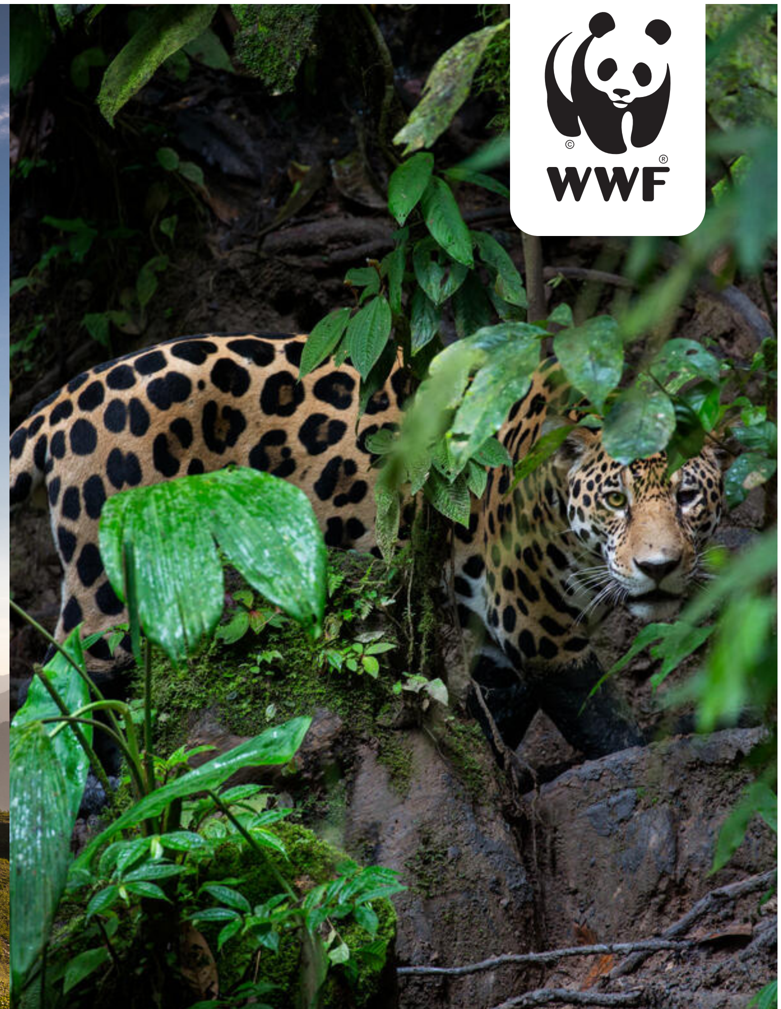

WWF

CRITICAL MINERALS AT A CRITICAL MOMENT

Assessing the impact of Energy Transition Mineral mining on nature globally

Contributors

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WWF is an independent conservation organization, with over 30 million followers and a global network active in nearly 100 countries. Our mission is to stop the degradation of the planet's natural environment and to build a future in which people live in harmony with nature, by conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful consumption. Find out more at **panda.org**.

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COVER (Clockwise from upper left): Wind turbines atop Pillar Mountain, overlooking the City of Kodiak, Alaska © WWF-US/Keith Arnold; Jaguar (Panthera onca) looking through forest leaves, Yasuni National Park, Ecuador. © Karine Aigner/naturepl.com/WWF; Wildfire in Brasília National Park on September 16, 2024, a conservation unit of Cerrado biome © Jacqueline Lisboa/WWF-Brasil

INTRODUCTION

Left: Sumatran Orangutan mother and baby sitting in tree (Pongo abelii) Gunung Leuser NP, Sumatra, Indonesia. Indonesia provided roughly half of the world's nickel supply in 2023. © naturepl.com/Anup Shah/WWF **Below:** Hurricane Ida makes landfall in Louisiana, leaving devastation in its wake. © 2021 Getty Images

The world is grappling with two grave and growing challenges caused by human acivity—the rapid loss of nature and a dangerously warming climate. These two problems are amplifying one another, creating a dangerous feedback loop. The destruction of forests, peatlands, grasslands and other ecosystems contributes to increased atmospheric carbon dioxide, intensifying global warming. At the same time, changes in weather and climate are accelerating the loss of critical species and disrupting ecosystems globally.

Addressing these dual challenges requires integrated solutions that tackle both of them simultaneously. Focusing on one while neglecting the other can unintentionally worsen the problem. Accelerating renewable energy deployment—critical to combatting climate change—requires dramatically increasing the supply chain for a wide range of materials. Resource extraction to supply these materials can degrade fragile ecosystems and negatively impact the rights and well-being of Indigenous Peoples and local communities (IPs and LCs). Advancements in battery technologies, large-scale wind and solar installations, and the expansion of transmission infrastructure necessitate an increase in the supply of energy transition minerals (ETMs), such as copper, cobalt, lithium and nickel. The International Energy Agency estimates that the current renewable energy trajectory will require doubling today's mineral inputs by 2040. Meeting the goals of the Paris Agreement would require four times today's mineral inputs by 2040.

Despite the tremendous projected growth of ETMs, the material requirements for a clean energy economy are far smaller than those of the current fossil fuel economy. For example, in 2022, global coal demand reached 8.4 billion tons, while the IEA projects that ETM demand by 2040 will be 25 million tons assuming current deployment rates—just 0.3% of 2022 coal demand. Advances in technology and implementation of circularity practices for ETMs will further reduce future energy extraction needs, though some extraction remains an unavoidable cost of the energy transition. Given the serious negative consequences of continued fossil fuel exploitation, a transition to a clean energy economy is logical and needed, coupled with efforts to minimize the environmental and social impacts of ETM extraction.

While there is a real risk that these minerals will be sourced through mining practices that disrupt ecosystems and harm species, to date there has been limited research on the potential environmental and social impacts of ETM mining. In the rush to scale renewable energy, the industry has yet to quantify the risks and tradeoffs of ETM extraction and agree on global mitigation strategies. **This report offers a novel analysis of the risks the energy transition poses to nature by examining the impact of ETM mines on terrestrial Key Biodiversity Areas (KBAs)**[1], or sites that significantly contribute to the global conservation of nature.

The world has a rapidly closing window to avoid the mistakes of legacy mining. Embedding innovative and responsible practices in the mining industry is critical to preserve species and ecosystems and protect IPs and LCs' rights and wellbeing. With thoughtful policy, strategic investment, and cross-sector commitment to environmental stewardship, a decarbonized and nature positive energy system is within reach. Responsibly sourcing critical energy transition minerals is a vital component of that transformation.

With thoughtful policy, strategic investment, and cross-sector commitment to environmental stewardship, a decarbonized and **nature positive** energy system is within reach.

1 This report centers solely on the terrestrial impacts of mining energy transition minerals.

KEY TAKEAWAYS

Approximately 7.0% of all ETM mines are found within Key Biodiversity Areas, impacting a land area that is roughly twice the size of Belgium. This analysis does not include indirect impacts of mining, which can be many times larger than the direct impacts.[2] Additional research is needed to better understand the full impact of ETM mining.

The impact of mining ETMs is considerably smaller than that of fossil fuel extraction. The difference in scale is enough that a transition to clean energy would result in a significant reduction in the area mined across all sectors. A 2023 study by WWF and BCG found that rapidly transitioning to clean energy by 2050 would result in a 25% reduction in actively mined area relative to today.

To minimize the environmental and social impacts of extracting ETMs, industry and policymakers should prioritize:

Ensuring nature-positive spatial planning: Avoid ETM mining activities in KBAs, and especially in protected and conserved areas. Assess and allocate the spatial and temporal distribution of activities like mining by balancing social, economic, and ecological objectives.

Implementation of responsible mining practices: Ensure mining companies prioritize rigorous environmental management, fair labor practices, meaningful community engagement, transparency in supply chains, and the protection of Indigenous rights.

