerbate biodiversity loss by impeding mine site management and rehabilitation[184]. When operations are suspended due to disputes, unmonitored tailings facilities can increase contamination risks[185], while invasive species may colonize unrehabilitated land[186]. For example, the bankruptcy of the Talvivaara nickel mine in Finland, which occurred amidst intense public conflict, left the state to manage a profound environmental liability defined by permanent waterway pollution, ongoing discharges, and the immense challenge of long-term site stewardship[187].

Environmental conflicts associated with the mining industry have far-reaching consequences. Although they often raise serious social and environmental concerns, increase business risks and costs[179], and might potentially disrupt the supply of minerals critical to the renewable energy transition, these conflicts can also serve as catalysts for positive change. By challenging unsustainable practices, communities and environmental movements are key to shaping debates on resource governance and fostering approaches that integrate social equity and ecological integrity[189].

[H1] Summary and future directions

The renewable energy transition will likely reduce the total volume of extracted materials compared to the status quo fossil fuel-based economy[3]. Shifting demand away from drilling and coal mining towards a diverse range of extraction methods and minerals needed for renewable energy technology and infrastructure will reshape both how and where mining impacts occur. As these impacts are driven by mining for both renewable energy transition metals and for building materials, the full spectrum of materials needed for both renewable energy technologies and infrastructure must be considered in material footprint and biodiversity assessments and social conflict analysis. However, key data and research gaps persist in quantifying mining implications of the energy transition, including the need for comprehensive data of volumes consumed and projections of all materials needed, and improved spatial data of mining of operations for non-metallic construction materials, for which global datasets are lacking. Addressing these data gaps is essential for better biodiversity footprint accounting and for assessing social implications on Indigenous Peoples and local communities, as biodiversity loss and social conflict are deeply intertwined. Further empirical research is also required on the effectiveness of legal and institutional safeguards, and on the role of community-led resistance movements in promoting equitable and sustainable resource governance[17,131].

Current rates of infrastructure decarbonisation and existing approaches to minimising the biodiversity impacts of mining are unlikely to be compatible with both climate and biodiversity goals[190-193]. Major changes to the global mining and infrastructure system are therefore needed that address both demand and supply sides to avoid and mitigate ecological and social impacts associated with mineral extraction[183,193]. Competing visions exist for these changes: a 'green growth' perspective[194] emphasises technological innovation and responsible sourcing to enable sustainable infrastructure expansion, whereas a 'post-growth'[195] approach argues that only structural reductions in consumption can address the root causes of mining-related impacts[193,196]. Regardless of the pathway, integrating efficiency improvements with demand reduction[197-199] is essential to ease mining pressures and align resource use with ecological limits.

Whatever the future efforts to reduce the impact of mining on biodiversity, substantial residual impacts on biodiversity are inevitable and must be addressed through high-quality ecological restoration and biodiversity offsets[200]. Restoration efforts should involve clear targets, participatory planning processes, robust indicators, and rigorous long-term monitoring similar to internationally recognised standards such as those developed by the Society for Ecological Restoration[201] to ensure ecological recovery aligns with international best practices. The mining industry has a unique opportunity to mobilise financial and technological resources to implement science-based restoration practices that mitigate residual impacts and support global biodiversity and climate objectives.

Ultimately, a just renewable energy transition will require moving beyond reliance on technological fixes and compensation schemes: structural change are required to address the root causes of overconsumption, safeguard biodiversity, protect community rights, and ensure equitable access to the benefits of decarbonisation. Bridging existing knowledge gaps, reducing material demand through enhanced resource efficiency and circular economy approaches, and strengthening environmental and social safeguards[202,203] are all essential to minimising harm and maximising benefits to biodiversity and people.

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Author contributions

B.A., A.T., L.S., D.F., S.O.S.E.z.E, S.M., and I.I.A. made substantial contributions to the conceptual development and overall discussion of the article's content. B.A. and A.T. researched the data for the article, including the literature review and environmental conflict datasets, with support from L.S.,S.M., and I.I.A. B.A. and A.T. also developed and created the visualizations. B.A., A.T., S.O.S.E.z.E, D.F., and T.J.L. were responsible for writing the manuscript. All authors—B.A., A.T., L.S., S.O.S.E.z.E, D.F., S.M., I.I.A., and T.J.S.—contributed to reviewing and editing the manuscript prior to submission.

