Resourcing the Energy Transition: Making the World Go Round

Geographical and geopolitical constraints to the supply of resources critical to the energy transition call for a circular economy solution.

March 2021

KPMG International

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From OPEC to 'OMEC'[1]: the new global energy ecosystem

An energy transition is occurring that relies upon new sources of power and will drastically redraw the global energy and minerals market – with economic, environmental and geopolitical consequences.

Energy is, once again, at the center of the new economy and geopolitical landscape. With the past five years the warmest on record[2], countries are scrambling to meet the ambitious targets established at the Paris Climate Agreement in 2015. The widely accepted target is to limit the increase in global temperatures to 1.5 degrees or 2 degrees at most; nine of the top 10 global economies today have either announced net zero plans or committed to doing so. Global firms and financial institutions are setting their own similarly ambitious goals - KPMG among many others, has pledged to become a net-zero carbon organization within the next decade.

Meeting these targets means decarbonizing[3] the energy sector – quickly. The necessary reduction in greenhouse gas emissions (GHGs) implied by these targets can only be met through the transition of the global economy from one based on fossil fuels, to one largely powered by renewable and low or zero-carbon production and consumption of energy. Net zero agendas adopted by energy-intensive economies will necessarily require large-scale roll-outs of renewable energy technologies to eliminate emissions from power generation and decarbonize the world's manufacturing and transport sectors that currently rely on coal, oil and gas.

Nearly three-quarters of total global GHGs (73.2%) come from the energy sector (electricity, heat and transport)[4].

But there is an underappreciated risk to the energy transition: **the supply of clean energy depends on mined natural resources, which are steeped in geological, geopolitical and governance challenges.**

The world's attention has been focused on the costs of renewable technologies themselves and comparatively little attention has been paid to the supply chain that make those technologies possible. The very beginning of that supply chain – the sourcing of metals, minerals and abiotic materials ('resources') – could turn out to be the weakest link.

Somewhat counter-intuitively, the core issue is not necessarily one of quantity of the minerals; global known reserves are in fact sufficient to meet current projections of demand for many of these resources.

Essential, but not critical? Demand for graphite (used to build anodes in automotive, grid and decentralized batteries) is predicted by the World Bank to grow the most in percentage terms as a result of the energy transition (by nearly 500%[5]) – but demand could theoretically be met through existing reserves (sitting at 440% of anticipated demand).

1.1 million
tons produced in 2020[6]

4.5 million
tons annually or
68.8 million
tons in cumulative demand by 2050[7]

320 million[8]
Reserves

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[1]Freshly minted acronym for 'Organisation of Mineral Exporting Countries' – this grouping may not yet exist, but the point remains: geopolitical power could shift from oil-dominated countries to critical metal-dominated countries.
[2]Climate change: 2020 was the joint hottest year on record (2021) New Scientist.
[3]Reduction of carbon emissions.
[4]2016 figures based on carbon dioxide equivalents. Emissions by sector (2020) Our World in Data.
[5]From 2018 production levels.
[6]Graphite data sheet – mineral commodities summaries (2021) USGS.
[7]A conservative estimate based on energy technologies only. Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition (2020) The World Bank ('World Bank Report 2020').
[8]An equally conservative estimate based on global mine production and reserves; inferred resources of recoverable graphite exceed 800 million tons. Graphite data sheet – mineral commodities summaries (2021) USGS.