Adoption of circularity practices: Invest in infrastructure needed to utilize the reduce, reuse, and recycle hierarchy in the sourcing of ETMs.

Investment in innovation: Develop novel technologies and methodologies that reduce the demand for and harm caused by mineral sourcing, processing, and usage.

2 Direct impacts occur within mining areas or are caused by the expansion of mining areas. Indirect impacts occur in the area surrounding mines due to, for example, the construction of infastructure needed to support raw material processing or transportation.

7% Percentage of **all ETM mines** that overlap with Key Biodiversity Areas (KBAs)

8.6% Percentage of **currently operating mines** located within KBAs

6.7% Percentage of mines in the **exploration phase**, which could soon become operational, located within KBAs

25% Percentage **reduction** in global mining area due to rapid transition to clean energy

2X The KBA land area affected by ETM mines is relatively small, **roughly twice the size of Belgium**

BACKGROUND AND CONTEXT

ENERGY TRANSITION MINERALS

The demand for ETMs is expected to surge with expanding infrastructure to support the clean energy transition. The scale of this growth will vary by mineral. Each mineral is an input into a subset of energy technologies, which impacts expected future need. Demand for each ETM will also be influenced by the pace and depth of global decarbonization, as well as by innovations that may become dominant within technology categories. For instance, the rise of alternative battery chemistries has likely tempered the demand for cobalt, a key component of Nickel Manganese Cobalt (NMC) batteries that have dominated the market but now face competition from newer battery chemistries. The need for minerals varies by technology. **Electrochemical batteries and electricity networks dominate mineral demand, accounting for over 80% of the minerals needed for clean energy technologies by 2040.** Solar and wind account for 6.6% and 6.2% respectively

A light rail transit train, powered by wind-generated electricity and part of the city's public transit system, rushes through on its dedicated rail line into the downtown core of the city, Calgary, Alberta, Canada. © Michael Buckley/WWF-Canada

What are critical minerals? Why are they relevant to the transition?

The world is in the midst of a transformation of our energy and transportation systems. Building a clean-energy powered world will require vast amounts of certain "critical minerals" that are fundamental inputs to solar panels, wind turbines, batteries, and transmission lines.

The term "critical minerals" does not have a universal definition. Countries maintain their own lists of materials they deem "critical" based on factors like scarcity, geographic origin, and technological application. This report focuses on "energy transition minerals" (ETMs) – a subset of those critical minerals and metals widely recognized as essential inputs for a renewable energy transition. Those include **chromium, cobalt, copper, graphite, lithium, manganese, molybdenum, nickel, rare earth elements, and zinc**.

ETM usage in clean energy technologies

Relevant clean energy technologies (*non-exhaustive)

Battery storage · EV batteries · Solar PV · Transmission · Wind

[Expected increase in demand relative to 2023
(Based on IEA projections for a Net Zero by 2050 scenario.)]

Chromium

[**3.9x** (2030)]

Cobalt

[**3.8x** (2030)]

Copper

[**2.4x** (2030)]

Battery-Grade Graphite

[**6.5x** (2030)]

Lithium

[**6.7x** (2030)]

Manganese

[**4.7x** (2030)]

Molybdenum

[**3.6x** (2030)]

Nickel

[**5.8x** (2030)]

Rare Earth Elements[3]

[**3.8x** (2030)]

Zinc

[**2.4x** (2030)]

3 While there are 17 elements that fall under “rare earth elements,” in their analysis IEA includes only those most critical for energy technologies: Neodymium, Dysprosium, Praseodymium, Terbium, Yttrium, and Lanthanum.

For many ETMs, only a fraction of total global demand is driven by clean energy technologies. For example, nickel - an input to battery cathodes, solar panels, and wind turbines - is a key component of stainless steel and therefore widely used across manufacturing industries. Still, as renewable deployment accelerates, demand for new clean energy resources will be a meaningful driver of future mineral demand. The nickel example is again useful: while clean energy technologies drove only 8% of global nickel demand in 2020, they are expected to generate 31-61% of demand by 2040, according to the IEA.

It is also important to put the scope of future ETM demand in context. **While the resources for the transition will often need to be mined, the extent of that need is far less than that of the fossil fuel economy**. The difference in scale is enough that a transition to clean energy would result in a significant reduction in the area mined across all sectors. A 2023 study by WWF and BCG found that rapidly transitioning to clean energy by 2050 would result in a 25% reduction in actively mined area relative to today.

While the resources for the transition will often need to be mined, the extent of that need is **far less than that of the fossil fuel economy**.

The concentrated nature of ETM supply chains further complicates concerns around the impacts of extraction of minerals needed for clean energy technologies. Unlike fossil fuel resources, which have a relatively dispersed supply chain, many ETMs are sourced from a small number of locations. For instance, while the top three oil-producing countries accounted for 42% of global output in 2019, the top three graphite producers were responsible for 83% of the world's supply and the top three lithium producers were responsible for 87% of the world's supply. This heavy dependence on a limited set of jurisdictions greatly constrains global leverage in enforcing responsible mining practices.

The bottleneck tightens even further in the refining and processing stages, which are largely dominated by China. For instance, in 2022, China alone controlled 65% of global lithium refining capacity, 76% of cobalt refining capacity, and an overwhelming 90% of rare earth element (REE) refining capacity. As other countries rush to establish alternative supply chains and reduce their dependence on China, there is a risk that they deprioritize environmental and social standards in favor of increased speed to market and lower investment costs.

Polluted waters of the Umkondo copper mine. Sabe Valley, Zimbabwe © John E. Newby/WWF

POTENTIAL IMPACTS OF MINING

Mining activities frequently negatively impact ecosystems and local communities, leading to habitat degradation and loss, pollution, and loss of wildlife. Proactive mitigation strategies are essential to minimize those impacts. Mine owners and operators must play a constructive role in this effort by working collaboratively with governments, impacted communities, and conservation organizations to identify best-fit strategies. Additionally, it is essential to evaluate whether mining in certain locations, due to factors like water scarcity or heightened risk to nearby people or threatened species, may pose too great a risk to communities or nature.

Ecological Impacts

Land use changes: The construction of mines and their associated infrastructure can have devastating effects on habitats. For instance, a WWF report revealed that up to one-third of the world's forest ecosystems are impacted by mining activities, directly or indirectly, with coal and gold mining alone accounting for 71% of global direct mining-related deforestation. Mining can exacerbate soil erosion, degrading nearby landscapes and increasing their vulnerability to mudslides and flooding.

Beyond the mines themselves, associated infrastructure such as access roads, railways, canals, conveyors, and transmission lines can fragment habitats and introduce noise, light, water, and air pollution. Mine access roads enable human encroachment into previously undisturbed areas, further intensifying habitat destruction by introducing new threats or worsening existing ones, like over-exploitation of resources (e.g., hunting, fishing) and the spread of invasive or domesticated species. Particularly if poorly planned or subject to weaker governance, infrastructure can lead to unintended development and activities such as illegal settlements, poaching, and slash and burn agriculture.

The importance of nature

WWF's 2024 "Living Planet Report" found that on average, **global populations of species have declined by 73% since 1970.** This analysis draws on nearly 35,000 population trends across 5,495 species, including amphibians, birds, fish, mammals, and reptiles.

Nature loss is not just an environmental concern; it also encompasses economic, developmental, security, and social dimensions through its provision of essential ecosystem services. The world relies on terrestrial, freshwater, and marine resources to provide essentials like food, fuel, and medicines. Plant and animal species serve a vital role in maintaining the quality of air and water by regulating the climate, minimizing soil erosion, and preventing extreme weather events. They are responsible for seed dispersal, pollination, pest control, and nutrient cycling. Protecting nature is not solely about safeguarding specific species; it is about maintaining the natural systems that sustain all life, including our own.

