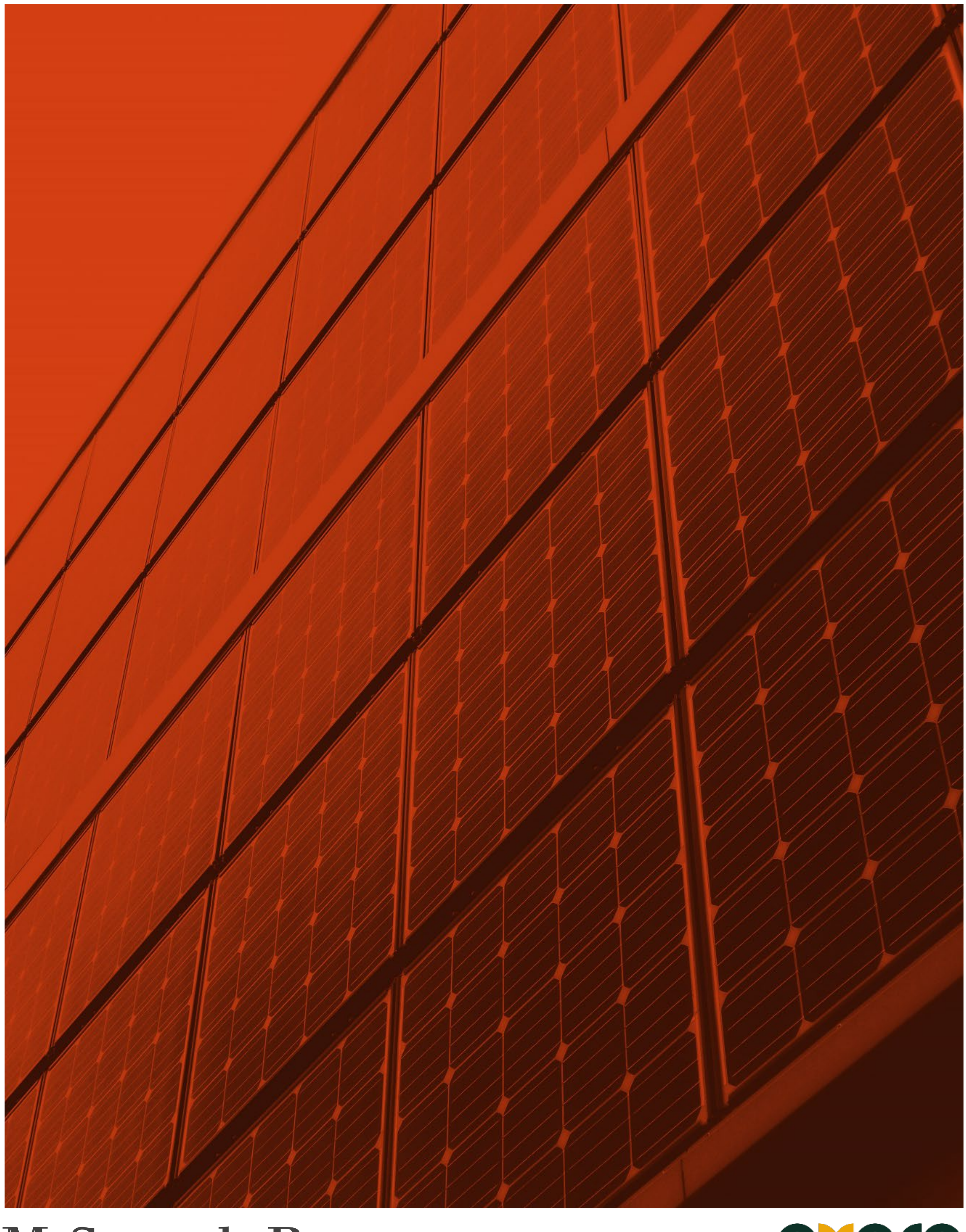
The strategic importance of natural capital mapping and mineral exploration in the context of the energy transition



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1. Objectives

This Report has been commissioned by Xcalibur Multiphysics ('the Report'). The Report presents the findings of a collaborative research project undertaken by Mishcon de Reya LLP and Oxera Consulting LLP. Oxera's research and data analysis is presented in sections 4.1, 7 and 8. The evidence presented in the Report comes from desk research, undertaken between January and February 2023.

In particular, we were asked to examine the global trends impacting natural capital mapping and minerals exploration, the role of minerals in the energy transition, the importance of natural capital mapping, financing options for mapping and exploration as well as the role of airborne exploration in light of these trends.

To explore these subjects, the Report is structured as follows:

- **Section 2** provides a brief overview of the global trends that are shaping the mapping and mining industries today and in the future;
- **Section 3** examines various global trends with relevance to minerals exploration and natural capital mapping—from energy security to biodiversity—in greater detail;
- **Section 4** analyses the rising role of minerals due to the energy transition;
- **Section 5** investigates the role of mapping in valuing nature services;
- **Section 6** reviews the importance of data and mapping to evaluate biodiversity services and mineral deposits;
- **Section 7** considers various financing options for mapping and exploration, highlighting some of the instruments' shortcomings; and
- **Section 8** explores the direct and indirect benefits and risks of minerals exploration and mapping.

Some of the key terms used in this paper are set out below.

Natural capital mapping
The mapping of the stock of renewable and non-renewable natural assets, including minerals, soils, air, water and ecosystems, that yield a flow of benefits to people. The term 'natural capital' is used to emphasise it is a capital asset.

Natural capital accounting
A rigorous audit of the economic worth of a country's natural resources to assess natural ecosystems' contributions to a country's economy, its level of reliance on natural systems, and to track changes in natural systems and their impacts.

Mineral exploration
Mineral exploration is the search for materials in the earth's crust that appear in high enough concentrations and amounts to be extracted and processed for profit. It comprises a number of different activities, which include airborne geophysical surveys, geological mapping, geophysics, geochemistry, drilling, and others.

Airborne geophysics
Airborne geophysics uses geophysical sensors to map the physical properties of the underlying geology and to make assumptions about the type of geology represented by the interpreted physical properties.

Airborne geophysics can be deployed in mineral exploration and in other natural resources exploration and mapping activities.

Executive summary

A number of trends are shaping global economic policy and geopolitics. Key trends include mitigating and adapting to climate change, concerns around energy security, pushing for the energy transition, and addressing biodiversity loss— all in the context of a global economic slowdown and debt crisis. In combination, these factors are increasing the relevance of natural capital mapping and sustainable mineral exploration.

Mitigating the effects of climate change will require an accelerated energy transition. The Paris Agreement established that mitigating the effects of climate change requires limiting the global temperature increase to 1.5°C above pre-industrial levels. To do this, greenhouse gas emissions must be reduced by 45% by 2030 and reach net zero by 2050. The energy sector is the source of around three-quarters of greenhouse gas emissions today, and as such, a wholesale transformation of the energy sector would be required to meet these targets. This transformation requires greater energy efficiency and the potential deployment of a myriad of green energy technologies. In addition, this transformation is likely to require large-scale deployment of new types of equipment and infrastructure.

An accelerated energy transition will lead to an increase in mineral demand. Demand for minerals is expected to grow in the coming years as green technologies have much higher mineral needs than their fossil fuel alternatives. The latest estimates by the IEA estimate that the supply of each critical mineral would need to increase by 1.5 and 7 times by 2030 to reach net zero targets by 2050. The list of critical raw materials is expanding: the EU's Critical Raw Materials List, which is updated every three years, started with a list of 11 items in 2011, and reached 30 items upon its last update in 2020. The USA has defined a list of 50 critical minerals, including various rare earth elements (REEs), cobalt, nickel and lithium. A number of minerals required for energy technology are also relevant to the defence, aerospace and communications industries. As such, the energy sector will compete for these minerals alongside other sectors. Increased exploration will be required to meet heightened demand.

Current and planned mines are not enough to meet future demand. Under a scenario in line with the Paris Agreement, lithium production will need to increase thirteenfold to satisfy demand in 2050. Cobalt supply will need to more than triple, and nickel and neodymium production will need to double. While the IEA expects some minerals, such as mined lithium and cobalt, to remain in surplus in the very near term (i.e. the next three years), lithium chemical products, battery-grade nickel and key REEs such as neodymium and dysprosium could face shortages. Current mining output is expected to be insufficient to support demand growth for some critical raw minerals as early as 2030. The supply from operational and planned mines is forecast to meet only about half of lithium and cobalt requirements, as well as c. 80% of copper needs.

More exploration is needed to diversify the sources and improve the security of the supply of mineral production. One area of concern is that the production of certain critical minerals is too dependent on a limited number of countries. The top producers account for two-thirds of production for three of the critical minerals identified, with market shares reaching as high as 95% for lithium. China, for instance, produces 60% of the global REEs supply; and the Democratic Republic of Congo (DRC) is responsible for 71% of global cobalt production. To increase security of supply, the global economy requires more diversified sources.

Quality data on natural resources can help enable investment, new mineral discoveries and sustainable mining practices. The expected increase in demand for minerals, and therefore mining activity, presents an opportunity for resource-rich countries to attract investment in exploration activities. There is potential for new discoveries of mineral deposits using cutting-edge geological data, which will assist with meeting demand and the diversifiying of supply. At the same time, the efficiency of mining activity and the associated environmental risks must be addressed. A key component of achieving investment, new discoveries, and sustainable mining is the availability of quality data. Research suggests that countries with a contemporary and technically superior geoscientific database may have a better chance of attracting exploration investment than a neighbouring state with a lesser or more dated database.

Countries rich in natural resources could consider taking steps to map and account for their entire natural capital to maximise its efficient use and drive sustainable development. The economic valuation of natural capital requires comprehensive mapping of these resources. The increasing recognition of the role and value of underlying natural assets, including ecosystem services provided by biodiversity, in driving economic growth and securing future nature-dependent economic opportunities. Recent studies put the explicit value of nature in the global economy at USD 9.8 trillion worth of goods and services. While this is significant and equivalent to 10% of global GDP, the actual value of nature to the global economy is under-priced. Countries rich in renewable and non-renewable natural resources could consider investing in mapping and accounting for their entire natural capital – not just their mineral potential – to maximise its efficient use and drive sustainable development. Critically, for developing nations, leveraging natural capital could be key for exploring new economic development opportunities, improving its fiscal position and access to capital markets, and to rebalancing its position as recipients of cooperation finance.

More funds must flow into natural capital mapping and exploration to close the expected gap between demand and supply. Financial innovation is required in the context of the global economy slowdown and debt crisis. Recent estimates indicate that anticipated investment ranges between US $180bn and US $220bn, but investments of US $360bn to US $450bn would be required between 2022 and 2030 to reach the expected level of production in line with a net zero target. The current economic headwinds will present challenges for investment from both the private and the public sector. A recent surge in debt servicing costs puts additional pressure on many highly indebted low-income countries. In order to close the financing gap, the private and public sectors and multilateral agencies, will all have a role to play. Closing this investment gap to meet future demand for critical raw materials might benefit from the systematic mapping of natural resources to obtain high-quality data on a country's natural resources potential and allow countries to undertake informed cost-benefits analyses on whether and where best to extract these natural resources. It will also require increased efforts concerning exploration and mine development.

Increased mapping and exploration can provide direct and indirect benefits and risks for economic performance, energy security and the environment. Key benefits of mapping and exploration—if they lead to increased mining activity—include a potential increase in employment opportunities, improvement in livelihood, rise in tax revenues and economic output. However, increased mining activities are associated with certain environmental and social risks. Failure to tackle these challenges could result in missed opportunities to encourage the growth of a profitable and responsible mining sector to deliver the energy transition and contribute to sustainable development. However, if managed responsibly, the mining industry has the ability to play a significant role in sustainable development. Good governance will be critical in achieving this.

An accelerated energy transition will benefit economies and societies worldwide. To achieve the Paris Agreement climate goal, the energy transition will need to accelerate markedly. It has been estimated that without policy action in addition to the status quo, there is less than a 10% probability that a temperature rise of below 2°C will be achieved. An accelerated energy transition has obvious benefits for biodiversity and our climate, but it has important benefits for economic performance and energy security as well. An accelerated energy transition will benefit economies and societies worldwide, including by providing lower energy bills, a likely increase in employment and GDP growth, as well as better health outcomes and improved energy security. Although benefits exist across countries and regions, some countries benefit more from an accelerated energy transition than others. An accelerated energy transition has been estimated to particularly benefit less developed countries. As such, IRENA and the African Development Bank (AfDB) predict GDP in Africa to rise by more than 6% by 2050 if the energy transition is accelerated in comparison to a scenario where only current policies are implemented—which is a much greater increase than the global average of 2.3%.

2. What trends are affecting the global economy and geopolitical agenda?

The World Economic Forum has identified a set of 'severe risks' that the world economy may face over the next ten years beyond low economic growth, deglobalisation and challenges to international cooperation.[1] These include:

- Failure to mitigate climate change;
- Failure of climate-change adaptation;
- Natural disasters and extreme weather events;
- Biodiversity loss and ecosystem collapse.[2]

Through desk research, we have identified a number of trends that are affecting the global economy and geopolitical agenda. While this section provides an overview of those trends, section 3 examines the extent to which these trends elevate the importance of natural capital mapping, both in terms of renewable and non-renewable natural resources and especially in terms of the need for greater mineral exploration.

The shift to security

Economies and supply chains are shifting from efficiency to security.[3] The global economy is splitting into two competing systems as some businesses begin to move away from globalisation and towards vertical integration and diversification.[4]

The push for the energy transition

Price volatility, supply shortages, security issues, climate change and economic uncertainty, exacerbated by the war in Ukraine, have created a global energy crisis and a long-term push for renewables.[5]

The race for natural resources

The increasing scarcity of natural resources leads to competition to secure water, food, land and minerals, among other natural resources.[6] New technologies and supply chains are more intensive in critical raw materials.[7] Countries such as China, Russia, India, Indonesia and Saudi Arabia, are increasingly active in the race.[8]

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[1] World Economic Forum (2023), Section 2 of 'Global Risk Report 2023', available at https://www.weforum.org/reports/global-risks-report-2023/in-full/2-global-risks-2033-tomorrow-s-catastrophes#2-global-risks-2033-tomorrow-s-catastrophes.
[2] World Economic Forum (2023), Section 2 of 'Global Risk Report 2023'.
[3] World Economic Forum, 'Making the future energy system secure means making it sustainable' (Davos, 12 January 2023), available at https://www.weforum.org/agenda/2023/01/davos23-energy-transition-security-sustainability-whitepaper/, accessed 23 February 2023.
[4] The Economist, 'The structure of the world's supply chain is changing' (16 January 2022), available at https://www.economist.com/briefing/2022/06/16/the-structure-of-the-worlds-supply-chains-is-changing, accessed 23 February 2023.
[5] See Section 3.2 and 3.3 below.
[6] See Section 3.5 below.
[7] See Section 5.1 below.
[8] See Section 3.5 below.

Biodiversity is the new emerging challenge

Since 2019, the World Economic Forum has placed biodiversity loss among the top 5 risks the global economy faces. 50% of the world's economic output significantly depends on natural capital.[9] Global investment needs on biodiversity are estimated at $700 billion yearly.[10]

Global economy slowdown

Global economy growth for 2023 is expected at 2.7%, 40% lower than last two years.[11] Challenges come from inflation pressures, global financial conditions, cost of living, deglobalisation, China's weak growth and global uncertainty.[12] The euro area and the UK will be heavily affected by flat growth. Growth in emerging markets and developing economies are expected to decelerate from 3.8% in 2022 to 2.7% in 2023.[13]

Global debt crisis is reaching a critical point

According to the International Monetary Fund (IMF), 60% of low-income countries and 25% of emerging markets are at risk of debt distress.[14] This is aggravated by monetary policy. About half of external debt stock of low- and middle-income countries is denominated in US dollars.[15] US-dollar appreciation is increasing the burden of dollar-denominated public sector debts.[16] Further, China is the main creditor in many middle-income countries,[17] and the IMF continues to keep austerity requirements for fiscal policy.[18] Saudi Arabia, UAE and Qatar have also increased lending to African projects.[19]

The role of natural capital mapping in light of these trends

The trends identified above impact the relevance and financing needs of natural capital mapping and minerals exploration. An accelerated energy transition is likely to lead to an increased mineral demand, which implies a need for increased mapping and exploration. Rising energy security concerns imply heightened attention towards diversifying natural resources supplies. A race for natural resources implies competition between countries to secure access to minerals and other natural resources with strategic relevance. Increased attention to biodiversity implies a greater role for mapping to evaluate the value of biodiversity services. The global economic slowdown and debt crisis imply that financing for mapping and minerals exploration might become more difficult in the years to come.