Despite this, future supply faces two key risks:

Extraction and **production will face increasing scrutiny from downstream industries, investors and the public over environmental, social and governance (ESG) issues;** and

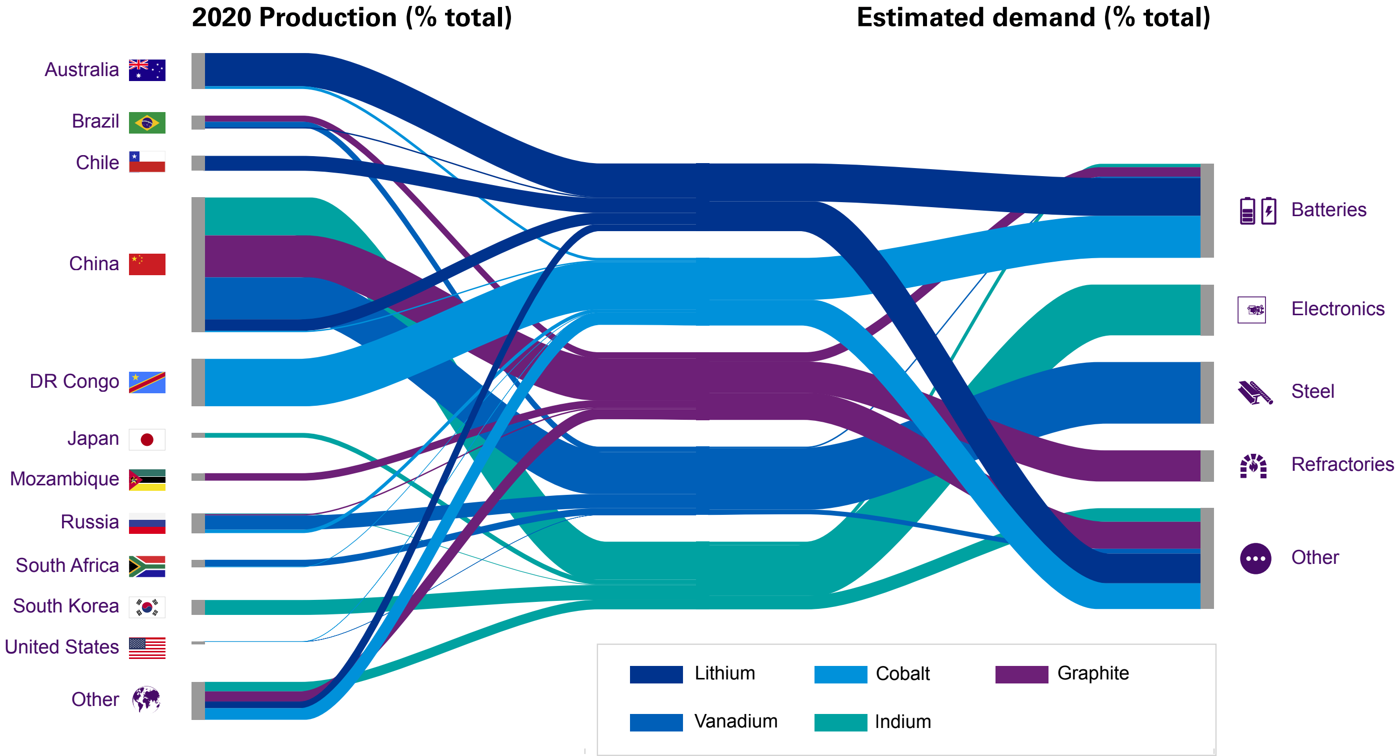
Even as the political agenda impacts the 'steepness' of demand (in pace and volume), **access to these 'strategic resources' will be politicized in the name of national security** given the centrality of their use to broader economic development and technological innovation, as well as the energy transition.

Given the material intensity of low-carbon technologies, any potential demand-supply gaps or constraints could impact the speed and scale at which certain technologies are able to be deployed[9]. As such, **a broad range of industries will be exposed to the terrestrial, oceanic and economic risks associated with the production and use of these resources.**

Sectors dependent on green technologies and energy storage solutions, such as infrastructure, transport and automotive, or on the alternate application of cross-cutting critical resources, such as industrial manufacturing and life sciences, will need to manage and assess these risks to ensure supply chain resiliency. In the following pages, we explore specific geographic and geopolitical factors that can influence comparative demand, availability and production of these resources – turning them from 'essential' to the energy transition to 'critical' for business operations.