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Figures

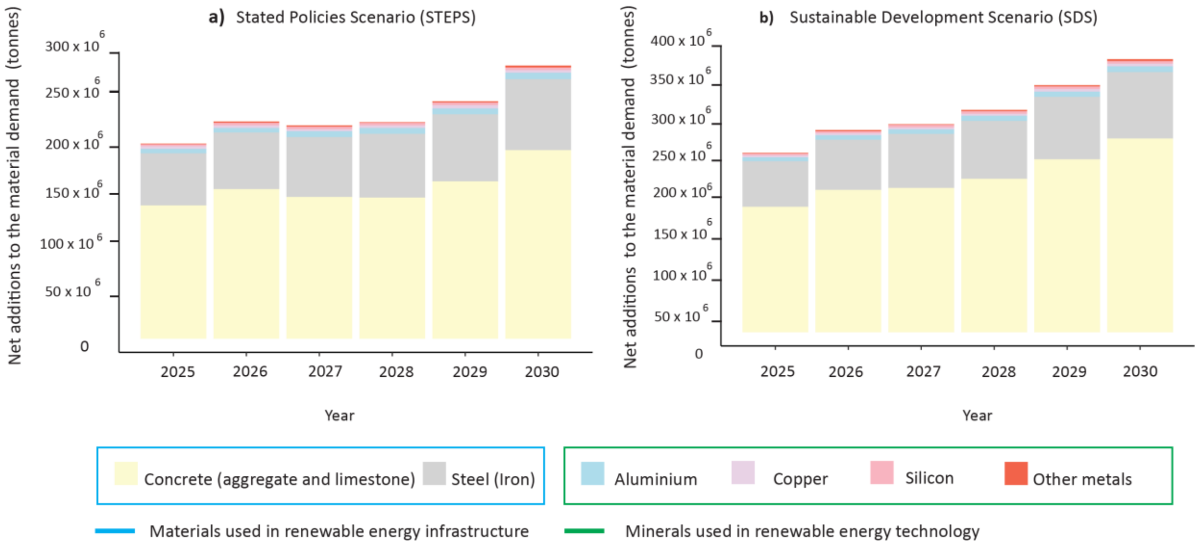


Figure 1. Net yearly additions in the demand for materials required for renewable energy production (wind, solar, hydropower) based on the International Energy Agency's scenarios from 2025 to 2030. **a)** Net yearly additions in the material demand under the Stated Policies Scenario (STEPS). **b)** Net yearly additions in the material demand under the Sustainable Development Scenario (SDS). Estimates are presented for materials needed for renewable energy infrastructure (concrete and steel) and materials needed for renewable energy technologies (aluminium, copper, silicon and other metals such as manganese, zinc, cobalt, nickel, molybdenum, and rare earth elements (Supplementary Information).