However, the current global environment could also prove to be an opportunity for natural resource mapping. Better-quality information on where the potential stocks of minerals may be located and on the state of biodiversity in countries can allow and facilitate diversification of sources of mineral supply, accelerate the energy transition, protect biodiversity and ecosystem services, and create opportunities and better access to finance in countries rich in natural capital.

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[9] World Economic Forum (2020), 'Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy', January.
[10] https://www.cbd.int/article/cop15-final-text-kunming-montreal-gbf-221222 ; see in particular, GOAL B and GOAL D.
[11] International Monetary Fund (2022), 'World Economic Outlook: Countering the cost-of-living crisis', available at https://www.imf.org/en/Publications/WEO/Issues/2022/10/11/world-economic-outlook-october-2022, p.8.
[12] International Monetary Fund (2022), 'World Economic Outlook: Countering the cost-of-living crisis', p.XVII.
[13] World Bank (2023), 'Global Economic Prospects', available at https://www.worldbank.org/en/publication/global-economic-prospects, p. 6.
[14] International Monetary Fund, 'CGD Talks: Compound Crises Call for Decisive Action' (13 September 2022), transcript available at: https://www.imf.org/en/News/Articles/2022/09/14/tr091322-cgd-transcript.
[15] World Bank (2022), 'International Debt Report 2022', available at https://www.worldbank.org/en/programs/debt-statistics/idr/products, p.24.
[16] Gita Gopinath, Pierre-Olivier Gourinchas, 'How Countries Should Respond to the Strong Dollar' (IMF Blog, 14 October 2022), available at https://www.imf.org/en/Blogs/Articles/2022/10/14/how-countries-should-respond-to-the-strong-dollar, accessed 23 February 2023.
[17] Guillaume Chabert, Martin Cerisola, Dalia Hakura, 'Restructuring Debt of Poorer Nations Requires More Efficien Coordination' (IMF Blog, 7 April 2022), available at https://www.imf.org/en/Blogs/Articles/2022/04/07/restructuring-debt-of-poorer-nations-requires-more-efficient-coordination, accessed 22 February 2023.
[18] https://mediacenter.imf.org/news/imf--fiscal-monitor-october-2022-update/s/a81de6e0-0000-4cde-90a1-31406095c439
[19] See for example, Sherif Tarek, 'Qatar joins UAE, Saudi Arabia in race for Egypt's assets as EGP declines' (The Africa Report, 29 September 2022), available at https://www.theafricareport.com/245305/qatar-joins-uae-saudi-arabia-in-race-for-egypts-assets-as-egp-declines/, accessed 22 February 2023; Sherif Tark, 'Africa: Maritime investment tightens UAE's grip on the continent' (The Africa Report, 14 July 2022), available at https://www.theafricareport.com/222929/africa-maritime-investment-tightens-uaes-grip-on-the-continent/, accessed 22 February 2023.

3. What is driving the increased relevance of natural capital mapping and mineral exploration on the global economic and geopolitical stage?

Box 3.1 Key messages

1. Increasing scarcity of renewable and non-renewable resources has led to competition among sovereign states to secure these resources. This is manifesting in foreign policy priorities, including investment in land and projects rich in natural resources. This is being felt acutely in the race to secure critical minerals, as countries look to decarbonise energy supply and increase energy security.

2. The increase in demand for critical minerals will lead to an increase in mining activities, which come with increased environmental and social risks. Amid growing concerns around environmental and social issues, including biodiversity loss, countries are also seeking to understand the value of their ecosystem services.

3. Ecosystem services provided by biodiversity are becoming increasingly scarce due to resource consumption. The importance of biodiversity to global economies is increasingly being recognised. Countries are increasingly considering how to make smart, long-term decisions that balance economic, social and environmental factors. This is becoming part of the development finance agenda.

4. Natural capital mapping is required to support efforts to integrate natural capital accounting into economic decision making. Financial innovation is required to bridge the $700 billion per year biodiversity funding gap.

This section examines various global trends that impact the relevance of natural capital mapping and minerals exploration in greater detail. In particular, we discuss the following topics:

- The extent to which climate change and concerns around supply chains, especially in terms of energy security, have led several countries to push for an energy transition.[20]
- The extent to which increased attention towards the energy transition, alongside greater recognition of the value of renewable as well as non-renewable natural resources, has led to a race for those resources. This is especially acute in terms of the race to secure the supply of critical minerals.
- The extent to which an increase in demand for critical minerals is likely to lead to an increase in mining activities, comes with increased environmental and social risks.
- The extent to which, amid growing concerns around environmental and social issues, including biodiversity loss, countries are seeking to understand the value of their ecosystem services and how to make smart, long-term decisions that balance economic, social and environmental factors, and focus international finance cooperation on how environmental services are provided and shared globally.

3.1. International focus on climate change

There is a considerable weight of scientific consensus that to preserve a liveable planet and avoid the worst effects of climate change; global temperature increase needs to be limited to 1.5°C above pre-industrial levels.[21] To achieve this, greenhouse gas emissions must be reduced by 45% by 2030, and reach net zero by 2050. According to the UN, the energy sector is the source of around three-quarters of greenhouse gas emissions today and holds the key to averting the worst effects of climate change.[22]

With the effects of climate change now being increasingly felt across the world, the Intergovernmental Panel on Climate Change has been calling for large-scale, rapid changes to governmental policy and the global economy to mitigate climate change.[23]

Climate, finance and energy policy are becoming increasingly linked.

This has defined the global policy agenda, which has focused on the decarbonisation of the energy sector and greater cooperation between developing and developed countries, in particular in the financial arena.[24] Today, climate, finance and energy policy are increasingly becoming linked.[25]

[20] The net zero tracker, compiled by the Energy and Climate Intelligence Unit, identified more than 100 countries with a net zero target (in law, declared or in a policy document). Several countries have committed to expanding the share of renewable energy and electric vehicles by setting national targets into law: for instance Sweden has a 'target of achieving 100% renewable electricity generation by 2040'. See IEA (2019), 'Sweden is a leader in the energy transition, according to latest IEA country review', 9 April.
[21] United Nations Climate Action, 'For a liveable climate: Net-zero commitments must be backed by credible action', available at https://www.un.org/en/climatechange/net-zero-coalition.
[22] United Nations Climate Action, 'For a liveable climate: Net-zero commitments must be backed by credible action', available at https://www.un.org/en/climatechange/net-zero-coalition.
[23] See The Guardian, 'IPCC climate change report calls for urgent action to phase out fossil fuels – as it happened' (8 October 2018), available at https://www.theguardian.com/environment/live/2018/oct/08/ipcc-climate-change-report-urgent-action-fossil-fuels-live, accessed 20 February 2023.
[24] For instance, the latest COP27 led to an agreement to mobilise more financial support for developing countries. In particular, the COP27 resolution contained a call for developed countries to provide further resources for the Least Developed Countries Fund which provides financing to the least developed countries. See for instance UN website, accessed 6 February 2023.
[25] See below in Section 3.3 for examples.

3.2. The shift in focus to security, including energy security

The COVID-19 pandemic and Russia's invasion of Ukraine has caused major disruption to global markets and exposed vulnerabilities in supply chains.

The COVID-19 pandemic provided a shock to the global economy that revealed the vulnerability of global supply chains. As a result, several businesses have started to move towards vertical integration and diversification to insulate themselves from supply chain shocks. One example of this is Tesla. In 2021 Tesla invested in the Goro nickel-cobalt mine in New Caldeonia[26] and now controls the design and manufacture of key components, as well as owning direct sales, service and charging networks for its EVs.[27]

Russia's invasion of Ukraine in February 2022 has been causing major disruption to the global markets and exposing further vulnerabilities in the security and resilience of supply chains. The resulting energy crisis, which has prompted high energy prices across Europe, has highlighted the risks associated with energy dependence.[28]

3.3. These combined factors have led to a push for the energy transition

Climate, energy and industrial policies around the world suggest a growing recognition that short-term policies aimed at combating the current energy crisis must be combined with medium- and long-term strategies to increase the sustainability, resilience and diversity of clean energy supply chains.

The war in Ukraine and the resulting shock to energy supply and security has underscored the cost of an energy system principally reliant on fossil fuels. The dual challenges of tackling climate change and addressing energy security have contributed to an increased awareness of the importance of the energy transition.

The IMF stress that while the energy transition may have some near-term adverse implications for the global economy, the cost of 'business as usual' would be "catastrophic"[29]. The IEA and IMF warn that the cost of inadequate action rises sharply the more the energy transition is delayed—especially for emerging and developing economies.[30]

Major economies such as the USA, the EU and Japan, as well as China and India, have begun to combine their climate, energy security, and industrial policies (see table below), which could indicate a growing recognition that short-term policies aimed at combating the current energy crisis must be combined with medium and long-term strategies to increase the sustainability, resilience and diversity of clean energy supply chains.

For example, the Inflation Reduction Act in the USA envisages hundreds of billions of dollars in investment into clean energy, intending to reduce carbon emissions by 2030, with clean electricity and transmission getting the lion's share.[31]

The EU is aiming to turn climate goals into law via the 'Fit for 55' package[32] and the REPowerEU plan, which aims to end the EU's reliance on Russian fossil fuels and tackle the climate crises in

[26] S&P Global, 'Tesla role in Goro nickel mine paves path to vertically integrated supply chain' (10 March 2021), available at https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/tesla-role-in-goro-nickel-mine-paves-path-to-vertically-integrated-supply-chain-63082771, accessed 23 February 2023.

[27] Hyunjoo Jin, 'Explainer: How Tesla weathered global supply chain issues that knocked rivals' (Reuters, 4 January 2022), available at https://www.reuters.com/markets/europe/how-tesla-weathered-global-supply-chain-issues-that-knocked-rivals-2022-01-04/, accessed 22 February 2023.

[28] See for instance IMF (2022), 'Surging Energy Prices in Europe in the Aftermath of the War: How to Support the Vulnerable and Speed up the Transition Away from Fossil Fuels', available at https://www.imf.org/en/Publications/WP/Issues/2022/07/28/Surging-Energy-Prices-in-Europe-in-the-Aftermath-of-the-War-How-to-Support-the-Vulnerable-521457, accessed 20 February 2023.

[29] IMF (2022), 'World Economic Outlook: Countering the cost-of-living crisis', available at https://www.imf.org/en/Publications/WEO/Issues/2022/10/11/world-economic-outlook-october-2022, p.xv.

[30] IMF (2022), 'World Economic Outlook: Countering the cost-of-living crisis', p xiv-xv; International Energy Agency (2023), 'Energy Technology Perspectives', available at https://iea.blob.core.windows.net/assets/a86b480e-2b03-4e25-bae1-da1395e0b620/EnergyTechnologyPerspectives2023.pdf, p.26.

[31] McKinsey & Company, 'The Inflation Reduction Act: Here's what's in it' (24 October 2022), available at https://www.mckinsey.com/industries/public-and-social-sector/our-insights/the-inflation-reduction-act-heres-whats-in-it.

[32] Council of the European Union, 'Fit for 55', available at https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/, accessed 20 February 2023.

tandem: diversification of supply, accelerating the rollout of renewables, reducing fossil fuel usage in industry and transport, and smart investment form the core tenets of the policy.[33]

Similarly, Japan's Green Transformation policy states that carbon neutrality is an opportunity for economic growth and environmental sustainability and to increase industrial competitiveness.[34] India has implemented a Production Linked Incentive scheme that encourages the manufacturing of solar PV and batteries.[35] China's latest Five-Year-Plan promotes increases in green energy compatibilities and sustainable mobility.[36]

Transformation of the energy sector is likely to require massive deployment of new equipment and infrastructure.

3.4. Enabling the energy transition

Enabling the energy transition depends on a wholescale transformation of the energy sector.

According to the IEA, the deployment of clean energy technologies and fuel shifts account for over 70% of total cumulative emissions reductions from 2021 to 2050.[37] The IEA states that this transformation requires greater energy efficiency and potential deployment of hydrogen, electrification, bioenergy, wind and solar, carbon capture utilisation and storage (CCUS), and other fuel shifts (e.g. switching from coal and oil to natural gas, nuclear, hydropower, geothermal, concentrating solar power and marine energy). This transformation will likely require the massive deployment of new types of equipment and infrastructure.[38]

The list of critical raw materials is expanding. A number of minerals are relevant to defence, aerospace and communications industries as well as the energy transition.

Clean energy supply chains look very different from fossil fuel supply chains. The materials needed for the equipment and components in clean energy technology are more reliant on and demand a wider range of critical minerals.[39] Further, the list of critical raw materials is expanding: the EU's Critical Raw Materials List, updated every three years, started with a list of 11 items in 2011,[40] and reached 30 items upon its last update in 2020.[41]

A number of minerals required for energy technology are also relevant to the defence, aerospace and communications industries. As such, the energy sector will be competing for these minerals alongside other sectors. The specific requirements of critical minerals for the various clean energy technologies are discussed in greater detail in section 6 below.

3.5. The race for natural resources

Population increase, increasing consumption, environmental degradation and climate change are placing significant and potentially unsustainable pressure on the availability and usability of natural resources. Increasing scarcity is driving a race for natural resources—both for renewable resources, such as food, water and ecosystems, and non-renewable resources, such as minerals, oil, and gas. As set out below, this appears to have manifested in increased

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[33] European Commission, 'Press Release: REPowerEU: A Plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition' (18 May 2022), available at https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131, accessed 20 February 2023.
[34] Japanese Ministry of Economy, Trade and Industry, 'Press Release: GX League Basic Concept Announced, Cal for Endorsing Companies Starts', available at https://www.meti.go.jp/english/press/2022/0201_001.html, accessed 22 February 2023.
[35] Sean Rai-Roche, 'India releases new Production Linked Incentive Scheme guidelines for solar manufacturers' (PV Tech, 4 October 2022), available at https://www.pv-tech.org/india-releases-new-production-linked-incentive-scheme-guidelines-for-solar-manufacturers/, accessed 22 February 2023.
[36] UNDP, 'Issue Brief – China's 14th Five-Year Plan' (23 July 2021), available at https://www.undp.org/china/publications/issue-brief-chinas-14th-five-year-plan, accessed 22 February 2023.
[37] International Energy Agency (2023), 'Energy Technology Perspectives', available at https://iea.blob.core.windows.net/assets/a86b480e-2b03-4e25-bae1-da1395e0b620/EnergyTechnologyPerspectives2023.pdf, p.46.
[38] International Energy Agency (2023), 'Energy Technology Perspectives', p.46.
[39] International Energy Agency (2023), 'Energy Technology Perspectives', p.52.
[40] European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (2017), 'Study on the review of the list of critical raw materials: final report', available at https://data.europa.eu/doi/10.2873/876644, accessed 30 January 2023.
[41] IEA, 'The 2020 EU Critical Raw Materials List' (26 October 2022), available at https://www.iea.org/policies/15274-the-2020-eu-critical-raw-materials-list, accessed 30 January 2023.

nationalism, resource-based foreign policy priorities, and investment in countries rich in natural resources.

Concerns around food security[42] are driving the increasing prioritisation of arable land for agriculture and protectionist policies relating to food. For example, China has been buying large tracts of farmland in rural areas of the USA, leading to the proposal of a US Senate bill prohibiting investment in US agriculture by Russian, Chinese, Iranian or North Korean entities.[43] Russia has expanded its use of arable land in the country's north, albeit with limited success,[44] and has disrupted the global food market due to the war in Ukraine.[45]

Increased agriculture has in turn led to increased soil degradation and water stress.[46] Continuing 'water nationalism 'remains an issue—for example, the continuing dispute between Egypt, Ethiopia and Sudan over the Grand Ethiopian Renaissance Dam,[47]—and water security is paramount, even in developed nations — for example, the USA recently announced its global action plan on water security.[48]

Investment into resource rich countries remains a priority for many countries.

Investment in resource-rich countries remains a priority for many countries. China has expanded its infrastructure investment to agriculture, solar, wind and other clean energy projects in Africa.[49] The USA seeks to emphasise private sector activity in Africa as an alternative to Chinese state-backed loans as it seeks to make up for a lack of engagement with African countries over the last decade.[50]

Many countries have developed critical mineral specific strategies and policies.