But unlike the 'old' energy sector, there is a circular solution; the redesign of products alongside the reuse, recycling and repurposing of these resources can relieve the pressure on commodity supplies to meet demand – ensuring the rapid pace of the energy transition, transformation of related industries, and reduction in temperature rises globally.

Geographic dominance of supply

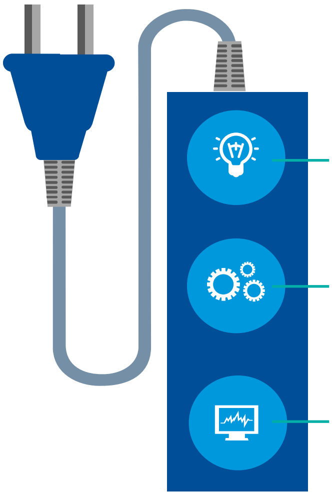


Demand breakdowns are estimates only based on publicly available information and may not be representative of 2020 figures. Sources: KPMG; USGS; NREL; GEMC; Roskill; CSA Global; DERA.

> "The circular economy and climate change mitigation are intrinsically linked. While greater circularity will reduce emissions, it's also critical to ensure that the rapidly expanding renewable energy grid is designed, installed and deployed using regenerative principles. We must avoid creating an energy infrastructure waste crisis in 20 years while solving today's climate emergency."
>
> – Federico Merlo, Managing Director, World Business Council for Sustainable Development

[9]World Bank Report (2020).

From 'essential' to the energy transition...



Low carbon technologies, including those enabling renewable power generation networks, require greater mineral supplies compared to traditional fossil-fuel driven systems[10]. There are a number of components to renewable systems that require a range of mineral inputs, including, for example:

Energy capture and output of renewable energy sources is dependent on certain resources used to build their structures, or as components in the generation of electricity, such as the use of indium as a transparent electrode in solar panels.

Energy storage is currently reliant on graphite, cobalt and lithium (lithium-ion batteries), or vanadium (vanadium redox flow batteries [VRFBs]). 'Rechargeable' solutions are critical for variable and intermittent forms of renewable energy supply (such as solar or wind) and 'cleaner' technologies like electric vehicles (EVs).

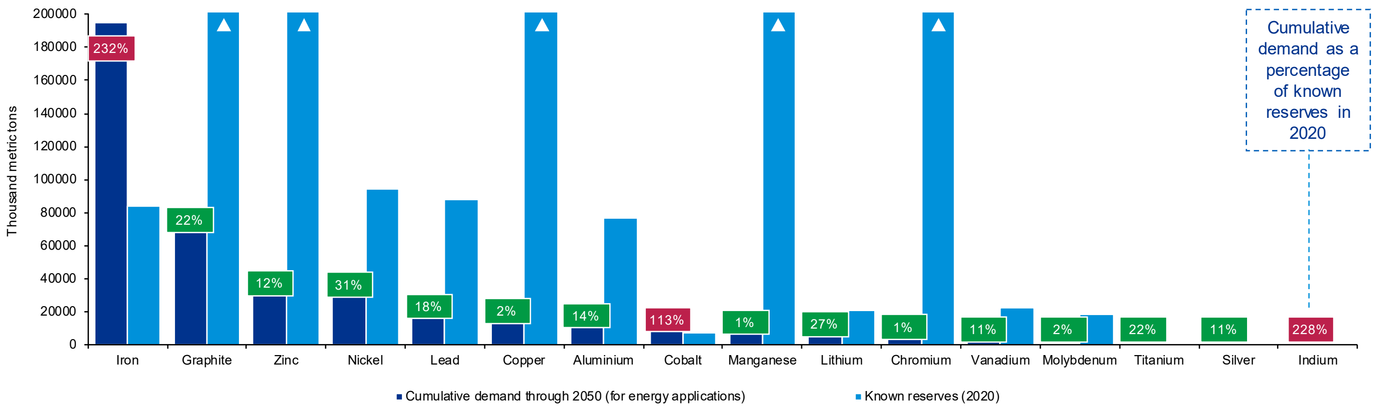
Energy efficiency, with conversion, transmission and distribution increasingly fulfilled by electronic components driving lower energy use across a range of electronic equipment, including data centers, smart grids, industrial applications and intelligent buildings.