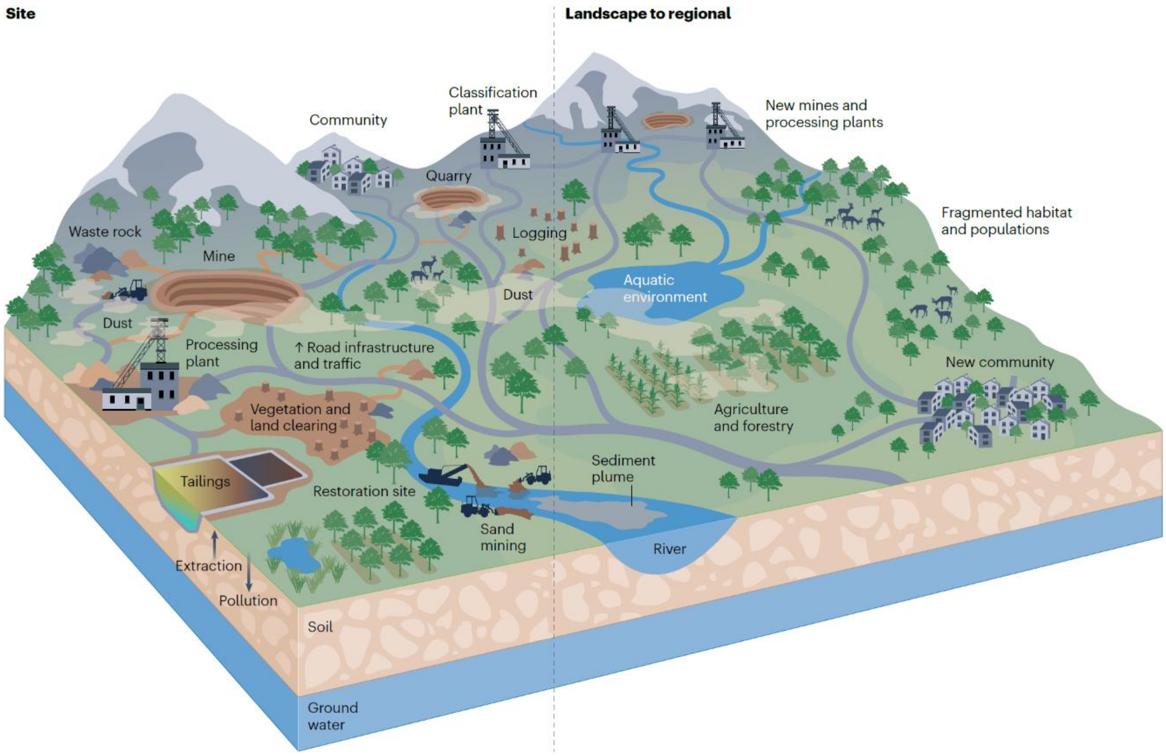


Figure 2. Pathways linking mining to biodiversity changes. Mining for minerals needed for the renewable energy transition affects biodiversity through three different causal pathways: direct impacts from mining activities within and beyond mining sites; indirect effects beyond mining sites from related industries and from external stakeholders not involved in mining operations.