As the world strives toward a clean energy future, it is vital to remain vigilant about potential unintended consequences of the energy transition on nature. While tradeoffs may be necessary, mitigating the worst impacts of climate change must be balanced against the cost of contributing to the global loss of nature. Mining activities have historically been a driver of nature loss. Achieving a rapid, sustainable energy transition calls for an integrated approach that safeguards both climate stability and the health of natural ecosystems, ensuring that our solutions to one challenge do not unintentionally fuel another.

Protecting nature is not solely about safeguarding specific species; it is about maintaining the natural systems that sustain all life.

Tailings / waste management: The disposal of tailings, or the waste produced in the process of extracting minerals from mined ore, can cause vast environmental harm if poorly managed. When stored on land, tailings are kept behind dams that, if they break, can cause significant human and environmental harm. For example, the collapse of the Brumadinho dam in Brazil in January 2019 led to a mudslide that killed over 240 people and flattened nearby ecosystems. Some countries allow deep sea disposal of tailings—a practice known to create a toxic environment for marine species.

Water use: In addition to the risk of contaminating nearby water sources due to chemical runoff, which can damage or disrupt species and ecosystems, many mines consume vast quantities of water, straining local supplies. Water is essential for processing ore, cooling machinery, and controlling dust. Lithium extraction, in particular, is highly water-intensive, as one common method requires that over 90% of the water from salt brine be evaporated to isolate the mineral. The World Resources Institute (WRI) reports that 16% of the world's critical mineral mines and reserves are situated in regions facing high water stress, or areas where water is already heavily used for other essential needs like agriculture. As climate change intensifies water scarcity, this challenge should only worsen.

Climate change: The mining industry is estimated to contribute approximately 10% of global greenhouse gas emissions, primarily due to the substantial energy required for extracting, processing, and transporting mined materials. Additionally, the construction and expansion of mining operations often leads to deforestation and habitat disruption, which further contribute to emissions by reducing the carbon storage capacity of natural landscapes. This loss of natural carbon dioxide sinks exacerbates the dangerous feedback loop, contributing to climate change which then further degrades ecosystems.

Human Impacts

Indigenous Peoples impacts: The focus of this report is KBAs; however, companies and policy makers must also prioritize impacts to Indigenous Peoples as they chart the trajectory of growth in mining for transition minerals. A study from the University of Queensland found that 54% of minerals needed for the energy transition are located either on or near Indigenous People's lands. In the United States, a significant portion of ETMs, (97% of nickel, 89% of copper, 79% of lithium, and 68% of cobalt reserves and resources) are located within 35 miles of Native American reservations. For example, a report from Global Witness found that over the past 30 years, Indigenous Peoples in the Philippines have lost an area of land that amounts to one-fifth of their designated territory to mining projects.

Wherever ETM mines are located, Indigenous Peoples and local communities should be engaged throughout the lifecycle of the project. That engagement should occur early and often and continue throughout every stage, from scoping to development to operation through closing. Securing Free, Prior, and Informed Consent is essential before developing a mine, and the outcome of that process needs to be respected and upheld. Indigenous Peoples and local communities should have full and effective participation in the process and decision-making to ensure respect for rights, safeguarded cultural heritages, and protected lands and territories.

Wherever ETM mines are located, Indigenous Peoples and local communities should be engaged throughout the lifecycle of the project.

Young gold miners digging up a river bank in the DRC. Nearby is the Itombwe Reserve, home to Gravers (eastern lowland) Gorillas. © Jaap van der Waarde /WWF-Netherlands

Land loss, degradation, and displacement: Mining operations can lead to abuse of rights and forced displacement of Indigenous Peoples and local communities from their lands, the vital source of their cultural, spiritual, and economic well-being, through significant land loss and degradation. The ecological impacts discussed above, like the contamination of soil and water, can disrupt livelihoods that depend on those resources, such as productive practices like agriculture, fishing, and hunting.

Health and safety: Communities residing near mining sites often face serious health risks due to exposure to hazardous pollutants. The release of toxic dust, fumes, and particulate matter during blasting, excavation, and transportation can lead to respiratory issues, cardiovascular disease, and increased rates of asthma among local populations. Additionally, mining activities frequently contaminate nearby water sources with heavy metals, chemicals, and other toxins, which can enter the drinking supply and accumulate in food chains. Vulnerable populations, such as women and children, are particularly at risk.

Human rights: Mine workers often face dangerous working conditions, particularly when proper safety protocols and equipment are lacking. This is especially true in artisanal and small-scale mining (ASM) operations, which are far less regulated than their large-scale mining counterparts. These mines may also exploit child labor. Amnesty International interviewed children working in Democratic Republic of the Congo (DRC) mines, who described injuries from carrying heavy loads, frequent illness, and long shifts with little time to rest or eat.

ANALYSIS AND KEY FINDINGS

METHODOLOGY

To assess the potential ecological impact of transition mineral mining, we examined the overlap between current and prospective Energy Transition Mineral (ETM) mines and Key Biodiversity Areas (KBAs)— sites identified as the most important places in the world for species and their habitats using a quantitative standard applied consistently in all regions. Using S&P Global's metals and mining data,[4] which provides detailed information on the locations of ETM mines and the location and size of mining claims, we conducted two key analyses:

Number of ETM Mines Overlapping KBAs: By mapping the precise points of each ETM mine against KBA locations, we identified the number of mines intersecting these critical areas for nature.

Total Area Impacted by ETM Mines: We linked each ETM mine to its corresponding mining claim and calculated the total land area (in km^2) where mining claims overlap with KBAs.[5]

We grouped these analyses using WWF's database of 847 terrestrial ecoregions to assess the impacts of ETM mines on different ecosystems. WWF's ecosystem database divides the Earth's land surface into ecoregions classified into major habitat types, or biomes, such as forests, grasslands, shrublands, and tundra.

While both analyses are indicative of the size and scale of ETM mining in these critical areas for nature, **the total impact on KBAs is almost certainly underestimated**. Not all mines are recorded in the S&P database. Small-scale mining operations are often unregistered. Furthermore, while the area analysis focuses on the direct impacts of mining claims, there are the significant indirect effects outlined above to consider, including infrastructure development and increased human incursion. Additionally, while the KBA dataset is robust in its criteria, it does not yet capture all areas of importance as there are still countries where comprehensive KBA assessments across all criteria have not yet been undertaken. The global KBA dataset does not include all areas of national or local importance for species and ecosystems. Maps of terrestrial ecoregions and KBAs, along with further data limitations, are included in the appendix.

4 The S&P Global dataset was selected as it is comprehensive in its aggregation of global mining projects (mines) and claims. S&P has conducted similar studies leveraging this data, including "Rocks and hard places: The ecosystem risks of mining for energy transition minerals," which looks at the impacts of minerals needed for the energy transition on ecosystems and species by mapping mining activity against S&P-identified "significant ecosystems." This report's analysis differs in its usage of the KBA dataset, which is produced and maintained by civil society.