In the critical minerals arena, most major powers continue to leverage increasingly state-directed investment in emerging export markets across Latin America and Africa to secure access to these resources.[51] However, protectionist policies are on the rise—for example, Mexico has begun to renationalise assets associated with key metals and minerals,[52] and Canada has ordered Chinese companies to divest states in lithium mines, claiming a threat to national security.[53]

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[42] Agricultural output in the USA, Russia and China has declined due to soil degradation. Ocean warming an acidification has caused declines in aquaculture and fisheries; see World Economic Forum (2023), 'The Global Risks Report 2023' (18th edition), available at https://www3.weforum.org/docs/WEF_Global_Risks_Report_2023.pdf, accessed 20 February 2023, p.62.
[43] Lars Erik Schönander and Geoffrey Cain, 'China is Buying the Farm: State-owned companies have bought many acres near U.S. military bases. What is Beijing up to?' (WSJ Opinion, 8 September 2022), available at https://www.wsj.com/articles/the-chinese-are-buying-the-farm-north-dakota-hong-kong-land-food-shortage-supply-chain-usda-11662666515, accessed 20 February 2023.
[44] World Economic Forum (2023), 'The Global Risks Report 2023' (18th edition), available at https://www3.weforum.org/docs/WEF_Global_Risks_Report_2023.pdf, p.62.
[45] Council of the European Union, 'Infographic – How the Russian invasion of Ukraine has further aggravated the global food crisis' (2 December 2022), available at https://www.consilium.europa.eu/en/infographics/how-the-russian-invasion-of-ukraine-has-further-aggravated-the-global-food-crisis/, accessed 22 February 2023.
[46] World Economic Forum (2023), 'The Global Risks Report 2023' (18th edition), p.65.
[47] AL-Monitor, 'Egypt warns of stalemate in Nile dam dispute' (27 September 2022), available at https://www.al-monitor.com/originals/2022/09/egypt-warns-stalemate-nile-dam-dispute, accessed 22 February 2023.
[48] See The White House, 'FACT SHEET: Vice President Harris Announces Action Plan on Global Water Security and Highlights the Administration's Work to Build Drought Resilience' (1 June 2022), available at https://www.whitehouse.gov/briefing-room/statements-releases/2022/06/01/fact-sheet-vice-president-harris-announces-action-plan-on-global-water-security-and-highlights-the-administrations-work-to-build-drought-resilience/, accessed 20 February 2023.
[49] Ministry of Foreign Affairs of the People's Republic of China, 'China and Africa: Strengthening Friendship, Solidarity and Cooperation for a New Era of Common Development' (18 August 2022), available at https://www.fmprc.gov.cn/eng/zxxx_662805/202208/t20220819_10745617.html, accessed 20 February 2023.
[50] Joseph Cotterill, David Pilling & James Politi, 'Janet Yellen to visit African countries as US steps up overtures to continent' (Financial Times, 16 January 2023), available at https://www.ft.com/content/23d66a41-e9ed-44d0-967f-279fee36dba7, accessed 20 February 2023.
[51] World Economic Forum (2023), 'The Global Risks Report 2023' (18th edition), p.63.
[52] White & Case LLP (David Bond, Francisco de Rosenzweig, Samuel Scoles), 'Mexico Nationalizes Lithium; Sets Up State-Owned Company' (9 September 2022), available at https://www.whitecase.com/insight-alert/mexico-nationalizes-lithium-sets-state-owned-company, accessed 20 February 23.
[53] Demetri Sevastopulo and Edward White, 'Canada orders Chinese companies to divest stakes in lithium mines' (Financial Times, 3 November 2022), available at https://www.ft.com/content/6ca9a470-59ee-4809-8a5b-35f6073c9907?desktop=true&segmentId=7c8f09b9-9b61-4fbb-9430-9208a9e233c8#myft:notification:daily-email:content, accessed 20 February 2023.

Some of the country-specific policies concerning minerals are set out in the table below.

Table 3.1 Country Specific Minerals Strategies and Policies

Country	Critical minerals strategies and policies
China	14th Five-Year Plan has codified its ambitions to invest heavily in technology and manufacturing, and pushing for new energy sources.[54]
The USA	Scaling up its investment in securing critical minerals amid concerns about Chinese dominance in critical mineral processing.[55]
India	Reported on its 'Efforts to Attain Self-Reliance in Critical and Strategic Minerals' and announced a collaboration with Australia in lithium and cobalt identification projects.[56]
Saudi Arabia	Sovereign wealth fund and state miner announced the creation of a fund intended for investment in non-operating minority stakes in mining projects across the world, in order to secure resources such as iron ore, copper, nickel and lithium for domestic mineral processing and other industrial activities like steelmaking.[57]
EU and Canada	The Strategic Partnership on Raw Materials extends the scope of the agreement beyond the development and financing of critical mineral projects to increased collaboration on related technologies.[58]
Indonesia	Considering the creation of an 'OMEC' to replace OPEC, there have been reports that this was considered by the 'lithium triangle' of Chile, Argentina and Bolivia.[59]

3.6. The biodiversity challenge

The global economy is heavily reliant on critical stocks of natural capital.

The increasing consumption of natural resources is accelerating biodiversity loss. Ecosystem services delivered by biodiversity, such as crop pollination, water purification, flood protection and carbon sequestration, are increasingly scarce and at risk. In 2022, it was estimated that humanity consumed nature 1.8 times faster than our planet's biocapacity can regenerate,[60] presenting a significant risk to the global economy as many sectors are heavily dependent on critical stocks of natural capital. The role and value of underlying natural assets in driving economic growth and securing future nature-dependent economic opportunities is increasingly being recognised.

[54] UNDP, 'Issue Brief – China's 14th Five-Year Plan' (23 July 2021), available at https://www.undp.org/china/publications/issue-brief-chinas-14th-five-year-plan, accessed 22 February 2023.
[55] The White House, 'FACT SHEET: Securing a Made in America Supply Chain for Critical Minerals' (22 February 2022), available at https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/22/fact-sheet-securing-a-made-in-america-supply-chain-for-critical-minerals/, accessed 20 February 2023.
[56] Indian Ministry of Mines, 'India's Efforts to Attain Self-Reliance in Critical and Strategic Minerals: India and Australia to Collaborate in Lithium and Cobalt Identification Projects' (29 March 2022), available at https://pib.gov.in/PressReleasePage.aspx?PRID=1810948, accessed 20 February 2023.
[57] Leslie Hook, Harry Dempsey and Samer Al-Atrush, 'Saudi Arabia launches mining fund in effort to reduce oil dependency' (Financial Times, 11 January 2023), available at https://www.ft.com/content/46bf21a4-e626-4581-ad85-8b74bbd82e4e, accessed 23 February 2023.
[58] Natural Resources Canada, 'Joint Statement by Canada's Minister of Natural Resources and the European Commissioner for Internal Market' (19 July 2021), available at https://www.canada.ca/en/natural-resources-canada/news/2021/07/joint-statement-by-canadas-minister-of-natural-resources-and-the-european-commissioner-for-internal-market.html, accessed 20 February 2023.
[59] Harry Dempsey and Mercedes Ruehl, 'Indonesia considers Opec-style cartel for battery metals' (Financial Times, 31 October 2022), available at https://www.ft.com/content/0990f663-19ae-4744-828f-1bd659697468?desktop=true&segmentId=7c8f, accessed 20 February 2023.
[60] Earth Overshoot Day, 'How Many Earths? How Many Countries?', available at https://www.overshootday.org/how-many-earths-or-countries-do-we-need/, accessed 20 February 2023.

Reaching the goals of the GBF will require significant investment into natural capital mapping and natural capital accounting.

There is currently a $700bn per year biodiversity finance gap.

In December 2022, the Kunming-Montreal Global Biodiversity Framework (GBF) was agreed upon four years of negotiation.[61] The GBF seeks to address biodiversity loss and restore natural ecosystems through four goals and 23 targets to be achieved by 2030.

The goals of the GBF make clear the importance of ensuring that ecosystem functions and services provided are valued, maintained and enhanced. Critically, the framework calls for fully integrating biodiversity and its multiple values into national accounting strategies to facilitate the progressive alignment of all relevant public and private activities, fiscal and financial flows.[62] This will require significant investment into natural capital mapping and natural capital accounting.

There is currently a $700bn per year biodiversity finance gap.[63] Bridging this gap and delivering on the GBF will require implementing financial resources, including innovation in financial instruments. The GBF states that stimulating innovative schemes, such as payment for ecosystem services, green bonds, biodiversity offsets and credits, and benefit-sharing mechanisms with environmental and social safeguards, will be key to achieving the framework's targets.[64]

[61] Conference of Parties to the UN Convention on Biological Diversity (2022), 'Kunming-Montreal Global Biodiversity Framework', CBD/COP/15/L25, available at https://www.cbd.int/article/cop15-final-text-kunming-montreal-gbf-221222.
[62] See Target 14, Conference of Parties to the UN Convention on Biological Diversity (2022), 'Kunming-Montreal Global Biodiversity Framework', CBD/COP/15/L25.
[63] See GOAL B and GOAL D, Conference of Parties to the UN Convention on Biological Diversity (2022), 'Kunming-Montreal Global Biodiversity Framework', CBD/COP/15/L25.
[64] Conference of Parties to the UN Convention on Biological Diversity (2022), 'Kunming-Montreal Global Biodiversity Framework', CBD/COP/15/L25.

4. A rise in demand for critical minerals for the energy transition is likely to require more exploration activities

Box 4.1 Key messages

1. Several minerals, including cobalt, copper, lithium, nickel and various rare earth elements (REEs) are critical enablers for the energy transition. They are needed for various green energy technologies such as wind and solar power, batteries for EVs, hydrogen electrolysers and the expansion of electricity networks.
2. The demand for each of these critical minerals will need to increase by 1.5 to 7 times by 2030 to reach net zero targets by 2050.
3. Increased natural resources mapping and exploration is likely to be needed to meet heightened future demand.

Inadequate mineral supply could result in more expensive, delayed and less efficient transitions.

4.1. Minerals in the context of the energy transition

Many minerals such as copper, lithium, nickel, cobalt and REEs are essential for producing renewable energy technologies such as wind, solar and batteries.[65] In recent reports, international bodies such as the IEA and the World Bank[66] have therefore warned that an 'inadequate mineral supply could result in more expensive, delayed and less efficient transitions'.[67] Given the importance of minerals for the clean energy transition, one of the key questions is whether sufficient amounts of sustainable and responsibly sourced minerals will be available to support the expansion of clean technologies in the years to come.

[65] International Energy Agency (2022), 'The Role of Critical Minerals in Clean Energy Transitions', available at https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions, p.28.
[66] See World Bank Group (2020), 'Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition', available at https://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action.
[67] International Energy Agency (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.117.

Supply of each of the critical minerals would need to increase by 1.5 to 7 times by 2030 to reach net zero targets by 2050.

Demand for critical minerals (CMs) is expected to grow in the coming years as green technologies have much higher mineral needs than fossil fuel alternatives. For instance, an onshore wind turbine needs approximately nine times more minerals than a gas-fired power plant, and an electric car's mineral requirements are around six times that of a conventional combustion engine car.[68] The IEA has recently estimated that the supply of each critical mineral would need to increase by 1.5 to 7 times by 2030 to reach net zero targets by 2050.[69] In absolute terms, combined demand for critical minerals is expected to increase from 6 Mt to 20 Mt.[70] However, the expected demand growth is subject to a degree of uncertainty, as it strongly depends on the development of technologies, future climate policies and resource availability.

Different clean energy technologies require different minerals. Wind power's mineral requirements depend on the turbine type (Direct Drive or gearbox) but include copper, zinc, REEs such as neodymium and others. While solar power relies mainly on chromium, copper, manganese and nickel, geothermal is a key driver for nickel, chromium, molybdenum and titanium demand. In addition, increased production of hydrogen could drive up the demand for nickel, platinum and other minerals.

The expansion of the electricity network—which will be needed to accommodate higher peak electricity demand and more intermittency requires large amounts of aluminium and copper. Batteries, mostly needed for EVs, will drive demand for a wide range of materials, including cobalt, copper, lithium, nickel, REEs, manganese and graphite. Hydropower, bioenergy and nuclear, in contrast, have limited mineral demands and will, therefore, not have a large impact on demand growth.[71]

While demand for most minerals will increase as the world transitions to a cleaner future, the IEA has identified a number of focus minerals that are particularly critical to meeting net zero targets by 2050: cobalt, copper, lithium, nickel and REEs. [72]

[68] International Energy Agency (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.5.
[69] International Energy Agency (2023), 'Energy Technology Perspectives 2023', p.146.
[70] International Energy Agency (2023), 'Energy Technology Perspectives 2023', p.151
[71] International Energy Agency (2022), 'The Role of Critical Minerals in Clean Energy Transitions', pp.42–115.
[72] The EU and the USA recognise 30 and 35 critical raw materials (CRMs), respectively, but nickel, copper, lithium and rare earth metals (neodymium and dysprosium) command particular attention for their relevance and supply challenges. See IRENA (2021), 'World Energy Transitions Outlook 2022', available at https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2022#page-7, accessed 16 January 2023.

Table 4.1 summarises the importance of the IEA's identified focus minerals to expanding various clean energy technologies.[73]

Table 4.1 Mineral needs vary by clean energy technology

	Solar PV	Wind	Hydro	Concen-trated solar power	Bioenergy	Geothermal	Nuclear	Electricity networks	EVs and batteries	Hydrogen
Cobalt	Low	Low	Low	Low	Low	Low	Low	Low	High	Low
Copper	High	High	Medium	Medium	High	Low	Medium	High	High	Low
Lithium	Low	Low	Low	Low	Low	Low	Low	Low	High	Low
Nickel	Low	Medium	Low	Medium	Low	High	Medium	Low	High	High
REEs	Low	High	Low	Low	Low	Low	Low	Low	High	Medium

High importance   Medium importance   Low importance

Source: Table 3.1 adapted from IEA (2022), 'The Role of Critical Minerals in Clean Energy Transitions', March, p. 45.

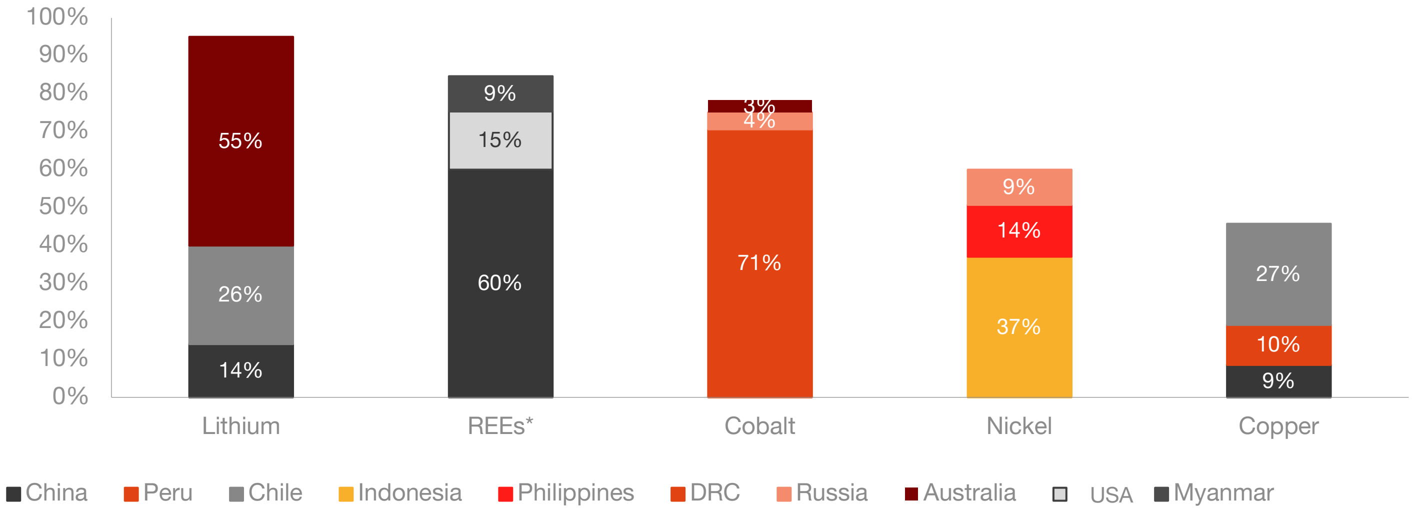
For some critical minerals, the market leader is responsible for more than half of global production.

A limited number of large producing countries dominates current mine production for these five critical minerals.[74] Figure 4.1 shows the market shares of the top three producers for each mineral in 2021. The top three producers account for over two-thirds of production for three of the critical minerals identified, with market shares reaching as high as 95% for lithium. In some cases, the market leader is responsible for more than half of global production. China, for instance, produces 60% of the global REEs supply and the Democratic Republic of Congo (DRC) is responsible for 71% of global cobalt production.[75] The concentration in the market for the production of these critical minerals exceeds the concentration in the gas and oil markets, whose top three players do not exceed market shares of 45%.[76]

A similar pattern exists in the minerals refinement and processing market, where China has developed a strong presence across the board. According to the IEA, China's market share in the refinement and processing market ranges between 35% for nickel and 90% for REEs.[77]

[73] Other entities have identified a broader range of CRMs that are essential for the wider economy and are not specifically focused on the energy transition. The European Commission today has a list of 30 CRMs including REEs, cobalt and lithium. See European Commission website, accessed 27 January 2023. The USA, instead, has defined a list of 50 critical minerals including various REEs, cobalt, nickel and lithium. See IEA website, accessed 27 January 2023.
[74] See IEA (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.30; and Oxera analysis based on U.S. Geological Survey (2021), 'Mineral commodity summaries 2021'.
[75] See IEA (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.30; and Oxera analysis based on U.S. Geological Survey (2021), 'Mineral commodity summaries 2021'.
[76] See IEA (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.30.
[77] See IEA (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.31.