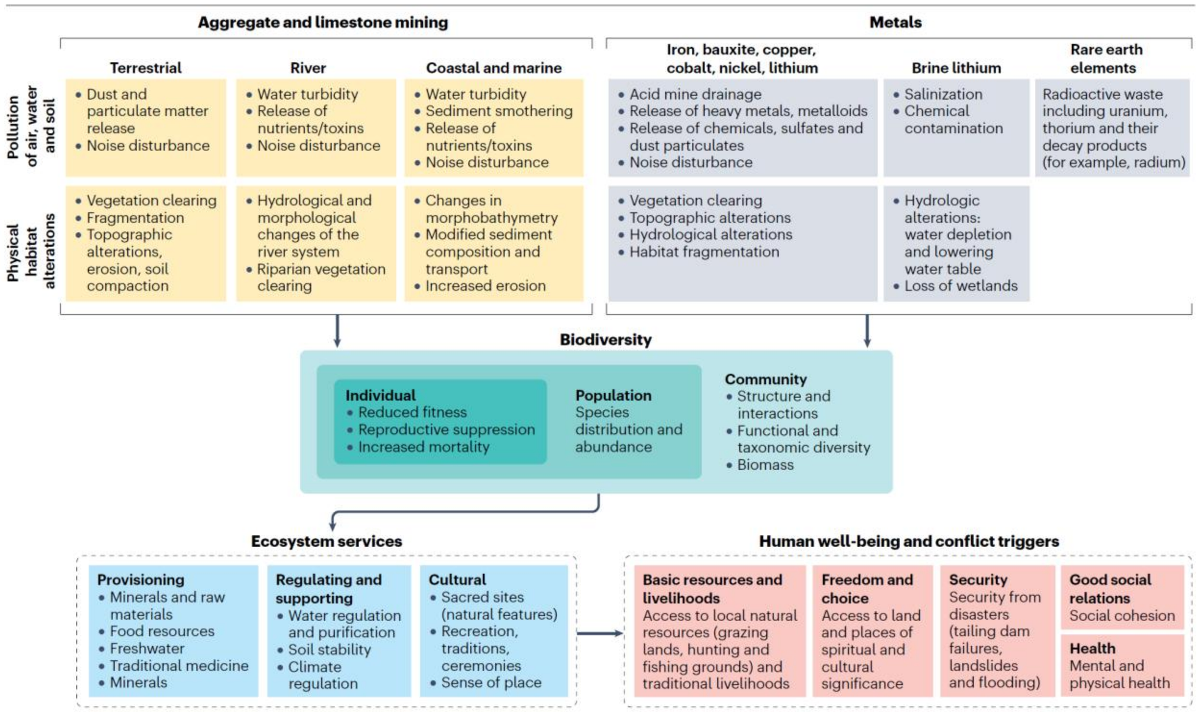


Figure 3. Direct and indirect impacts from mining lead to pollution and physical habitat alterations that influence biodiversity and the provision of essential services to people. These disruptions can affect the well-being of local communities, including Indigenous peoples and peasants, potentially triggering conflicts. In turn, such conflicts may influence mining activities, halting, delaying or altering project conditions. Adapted from Leyton-Flor and Sangha (2024)[103], CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