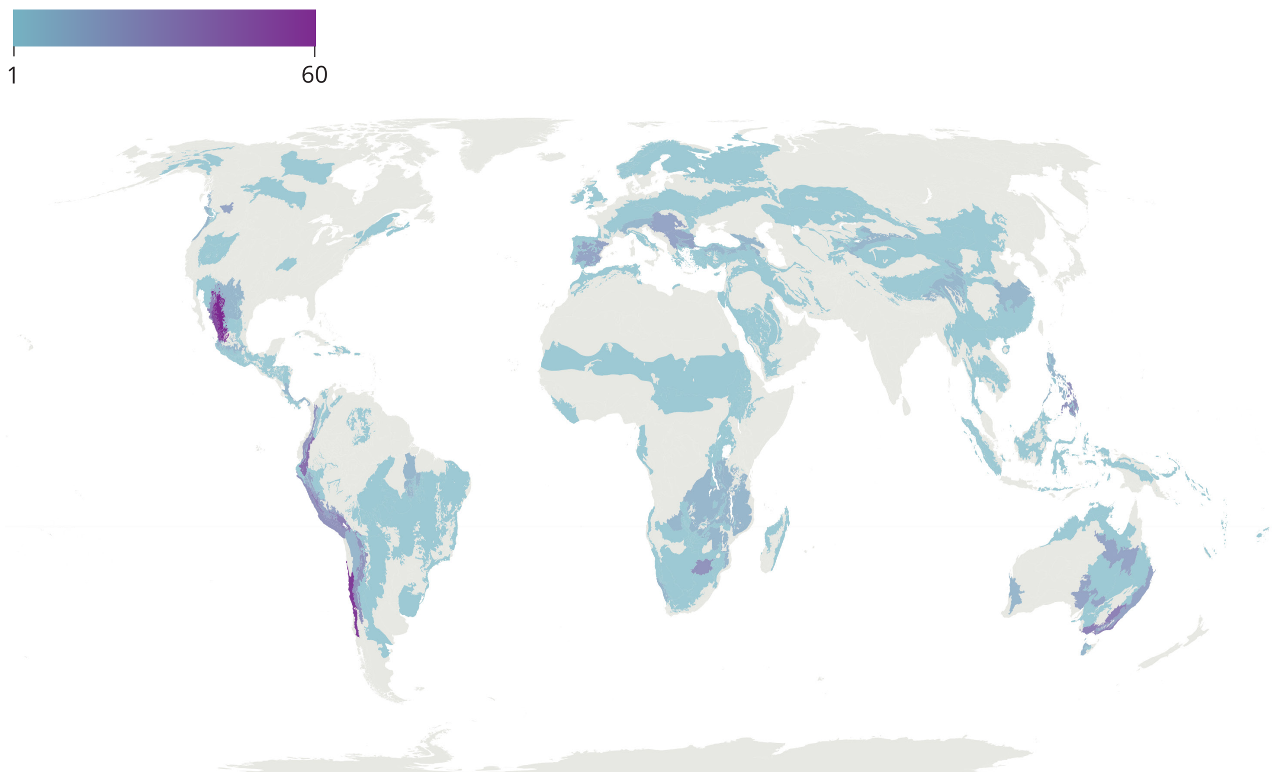
5 A mining claim is a legal right granted to an individual, company, or entity to explore, extract, and manage mineral resources within a designated area of land. While the footprint of a mine does not necessarily match the full extent of the claim it occupies, the environmental and ecological impacts of a project often extend far beyond its immediate boundaries—hence our extrapolating the potential impact of a mine on its surrounding areas.

RESULTS

Number of mines

Approximately 7.0% of all ETM mines—980 out of 14,024—sit within KBAs. This percentage is even higher among currently operating mines, with 207 of 2,419 active projects overlapping with KBAs, or roughly 8.6%. For mines still in the exploration phase, which could soon transition to operational status, 6.7% (725 of 10,902) are situated within these critical biodiversity zones.

# of ETM mines that overlap with KBAs, by ecoregion, across all projects



This impact is meaningful but far smaller than that of fossil fuel mining. By comparison, a recent study found that 518 KBAs (or 18% of KBAs by area) contain active and potential oil and gas concessions in the pantropics (the Amazon Basin, Congo Basin, and Southeast Asia) alone.

Copper accounts for the largest share of mines that overlap with KBAs, with 754 projects, or 7% of all copper mines, intersecting these critical habitats. Nearly half of these overlaps occur in Central and South America, with 48 within the Sierra Madre Occidental pine-oak forests, a region extending from the southern United States into Mexico and encompassing roughly two-thirds of Mexico's remaining forest cover. This **biodiversity hotspot**, renowned for its diverse pines and oaks and a habitat for rare species such as the Mexican wolf, already faces significant threats from logging and climate change.

The Mexican Gray Wolf (Canis lupus baileyi), one of the most endangered mammals in North America, lives in the Sierra Madre Occidental Pine–Oak Forests of Mexico and the United States. © Shutterstock.com/ Nagel Photography

Copper's extensive footprint can be partly explained by its high demand compared to other ETMs. The **IEA projects** that the world will need 13,000 kt of copper in 2050 to support clean energy technologies, relative to 1,000 kt of lithium. Still, given the significant number of KBAs currently affected—or at risk of being affected—by copper projects, it is crucial to explore strategies to mitigate these ecological impacts as demand continues to grow.

ETM Mine Overlap with KBAs[6]

Commodity	Total Mines[7]	Total Mines in KBAs	Operating Mines in KBAs	Mines in Exploration Phase in KBAs
Copper	10,054	754	141	577
Zinc	4,891	326	70	244
Molybdenum	1,775	160	25	130
Nickel	2,408	112	28	79
Cobalt	1,484	71	20	47
Lithium	960	36	10	26
Manganese	427	35	10	23
All Rare Earth Elements	300	11	0	10
Graphite	371	2	0	2
Chromium	86	1	1	0

Out of 847 assessed terrestrial ecoregions, 221 contain ETM projects within KBAs. Roughly one-third of the overlapping projects fall within 12 ecoregions that include temperate forests and dry forests as well as mountains and grasslands.

Ecoregions with largest # of ETM mines within KBAs (top 12)[8]

Ecoregion	Mines in KBAs
1. Sierra Madre Occidental pine-oak forests	58
2. Chilean Matorral	41
3. Sinaloan dry forests	38
4. Eastern Cordillera Real montane forests	29
5. Sonoran-Sinaloan subtropical dry forest	23
6. Central Andean wet puna	22

Ecoregion	Mines in KBAs
7. Southeast Australia temperate forests	22
8. Southern Andean steppe	20
9. Central bushveld	19
10. Mindanao-Eastern Visayas rain forests	19
11. Sechura desert	19
12. Northwest Andean montane forests	17

6 Many mines extract multiple commodities, which is why the total obtained by summing the number of mines for each individual commodity exceeds the actual number of mines analyzed.

7 Commodity total may not equal sum of mines in each stage, as not all projects are assigned a development stage in the S&P mining and metals dataset.

8 Sierra Madre Occidental pine-oak forests, Chilean Matorral, Mindanao-Eastern Visayas rain forests, Sechura desert, and the Northwest Andean montane forests are among WWF's Global 200 Ecoregions identified as priorities for conservation.

Area of mines

To better understand the spatial impact of KBA overlap, we linked each ETM mine to its mining claim (as described above). This estimate does not include indirect impacts on the areas surrounding mines from infrastructure associated with mining activities, which can be many times larger than the direct impacts.

The land area directly affected by these ETM projects is 59,747 km², roughly twice the size of Belgium. The distribution and impact of these overlaps vary across regions.

Approximate area overlapped (km²) by continent

A recent study examining the impact of all extractives, including oil and gas, highlighted **the Global South as areas of high risk for future extraction in KBAs**, a conclusion which is bolstered by this report's analysis of ETM impacts.

Desert adapted elephant (Loxodonta africana africana) and calf near the Skeleton Coast Park in the Namib Desert of Namibia. © Tania Curry/WWF-US

Africa is the most impacted continent, with over 20,000 square kilometers of overlap across 36 ecoregions. The **Namib Desert**, which is home to vulnerable and endangered species like the mountain zebra and African elephants, accounts for over 6,745 km² of mining overlap, or 13% of the total KBA area in the ecoregion. An additional 15,000 km² of overlap is largely concentrated in biodiverse forests, savannas, and woodlands, underscoring the vulnerability of Africa's critical habits to mining activities.

Oceania, with its mix of island and continental ecosystems, also experiences significant overlap. Australia has one of the highest area impacts, with around 14,000 km² across forests, savannas, and grasslands that are critical habitats for native species. Eighteen percent of KBAs in the Tirari-Sturt stony desert in Australia is overlapped by an ETM mining claim. Island ecosystems in Oceania are particularly sensitive to habitat disruption, as they often harbor species that evolved in isolation and are highly susceptible to environmental changes.

In Asia, mining overlaps with KBAs are notably concentrated in forest ecosystems that harbor high biodiversity. In North America, ETM mining overlaps with KBAs largely occur in forest, tundra, and desert ecosystems in Mexico. In South America most overlap occurs in forests and high-altitude punas.