The recent World Bank report estimates that over three billion tons of minerals in total are required to match the energy production and storage demands of a two-degree future (2DS) by 2050[11]. Significant even in absolute terms, this represents an increase in demand of up to nearly 500% for certain minerals from current levels, such as lithium, graphite and cobalt which are utilized in energy storage technologies. Other estimates place demand for specific resources, like indium, at over 12 times current production levels by 2050[12].

Notably, these estimates often exclude other industrial applications that place further upwards pressure on demand – like the end-use of tungsten in drilling and cutting within manufacturing, integration of gallium, silicon, indium and germanium in other digital technologies, reliance on cobalt and vanadium in 3D printing, and the use of cobalt in steel production[13].

Despite the pervasive myth[14], even this significant uptick in **demand for essential resources could be met by mining resource deposits** in many cases[15]**.** For most resources, known reserves (and as-yet unexplored deposits) would offer adequate supply to meet global production requirements, particularly in the medium term – and, like oil and gas, offers a significant opportunity for resource-rich countries and territories. As extraction, refinement and manufacturing technologies also improve, fewer minerals are likely to be required to achieve the same end output – conserving these supplies.

Estimated cumulative demand against known reserves



Sources: World Bank Report; USGS; European Commission Joint Research Centre (Indium reserves only); KPMG[16].

Of course, when geopolitics is at play, things are never that simple.

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[10] World Bank Report (2020).
[11] Ibid. This is independent of the associated infrastructure required to deploy or utilize these technologies (such as transmission lines or chassis of EVs) and includes 17 in-scope minerals.
[12] Metal Demand for Renewable Electricity Generation in the Netherlands (2018) Universiteit Leiden.
[13] The World Bank Report (2020); Critical Raw Materials for Strategic Technologies and Sectors in the EU (2020) European Commission ('Critical Raw Materials Report').
[14] Mineral resources: Exhaustion is just a myth, say scientists (2017) University of Geneva.
[15] Albeit not all, such as iron, indium and cobalt, where estimated demand for energy applications exceeds known reserves.
[16] Neodymium is the only resource identified in the World Bank report that has not been included here; unlike the others, reserves of neodymium are not reported by the USGS or EU JRC.

...to 'critical' for business

Similar to the oil and gas industry, a number of political and geographic factors could influence the comparative demand and supply of these resources, creating supply risks for business and ultimately challenging the pace and scale of the energy transition. These trends have the potential to turn 'essential' materials into a 'critical' component for businesses, not just within clean technology but across multiple sectors, including industrial manufacturing, life sciences and automotive.

Demand: you can't predict winners

Although deposits are anticipated to be able to meet global demand in many cases, unanticipated upwards swings in demand (and resultant lags in supply) have the potential to result in shorter-term price volatility and shortages in the production of several critical metals.

#1 Politics and policy

Geopolitics features in both sides of the demand-supply equation. Here, **domestic politics and appetite for a 'green' agenda will likely influence the 'steepness' (in volume and pace) in demand** for certain resources. Specifically, political agendas will change:

1. **'Who' you compete with: setting the domestic ambition on climate change.** Resource demand is anticipated to significantly increase (and quickly) under a 2DS scenario, compared to a 'business as usual' four degrees. Although global collaboration will be needed to achieve these targets, the pace and appetite to support the disruptive transformation will vary between countries, impacting policy support (from subsidies to carbon border adjustment mechanisms) and demand for green technologies and associated resources.

2. **'What' you compete for: influencing the mix of renewable technologies adopted.** For example, the role of nuclear power in the energy transition remains uncertain for political and social reasons - despite providing more than 10% of global electricity at one of the lowest levels of GHG emissions in the combined lifecycle of power-generating technologies[17]. Unanticipated limits or restrictions to this technology may cause demand for solar, wind and hydroelectric power (and their associated resource dependencies) to rise.