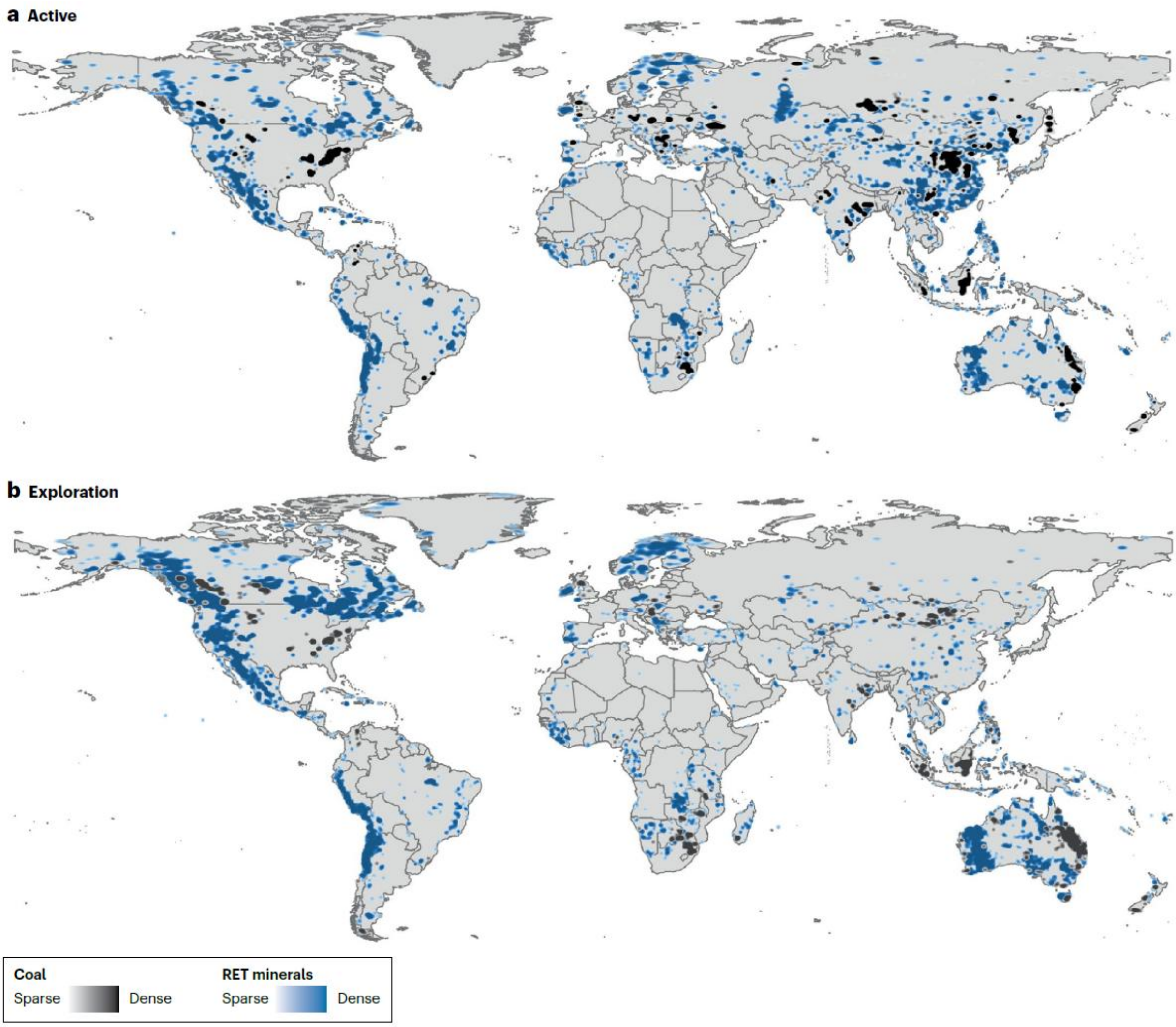
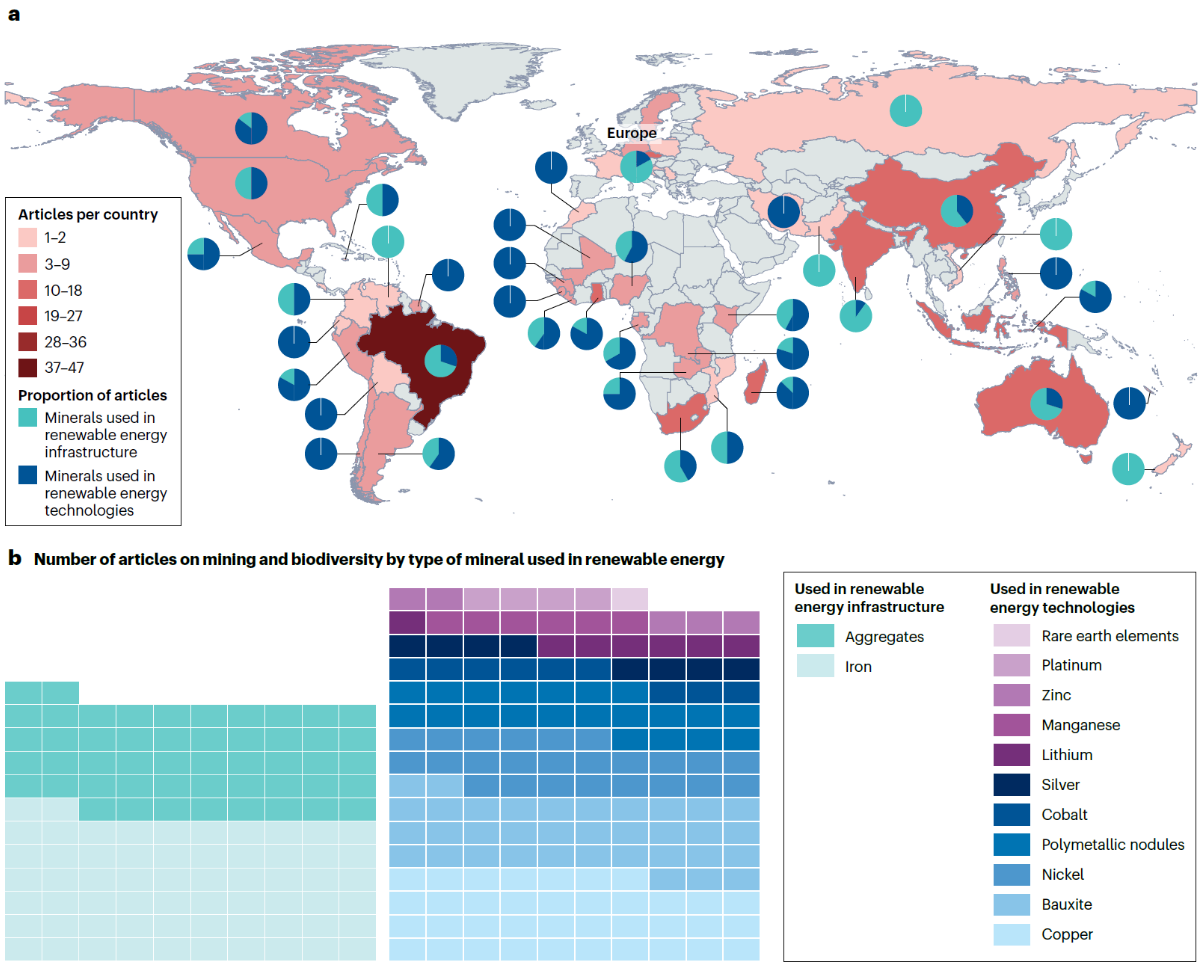