Figure 4.1 Current mine production of CMs is dominated by a few global players



Note: Market shares are shown for the top three players only. *Value for China indicates production quota; does not include undocumented production.
Source: Oxera analysis based on U.S. Geological Survey (2021), 'Mineral commodity summaries 2021', January.

Continued efforts in exploration of new reserves and natural resource mapping could help reduce risks around security of supply.

The high concentration in the production of critical minerals is an increasing concern for companies in the renewable energy industry, but also in many other sectors that mainly rely on imported minerals.[78] Shocks to even a small number of jurisdictions, such as political instability, regulatory change or trade policy adjustments, as well as wider geopolitical events and changes in the global policy agenda could potentially have a significant impact on the supply chains of companies in the clean energy sector. Therefore, continued efforts in the exploration of new reserves and natural resource mapping could help reduce the risks around the security of supply.

Of the five minerals identified by the IEA as being particularly critical for the clean energy transition, the lithium supply will need to increase the most. According to IEA calculations, the production of this mineral will need to increase thirteen-fold to satisfy demand in 2050 under a scenario that is in line with the Paris Agreement. As shown in Figure 4.2, cobalt supply will need to be more than triple, and nickel and neodymium production will need to double.[79]

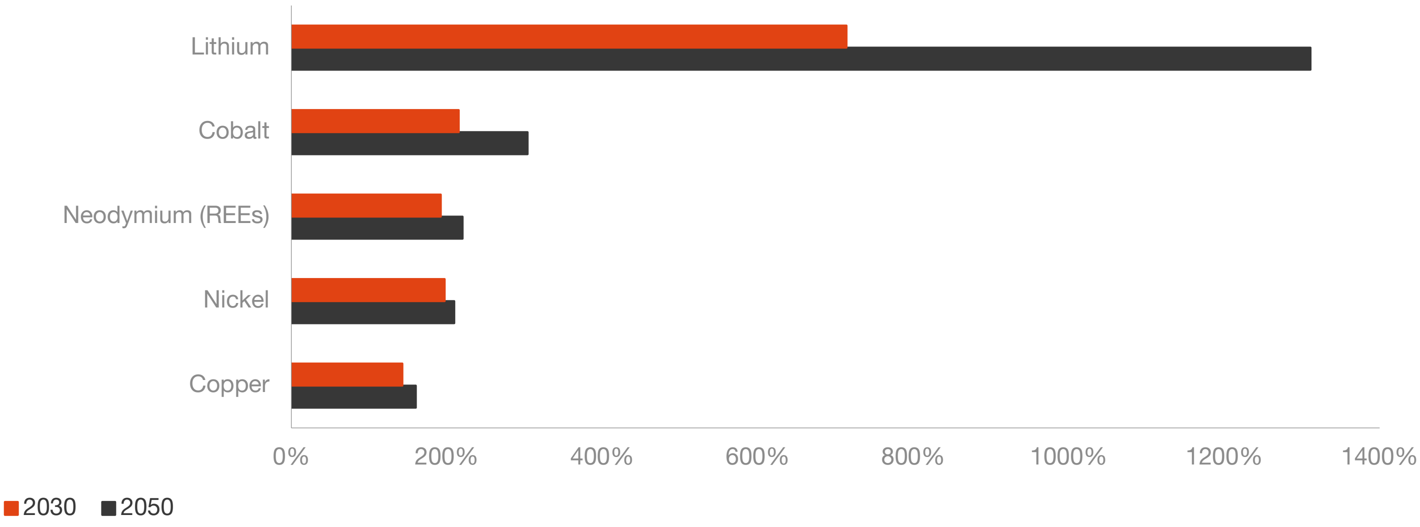
Box 4.2 Technological innovation and policy action will drive future demand growth

It is important to note that the forecasts presented below make assumptions about technologies and future policy action, both inherently uncertain. If a different set of technologies is developed in the future requiring a different group of critical minerals, the overall demand for minerals might develop quite differently than portrayed here. While the forecasts below are best estimates at this time, actual future needs depend on innovation, recycling efforts and policy action.

Source: Oxera

[78] See for instance IEA (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.32.
[79] It needs to be highlighted, though, that the expected demand growth varies greatly between sources and assumptions. For example, while the IEA expects lithium demand to increase to c. 1.05m tons in 2040, the World Bank estimates that lithium demand will only reach 415,000 tons by 2050, see World Bank Group (2020), 'Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition', Table B.2.

Figure 4.2 **Annual demand for minerals in 2050 will need to exceed 2020 mine production significantly to meet net zero targets**



Source: Oxera analysis based on IEA (2023), 'Energy Technology Perspectives 2023', January p153.

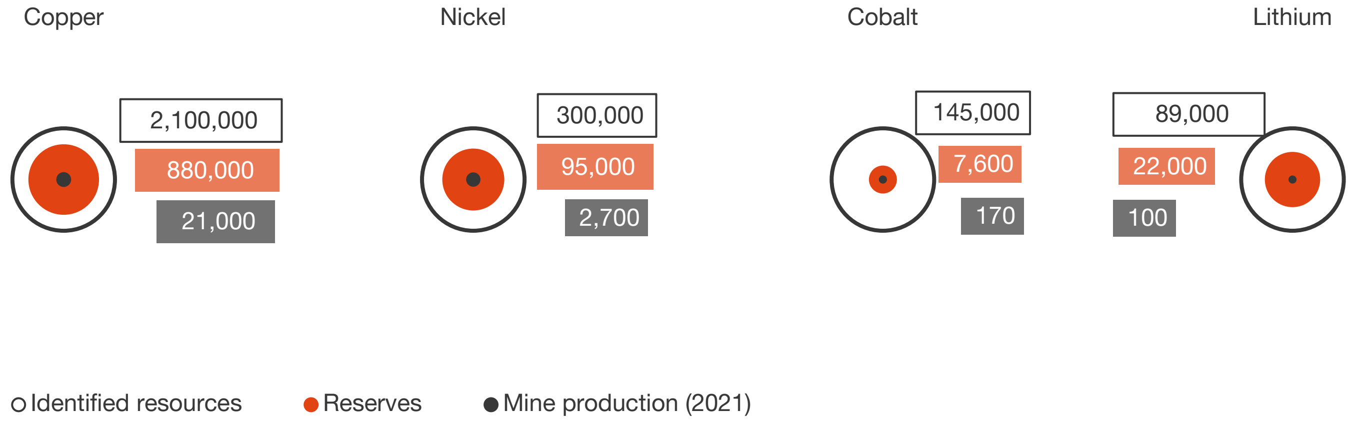
Additional mapping of natural resources could help provide an updated picture of mineral resources available and even facilitate discovery of new resources.

While these increases in demand seem sizeable on the face of it, it is important to note that reserves and identified resources[80] are reported to exceed the current and expected demand for most minerals. By way of example,
Figure 4.2 shows the ratio of identified resources to current mine production for the IEA's five critical minerals.

Reserves and identified resources describe the known *potential* volume of minerals that could be extracted in the future, in contrast to current production. However, data on reserves and resources might not be complete and might rely on geological surveys that were conducted several years and, in some cases, several decades ago.[81] Additional mapping of natural resources could help provide an updated picture of the mineral resources available and even facilitate the discovery of new resources. Technologies like airborne exploration could also assist in revealing target geological provinces to optimise discovery of new resources.

[80] Reserves refer to the 'part of the reserve base that could be economically extracted or produced at the time of determination'. Identified resources refer to deposits 'for which location, grade, quality, and quantity are known or estimated from specific geologic evidence. Identified resources include economic, marginally economic, and sub-economic components.' See U.S. Geological Survey (2021), 'Mineral Commodity Summaries 2022', available at https://www.usgs.gov/publications/mineral-commodity-summaries-2022, p.197.
[81] For a description of the data available, see section 6.2.

Figure 4.3 **Reserves and resources exceed current production for all critical minerals**



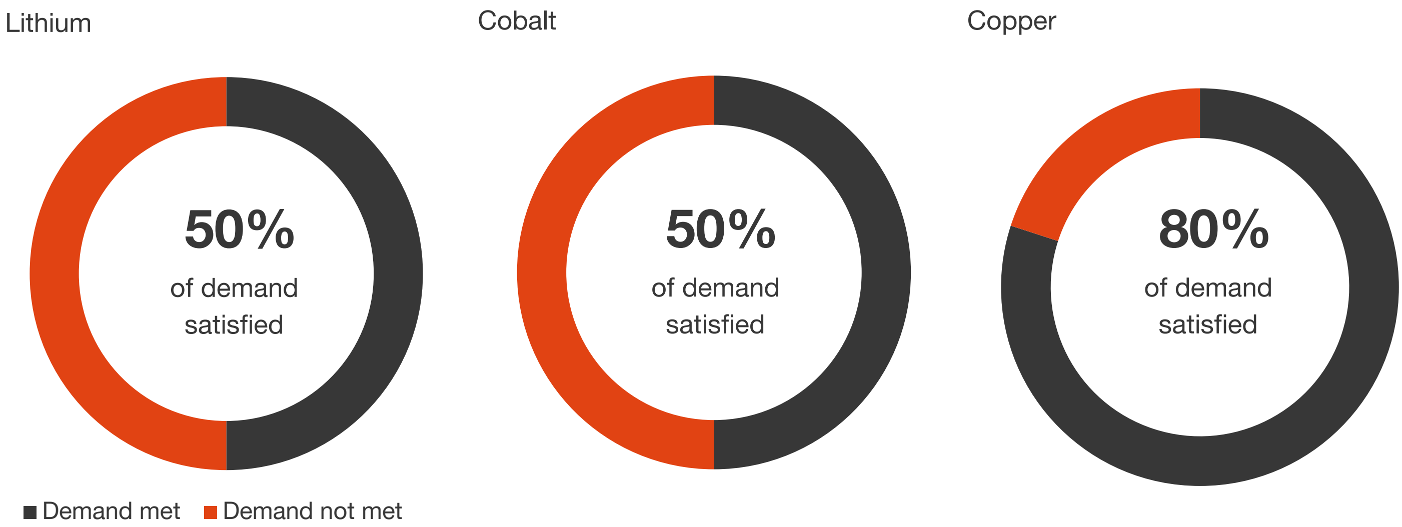
Note: Data in thousand metric tons. Reserves and identified resources refer to minerals that are likely to be available for extraction but are currently not extracted, and no concrete plans for extraction exist. These measures, therefore, indicate the potential of minerals available that require further exploration to become productive. See footnote [81] above for a technical explanation of the terms.
* Of cobalt resources, 120m t have been identified as non-terrestrial, i.e. in polymetallic nodules and crusts on the floor of the Atlantic, Indian and Pacific Oceans.
Source: U.S. Geological Survey (2022), 'Mineral Commodity summaries 2022', own representation.

> Supply from operation and planned mines is forecasted to meet only about half of lithium and cobalt requirements as well as c.80% of copper needs.

The analysis above considers the long-term need and potential for additional production (and exploration) of critical minerals. While the IEA expects some minerals, such as mined lithium and cobalt, to remain in surplus in the very near term (i.e. the next three years), lithium chemical products, battery-grade nickel and key REEs such as neodymium and dysprosium could face shortages.[82] Current mining output is expected to be insufficient to support demand growth for at least three more of the critical minerals as early as 2030.[83] The supply from operational and planned[84] mines is forecasted to meet only about half of lithium and cobalt requirements, as well as c. 80% of copper needs.[85] As such, the IEA suggests that additional exploration is needed to satisfy demand if the global economy is to remain on a 1.5°C warming path.[86]

[82] International Energy Agency (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.11.
[83] International Energy Agency (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.11.
[84] Here, planned mines include only mines that are currently under construction.
[85] International Energy Agency (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.11.
[86] International Energy Agency (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.140.

Figure 4.4 **Gap between mineral supply and demand in 2030**



Source: Oxera visualisation of IEA forecast (2022), 'The Role of Critical Minerals in Clean Energy Transitions', March.

A range of measures are available to governments that could help prevent a scarcity of minerals needed for the clean energy transition.

A situation in which minerals demand exceeds global mining capacity is difficult to remedy in the short term, as lead times for new mines are long. Lead times range from a couple of years to decades depending on the type of mineral, size of reserve and grade of ore contained, and country characteristics, including financing conditions and commodity prices.[87] Average lead times from discovery to production can range from four years for lithium reserves to almost 20 years for nickel.[88]

A range of measures exists that could help prevent a scarcity of minerals needed for the clean energy transition. Governments could facilitate or support international cooperation to provide certainty to potential investors in the mining and exploration sectors by setting clear and binding climate targets. Furthermore, they could hedge against geopolitical threats by diversifying their mineral supply. They could support project development by providing financing support to project developers, easing permitting procedures, boosting geological mapping and raising public awareness of the contribution that such projects play in the green transformation.[89] Furthermore, recycling, reducing material intensity, and material substitution[90] can help reduce the demand for critical minerals.

4.2. Supply of critical minerals is turning into a strategic priority

As the strategic importance of critical minerals for the global decarbonisation agenda intensifies, so too does the strategic importance of mining. With the expected increase in the mining of critical minerals in the next few decades, there is a risk that mining could intensify pressure on

[87] See World Bank Group (2016), 'Special Focus - From Commodity Discovery to Production: Vulnerabilities and Policies in LICs' (Global Economic Prospects, January 2016); UNECA (2011), 'Minerals and Africa's Development: The International Study Group Report on Africa's Mineral Regimes', available at https://repository.uneca.org/handle/10855/21569.
[88] See International Energy Agency (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.122.
[89] See International Energy Agency (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.14.
[90] We note that researchers are currently investigating alternatives to REEs for usage in high-performing magnets, which are 'vital for building a zero-carbon economy'. However, the substitution of REEs is still a long way off as alternative technologies are only being developed. See University of Cambridge, 'New approach to 'cosmic magnet' manufacturing could reduce reliance on rare earths in low-carbon technologies' (25 October 2022), available at https://www.cam.ac.uk/research/news/new-approach-to-cosmic-magnet-manufacturing-could-reduce-reliance-on-rare-earths-in-low-carbon, accessed 22 February 2023.

natural habitats and local communities in host countries, exacerbating existing environmental and social challenges.

Mines are geographically fixed due to the geological occurrence of economically viable mineral deposits. This makes local factors around current and future mines a particularly important consideration.

As set out above, many of the world's current critical minerals are concentrated in a few countries, some of which are economically or politically challenging.[91] Mining operations can also have negative social impacts stemming from bribery and corruption, the misuse of government resources, encroachment into conservation areas,[92] fatalities and injuries to workers and members of the public, and human rights abuses, including child labour and unequal impacts on women and girls.[93] Further, the Extractive Industries Transparency Initiative (EITI) has found that among 700 critical mineral projects (mines and known mineral deposits) in EITI-implementing countries, 50% are located in proximity to nature conservation areas, including key biodiversity areas, biodiversity hotspots, and land and marine protected areas.[94]

If increased mining is managed responsibly, the mining industry can play a significant role in sustainable development. Good governance is critical.

Failure to tackle these challenges head-on could result in a missed opportunity to encourage the growth of a profitable and responsible mining sector to deliver the energy transition and contribute to sustainable development. However, if managed responsibly, the mining industry can play a significant role in sustainable development. Good governance will be critical to achieving this.

There has been a significant international effort to develop instruments to address governance gaps in the extractive sector.[95] Most recently, Canada, Australia, France, Germany, Japan, the USA and the UK have forged the Sustainable Critical Minerals Alliance, which focuses on making mining more sustainable and inclusive. It includes, among others, the following initiatives.

- Net zero and nature-positive strategies to prevent biodiversity loss.
- Restoring ecosystems and returning mine sites to their natural state.
- Fostering ethical corporate practices, including Sustainability Reporting and supply chain due diligence intelligence.
- Developing an ESG agenda for local communities.[96]

Looking ahead, frameworks that govern this space are rapidly evolving in line with increasing international stakeholder demands, and legislation will likely follow voluntary standards. In any case, increased scrutiny is expected from investors and policymakers on all companies especially in the mining value chain.