Europe has relatively low KBA overlap from ETM mining compared to other regions, with no individual ecoregion seeing more than 1,000 km² of overlap. This lower impact in part reflects the continent's more rigorous environmental regulations and established conservation frameworks, which limit the extent of mineral extraction in biodiversity-sensitive areas.

Ecoregions with largest KBA area overlapped by ETM mining claims

Ecoregion	Total KBA area (km²) in ecoregion	KBA area (km²) in ecoregion overlapped by ETM mining claim	% of KBA area overlapped by ETM mining claim
Namib Desert	50,716	6,745	13%
Tirari-Sturt stony desert	26,866	4,823	18%
Congolian coastal forests	46,222	3,782	8%
Sierra Madre Occidental pine-oak forests	52,778	2,992	6%
Southeast Australia temperate forests	33,172	2,794	8%
East Sudanian savanna	140,987	2,409	2%
Mitchell Grass Downs	14,983	1,360	9%
Sahelian Acacia savanna	198,952	1,246	1%
Sinaloan dry forests	20,368	1,241	6%
Huon Peninsula montane rain forests	7,793	1,156	15%

MITIGATION STRATEGIES

KBAs represent the most globally important sites for biodiversity and must be protected. Nuanced, proactive, region-specific mitigation strategies, following the biodiversity mitigation hierarchy (with a particular emphasis on the "avoid" stage to protect these habits), are needed to balance the growing demands of mineral extraction with the imperative to protect and preserve these regions. Mining activities in KBAs should be avoided, regardless of the end use of extracted materials.

To minimize environmental and human harm, mine owners, operators, and end users of ETMs will need to invest in technological innovation and the circular economy to reduce the need for new raw materials, reducing the rate of demand increase as the ETM industry grows.

As the world scales up renewable energy deployment, it faces a shrinking window to act and ensure that resource extraction needed for clean energy technologies does not repeat the historical environmental and social harms of mining. Implementing the strategies listed below is essential to achieving that goal.

AVOIDANCE (NATURE-POSITIVE SPATIAL PLANNING)

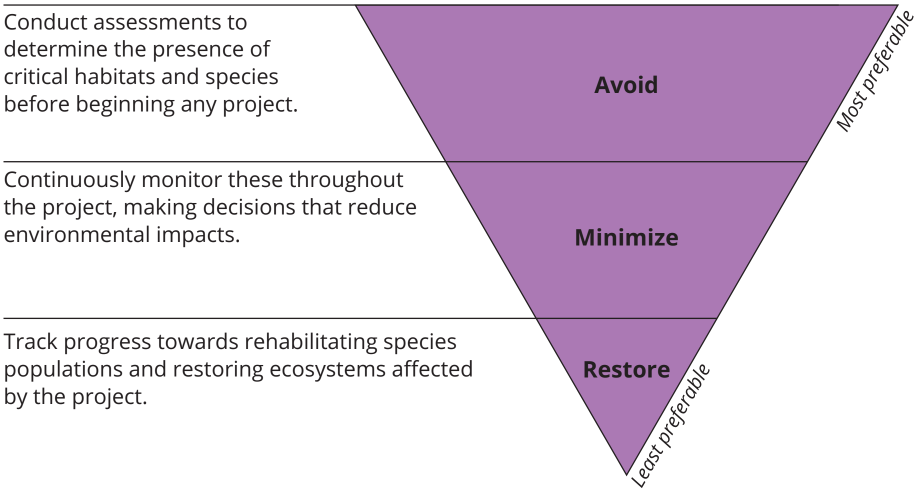
The most effective way to reduce the harmful impacts of mining is to avoid it in protected and conserved areas like KBAs, World Heritage Sites, OECMs, and Ramsar sites.[9] Avoidance is the first step of the biodiversity mitigation hierarchy and the most effective way to limit negative impacts. Evaluating potential mining locations is critical, as factors such as community impact or risks to threatened species and ecosystems can make the cost of environmental and social damage unacceptably high. To prevent significant nature loss, robust and proactive spatial planning is essential to identify ecosystem protection, conservation, and development priorities and trade-offs.

WWF-US's program, Community Positive Energy Transition (CPET), is committed to charting a path forward that enables the acceleration of renewable energy deployment, including the sourcing of the ETMs required for the transition, while minimizing impacts on people and nature. In order to do that, the program is committed to:

1. **Addressing knowledge gaps** around the impact of transition mineral sourcing, leveraging WWF's scientific expertise.
2. **Building cross-sector consensus** and uptake around responsible mineral sourcing.
3. **Jumpstarting needed innovation** to reduce future demand for transition minerals.

9 While the focus of this paper is KBAs, mining operations should be avoided when the mines and associated infrastructure impact any protected and conserved area, including KBAs, World Heritage Sites, OECMs, high conservation areas, Ramsar sites, intact forest landscapes, and ecological corridors, unless mining can be conducted while maintaining the flow of wildlife and ecological processes.

The Mitigation Hierarchy



Policymakers can leverage publicly available geospatial tools, like the KBA database used in this analysis, to understand areas that are highly important for species. This approach enables governments to assess and allocate the spatial and temporal distribution of activities like mining, balancing social, economic, and ecological objectives, including maintaining ecosystem services critical to local communities and larger economies. By prioritizing nature in these decisions, nature-positive spatial planning ensures that mining and other harmful activities are excluded from areas of critical ecological importance, such as KBAs.

This concept is central to Target 1 of the **Convention on Biological Diversity's Global Biodiversity Framework**, which calls for "participatory, integrated, and nature-positive spatial planning." Effective implementation of this target at national and local levels is vital to safeguarding nature by steering mining operations away from the world's most valuable ecosystems.

RESPONSIBLE MINING PRACTICES

The adoption of responsible mining practices is crucial to ensure that the extraction of critical minerals for the energy transition minimizes harm to the environment, local communities, and human rights. Responsible mining entails rigorous environmental management, fair labor practices, meaningful community engagement, transparency in supply chains, and the protection of Indigenous rights. It also involves minimizing the ecological footprint of mining operations and promoting the rehabilitation of land post-extraction. By adhering to these principles, mining can contribute to both a sustainable energy future and the well-being of the planet and its people.

The most effective way to reduce the harmful impacts of mining is to avoid ETM mining activities in protected and conserved areas like KBAs, World Heritable Sites, OECMs, and Ramsar sites.

There are standard setting bodies that have mapped out what good looks like in the responsible mining space. One such body, the **Initiative for Responsible Mining Assurance (IRMA)**, developed its standards through extensive consultation with industry, advocates, and communities. IRMA's guidelines cover key areas like governance, transparency, human rights, and environmental management. Companies can have their mines undergo independent third-party audits to assess compliance with these rigorous standards, ensuring they meet the expectations of responsible and sustainable mining. Already, five mining companies and eleven mining exploration companies have joined IRMA, and a number of ETM mines have successfully undergone a third-party audit.

Responsible mining requires acknowledgement that some areas present more risks than rewards such that the environmental and social costs of extraction far exceed the potential benefits, as discussed above. Critical habitats for threatened species, regions with high carbon sequestration capacity, or locations of significant cultural importance may qualify as "no-go" zones for mining.The findings in this study suggest that the scale of sensitive areas may be small relative to commercially viable global mineral deposits, however further analysis is needed to assess the impacts of ETM mining on a range of sensitive areas. In addition to avoiding mining expansion in sensitive areas, responsible mining must incorporate circular economy principles to make the most efficient and effective use of ETMs.

REDUCE, REUSE, AND RECYCLE

Policy and investment are needed to ensure that the circular economy can eventually become the primary source of ETMs. Players across the renewable energy value chain should adopt the "Reduce, Reuse, Recycle" approach to minimizing reliance on raw material extraction. The highest priority should be placed on reducing the demand for ETMs and the waste generated during their processing (as discussed further under innovation). Reuse and recycling should complement reduction efforts by extending the lifecycle of materials and further decreasing the need for virgin resource extraction.