Figure 4. Global active and exploration (or early pre-mining phases) areas for metals needed for renewable energy transition and coal according to S&P Global[204] (see Supplementary Information for further details). Mining areas with properties targeting metals needed for renewable energy technologies and infrastructure (excluding aggregates and limestone, as they are not covered by the S&P Global database) are shown in blue, areas with properties targeting coal are shown in black.



Number of articles on mining and biodiversity by type of mineral used in renewable energy

Figure 5. Literature assessing the biodiversity impacts of mining for renewable energy-related minerals. a, Global distribution of studies (*n* = 269) evaluating the biodiversity impacts of mining for minerals used in renewable energy technologies and infrastructure. Multi-country studies are counted once per country; globally scoped studies are excluded. Pie charts indicate the proportion of papers focused on renewable energy technologies versus renewable energy infrastructure. b, Article counts examining threats associated with minerals used in renewable energy technologies and infrastructure. Each cell represents a single study included in the analysis.

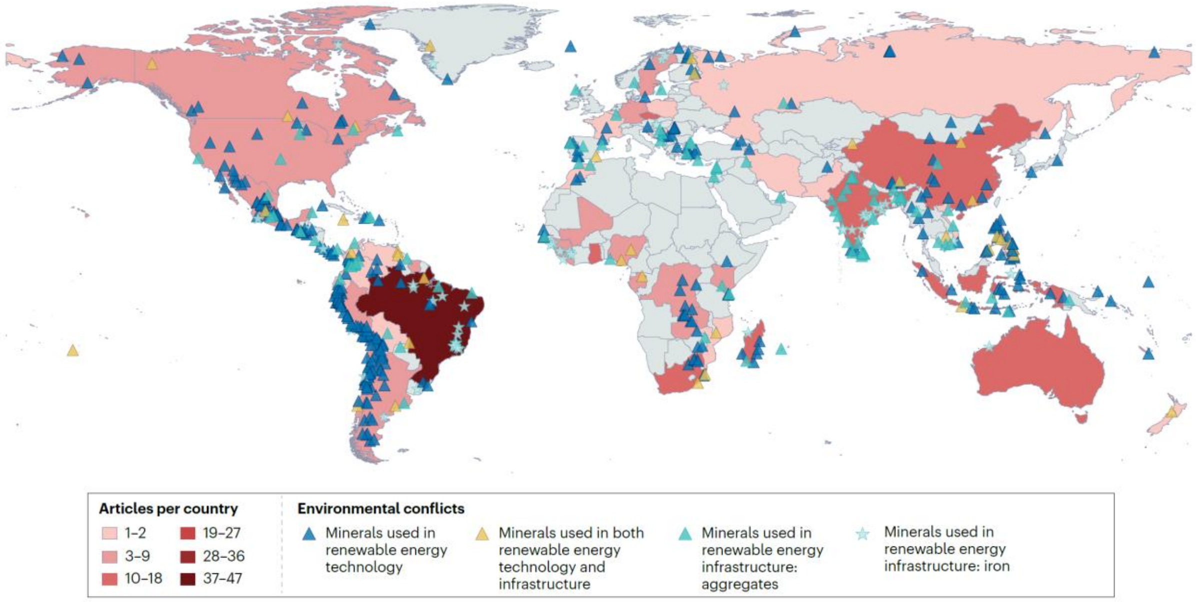


Figure 6. Global distribution of environmental conflicts documented in the Global Atlas of Environmental Justice (EJAtlas)[142] related to mining projects for minerals used in renewable energy technologies, minerals used in renewable energy infrastructure (aggregates, iron), and mining projects extracting both minerals needed for renewable energy technologies and infrastructure. The colour legend for countries indicates the total number of studies evaluating the biodiversity impacts from mining for minerals used in renewable energy production (n = 269, with multi-country articles counted for each country, and global studies excluded).