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[91] See IEA, 'Critical minerals', available at https://www.iea.org/topics/critical-minerals, accessed 27 January 2023.
[92] EITI (2022), 'Mission Critical: strengthening governance of mineral value chains for the energy transition', available at https://eiti.org/documents/mission-critical, p.9.
[93] IEA (2021), 'The Role of Critical Minerals in Clean Energy Transition', p.192.
[94] See EITI (2022), 'Mission critical: strengthening governance of mineral value chains for the energy transition', p.36.
[95] Examples include the Africa Mining Vision, United Nations Guiding Principles on Business and Human Rights, the Extractive Industry Transparency Initiative, the Dodd-Frank Act, the Global Reporting Initiative, the Model Mining Development Agreement, the Initiative for Responsible Mining Assurance, the National Resource Charter, International Council on Mining.
[96] Natural Resources Canada, 'Countries Commit to Sustainable Development and Sourcing of Critical Minerals' (12 December 2022), available at https://www.canada.ca/en/natural-resources-canada/news/2022/12/countries-commit-to-the-sustainable-development-and-sourcing-of-critical-minerals.html, accessed 22 February 2023.

5. The business case for natural capital mapping and accounting

Box 5.1 Key messages

1. Traditionally, the services and goods provided by global ecosystems were not priced or traded on a market. Recent studies put the explicit value of nature in the global economy at $9.8 trillion worth of goods and services. While this is significant, and equivalent to 10 percent of global GDP, the actual value of nature to the global economy is under-priced.

2. The failure to properly account for the value of natural resources leads to inefficient use of these resources. A proper valuation of natural capital could act as an inventory list, or portfolio of assets which can "revalue" the net wealth of a country. Natural capital accounting can monitor a country's capacity for sustainable development and provide the basis for long term policy decisions for growth.

Countries rich in renewable and non-renewable natural resources could consider taking steps to map and account for their whole stock of natural capital, maximise its efficient use, and drive sustainable development. Critically, for developing nations, leveraging natural capital could be key for a number of things: to explore new economic development opportunities, to improve its fiscal position and access to capital markets and to rebalance its position as recipients of cooperation finance.

Traditionally, services and goods provided by global ecosystems were not priced or traded on a market. The actual value of nature to the global economy is under-priced.

5.1. The value of natural capital

As set out in section 3, the need to address climate change and concerns around supply chain security have led to a push for the energy transition and a race for natural resources. Tackling these interconnected issues requires carefully balancing driving development and mitigating the potential harms associated with the race for natural resources, including biodiversity loss.

Traditionally, the services and goods provided by global ecosystems were not priced or traded on the market. The costs of exploiting these resources for commercial purposes were therefore not adequately priced, leading to widespread degradation of natural habitat and biodiversity. Establishing markets for natural capital can help internalise the traditionally externalised costs of ecosystem exploitation.

Natural capital accounting could rebase national wealth, monitor capacity for sustainable development and ameliorate a variety of economic stresses.

Natural capital mapping and accounting are increasingly being recognised as critical tools for sustainable development decisions and economic forecasting.

Recent studies put the explicit value of nature in the global economy at $9.8 trillion worth of goods and services.[97] While this is significant and equivalent to 10%of global GDP, the actual value of nature to the global economy is underpriced. For example, a mining operation may contribute to GDP growth in a year, but the value contributed by a water source that is existential to that mining operation will not be accounted for. The failure to properly account for the value of natural resources leads to inefficient use of these resources.[98]

5.2. Natural capital is the key to sustainable development

A proper valuation of natural capital could act as an inventory list, or portfolio of assets which can revalue 'the net wealth of a country'. Natural capital accounting can monitor a country's capacity for sustainable development and provide the basis for long-term policy decisions for growth.

For countries that are looking to attract investment, a rebasing of national wealth would increase their fiscal margin, unlocking potential for greater access to borrowing, which can be used for development directly, but can also be used to ameliorate other economic stresses which prevent sustainable development, especially in the context of the global economic slowdown and global debt crisis. Data from the World Bank shows that Sub-Saharan Africa is facing a ratio of 45% of external debt to its gross national income, with many countries having a ratio over 50% and some as much as 125%[99]—despite the actual and potential value of many African countries' natural resources in combatting climate change, in providing environmental services to the rest of the global economy, and in accelerating the energy transition.

Therefore, for any given country to maximise sustainable development, a comprehensive understanding of its natural capital and the ecosystem services provided by its natural capital could be essential. This requires 1) comprehensive mapping of natural resources, and 2) a systematic programme of natural capital accounting to be integrated into development decisions.

Natural capital mapping and accounting are increasingly recognised as critical tools for sustainable development decisions and economic forecasting.

[97] Nature Finance (2022), 'Global Nature Markets Landscaping Study', available at https://www.naturefinance.net/resources-tools/global-nature-markets-landscaping-study/, p.7.
[98] Nature Finance (2022), 'Global Nature Markets Landscaping Study', p.4.
[99] World Bank Group (2022), 'International Debt Report 2022: Updated International Debt Statistics', available at https://openknowledge.worldbank.org/bitstream/handle/10986/38045/9781464819025.pdf?sequence=8&isAllowed=y, p.35.

Table 5.1 provides some examples.

Table 5.1 Natural Capital Accounting Trends and Strategies

Country	Natural Capital Accounting Trends and Strategies
USA	On 19 January 2023, the US government released the final version of the' National Strategy to Develop Statistics for Environmental-Economic Decisions '. The objective of the policy is to expand the national economic accounting system to include natural capital and allow the USA to improve economic growth forecasts and ultimately make better informed choices to enhance economic prosperity.[100] The US strategy has placed an emphasis on gathering' better data to understand nature's critical contributions to the U.S. economy and to guide policy and business decisions moving forward.'
Gabon	The UN Economic Commission for Africa, UN Environment Programme and UN Development Programme are currently working with the government of Gabon to use natural capital accounting to audit its forests and determine the exact value of the carbon sink they provide to help store greenhouse gases from worsening the global climate challenge. Less than 1% of the country's 230,000 square km of forest has been depleted.[101]
Ghana	Ghana has established a natural capital accounting technical working group, which is supported by the World Bank and United Nations Statistics Division. The programme is focused on building technical capacity and the development of natural capital accounts and policy analysis tools. The aim is for these tools to inform policy at all levels, for example, in the implementation of projects like the Ghana Landscape Restoration and Small-Scale Mining Project, financed by the World Bank.[102]
Zambia	In 2016, Zambia began work on a system to account for its valuable natural resources, underpinned by two principles: 1. GDP may increase in the short term, but if environmental degradation is not accounted for, it will be at the expense of future prosperity; 2. future prosperity need not, and should not, compromise communities that depend on natural resources for their daily lives. According to the national wealth accounts prepared by the World Bank, natural resources make up 40% of the country's wealth and are a cornerstone for its economic growth and strategies for poverty reduction. So far, Zambia has developed four natural capital accounts: Forestry, Water, and Land were published in 2019; Tourism is in its final stages. Work is also underway on an Energy & Minerals account.[103]

[100] The White House, 'Fact Sheet: Biden-Harris Administration Releases National Strategy to Put Nature on the Nation's Balance Sheet', (19 January 2023) available at https://www.whitehouse.gov/ostp/news-updates/2023/01/19/fact-sheet-biden-harris-administration-releases-national-strategy-to-put-nature-on-the-nations-balance-sheet/, accessed 20 February 2023.
[101] Joint SDG Fund, 'Using what you have to get what you want: why Central African countries must put their natural capital accounting at the centre of their development' (19 April 2022), available at https://jointsdgfund.org/es/node/1128, accessed 21 February 2023.
[102] World Bank (2022), 'Event: Strengthening Ghana's Capacity to Measure and Value Natural Capital', available at https://www.worldbank.org/en/events/2022/11/28/strengthening-ghana-s-capacity-to-measure-and-value-natural-capital#1, accessed 21 February 2023.
[103] World Bank, 'In Zambia, Natural Capital Accounts Ensure Future Prosperity for All' (18 November 2022), available at https://www.worldbank.org/en/news/feature/2022/11/18/in-zambia-natural-capital-accounts-ensure-future-prosperity-for-all, accessed 21 February 2023.

Country	Natural Capital Accounting Trends and Strategies
Liberia	In 2021, the Liberian government, in partnership with Conservation International and NASA piloted an innovative and replicable approach to more accurately map ecosystems to support effective planning and sustainable decision-making. The project forms a part of Liberia's delivery on their commitment to Gaborone Declaration for Sustainability in Africa. The overall objective of the Declaration is "To ensure that the contributions of natural capital to sustainable economic growth, maintenance and improvement of social capital and human well-being are quantified and integrated into development and business practice." According to NASA, their satellite data and expert analysis "will provide a country-wide picture of Liberia's hardwood forests, mangroves, and other ecosystems". They also state that "Conservation International and the Liberian Government through the EPA will augment that data with their expertise in ecosystem accounting, field studies, and local knowledge to quantify the value of the country's natural resources and related ecosystem services."[104] It has been reported that while the project is focusing on Liberia for now, there are plans to expand to Botswana and Gabon in the future.[105]

[104] NASA, 'Economics of Nature: Mapping Liberia's Ecosystems to Understand Their Value' (11 March 2021), available at https://www.nasa.gov/feature/goddard/2021/economics-of-nature-mapping-liberia-s-ecosystems-to-understand-their-value, accessed 21 February 2023.
[105] NASA, 'Economics of Nature: Mapping Liberia's Ecosystems to Understand Their Value' (11 March 2021), available at https://www.nasa.gov/feature/goddard/2021/economics-of-nature-mapping-liberia-s-ecosystems-to-understand-their-value, accessed 21 February 2023.

6. How can airborne exploration play a role?

Box 6.1 Key messages

1. Good quality data can help make mining operations more efficient at the mapping and exploration stages.
2. Quality data can also help to attract investment in mining exploration. Many countries either do not possess geological mapping data, or have which has been collated many years ago, without the benefit of modern techniques.
3. Part of this data can be provided using airborne exploration in the mapping and exploration stages of the mining cycle.

As indicated above, obtaining data in relation to natural resources can play an important part of mitigating climate change, accelerating the energy transition and promoting sustainable development, all while mitigating environmental damage to key ecosystem services. Within natural capital tools and techniques, airborne exploration plays a more specific role.

The anticipated increase in demand for minerals, and therefore mining activity, presents an opportunity for resource-rich countries and to attract investment in exploration activities in countries which are under explored, yet have geology conducive to the possible critical mineral deposits. There is potential for making new discoveries of mineral deposits using cutting-edge mapping data, which will assist with meeting demand and diversification of supply. At the same time, the efficiency of mining will become an important issue and the associated environmental risks must be addressed. A key component of achieving investment, new discoveries, and sustainable mining, is the availability of quality data.

6.1. Geophysical data is key to the "mapping" and "exploration" stages of the mining cycle

Airborne geophysics is deployed in both the regional mapping stage, and in greenfield or "grassroots" and in in-mine brownfields exploration stages of the mining cycle.

Regional mapping comprises substantial airborne geophysical analysis of a country's territory, deploying various airborne sensors to better understand the underlying geology.

Greenfield exploration involves locating new mineral deposits in places that have not already been mined. Occasionally, it is also deployed in brownfield (in or near mine) environments to assist in the detection of any satellite, deeper or extension mineral deposits.

The ability to take a holistic view, both in terms of renewable natural resources and ecosystem services, and non-renewable resources like critical minerals, requires good quality data.

The data collected using airborne geophysics during these stages is then used alongside other exploration techniques to assess the potential for mineral deposits.

6.2. The importance of data

The ability to take a holistic view, both in terms of renewable natural resources and ecosystem services, and non-renewable resources like critical minerals, requires good-quality data. Robust natural capital accounts will be informed by data gathered at the regional mapping and exploration stages of the mining cycle. Not only may this data contribute to improving the efficiency of mining operations, and mitigating the environmental risks associated with these operations, but it can also play a role in integrated natural resource management.

Box 6.2 Case Study: How geological data can inform natural resource management

Groundwater is the most commonly extracted natural resource in the world, with an estimated annual withdrawal of 600-1,100 km^3 per year.[1] The increasing demand for groundwater due to changes in surface water availability, climate, population growth, and management has led to significant stress on global groundwater systems. Despite its critical importance, aquifers have not been explored in detail compared to other natural resources like oil and gas reservoirs. As a result, groundwater remains a mostly hidden resource.[2]

Airborne geophysical survey can inform the management of groundwater resources by providing detailed information on fault locations, sedimentary layers, and other geological features.[3] This information is key for understanding a region's hydrology and subsurface structures. Thereby, airborne electromagnetic (AEM) methods can fill a critical scale gap between ground-based and satellite methods.[4] In combination with ground-based observations, remotely sensed data of changes at the Earth's surface are greatly improving the predictive capabilities of groundwater simulations and management.[5]

One of the first regional AEM studies has been conducted on the Lower Mississippi Valley. The study shows that having a better understanding of the surficial aquifer structure and surrounding geological formations is crucial not only for effective water resource management but has implications for hazard investigations as well.[6]

Sources: [1] See Siebert, S. et al. (2019), 'Groundwater use for irrigation – a global inventory', *Hydrol. Earth Syst. Sci. 14*, pp.1863–1880; and Margat, J. and van der Gun, J. (2013), 'Groundwater Around the World: A Geographic Synopsis', CRC Press/Balkema. [2] Minsley, B.J. et al (2021), 'Airborne geophysical surveys of the lower Mississippi Valley demonstrate system-scale mapping of subsurface architecture', *Commun Earth Environ 2.* [3] Ibid. [4] Ibid. [5] National Academies of Sciences (2019), 'Engineering, and Medicine. Groundwater Recharge and Flow: Approaches and Challenges for Monitoring and Modeling Using Remotely Sensed Data: Proceedings of a Workshop', The National Academies Press. [6] Minsley, B.J. et al (2021), 'Airborne geophysical surveys of the lower Mississippi Valley demonstrate system-scale mapping of subsurface architecture', *Commun Earth Environ 2*. More information on the data collection methods of the Lower Mississipi Valley study has been published by USGS (2021), 'Airborne electromagnetic, magnetic, and radiometric survey of the Mississippi Alluvial Plain, November 2019 - March 2020', February 10.

Further, quality data can reduce uncertainty in the exploration stages of mining. Host countries typically place natural resources mapping data on an open file system to attract exploration companies to invest. Exploration is extremely time consuming (sometimes taking up to 10 years) and expensive, with a low rate of return on investment (see Box 7.2).

Box 6.3 Case Study: AusAEM, Australia-wide Airborne Electromagnetic Project

AusAEM is the world's largest airborne electromagnetic (AEM) survey ever undertaken and is part of the Australian Government's Exploring for the Future Program (EFTF). The EFTF initiative recognizes that most of Australia is covered by surficial sediments and sand/soils, which increases explorer risk and cost, and deters exploration investment in many covered areas.

In response, the AusAEM Project, aims to cover the entire Australian Continent with regional airborne electromagnetic lines to:

- Map the cover thickness, character and variability
- Map basement geology under cover
- Map the potential of mineral, groundwater and energy resources

The information acquired is used to effectively de-risk, inform and focus exploration investment.[1] AusAEM's strategic priorities, progress against which are reported on each year, are:

- Building Australia's resources wealth—to maximise benefits from our mineral and energy resources, now and into the future.
- Supporting Australia's community safety—to strengthen our resilience to natural hazards.
- Securing Australia's water resources—to optimise and sustain their use.
- Managing Australia's marine jurisdictions—and supporting sustainable use of our marine environment.
- Creating a location-enabled Australia—to increase economic, environmental and social prosperity of Australia.
- Enabling an informed Australia—to equip government, communities and industry with geoscience data and information to make decisions for our nation.[2]

In 2019, the survey provided "*new insights into mineral-rich areas in Northern Australia that have been extensively explored previously*". These new potential mineral deposits included gold, copper, nickel, lead, zinc and manganese, as well as critical minerals such as cobalt, platinum-group elements and rare-earth elements.[3]

In 2022, the "Mineral Potential Mapper" project, enabled by new digital datasets at continental scale, predicted high potential for nickel, copper and platinum group sulfide deposits in a wide range of geological regions across Australia. The project also modelled two hypothetical mine development scenarios. The models estimate that the two development scenarios could generate an overall benefit to the Australian economy of between $3.48 billion and $4.57 billion and between $1.21 billion and $1.56 billion in net benefits to the Commonwealth in terms of taxation.[4]

Sources:

[1] Australian Government, Geosciences Australia : available at: https://www.ga.gov.au/about/projects/resources/geophysical-acquisition-and-processing/airborne-electromagnetics, accessed 24 February 2023

[2] Geoscience Australia Corporate Plan 2022-23 to 2025-26, available at: https://www.ga.gov.au/__data/assets/pdf_file/0006/122919/2022-23-Corporate-Plan-FINAL.pdf , Accessed 20 March 2023

[2] Asia Miner, "World's largest airborne electromagnetic survey reveals more mineral potential in Australia's north", available at: https://www.asiaminer.com/news/latest-news/9706-world-s-largest-airborne-electromagnetic-survey-reveals-more-mineral-potential-in-australia-s-north.html#.Y-46fXbP2Uk Accessed 24 February 2023.