A **WWF study** found that by 2050, most minerals needed to support the clean energy transition could be supplied through recycling. To leverage recycling and reuse in production, sufficient material must be in circulation from products that have reached their end of life. According to WWF, the secondary market could supply about 20% of critical transition minerals between 2022 and 2050, as more minerals enter circulation and recycling processes and facilities are built out. A **similar study** by the IEA looked at the potential for circularity to supply future demand. It found that recycling could reduce demand for new mining by up to 40% by 2050, and that without an increase in recycling, the financial cost of new mining needed to reach net zero would be 30% higher. Investment is needed to build infrastructure and develop and refine recycling and reuse processes to ensure a future that relies largely on recycled inputs.

Batteries for EVs and the electric grid are critical to ensure that future supply, as they could **represent** over 90% of global feedstock by 2050. Estimates show that currently, **only about 5%** of EV batteries are recycled. In many cases, older batteries can be used **to provide grid services** even if they are no longer fit for EV use. At the end of life, the minerals inside those batteries can be recycled for reuse in new batteries. Currently, most end-of-life recycling **relies** on metal recovery through smelting (heat-based) or leaching (liquid-based) methods. However, researchers are actively **working** to develop and refine recycling techniques that are more cost effective and can recover a greater proportion of materials.

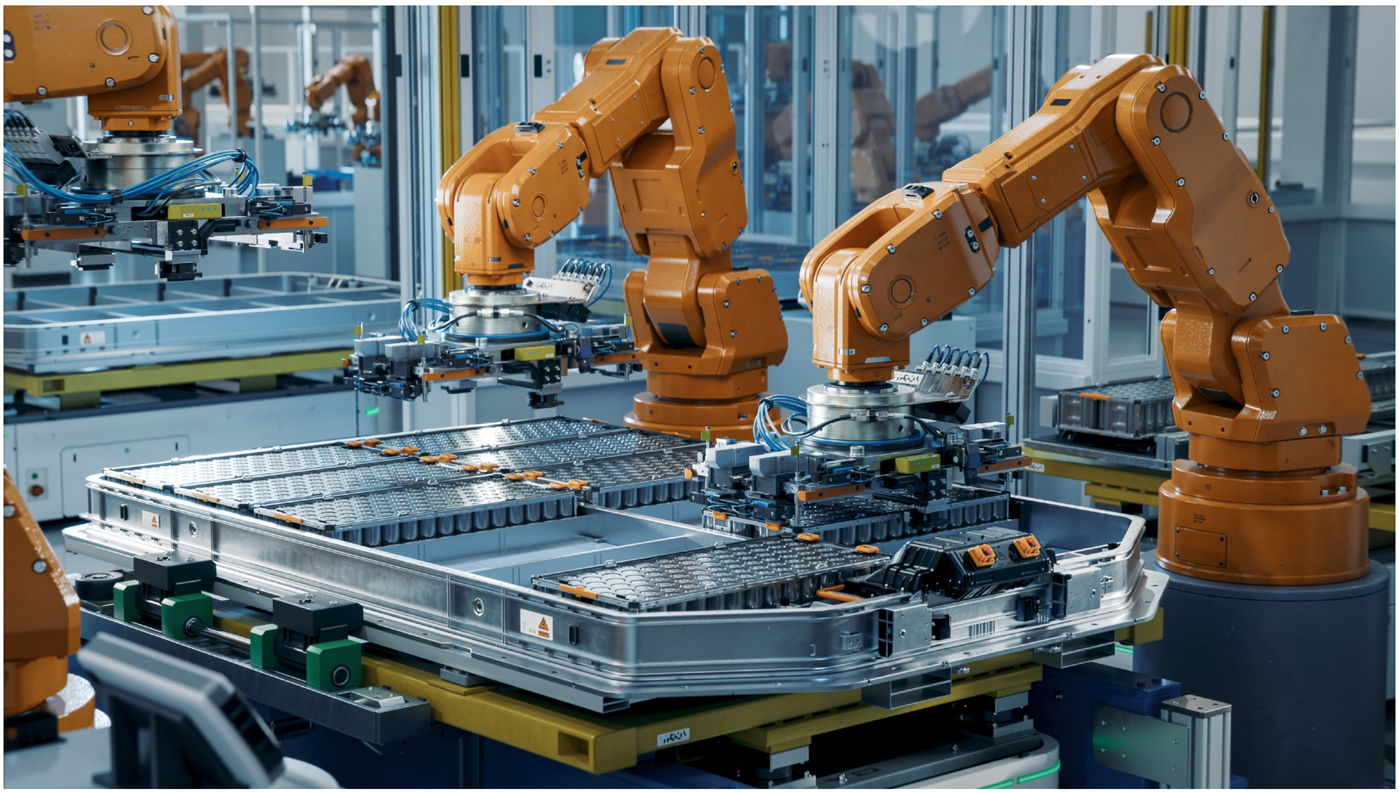
Used electronics waiting to be recycled in Finland. © Ella Kiviniemi/WWF

Uptake in recycling needs to rise dramatically to meet the rate at which electric vehicles are expected to proliferate in the coming years. The EU's **Critical Raw Materials Act** addresses the recycling challenge by setting ambitious targets for end-of-life battery collection and recycling rates for the minerals within those batteries. These measures aim to create a sustainable supply chain for transition minerals, crucial for the clean energy transition.

Circularity can also lower the impacts of mineral sourcing across the value chain. Current processes for recycling aluminum, for example, **require** 5% of the energy needed for raw aluminum extraction and processing.

INNOVATION

Alternative technologies for clean energy products can proactively reduce future need for further extraction. Already **researchers are identifying** and **companies are investing** in battery chemistries that do not use cobalt, given the labor concerns that have been widely linked to mining of the mineral. Policymakers should incentivize, and companies should invest in, developing technologies that either use fewer minerals or require mineral resources that are less harmful to extract and process.



A row of advanced robotic arms assemble batteries. © 2023 IM Imagery/ Shutterstock

Innovation also applies to developing new and better avenues for mineral extraction. For example, tailings, or the waste created after processing of raw ore, have historically been discarded, but could offer a viable source of needed resources. **Studies** suggest that minerals like copper, cobalt, rare earth elements, and zinc can be recovered through additional processing. One **company** recently announced that it will produce 800,000 pounds of copper annually by processing tailings at its existing U.S. mines. Other **companies** are working to enhance extraction from existing reserves by developing innovative techniques, such as a new method for isolating lithium that significantly reduces water usage and enables access to previously unreachable sources.

AREAS FOR FUTURE STUDY

As the needed transition to a clean energy economy picks up pace, the world also faces a closing window for action to ensure that the impacts of sourcing ETMs are mitigated. **There are meaningful gaps in existing literature that must be addressed to inform industry and policymakers and ensure mitigation strategies are targeted and effective.** With that in mind, WWF has outlined the following key areas for future study:

- **Detailed Study of Nature and Ecosystem Services Impacts:** This paper looked at the impacts of ETMs through the lens of KBAs, but more analysis is needed to better understand the impacts on nature globally. Ecosystem service analysis is needed to offer policy makers, the mining industry, and supply chain partners actionable information to manage specific impacts on communities and ecosystems, with a focus on the services they provide, including climate mitigation and resilience.

- **Analysis of Indirect Impacts of Mining:** As discussed in this analysis, the indirect impacts of mining from associated infrastructure can be far greater than the direct impacts. To inform industry and policymakers in their decisions as they build out new projects, this analysis will quantify those indirect impacts, as well as provide recommendations for mitigation strategies.

- **Regenerative Mining Practices Case Studies:** The reclamation and restoration of land degraded by mining activities is already an integral part of any mining project, with plans developed prior to the start of construction. Highlighting successful projects—such as those that restore ecosystems to previous biodiversity levels or stimulate economic development for nearby communities—offers valuable models for mining companies to follow when designing their own operations.