#2 Technology and innovation

Efficiency improvements and **technologicial advancements, including the application to new industries, could place upwards pressure on the demand for individual resources**, depending on the subtechnologies (green or otherwise) that are the most widely deployed in the longer-term.

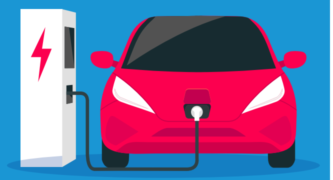
For example, growth in off-shore wind farms may spur demand for neodymium and dysprosium (used in the magnets of turbines). The role of hydrogen as a medium for energy portability (i.e. storage of excess renewable energy and transportation to regions with less renewable resources) increase demand for iridium and platinum (in electrolysers). The use of rhenium as a catalyst in carbon capture and storage solutions for harder-to-decarbonize industries could cause shortages for the aerospace industry (as a component of turbine blades in engines). Helium was recently removed from the EU's critical raw materials list given a decline in economic importance, but may be re-added given its relevance to a range of emerging digital applications[18].

As identified by the World Bank Report, concentrated materials that are only needed for one or two technologies may be more prone to demand fluctuations stemming from technological disruption in the longer-term; however, it is the recognized versatility of cross-cutting materials that may also expose them to (unanticipated) demand from new innovations and competition from different industries.

> "Technology and subtechnology choice, material substitution, and technological improvements will shift the demand for individual minerals under different low-carbon scenarios...**The technology pathway that will emerge to decarbonize electricity production will shape the minerals that will experience the largest increases in demand**. It is possible that new technologies such as floating offshore wind, green hydrogen, or solid-state batteries may change the shape of the future energy system. These technologies require different minerals and carry different mineral demand implications." – World Bank Report (2020)

[17]Nuclear power has a big role to play in the energy transition. Here's why. (2020) World Economic Forum.
[18]Critical Raw Materials (2020) European Commission.

‘Critical’ energy storage



Mass adoption of EVs across the US, Europe and China is being accelerated by policies to increase EV uptake, including new regulations banning the sale of new Internal Combustion Engines and subsidies for EV manufacturers. A number of vehicle manufacturers have recently been forced to temporarily halt production of EVs due to battery supply bottlenecks – specifically, the unavailability of the key resources[19].

Lithium, graphite, and cobalt are currently primarily used in energy storage, including batteries for EVs, and have the highest demand figures relative to 2018 production levels[20]. But these resources also have the highest level of demand risk: there are a number of energy storage subtechnologies currently under research and development (R&D).

Like sodium-ion batteries, for use in EVs, smartphones and laptops; unlike lithium, sodium is already widely and cheaply available[21]. Or VRFBs – longer-life battery technology with almost unlimited energy capacity and well-suited to industrial applications. Uptake has been currently constrained by the high costs of its base mineral, vanadium.

Supply: you can’t diversify away

Similar to the oil and gas industry, supply chains of these materials are complex and largely linear in nature. Diversification is limited in every aspect: these resources originate from a small set of countries, refining is concentrated in even fewer countries, and often there are very few resources that can act as a substitute[22].

#3 Geopolitics

Climate change is a 2021 entrant to the list of drivers of a ‘G-Zero’ world, defined by no country or group of countries having the political and economic leverage to drive an international agenda. Major emitters and market movers will likely press ahead with climate action, but weak geopolitical connective tissue have the potential to turn these into sources of conflict.