[3] ACIL Allen Consulting, Mineral potential mapper A GEOSCIENCE AUSTRALIA CASE STUDY, available at: https://d28rz98at9flks.cloudfront.net/147074/147074_00_0.pdf, accessed 24 February 2023;

Box 6.4 Case Study: Angola

Angola's mining and exploration potential has long been associated with diamonds, and oil and gas, despite its vast territory and mineral potential. A lack of up to date geological data had historically caused investor uncertainty. 'In 2013, in a bid to make Angola a more attractive mining destination, the Geological Institute of Angola (IGEO) established the National Geology Plan (Planageo). Planageo's objective was to conduct geophysical surveys to map Angola's mineral resources, and diversify the nation's economy away from oil and gas.[1]

In 2023, after completion of Planageo, the Minster of Mineral Resources, Oil and Gas, announced that Angola a large stock of critical minerals, including chromium, cobalt, copper, graphite, lead, lithium and nickel, among others.[2] After this announcement, it was reported that three major mining companies intended to invest in Angola's mining industry.[3]

Sources:
1 Economist Intelligence, "Government pushes mining sector development" available at: http://country.eiu.com/article.aspx?articleid=712518455&Country=Angola&topic=Economy&subtopic=For_7 , accessed 22 March 2023.
2 Ver Angola, Government confirms that Angola has 36 of the 51 critical minerals considered most critical in the world, available at: https://www.verangola.net/va/en/022023/RawMaterials/34367/Government-confirms-that-Angola-has-36-of-the-51-minerals-considered-most-critical-in-the-world.htm, accessed 22 March 2023.
3 All Africa, Angola's mining potential attracts multinationals, available at: https://allafrica.com/stories/202302090067.html accessed 22 March 2023.

Lack of up-to-date geological data can hamper exploration investment and success.

There are clear regional differences in mineral exploration investment, but these differences are often disproportionate to actual mineral production. The UNDP has reported that the regional differences in mineral exploration investment and success have less to do with a lack of geological potential and more to do with a combination of several factors aggravating factors, of which a lack of geological data is one.[106][107]

Box 6.5 Exploration expenditure vs land mass

In 2017, Canada and the United States netted 21% share of global expenditure on exploration, despite only making up a 12% of production and land mass. Australia, Canada and the United States together accounted for one third of the total global exploration expenditure. Conversely, Africa, which has around 20% of the global land mass area, only attracted about 14% of total global mineral exploration expenditure. Latin America accounts for 12% of land mass and attracted more than 20% of global exploration expenditure.

Source: Data from Ericsson, M. and Olöf, O.(2017). Mining's contribution to low-income and middle-income economies. UNU-WIDER Working Paper 148. Helsinki, Finland: United Nations University World Institute for Development

The USGS has stated that there is "generally is a good correlation between land area and the number of mineral commodities",[108] but that alongside levelling the economic and environmental playing fields, more basic geological information is required.[109] According to the USGS,

[106] These include political instability, political and legal uncertainty, lack of transparency, corruption, lack of geological data, poor transport and/or energy infrastructure.
[107] UN Environment Programme (2020), 'Mineral Resource Governance in the 21st Century: Gearing extractive industries towards sustainable development', available at https://www.unep.org/resources/report/mineral-resource-governance-21st-century, p.65-67.https://www.unep.org/resources/report/mineral-resource-governance-21st-century p65-67
[108] Stephen E. Kesler, 'Mineral Supply and Demand into the 21st Century', *Proceedings, Workshop on Deposit Modelling, Mineral Resource Assessment, and Sustainable Development,* available at https://pubs.usgs.gov/circ/2007/1294/reports/paper9.pdf, accessed 20 February 2023, p.59.
[109] Stephen E. Kesler, 'Mineral Supply and Demand into the 21st Century', Proceedings, Workshop on Deposit Modelling, Mineral Resource Assessment, and Sustainable Development, p.60.

conducting geologic mapping and related geochemical and geophysical surveys and compiling data on known deposits, prospects, and favourable geologic environments will provide critically important background data on the surface and near-surface part of our planet to guide future exploration.[110]

Some key trends in the collation of robust natural resources data that reflect the increasing importance of investing in mapping include:

- The USA announced that it would improve its mapping of critical mineral deposits[111]and also its plan to assess its natural capital and integrate it into economic decision-making.[112]
- Japan is providing subsidies for both public and private resource exploration projects and is also investing in expanding knowledge of its submarine mining deposits.[113]
- In Australia, the government has launched a programme to fund projects that use innovative technologies to improve geological surveys.[114]

Increasing and diversifying supply

Greater investment in natural resource mapping can also assist in diversifying the supply of critical minerals, by helping with the discovery of deposits in the same countries or in others.

Box 6.6 Case Study: Namibia

Namibia has a long history of proactive airborne geophysical survey coverage. The Government funded a large-scale project from circa 1974, progressively acquiring data over the whole country at a 1,000 metre line spacing comprising magnetic and radiometric coverage. In 2000, Namibia received EU-SYSMIN funding to survey the country at a 200-metre line spacing, deploying fixed-wing survey platforms and acquiring magnetic and radiometric data. Subsequently, the Government commissioned added technology pilot surveys, including Gravity, Electromagnetic and hyperspectral data surveys over designated target areas.

The country has the potential to develop new mining projects for cobalt and lithium. Global lithium exploration and development company Lepidico Ltd. is developing a lithium mine in western Namibia and is in discussion with multiple U.S. companies on possible off-take for its lithium as well as by-products cesium and rubidium. Desert Lion began shipping lithium ore in 2018, with the first shipment of 30,000 tons. Gecko Opuwo Cobalt is developing a cobalt deposit in Kunene Region.

In 2022, Namibia announced a significant find of Rare Earth Elements (REEs) on a farm in north central Namibia. With a proven ore body of 579 million tons and a cut-off grade of 0.02 to 1.00 percent of REE-bearing materials, prospects seem highly positive. Namibia is keen to partner with U.S. investors and off-takers.

Source: Xcalibur

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[110] Stephen E. Kesler, 'Mineral Supply and Demand into the 21st Century', Proceedings, Workshop on Deposit Modelling, Mineral Resource Assessment, and Sustainable Development, p.60.
[111] IEA (2021), 'Critical Minerals and Materials: US Department of Energy's Strategy to Support Domestic Critical Mineral and Material Supply Chains', available at https://www.iea.org/policies/15533-critical-minerals-and-materials-us-department-of-energys-strategy-to-support-domestic-critical-mineral-and-material-supply-chains, accessed 20 February 2023.
[112] The White House, 'A New National Strategy to Reflect Natural Assets on America's Balance Sheet' (18 August 2022), available at https://www.whitehouse.gov/omb/briefing-room/2022/08/18/a-new-national-strategy-to-reflect-natural-assets-on-americas-balance-sheet/, accessed 22 February 2023.
[113] IEA (2022), 'Critical Minerals Policy Tracker: Promoting exploration, production and innovation', available at https://www.iea.org/reports/critical-minerals-policy-tracker/promoting-exploration-production-and-innovation.
[114] IEA (2022), 'Critical Minerals Policy Tracker: Promoting exploration, production and innovation'.

Where is data lacking?

Despite, in some cases, already playing a significant role in the supply of critical minerals, many countries do not have modern and publicly available geological data. Some examples listed below include the Democratic Republic of the Congo, Zambia, Kazakhstan, Argentina, Peru and Mexico.

Table 6.1 Examples of insufficiencies in mapping data for various countries

Country	Last known mapping data
Democratic Republic of the Congo	1980s, analogue, low resolution and limited to magnetic data
Zambia	Various survey companies have flown the entire country between 1970 and 1985; the data acquired is magnetic and occasionally radiometric. The data is analogue, and some were digitised; however, the resolution is low as it is limited to the contour interval. As a result, the information is low resolution, dated and generally missing essential radiometric data.
Kazakhstan	Kazakhstan's existing data has coverage primarily collected using older techniques starting in the 1950s, with some more modern, prospect size, coverage collected in the last 10 years on a smaller scale.
Argentina	Argentina has very sparse and old geophysical public data available in the country, primarily Magnetic and Radiometric data, according to SEGEMAR website (Geological Survey of Argentina).
Peru	Peru has very sparse and old geophysical public data available in the country, primarily Magnetic data. Most surveys were flown three decades ago.
Mexico	Has airborne magnetic data covering almost the entire country, but the data is old and collected decades ago.

7. Bridging the funding gap

Box 7.1 **Key messages**

1. More funding into exploration activities is needed to fuel the energy transition.
2. The recent surge in commodity prices could make private investments across the value chain more attractive.
3. Differences in needs and issues across segments of the value chain should be taken into account when designing new financial instruments or policies.

Despite recent efforts by mining companies to map their concessions and show their potential, exploration activities have not kept pace with the needs of the transition to a low-carbon economy. The mapping, exploration and mining sectors face a significant investment challenge to ensure that future demand can be met.

The capacity to increase output at existing mines is relatively limited, meaning most of the increased demand will need to be met by new mines. Recent estimates indicate that over 70 new average-sized lithium and nickel plants are needed by 2030 to meet the mineral requirements consistent with a net zero path. In addition, 30 new cobalt mines and 80 new copper mines would be required to satisfy the expected demand.[115]

More funds are needed to bridge the gap in the supply of raw materials.

As noted in section 6, lead times from exploration to production can range between several years to two decades,[116] meaning that new investments are time-sensitive. Recent estimates indicate that anticipated investment ranges between US $180bn and US $220bn, but investments of US $360bn to US $450bn would be required between 2022 and 2030 to reach the expected level of production in line with a net zero target. This implies that a funding gap exists, as presented in Figure 7.1. A significant part of the additional investment would be needed for copper (62%) and nickel (33%).[117]

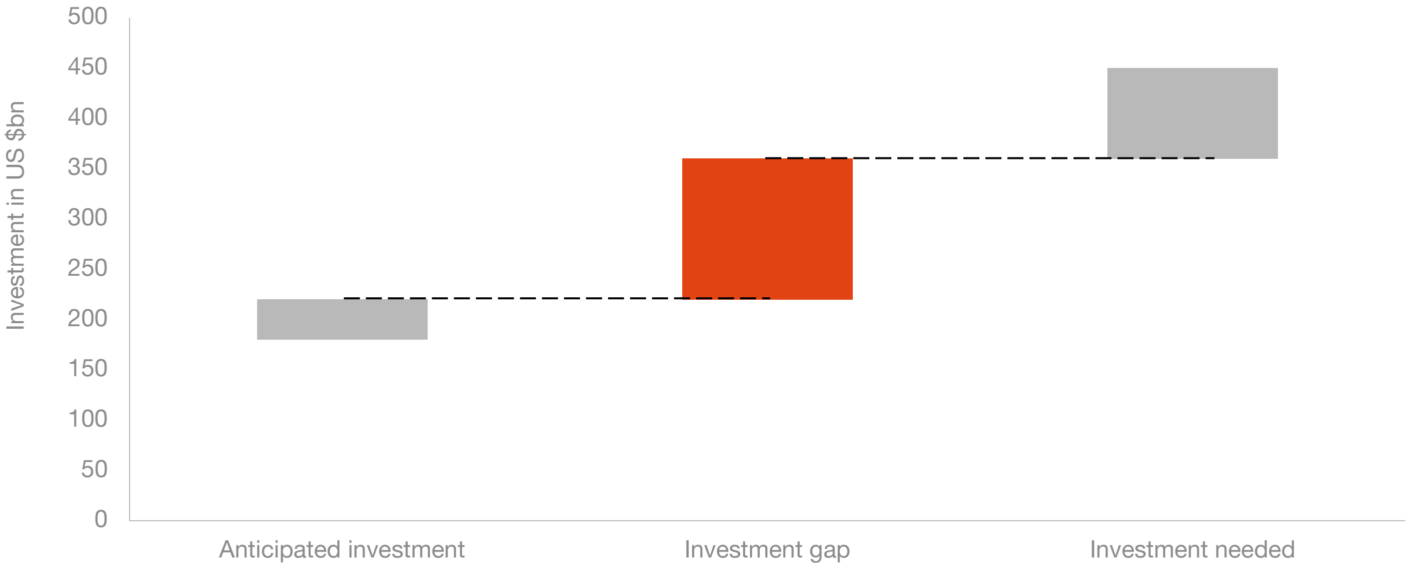
[115] IEA (2023), 'Energy Technology Perspectives 2023', p.164.
[116] IEA (2022), 'The Role of Critical Minerals in Clean Energy Transitions', p.12.
[117] IEA (2023), 'Energy Technology Perspectives 2023, p.165.

Box 7.2 The increasing cost of mineral reserve discovery

In recent years, the value of mineral discoveries has not kept up with the cost of exploration activities. Industry experts estimate that the money spent on exploration activities between 2011 and 2020 exceeded the value of discoveries by 57%.[1] This implies that for every dollar spent on exploration activities, only c. 60 cents of value were generated in return. More efficient and targeted exploration to verify the quality of mineral deposits could help better allocate on-the-ground exploration activities to the most promising areas and could thereby help reduce the environmental impact of mining. Furthermore, airborne geophysical mapping technology can help reduce the cost of discovery as it is considerably cheaper and faster than traditional mapping and ground techniques. This is particularly true in complex orographies such as forests, mountains and deserts.

Source: [1] Schodde (2022), 'Indonesia's Discovery Performance', August.

Figure 7.1 Investment needed to meet mineral demand over 2022–30 to reach net zero by 2050



Note: Grey bars indicate estimated ranges of anticipated and needed investments. The red bar indicates the definitive investment gap.
Source: Oxera analysis based on IEA (2023), 'Energy Technology Perspectives 2023', January.

Systematic mapping of natural resources to obtain high-quality data on a country's potential natural resources could assist in closing this investment gap. Increased efforts with respect to exploration and mine development are likely to be needed to meet future minerals demand. Each of these activities is costly and relies on different sources of financing and funding.

Box 7.3 **Case Study: How minerals mapping and exploration helped attract investment in the Australian mining industry**

Up-to-date data on natural resources is missing in many places that might be resource-rich (see section 6.2). This lack of accurate data could prevent investments into exploration and thereby prevent local economies from taking advantage of their natural resources. Natural resources mapping can enable the economic benefits described above by attracting mining exploration investment.

Australia is one of the countries that has been successful in mapping and attracting investment. The Australian government is investing into critical minerals funding and exploration activities.[1] It is one of the locations using advanced airborne geophysical technologies to complement existing geological and geochemical data.

It became famous for mining during the first goldrushes of the 1850s.[2] In the 20th century, systematic geological surveys mapping the Australian surface created the basis for commercial exploration on a larger scale, which helped the sector grow.[3] Today, Australia has become one of the world's most important producers of raw materials and the sector makes up about 15% of the country's GDP.[4] The Australian government continues to put a high priority on minerals mapping and has launched several initiatives and programmes to promote explorations including airborne mapping.[5]

Sources: [1] Australian Government Department of Industry, Science and Resources website, https://www.industry.gov.au/mining-oil-and-gas/minerals/critical-minerals, accessed 23 March 2023. [2] Australian Mining History Association (2023), 'Australian Mining History', accessed 30 January 2023. [3] Australian Academy of Science (2010), 'Searching the Deep Earth: The Future of Australian Resource Discovery and Utilisation', 19–20 August. Canberra. [4] Reserve Bank of Australia (2023), 'Composition of the Australian Economy', 5 January, accessed 30 January. [5] See, for example, Geoscience Australia (2023), 'Critical Minerals at Geoscience Australia: Critical Minerals Mapping Intiative'; Geoscience Australia (2023), 'Airborne Electromagnetics', accessed 30 January 2023.

The recent surge in commodity prices could make private investments across the value chain more attractive.