Boxes

Box 1 | **Definitions of energy transition minerals and criticality**

The global transition to renewable energy and the expected increase in demand for minerals and materials is most often framed with reference to the term ‘critical minerals’ — metallic and non-metallic minerals deemed essential by a country for its economic and national security, especially for advanced manufacturing and technology, that are at risk of supply chain disruption. For instance, the US Energy Act of 2020 defines a critical mineral as “a non-fuel mineral or mineral material essential to the economic or national security of the U.S. and which has a supply chain vulnerable to disruption,” while the European Union defines critical raw materials as “raw materials of high importance to the economy of the EU and whose supply is associated with high risk”[205]. The two main parameters, economic importance and supply risk, are used to determine the criticality of the material for the EU. Critical minerals are therefore not necessarily those that are of ‘critical importance’ for the energy transition, instead they are minerals that a country determines to be in a ‘critical condition’ in terms of supply.

The countries that have produced lists of critical minerals are most often those with large manufacturing and defence sectors (US, European Union, India, Japan, Republic of Korea and United Kingdom) or major mineral-producing nations that supply these importers (Australia, Canada and South Africa). The latter group has often adapted their definitions of critical minerals to refer to the minerals critical to their strategic partner countries, as seen in the lists of Australia and Canada). Indeed, most critical minerals are not minerals with a use case in renewable energy technologies. For instance, 61% (21 out of 34) of the minerals on the European Union’s list, 58% (29 out of 50) on the US’ list, and 60% (18 out of 30) on Australia’s list are not directly used in renewable energy technologies. Furthermore, and as an illustration of the challenges of adopting the term ‘critical minerals’ in the context of the energy transition, the European Union currently classifies coking coal as a critical raw material. Likewise, many of the most important energy transition minerals have not been designated as critical. Of the 17 minerals identified by the World Bank as important for energy transition technologies, including aluminium, chromium, cobalt, copper, graphite, indium, iron, lead, lithium, manganese, molybdenum, neodymium, nickel, silver, titanium, vanadium, and zinc[27], along with cement and sand, which are key to renewable energy infrastructure, a substantial share are not included on the EU, US, and Australian lists. Specifically, 36% (7 out of 19) are missing from the EU’s list, 63% (12 out of 19) from the US list, and 42% (8 out of 19) from Australia’s list.

The primary justification for not (yet) including certain minerals important for energy transition technologies is their wide geographic production base, even if their production is currently much lower than the anticipated future demand. Copper and nickel, for example, do not commonly appear on critical minerals lists even though they are essential for renewable energy technologies. Exceptions to the exclusion of copper include Canada and the European Union. Australia added nickel to its critical minerals list in February of 2024 (outside of the official update period of the list), not because of supply risk, but because oversupply by Indonesia threatened the viability of Australian operations. Iron, limestone, sand and other aggregates are also excluded from 'critical minerals' lists, despite being, by volume, the most important minerals for building renewable energy infrastructure (steel, cement, concrete), and subject to substantial sustainability and mineral security issues in many regions[206,207]. However, New Zealand's critical minerals list, released in early 2025, designates sand and aggregates as critical minerals for the local economy[208]. As a result, academic analyses of energy transition minerals and their associated impacts and conflicts have overlooked key mineral value chains, leading to a major gap in footprint assessments and scientific literature.

Box 2 | **Pacific river gravel mining is driving conflict and ecosystem change**

Sand and river gravel mining are the main source of aggregate used for infrastructure projects across the South Pacific's Developing States (SIDS), supporting both climate change adaptation efforts(land reclamation, seawalls) and renewable energy transition projects (solar, wind, and hydro)[209,210]. Fiji currently sources 60% of its energy from renewables and is aiming for 100% by 2036. Meeting this target will require aggregates and limestone for constructing 10 hydro systems, 2 hybrid systems, 1,100 solar systems and 600 grid extension. Despite government efforts to reduce reliance on environmentally destructive large-scale river extraction and move towards a network of hard rock quarries, river-sourced aggregates remain preferred for exports to neighbouring SIDS owing to easier access[209,211,212].