Meaning, unlike other resources in short supply, one of the most likely constraints on ‘critical’ resources are inherently geopolitical in nature: **strategic competition over these resources has the potential to upset existing regional power balances and significantly disrupt supply.**

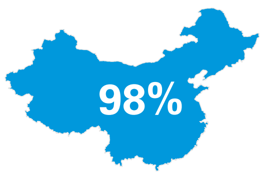
Of particular importance is the speed at which these geopolitical constraints could hit. In recognition of the potential for resource-rich organizations and countries to take control of mineral supply chains, the US, UK, EU, Japan and Australia have all published lists of ‘critical’ raw materials that are considered “vital to… security and economic prosperity”[23]. As part of a broader strategy to reduce reliance and minimize supply chain risks, these lists consider the centrality of these resources to continued economic development, technological innovation and the energy transition, balanced against potential reserves and reliance on imports.

eurasia group politics first

> Geopolitical power could shift from oil-dominated countries to critical metal-dominated countries. The sourcing of critical minerals and diversification away from hostile trading partners has repositioned a number of countries in a strategic position to engage with the US and like-minded countries.

With global momentum around the energy transition accelerating, competition for secure sources will catalyze an international effort to mine these minerals at home (where possible) and to source them sustainably.

“China provides 98% of the EU’s supply of rare earth elements (REE), Turkey provides 98% of the EU’s supply of borate, and South Africa provides 71% of the EU’s needs for platinum and an even higher share of the platinum group metals iridium, rhodium, and ruthenium. The EU relies on single EU companies for its supply of hafnium and strontium.” – European Commission



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[19]Manufacturers Are Struggling To Supply Electric Vehicles With Batteries (2020) Forbes.
[20]World Bank Report (2020).
[21]The batteries of the future (2020) DW.
[22]Notably, two of the three pillars of R&D investments being coordinated by the US Department of Energy to address supply chain risk focus on the diversification of supply and development of substitutes. The third is driving recycling, reuse, and more efficient use of critical materials. Critical Materials Rare Earths Supply Chain: A Situational White Paper (2020) US Department of Energy.
[23]Final List of Critical Minerals (2018) US Department of the Interior.

#4 Exploration

Absolute production numbers and relative increases in demand for each mineral will play a role in their ability to meet supply, particularly if additional exploration is necessary. Not all theoretical reserves are technically or economically extractable.

Critical metal production scales slowly: history would suggest that it would take around 10 years from discovery to mining (although pending on size, this could fluctuate between seven to 13 years). It also requires large capital investments. In an age of a disjointed global public policy landscape related to the energy transition, mixed market signals and varying degrees of natural resource deposits and industrial demand build out have forestalled a fever pitch of mineral sourcing – until now.

On the supply side of *#1 Politics and Policy*, a **rapid increase in global demand will therefore be hard to meet with a rapid increase in global supply**. As noted previously, use of mineral resources will vary depending upon climate policies adopted across the world. Ultimately, resultant price hikes from demand, or subsidies from government, could open up reserves that were not previously commercial or accessible via new technologies. However, companies in different parts of the relevant value chains at hand, as well as investors or trade and commodity financiers, require a global, long-term investment assurance to be able to fund the supply side – at the pace necessary to meet climate ambitions.

#5 Access

Extraction of deposits also come with a range of climate and environmental implications. These materials may not be rare, but they are precious, requiring huge amounts of energy, labour and effort to extract, refine and consume.

> "The scale of associated greenhouse gas emissions is a fraction of that of fossil fuel technologies. However, the carbon and material footprints cannot be overlooked."
>
> — World Bank Report (2020)

Outside of cost considerations, **accessibility to reserves can be restricted by factors that open companies to ESG-related regulatory, ethical and reputational exposure**, such as:

Physical damage: the environmental impacts of mining can occur at local, regional, and global scales through direct and indirect mining practices. Mining can result in sinkholes, erosion or the contamination of soil, groundwater, and surface (including drinking) water to name a few.

Human cost: in some regions such as the Democratic Republic of the Congo (DRC), the human cost of extracting rare earths can be severe, with the quality of life of the miners detrimentally impacted. Supply chains are at risk of conflict issues and human rights abuses, unsafe working conditions, and child labour, as well as social impacts from eco-toxicity[24]. Extraction also consumes a large amount of resources which incidentally diverts away or makes it harder for locals to access the same resources.