Mappings are often financed by governments in order to attract inward investment (see section 5). However, the largest reserves of relevant raw materials are often located in regions where governments may not have the financial means to invest in mapping activity.[118] The economic headwinds discussed in section 2 will likely pose further challenges for such investment from both the private and the public sector, and a recent surge in debt servicing costs is putting additional pressure on many highly indebted low-income countries.[119]

One possible solution to these issues is increased multilateral cooperation to support countries in mapping their natural resources. Examples of multilateral development cooperation projects include the IMF's 'Managing Natural Resource Wealth Thematic Fund', which helps countries to manage natural resource wealth,[120] and the World Bank's 'Climate-Smart Mining Facility', a multi-donor trust fund that aims to work with developing and emerging economies to implement sustainable strategies and practices across the mineral value chain. The facility includes support for 'the strategic use of geological data for a better understanding of "strategic mineral" endowments'.[121]

To finance regional mapping in developing countries, private and public finance is often combined.[122] Multi-client models which have been used in the oil and gas industry could prove helpful in financing clean energy minerals projects in the future. Other options for developing markets include private financing with guarantees from multilateral entities or from developed

[118] IEA (2023), 'Energy Technology Perspectives 2023, p.87.
[119] UNCTAD, 'World leaders call for stronger multilateral solutions to debt crisis' (5 December 2022), available at https://unctad.org/news/world-leaders-call-stronger-multilateral-solutions-debt-crisis, accessed 27 January 2023.
[120] IMF. 'Press Release: IMF and Partners launch new phases of the Managing Natural Resource Wealth and Revenue Mobilisation Trust Funds' (16 June 2016), Press Release No. 16/288, available at https://www.imf.org/en/News/Articles/2015/09/14/01/49/pr16288, accessed 23 February 2023.
[121] World Bank, 'Press Release: New World Bank Fund to Support Climate-Smart Mining for Energy Transition' (1 May 2019), available at https://www.worldbank.org/en/news/press-release/2019/05/01/new-world-bank-fund-to-support-climate-smart-mining-for-energy-transition, accessed 18 January 2023.
[122] See, for example, IEA (2022), 'METI Geological survey funding', https://www.iea.org/policies/16637-meti-geological-survey-funding, accessed 23 March 2023.

economies that seek access to critical raw materials and participation in the clean energy value chain.[123]

While the private sector is also affected by the global economic outlook, the recent surge in commodity prices may offer an incentive across the mining sector to attract more investment[124] and fund activities such as mapping and data collection which are further up in the value chain.

For exploration and extractive activities, similar to resource mapping, financing options can be broadly categorised into private, public and development finance. There are a wide variety of market-based financing instruments ranging from equity to debt financing. While not commonly used in the mining sector at present, these can include sustainable finance instruments such as green, social or sustainability-linked bonds (examples of use cases in the mining sector can be found in Box 7.4).

Box 7.4 Use-cases of sustainable finance in the mining industry

Green bond
In 2019, the Swedish state-run mining company Luossavaara-Kiirunavaara was the first firm to issue a green bond from within the mining sector. The proceeds from the $210m, dual-tranche green bond are earmarked for:

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the company's electrification and research on decarbonising iron ore mining and steel production;
relocating the town of Kiruna, which is threatened by subsidence from the iron ore mining beneath it, using climate-resilient materials and low-carbon building methods.[1]

Sustainability-linked bond (SLB)
In 2022, Anglo American plc issued a €745m SLB, which is tied to the company's targets of:

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reducing absolute greenhouse gas emissions (Scopes 1 and 2) by 30% by 2030, compared to 2016;
reducing the abstraction of fresh water in water-scarce areas by 50% by 2030 compared to 2015;
supporting 5 jobs off site for every job on site by 2030.[2]

Source: [1] Environmental Finance (2019), 'First green bond from mining company issued', 4 December, accessed 20 January 2023. [2] Anglo American (2022), 'Anglo American launches €745 million sustainability-linked bond', 14 September, accessed 20 January 2023.

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[123] Example include the Partial Risk Guarantee provided by the African Development Bank, or the World Banks Multilateral Investment Guarantee Agency, see OECD (2023), 'International Financial Institutions', https://www.oecd.org/fr/sites/mena/competitivite/ismed-international-financial-institutions.htm, accessed 23 March 2023.
[124] Morgan Stanley, '2023 Global Investment Outlook: A Year for Yield' (22 November 2022), available at https://www.morganstanley.com/ideas/global-investment-strategy-outlook-2023, accessed 23 January 2023.

Differences in needs and issues across segments of the value chain should be taken into account when designing new financial instruments or policies.

These instruments aim to align financial decision-making with long-term sustainability goals and could help the sector ensure that minerals are mined responsibly, minimising any negative environmental and social impact.[125] The lack of standardisation of instruments and data availability, however, makes it difficult for the companies in the sector to meet monitoring and reporting requirements and convince investors of their sustainability.[126] Another example of market-based financing is joint ventures, i.e. arrangements in which the provision of risk capital is shared between two or more firms or investors for the purpose of jointly carrying out projects.

Due to the high costs and risks associated with exploration and mine development, financing from the private sector can, however, be difficult to secure.[127] It is therefore important to acknowledge that where markets fail to deliver socially optimal outcomes, there may also be scope for government intervention.[128] Interventions to address market failures can come in many forms. Examples include the reduction of red tape (including speeding up licencing and planning procedures), tax incentives[129] and support programmes for companies that want to start exporting or expanding their business.[130]

In order to close the financing gap to meet the demand for raw materials for the energy transition, the private and public sectors as well as multilateral agencies, could all have a role to play. While investment will be necessary across the entire value chain of critical raw material production, different segments of the value chain are subject to different issues and needs. This will be important to consider when designing both market-based financial instruments as well as government schemes or development projects.

[125] S&P Global, 'More metals, mining companies expected to issue ESG bonds' (23 July 2019), available at https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/more-metals-mining-companies-expected-to-issue-esg-bonds-52997113, accessed 20 January 2023.
[126] Ben Payton, ''Critical minerals': the race to finance responsible mining' (Responsible Investor, 24 August 2022), available at https://www.responsible-investor.com/critical-minerals-the-race-to-finance-responsible-mining/, accessed 23 January 2023.
[127] ESFC Investment Group (2023), 'Financing mining projects', available at https://esfccompany.com/en/projects/mineral-processing-and-mining/mining-and-processing-plants/, accessed 20 January 2023.
[128] In the context of technologies needed for the energy transition, such market failures may, for example, arise from long project lead times. Both mining projects as well as many renewables projects more generally (e.g. wind farms) typically have long lead times, which can result in coordination problems across the value chain (see IEA (2022), 'The Role of Critical Minerals in Clean Energy Transitions', March, p. 12, and EWEA (2010), 'Wind Barriers', July, p. 7).
[129] See, for example, the Australian Junior Minerals Exploration Incentive programme: Australian Government (2021), 'Junior Minerals Exploration Incentive', available at https://www.ato.gov.au/business/junior-minerals-exploration-incentive/, accessed 1 February 2023.
[130] See, for example, a Spanish export credit programme: Eurofund (2023). 'Fund for the internationalisation of the company (FIEM)', available at https://static.eurofound.europa.eu/covid19db/cases/ES-2010-27_2620.html, accessed 23 January 2023.

8. The benefits and risks of increased mining exploration and resource mapping for the energy transition

Box 8.1 Key messages

1. The mining of critical minerals is likely to have direct impacts on the economies and societies of resource-rich countries. Key benefits include an increase in employment and economic output, key risks include environmental degradation and a loss of biodiversity.

2. The mining of raw materials is a critical enabler of the energy transition. An accelerated energy transition will benefit economies and societies worldwide, including by providing better health outcomes and improved energy security.

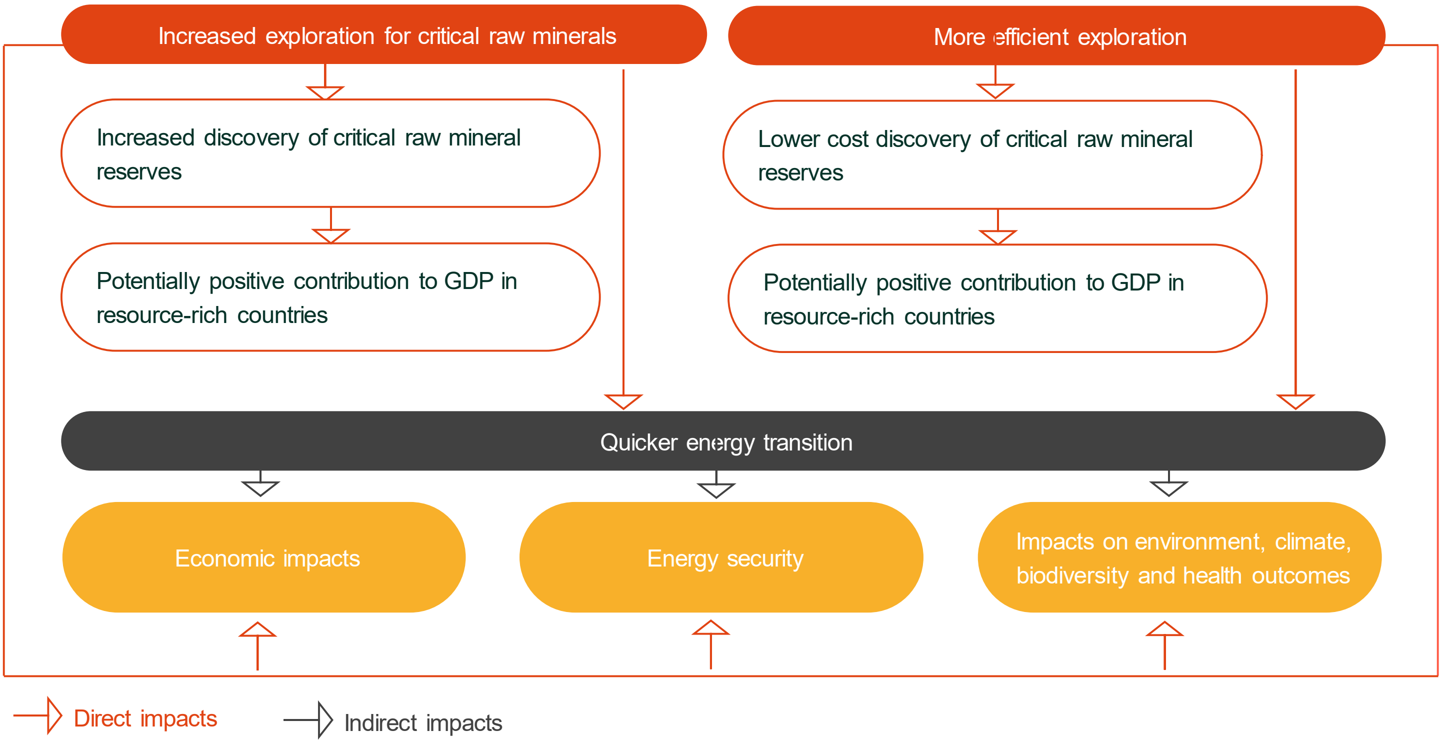
3. An accelerated energy transition is likely to benefit the global economy as a whole, but regional differences exist.

Increased and more efficient mineral exploration and natural resources mapping is likely to be needed to support the energy transition. Increased and more efficient exploration and mapping activities can help discover more valuable reserves at lower cost, which can help meet future demand for critical minerals.

Increased and more efficient mining exploration and mapping is likely to have direct and indirect impacts on a global level. We define direct impacts as those resulting immediately from the exploration activity, e.g. the creation of jobs at a mine once a discovery has been made. We can also identify a number of indirect impacts on the economy and wider society, such as the facilitation of a quicker or lower-cost energy transition (see Figure 8.1).

The rest of this section explores the risks and benefits of increased exploration and mapping activities. Section 4 focuses on the impacts of mining. Section 8.2 focuses on the impacts of accelerating the energy transition.

Figure 8.1 Direct and indirect impacts of critical raw minerals exploration for the energy transition



Source: Oxera.

8.1. What are the risks and benefits of increased exploration activities, and in particular of mining?

Increased mapping and exploration activities are likely to have a direct impact on economic performance, energy security and the environment.

Economic performance

Increased exploration activity can lead to an increased discovery of minerals. The discovery of critical mineral reserves can lead to the creation of critical mineral mining activity, which implies an increase in employment opportunities, an improvement in livelihood and a rise in tax revenues. More mining activity can also lead to an increase in economic output in resource-rich countries as well as those with large processing capacities.

However, increased mining activity is not risk-free. Fluctuating prices of minerals may cause job insecurity among mine contract workers,[131] and large mining activities can create an export dependence on the sector. Many of the mining-dependent states are located in developing countries: ten of the 16 countries with the highest dependency on extractive mining are in Sub-Saharan Africa.[132]

In the past, the discovery of natural resources has not necessarily led to economic development. The rapid development of one sector of the economy, particularly natural resources, can precipitate a decline in other sectors—a phenomenon called 'Dutch disease'.[133]

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[131] See International Institute for Sustainable Development and Malan, S. (2021), 'How to Advance Sustainable Mining', Table 1.
[132] Dependency on mining is measured by the mining contribution index (MCI), developed by the International Council on Mining and Metals (ICMM). The MCI is a composite index that capture various aspects of the mining sector's contribution to an economy. According to the 5th MCI edition, the DRC, Zambia, Guinea, Burkina Faso, Sudan, Mali, Zimbabwe, Mozambique, Namibia and Ghana belong to the economies most dependent on the extractive industries. See ICMM (2020), 'Role of Mining in National Economies', December.
[133] See, for instance, Christine Ebrahimzadeh, 'Dutch Disease: Wealth Managed Unwisely' (IMF, Finance & Development), available at https://www.imf.org/en/Publications/fandd/issues/Series/Back-to-Basics/Dutch-Disease, accessed 23 February 2023.

However, as set out in section 5.2 above, if managed responsibly, the mining industry has the ability to play a significant role in sustainable development and the delivery of the energy transition.

Energy security

Reliable, affordable access to energy is vital for the functioning of the economy.[134] In previous decades, discussions about energy security were largely focused on the supply of fossil fuels—in recent months, particularly gas. In the future, energy security may instead centre increasingly around the reliability of clean energy supply chains. Given the reliance on clean energy technologies on critical minerals, the traditional energy security paradigm is likely to shift from oil and gas to global supply chains for critical minerals.[135] As already mentioned above, as the world energy order is reshaped, the following vulnerabilities in the security of supply of these materials will likely need to be addressed.

- High geographical concentration of production and exports. More than 80% of global production of most of the critical minerals is concentrated among the top three players. The top three players are predominantly non-G7 countries.[136]
- Policy risk. Distorting effects on international markets by reduction of supply and raising of prices through policy measures, primarily export restrictions.[137]
- Complex supply chain dependencies. Complex chains of supply dependencies between specific countries, not just in terms of imports but also include the refining and processing of ore in locations other than where it is mined.[138]

Increased exploration could help remedy some of these supply chain risks and increase energy security. Firstly, elevated exploration efforts could help new producers enter the mining market and reduce the dependency on large producers. Secondly, it could alter the distribution of mines by enabling discoveries in parts of the world with lower current mining output. Diversification would reduce dependence on a few countries and would therefore be beneficial for the security of supply.

Environment and biodiversity

Although the mining industry itself causes greenhouse gas (GHG) emissions, it can help save GHG emissions downstream if used for clean energy technologies.

With increasing demand and falling ore quality, it is likely that global CO_2 emissions from mining critical minerals might increase in the years to come.[139] However, clean energy technologies have lower life-cycle CO_2 intensities than their fossil counterparts. Today, for instance, an EV emits c. 50% less CO_2 throughout its life cycle than an average combustion engine car—even when taking the current electricity mix into account.[140] Furthermore, mining activities only contribute a minor share to the life-cycle CO_2 emissions from clean energy technologies. For example, recent estimates indicate that mining contributes between 2% and 11% of CO_2 emissions across the supply chain for the production of solar PV and heat pumps, respectively.[141]

Although mining is likely to always have an impact on the local environment (as explored in section 5.2 above), the IEA recommends it 'be carried out in a way that minimises damage.'[142] One way to minimise environmental damage is by improving exploration activities to identify the

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[134] See, for instance, Jianguo Wu and Tong Wu, 'Goal 7 – Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All' (UN Chronicle 4(51), April 2015), available at https://www.un.org/en/chronicle/article/goal-7-ensure-access-affordable-reliable-sustainable-and-modern-energy-all, accessed 5 February 2023.
[135] International Energy Agency (2023), 'Energy Technology Perspectives 2023', p.51-53.
[136] OECD (2022), 'Security of Supply for Critical Raw Materials. G7 Leaders' Summit, 26-28 June 2022, Schloss Elmau', p. 5.
[137] Ibid, p. 7ff.
[138] Ibid, p. 9ff.
[139] IEA (2023), 'Energy Technology Perspectives 2023', p.59.
[140] This assumes an average car to travel 200,000km in its life-cycle; IEA (2023), 'Energy Technology Perspectives 2023', p.132, 134.
[141] See IEA (2023), 'Energy Technology Perspectives 2023', Figure 2.24
[142] IEA (2023), 'Energy Technology Perspectives 2023', p.136.