- **Indigenous Peoples and Local Communities Impact Case Studies:** Indigenous Peoples and local communities should be engaged throughout the lifecycle of a mine. That engagement should occur early and often and continue throughout every stage, from scoping to development to operation through closing. Conducting in-depth case studies on communities affected by ETM mining, highlighting opportunities to create meaningful benefits, bolsters the case that industry must prioritize this engagement in their operations.

- **Assessment of the Circular Economy for ETMs:** The development of a circular supply chain for ETMs offers a viable solution to meet expected increases in global demand while minimizing reliance on new resource extraction. This analysis will evaluate and demonstrate the economic viability of establishing a circular economy (including an assessment of the social and environmental costs and benefits), presenting a compelling business case for innovators and investors.

APPENDIX

DATA LIMITATIONS IN CRITICAL MINERAL ASSESSMENT OVER KBAS

Conducting a global assessment of critical minerals inevitably involves methodological and data limitations. As a result, the findings presented here may be subject to errors or biases, necessitating further due diligence to validate the results.

The assessment provides a high-level overview of the spatial overlap of extractive assets specially for critical minerals to Key Biodiversity Areas (KBAs). However, it does not quantify the extent or severity of potential 'threats' or 'impacts' posed by these assets. Some extractive assets included in the analysis may pose no past, current, or future risk. A more detailed, site-specific assessment—beyond the scope of this study—would be required to accurately evaluate the physical and ecological impacts of the extractive sector.

Key Data and Methodological Limitations

1. Data Coverage Gaps: While this assessment is global, it is not fully comprehensive. National data gaps for extractive assets persist. For example, while mining project data is globally available, mining concession data is limited to 94 countries. Additionally, the S&P database may not capture all mining projects within a country.

2. Definition of Claims: A 'claim' refers to a license issued by a state to companies or individuals, permitting resource exploration or extraction within a defined area for a specified period. These licensed areas can be extensive, but actual impacts are often restricted to smaller drill or mine sites, which may or may not overlap with KBAs. In addition, the S&P dataset excludes small-scale mining operations, which are frequently unregistered.

3. Indirect Impacts: While the assessment focuses on the spatial overlap of mining claims with KBAs, indirect impacts—such as roads built to access mining concessions and associated land-use changes—can also cause significant environmental degradation beyond the boundaries of the claims.

4. Data Inaccuracies: Considering the vast number of extractive asset datasets analysed, inaccuracies are possible within individual data points. Such errors could affect the overall results. Although geolocation inaccuracies are rare within the datasets used, they typically remain within a 1-kilometer margin.

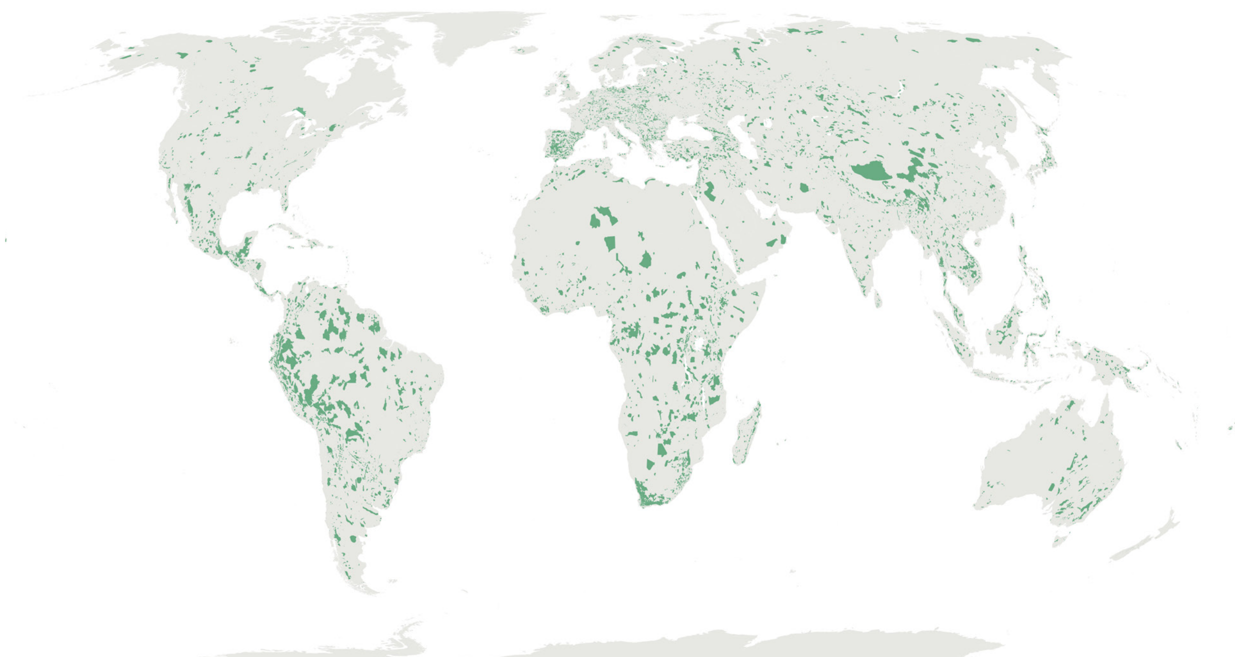
5. Temporal Considerations: The study does not consider the licensing dates of extractive assets relative to the KBA designation dates, which could influence the interpretation of potential impacts.

6. Specific Considerations: While the KBA dataset is robust and adheres to established criteria, it does not cover all ecologically significant areas. Some critical ecosystems may remain unassessed or fail to meet the specific KBA designation criteria despite hosting important species.

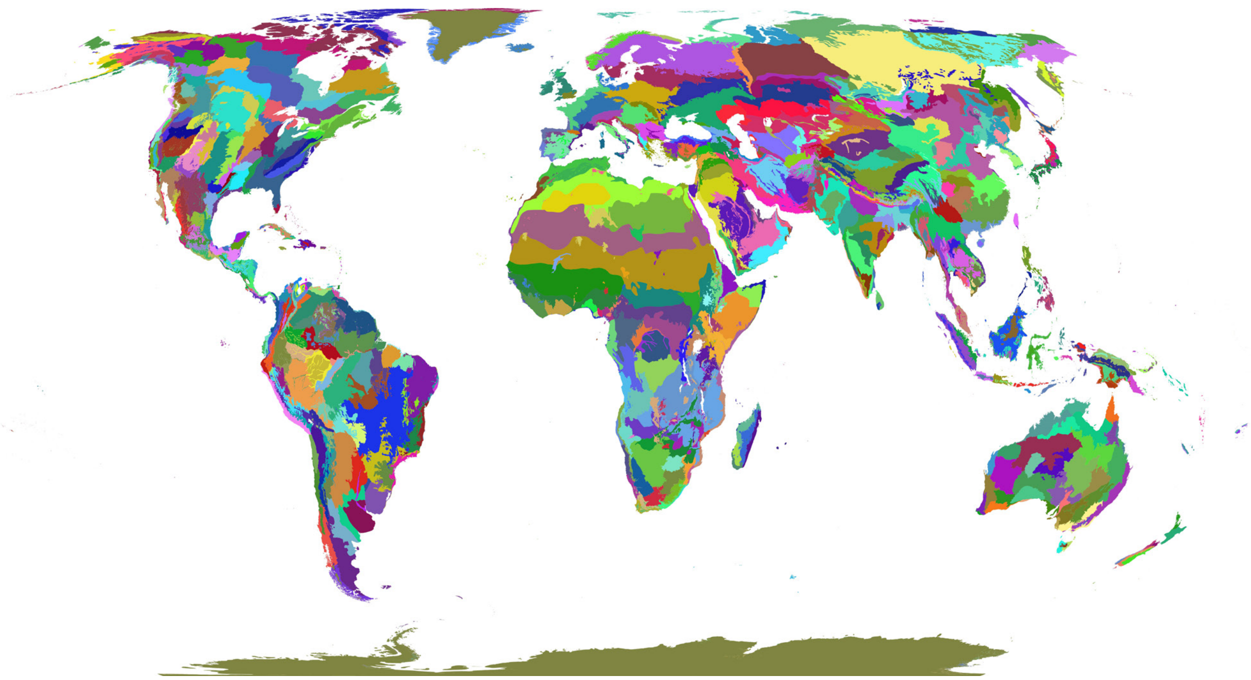
ADDITIONAL MAPS AND RESULTS VISUALIZATIONS

Approximately 7% of all ETM mines are located within KBAs, but this percentage varies based on the operational status of the mines. Among operational mines actively extracting materials, 8.6% overlap with KBAs. The overlap decreases to 6.7% for mines still in the exploration phase--projects that are not yet extracting materials but could transition to operational status in the near future. The maps below provide further detail on these variations.