A prominent example is the Dawasamu river gravel site, among the largest aggregate extraction activities in Fiji, which supplies growing aggregate demand for national infrastructure and regional climate adaptation. This site reportedly produces 500,000 to 1 million m^3 of gravel annually; however, assessments by Fiji's Department of Mineral Resources estimate the site's sustainable yield at only a tenth of this volume.

Site preparation and road access led to 12,000 m^2 of land use change and notable amounts of riparian vegetation loss. The quarry operation has also caused detrimental impacts on river systems. Washing of gravel in or adjacent to the river channel, removal of boulders and gravel, insufficient site drainage, and the lack of sediment control measures have resulted in increased sediment suspension[209]. Site visits have revealed that gravel is not only being extracted from pits along the river or above the high-water mark[213], but also from the riverbed, significantly changing its geomorphology and intensifying sediment runoff.

These environmental changes have serious implications for both biodiversity and local livelihoods. Fiji's freshwater ecosystems host 166 species, including 13 endemic species. Many of these species spend almost half of their adult life in freshwater and are also linked to downstream marine ecosystems, including coral reefs, which can be affected by sediment runoff traveling from upstream sources. The operation is located approximately 3 km from a Marine Protected Area (MPA) and 11 km from the Moon Reef Marine Reserve — home to a school of spinner dolphins which are important for the local tourism industry.

In 2017, a visible sediment plume was observed extending in a northeast direction from the mouth of the river out into traditional fishing grounds and MPAs[209]. During a site visit in 2024, coral smothering was recorded near the tourist resort in Nataleira village, which residents attribute to increased sedimentation from upstream gravel extraction. National MPAs and Locally Managed Marine Areas (LMMAs) are crucial for conserving biodiversity and managing the impacts of fisheries in Fiji[214]. However, degradation of these protected areas could lead to decreased fish and coral diversity, reduced food availability, and threatens vulnerable species such as parrotfishes.

Local communities, particularly those living adjacent to the Dawasamu River, rely heavily on the river for drinking water, cooking, bathing, laundry, and farming. Women, in particular, depend on both marine and freshwater iqoliqoli (customary fishing areas) for subsistence and income. Residents have reported a marked decline in fish species diversity and abundance, directly affecting protein availability and livelihoods[209].

The extraction operation has led to ongoing conflict since its formal initiation in 2019. Community members from both upstream and downstream villages have raised concerns in provincial and district forums, as well as with the Ministry of Fisheries and the Ministry of Waterways and Environment. Tensions have emerged within and between government agencies, and police have intervened to halt operations, although operations resumed shortly thereafter. A core issue lies in institutional fragmentation: the Ministry of Lands and Natural Resources lacks the authority to suspend operations, and extraction permits are issued under different regulatory frameworks depending on land tenure. The Department of Lands (within the Ministry of Lands and Mineral Resources) oversees riverbed extraction, whereas operations on iTaukei (Indigenous) land above the high-water mark fall under a different permitting regime. Meanwhile, the Ministry of Waterways and Environment oversees Environmental Impact Assessments (EIAs) and environmental monitoring, including compliance with Environmental Management Plans. This fragmented governance structure, combined with the economic benefits provided to traditional landowners, such as royalties, employment opportunities, and investments in local infrastructure (such as roads and schools)[215], has created a complex social dynamic. Although some landowning groups benefit financially, downstream communities disproportionately bear the environmental and health costs.

Despite the visible environmental and social impacts, compliance and enforcement of regulations remain limited. EIAs frequently fail to assess sustainable extraction rates, geomorphological changes, and cumulative biodiversity impacts, and monitoring of extraction volumes and mitigation measures is often weak or inconsistent, limiting the effectiveness of existing safeguards. The Dawasamu case illustrates the urgent need for integrated environmental governance and sustainable resource management in SIDS. Rising demand for aggregates, driven by climate adaptation, infrastructure expansion and the energy transition, requires coordinated regulatory oversight, biodiversity-informed planning, and mechanisms to resolve competing local interests equitably.

ToC blurb

Meeting climate goals requires minerals for renewable energy technologies and infrastructure. However, the mining to obtain these minerals negatively impacts biodiversity and local communities, undermining conservation and sustainability goals. This Review explores the effects of mining for the renewable energy transition on biodiversity and social conflict.