The mining of critical minerals is likely to have direct impacts on the economies and societies of resource-rich countries. Key benefits include an increase in employment and economic output, key risks include environmental degradation and a loss of biodiversity.

most promising areas for invasive activities. Airborne exploration could play a role in this by identifying anomalous zones, potentially representing mineral deposits, before engaging in any drilling operations. Using airborne exploration in conjunction with remote sensing data interpretation can provide a comprehensive overview of the natural capital reserves. This can facilitate informed decision-making regarding the environmental trade-offs associated with mining operations, limiting the amount of biodiversity loss and preventing unnecessary drilling as far as possible. Apart from improved exploration technology, effective regulation and responsible corporate practices can also help reduce the environmental damage caused by mining operations.[143]

8.2. What are the benefits of an accelerated energy transition for economies worldwide?

In the 2015 Paris Agreement, the world's major economies committed to keeping global warming well below 2°C above pre-industrial temperatures. This is likely to require net zero emissions at the global level between 2050 and 2070.[144] To reach this goal, policy action is needed. As CO_2 remains in the atmosphere for centuries, continued emissions will cause temperatures to continue to increase in the decades to come.[145]

To achieve the Paris Agreement climate goal, the energy transition will need to accelerate markedly. A recent study estimates that without policy action in addition to the status quo, there is less than a 10% probability that a temperature rise of below 2°C will be achieved.[146] An accelerated energy transition has clear benefits for biodiversity and our climate, but it is likely to benefit economic performance and energy security as well.

Economic performance

Recent research studying the impact of an accelerated energy transition on economic performance is abundant.[147] Most analyses agree that on a global level, and in most countries, the socio-economic benefits of an accelerated transition outweigh the risks in comparison to a business-as-usual (BAU) scenario—at least in the long run.[148] Progressive policies and programmes phased in gradually over the coming years, could help mitigate the potential employment and welfare losses associated with the decline in the fossil fuels industry and trade.[149]

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143 IEA (2023), 'Energy Technology Perspectives 2023', p.136.
144 UNFCCC (2022), 'United Nations Climate Change Annual Report 2021', available at https://unfccc.int/sites/default/files/resource/UNFCCC_Annual_Report_2021.pdf.
145 Archer et al. (2009), 'Atmospheric Lifetime of Fossil Fuel Carbon Dioxide', 37(1) *Annual Review of Earth and Planetary Sciences 2009*, pp.117-134.
146 See, for instance, Liu, P.R. and Raftery, A.E. (2021), 'Country-based rate of emissions reductions should increase by 80% beyond nationally determined contributions to meet the 2 °C target', *Communications Earth & Environment 2*, 9 February.
147 See, for instance, IRENA (2022), 'World Energy Transitions Outlook', available at https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2022#:~:text=In%202022%2C%20the%20need%20for,highly%20dependent%20on%20fossil%20fuels; We Mean Business Coalition (2022), 'Cutting Bills and Creating Jobs: The economic opportunities of a clean energy transition', available at https://www.wemeanbusinesscoalition.org/policy/the-economic-opportunities-of-the-clean-energy-transition/; IMF (2022), 'World Economic Outlook Report October 2022', available at https://www.imf.org/en/Publications/WEO/Issues/2022/10/11/world-economic-outlook-october-2022.
148 IRENA (2022), 'World Energy Transitions Outlook'; IMF (2022), 'World Economic Outlook Report October 2022'.
149 IMF (2022), 'World Economic Outlook Report October 2022', Chapter 3.

The economic benefits of an accelerated energy transition could be achieved via the following channels:

- Lower energy bills for consumers. A recent study published by a group of non-profit organisations estimates that per capita expenditures for energy could reduce as a result of an accelerated energy transition. The reduction is mainly driven by a fall in gas, petrol and diesel expenditure as heating and transport electrify—which is expected to be cheaper and largely independent of geopolitical events in the long run.[150]
- Increase in employment. Although some jobs in the fossil fuels industry will be lost, an accelerated energy transition is likely to create additional jobs (in comparison to a BAU scenario) in many places through the onshoring of energy generation.[151] IRENA has estimated that by 2030 an accelerated energy transition could create close to 85m additional energy transition-related jobs compared to 2019. These include c. 27m jobs in renewables and c. 58m extra jobs in energy efficiency, power grids, flexibility, and hydrogen, which could more than offset 12m jobs lost in the fossil fuel and nuclear industries.[152]
- GDP growth. Recent research indicates that a large majority of countries could experience a growth in economic output if the energy transition were to be accelerated. Estimates range between additional GDP growth in 2030 of more than 6% in South Africa to less than 0.5% in the USA.[153] Based on the current GDP/capita, this would imply an increase of US $435 in GDP/capita in South Africa and US $314 in GDP/capita in the USA.[154] These estimates do not take into account the benefits of mitigating climate change.
- Welfare gains. IRENA estimated that welfare gains greatly outweigh benefits in GDP and jobs. If global warming were to be kept below 1.5°C above pre-industrial temperatures with an accelerated energy transition, welfare gains might rise by 20% by 2030, with further improvements by mid-century.[155] Climate-resilient development, more broadly can generate substantial co-benefits for health and well-being, which are expected to outweigh the financial cost of mitigation.[156]

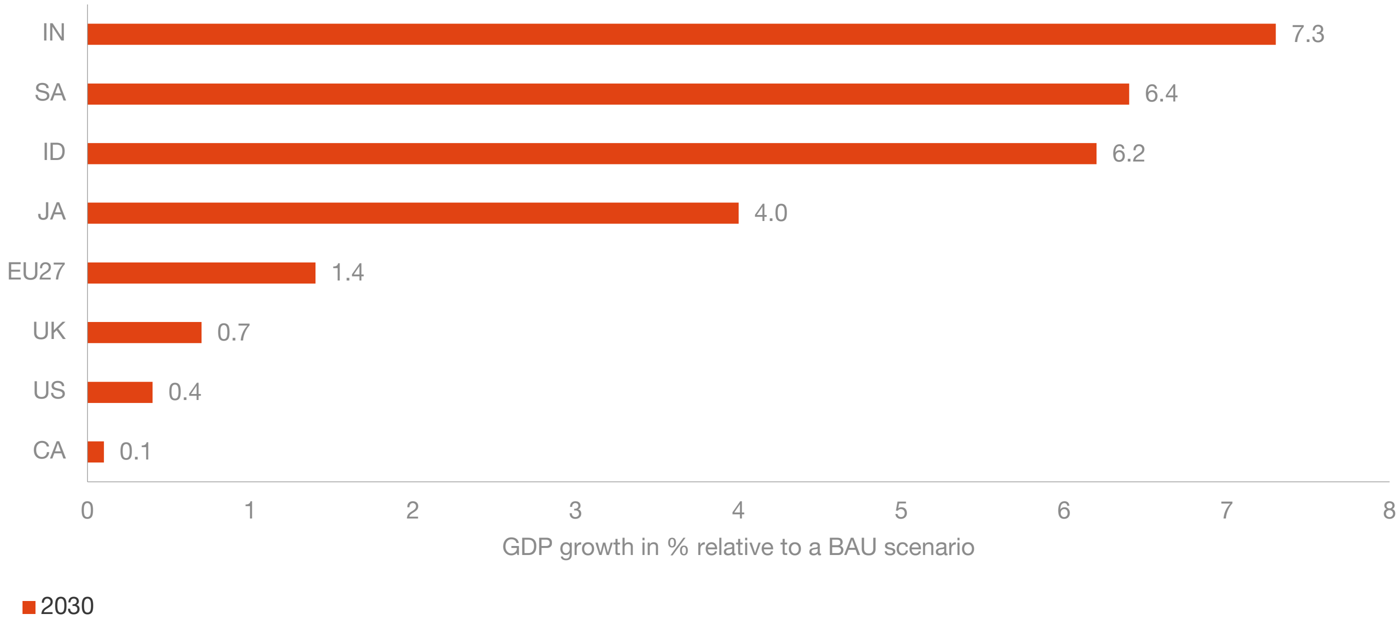
[150] We Mean Business Coalition (2022), 'Cutting Bills and Creating Jobs: The economic opportunities of a clean energy transition' p.20.
[151] We Mean Business Coalition (2022), 'Cutting Bills and Creating Jobs: The economic opportunities of a clean energy transition', p.11.
[152] IRENA (2022), 'World Energy Transitions Outlook', p.26.
[153] We Mean Business Coalition (2022), 'Cutting Bills and Creating Jobs: The economic opportunities of a clean energy transition', p.7, 40.
[154] In 2023, GDP/capita (in US $, current prices) has been estimated at 2.690 in India and 78.420 in the USA; see IMF, 'GDP per capita: current prices (Map, 2023)', available at https://www.imf.org/external/datamapper/NGDPDPC@WEO/IND/BGD/USA, accessed 30 January 2023.
[155] See IRENA (2022), 'World Energy Transitions Outlook'. IRENA's energy transition welfare index has five dimensions: economic, social, environmental, distributional and energy access.
[156] IPCC (2022), 'Climate Change 2022: Impacts, Adaptation and Vulnerability - Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate' (Cambridge University Press), available at https://www.ipcc.ch/report/ar6/wg2/, p.1044.

Box 8.2 Economic benefits of mitigating climate change

The economic damage that an additional ton of CO_2 emissions is expected to cause is measured by the social cost of carbon (SSC). Estimates for the social cost of carbon vary greatly (between US $10 and US $1,000),[1] but recent academic studies estimate that the SSC might be above US $300/t$CO_2$.[2] Recent research indicates that following the current trend of emissions—i.e. following a business-as-usual scenario—could lead to c.1,111 additional gigatons of GHG emissions between 2023 and 2050 in comparison to a net zero pathway.[3] Assuming an SCC of US $300/t$CO_2$ and additional GHG emissions of 1,111 gigatons, this very preliminary analysis implies that failing to accelerate the energy transition might impose costs of more than US $300 trillion between 2023 and 2050—which amounts to more than three times the world's GDP in 2021.[4] In a similar vein, IRENA has estimated that if an accelerated energy transition is not pursued, the effects of climate change might lead to a reduction of 15.5% of global GDP by 2050.[5]

Source: [1] Ricke, K. et al. (2018), 'Country-level social cost of carbon', Nature Climate Change, 24 September, p. 2; [2] Ricke, K. et al. (2018), 'Country-level social cost of carbon', Nature Climate Change, 24 September; Kikstra, J.S. et. al. (2021), 'The social cost of carbon dioxide under climate-economy feedbacks and temperature variability', Environmental Research Letters, 16. [3] This data comes from the World Emissions Clock, which tracks emissions over time. [4] The World Bank has estimated GDP in 2021 at 96.51 trillion (US $, current prices). [5] RENA (2019), 'Global Energy Transformation: A Roadmap to 2050'.

Figure 8.2 GDP growth expected to be higher in 2030 due to accelerated energy transition in various jurisdictions



Note: These estimates do not take into account the benefits of mitigated climate change. They rely only on saved energy costs for consumers and the employment created through the accelerated energy transition.
Source: Oxera based on We Mean Business Coalition (2022), 'Cutting Bills and Creating Jobs', Appendix B, June.

Box 8.3 Welfare gains from an accelerated energy transition

The IPCC states with high confidence that various wellbeing outcomes for societies are affected by climate change. Failing to accelerate the energy transition—and thereby letting global warming go beyond 1.5°C—has been found to increase 'climate-related illnesses, premature deaths, malnutrition and threats to mental health' and is a 'growing driver of involuntary migration and displacement'. The IPCC has further found that climate change contributes to 'food insecurity' and may have an impact on 'susceptibility to violent conflict'.[2] The IPCC report shows that limiting global warming is likely to benefit many aspects of global welfare, including health, food security and peace.

Sources: IPCC (2022), 'Climate Change 2022: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change', p. 1044. [2] Ibid., p. 1046.

An accelerated energy transition is likely to benefit the global economy as a whole, but regional differences exist.

Although benefits exist across countries and regions, some countries benefit more from an accelerated energy transition than others. An accelerated energy transition has been estimated to benefit some less developed countries. As such, IRENA and the African Development Bank (AfDB) predict GDP in Africa to rise by more than 6% by 2050 if the energy transition is accelerated in comparison to a scenario where only current policies are implemented, which is a much greater increase than the global average of 2.3%.[157]

The energy transition is also likely to shape global geopolitics. Countries with high potential for renewable energy production (such as Australia or Chile) as well as technological innovation leaders (such as China, Japan or Germany) are set to benefit most from the energy transition. Equally, countries rich in minerals (such as Bolivia, Mongolia or the Democratic Republic of Congo) can take advantage of the opportunity to participate in the value chains required for renewable technologies. Their economic growth will be enhanced if they establish appropriate policies and governance frameworks.[158]

Energy security

An accelerated energy transition would benefit energy security as energy production moves onshore and the dependency on fossil fuel imports reduces. However, as highlighted in section 4, energy security concerns will likely evolve around the reliability of clean energy supply chains and CMs in particular. Expanded exploration activities could help reduce the dependence on the small number of countries that currently dominate the export and refinement of critical minerals.

[157] IRENA (2022), 'World Energy Transitions Outlook', p.118.
[158] IRENA (2019), 'A New World: The Geopolitics of the Energy Transformation', p.39ff.

Table 8.1 summarises the direct and indirect benefits and risks of increased exploration and natural resource mapping activities described in greater detail above.

Table 8.1 Direct and indirect benefits and risks of increased exploration and natural resource mapping activities

		Economy	Energy security	Environment and society
Benefits	Resource-rich countries	— Increased employment — Potential for GDP growth		— Improved leveraging of natural resources
	Economies that are transitioning to a low-carbon future	— Reduced energy bills for consumers — Increased GDP growth — Improved welfare	— Onshoring of energy generation — Improved energy security from local renewable sources — Reduced dependence on mineral imports from few players	— Better health outcomes — Lower water and air pollution
Risks	Resource-rich countries	— Potential to develop a dependence on the mineral extraction sector		— Potential for low-value-add jobs — Potential environmental degradation and biodiversity loss due to increased mining activity — GHG associated with mining and exploration activities
	Economies that are transitioning to a low-carbon future	— Potential job losses in fossil fuel industries		

Source: Oxera.

9. Conclusion

This Report has explored the global trends impacting natural capital mapping and minerals exploration, the role of minerals in the energy transition, the importance of natural capital mapping, financing options for mapping and exploration, as well as the role of airborne exploration in light of these trends.

In summary, a number of trends are impacting the importance of natural capital mapping and mineral exploration. These include mitigating and adapting to climate change, concerns around energy security, pushing for the energy transition, and addressing biodiversity loss, and all in the context of a global economic slowdown and debt crisis.

Mitigating the effects of climate change will require an accelerated energy transition. An accelerated energy transition will lead to an increase in mineral demand. Current and planned mines are not enough to meet future demand. More exploration is needed to diversify the sources and improve the security of the supply of mineral production.

The expected increase in demand for minerals, and therefore mining activity, presents an opportunity for resource-rich countries to attract investment in exploration activities. There is potential for making new discoveries of mineral deposits using cutting-edge geological mapping data, which will assist with meeting demand and the diversification of supply.

The efficiency of mining activity will become a key issue, and the associated environmental risks must be addressed. Quality data on natural resources can help enable investment, new mineral discoveries and sustainable mining practices. Research suggests that countries with a contemporary and technically superior geoscientific database may have a better chance of attracting exploration investment than a neighbouring state with a lesser or more dated database.

Countries rich in natural resources could consider taking steps to map and account for their entire natural capital to maximise efficient use and drive sustainable development. For developing nations, leveraging natural capital could be the key to explore new economic development opportunities, to improve its financial position and access to capital markets, and to rebalance its position as recipient of cooperation finance.

More funds need to flow into natural capital mapping and exploration to close the expected gap between demand and supply. Financial innovation is required in the context of the global economic slowdown and debt crisis. Increased mapping and exploration can provide direct and indirect benefits and risks for economic performance, energy security and the environment. An accelerated energy transition will benefit economies and societies worldwide.

Our research suggests that an increase in natural capital mapping activities may lead to increased exploration and therefore increased mining, which will help to accelerate the energy transition.

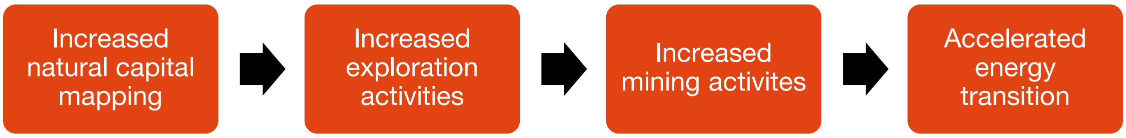


Table 9.1 summarises some of the overall benefits and risks of each of these activities.

Table 9.1 **Benefits and risks from natural capital mapping, increased exploration, increased mining and accelerated energy transition**

	Natural capital mapping	Increased exploration	Increased mining	Accelerated energy transition
Benefits	— Expand economic opportunities and investment — Expand fiscal capacity	— Attract investment	— Increased output — Greater security of supply — Increased tax revenue — More jobs	— Economic growth — Energy security — Protection of biodiversity — Climate mitigation
Risks		— Environmental degradation	— Environmental degradation — Low-quality jobs — Dutch disease	

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