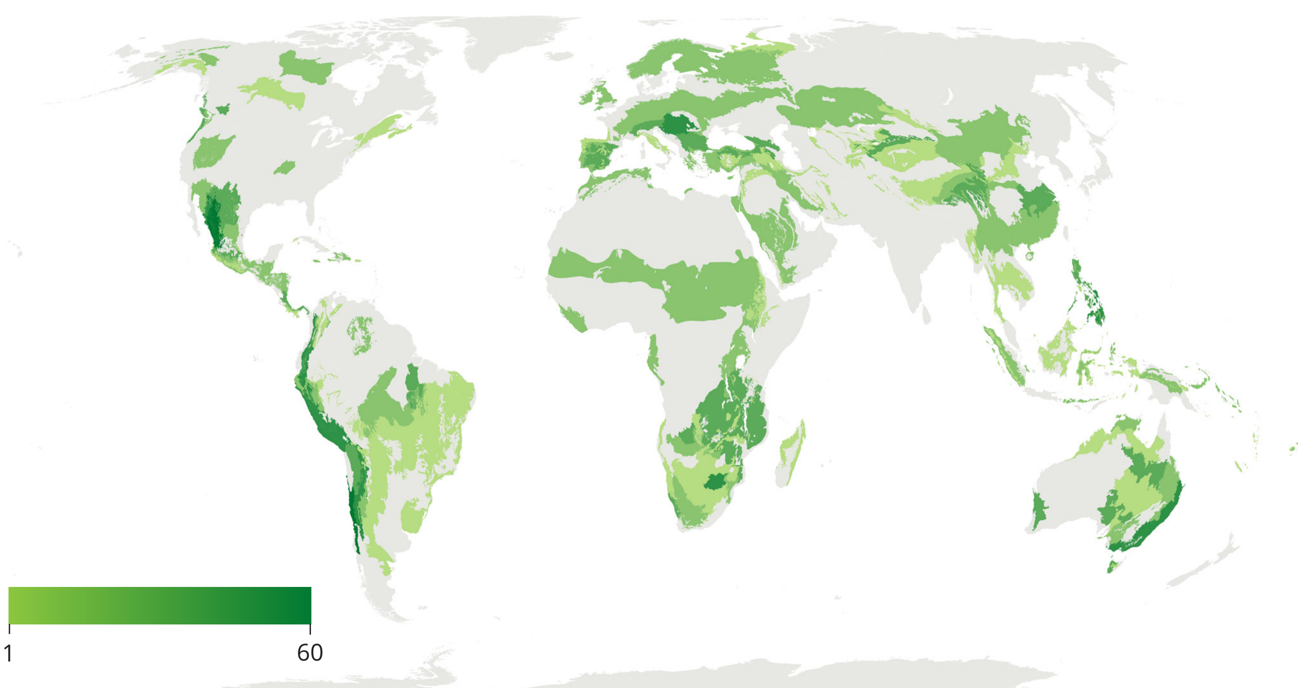
Terrestrial Key Biodiversity Areas (KBAs)
The highlighted areas are terrestrial Key Biodiversity Areas - or land areas critical for maintaining species and habitats and the planet's overall health.



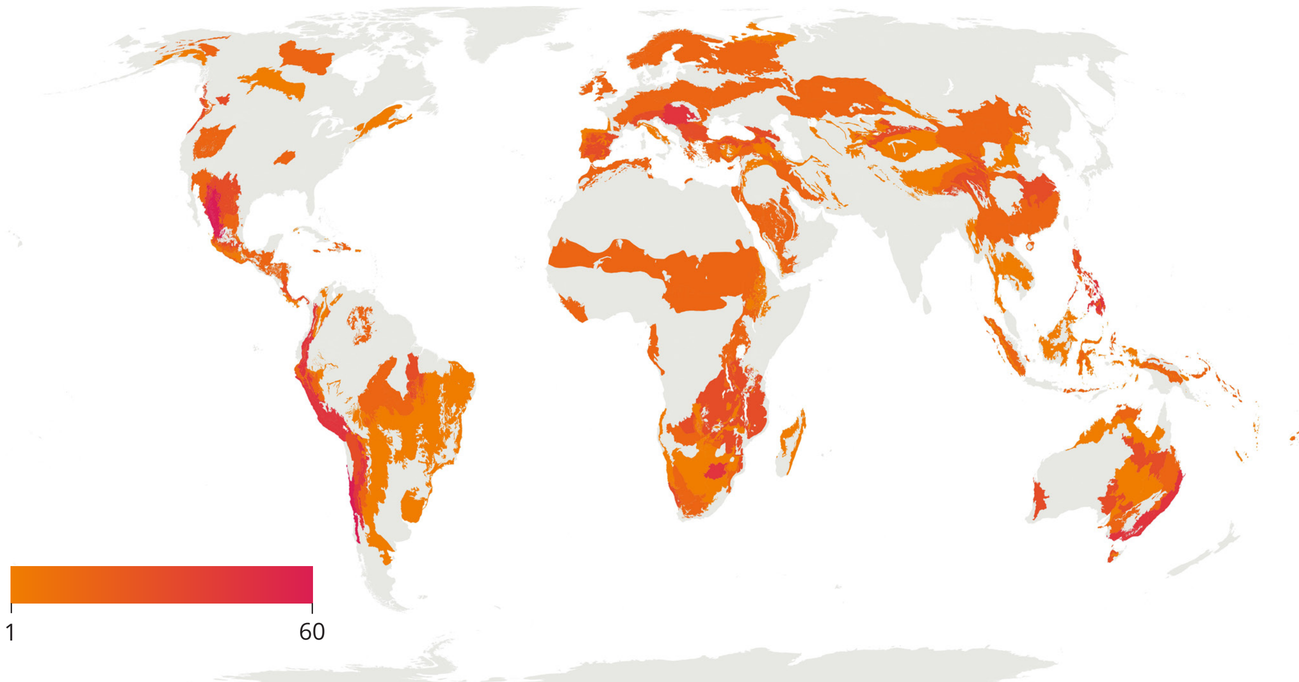
Terrestrial Ecoregions
WWF's database of 847 global terrestrial ecoregions divides the world's surface into regions, classified by major habitat types, such as forests, grasslands, shrublands, and tundra.



# of pre-development mines that overlap with KBAs, by ecoregion, across all projects
(Exploration, Feasibility, Feasibility Started, Feasibility Complete, Grassroots, Prefeasibility/Scoping, Reserves Development, Target Outline)



# of operating mines that overlap with KBAs, by ecoregion, across all projects
(Advanced Exploration, Commissioning, Construction Planned, Construction Started, Expansion, Limited Production, Operating, Preproduction, Residual Production, Satellite)



Above: Aerial view of Discovery National Park, Prado, Bahia, Brazil. Known for its giant trees, the park is a sanctuary of biodiversity, with stunning views and significant national heritage. © Adriano Gambarini/WWF-Brazil