Biodiversity cost: major risks include habitat loss and fragmentation, disturbance of migratory species, introduction of invasive species and in some cases region-wide declines in rare and threatened species and ecosystems (such as the influence of coltan mining on Grauer's gorillas in the DRC)[25].

Deep sea mining is often cited to having the potential to address terrestrial supply constraints, however similar challenges exist.

Scientists are warning that deep-sea mining can wipe out entire species – many yet to be discovered[26]. The scraping of the ocean floor by machines can alter or destroy deep-sea habitats, leading to the loss of species and fragmentation or loss of ecosystem structure and function. Many species living in the deep sea are endemic – meaning they do not occur anywhere else on the planet – and physical disturbances in just one mining site can possibly wipe out an entire species (for example, 85% of the wildlife living around hydrothermal vents are found nowhere else in the oceans). Sediment plumes and pollution (noise, light and vibrations) can also have significant impact upon wildlife populations[27].

Importantly, none of these factors operate in isolation – for example, political concerns around access to cobalt supplies could lead to industrial policies championing the primacy of VRFB technologies, changing the demand mix for (and continued investment in) certain minerals.

[24] The high human cost of cobalt mining (2019) Mining Review Africa.
[25] Agriculture, mining, hunting push critically endangered gorillas to the brink (2019) Mongabay; Mining and biodiversity: key issues and research needs in conservation science (2018) The Royal Society Publishing.
[26] Deep Sea Mining (2018) IUCN.
[27] Ibid.

The five resources to rule them all

To illustrate, we have focused on five metals and materials that are considered integral to the smooth operation of future global energy supply chains and related manufacturing. These are certainly not the only resources that face these issues; for example, copper, aluminum and nickel face similar challenges around increases in demand and criticality across sectors. However, lithium, cobalt, vanadium, indium and graphite have been chosen as they are expected to experience the greatest growth in demand (in percentage terms) from energy technologies by 2050[28] - and geographical and geopolitical constraints have the potential to bottleneck supply chains.

Lithium: what's your competition doing?

5.6m tons (27% of known reserves)
Cumulative demand by 2050

21m tons
Reserves in 2020

50%[29]
Indicative recycling rates

A light silver metal that is highly reactive and flammable, it is one of the main cross-cutting resources in terms of its applications. It is a critical component for energy storage (EV batteries, consumer electronics and grid scale energy storage), but also a range of other products including: aircraft; glass ceramics; aluminum alloys; and pharmaceuticals.

The main driver of demand (lithium-ion battery) faces significant demand pressure from new energy storage technologies; however, it is anticipated to remain the primary sub-technology used in automotive, decentralized and grid-scale energy storage by 2050[30]. Production has already skyrocketed to meet demand in recent years, nearly doubling between 2017 and 2018[31] and causing a short-term drop in lithium prices. However, there are two longer-term potential critical constraints on extraction and access to lithium deposits.

Though mined across six continents, the top four global producers are Australia, China, Argentina and Chile. Bolivia holds nearly a quarter of all identified lithium resources globally (21m tonnes of 86m estimated total)[32], however state control and limited mining infrastructure mean that production is largely untapped. Growth in supply will thus be heavily linked to geopolitical conditions and accessibility to these reserves in a landlocked country. Eurasia Group predicts that the US may experience particular geopolitical headaches relating to supply – of the countries with the top five largest reserves, only Australia can be considered a particularly friendly nation.

There are also ESG concerns associated with extraction. In Chile, lithium uses approximately 500,000 gallons of water per tonne extracted, which diverts away 65% of available water in some regions, causing adverse impacts on local farmers growing produce and rearing livestock[33].

Cobalt: how reliant are you?

8m tons (113% of known reserves)
Cumulative demand by 2050

7.1m tons
Reserves in 2020

68%[34]
Indicative recycling rates

Cobalt has various applications in industrial processes (as an alloy), animal feed, biotechnology processes and pharmaceuticals, as well as batteries, laptops and smartphones. Despite aforementioned supply concerns, it is an abundant metal element; identified terrestrial resources of cobalt stand around 25 million tonnes, with a further 120 million tonnes existing in manganese nodules and crusts on the floor of the Atlantic, Indian and Pacific Oceans[35]. It is predominantly extracted as a co- and by-product of copper and nickel, so is also dependent on the demand conditions for these other metals.

However, it is perhaps the most often-cited mineral example for supply chain risk stemming from geopolitical chokepoints and responsible sourcing issues; this has led to significant R&D efforts to minimize the amount of cobalt required in energy storage.

Specifically, there is currently a high concentration of cobalt supply in one country – the DRC, where approximately 70% of total production is sourced[36]. Economic and political instability, alongside labor and corruption concerns, means cobalt supply is highly unpredictable. Responsible investment principles including transparency and accountability guidelines have the potential to curtail capital away from these operations, however a lack of alternatives limits this as a meaningful solution.

Geographic dominance of the upstream supply chain, with two thirds of refinement capability located in China[37], also creates potential supply chain chokepoints - which assume particular importance during times of increased geopolitical tension.

[28] World Bank Report (2020).
[29] Innovation boosts lithium (2019) PV Magazine.
[30] World Bank Report (2020).
[31] Ibid.
[32] Lithium data sheet - mineral commodities summaries (2021) USGS.
[33] The spiralling economic cost of our lithium battery addiction (2018) Wired.
[34] 2011 figure; Recycling perspectives for cobalt in the Hague (2018) Universiteit Leiden.
[35] 25m tonnes terrestrial reserves include identified deposits that have not been leased to the mining sector (across the DRC, Zambia, Australia, Cuba, Canada, Russia and the US). Some of the oceanic reserves are located in Exclusive Economic Zones and sovereign territories, others in international waters. Cobalt data sheet - mineral commodities summaries (2021) USGS.
[36] Ibid.
[37] Cobalt crunch? Dealing with the battery industry's looming supply challenges for cobalt (2018) Apricum.

Indium: what's the alternative?

34,000 tons (228% of known reserves)
Cumulative demand by 2050

15,000 tons
Reserves in 2020

0-1%[38]
Indicative recycling rates

Indium tin oxide (ITO) remains the best material to fill the growing need for LCDs (liquid crystal displays) in touch screens, flat screen TVs and solar panels.

In nature, indium is quite rare and nearly always found as a trace element in other minerals — particularly in zinc and lead — from which it is typically obtained as a by-product. Low levels of extraction from indium results in lower availability and resource inefficiency; overall extraction efficiency from mine to product is between 23% and 28%, although much of that indium does not enter the market.

China is the major producer of indium, representing 56% of global refinery production in 2020[39]. In late 2020, China proposed a new Export Control Law that enables the country to limit exports of dual-use items related to national security and interests, including rare earth elements.

The current geographic concentration of supply, combined with the criticality of this mineral to technologies beyond the energy transition, offers a sizable opportunity for 'Western' allied countries to develop raw and urban mining. Take Canada: of the 35 critical metals identified by the US, it is a sizable supplier of 13 of such minerals, including indium. Eurasia Group suggests that this advantage has opened up the opportunity for a broader bilateral partnership on industrial cooperation, defense priorities, and collaboration on the international stage. This trend is likely to continue: securing a reliable stream of resources while driving a club of ally nations that exploit each country's network of geopolitical ties.

Vanadium: where's your next supplier?

2.4m tons (11% of known reserves)
Cumulative demand by 2050

22m tons
Reserves in 2020

30%[40]
Indicative recycling rates

Vanadium is a silver metallic element thatthat has a variety of a variety of large-scale and high-tech uses, such as space vehicles, nuclear reactors and superconducting magnets. It is also the key material in VRFBs, an alternative to lithium-based batteries in some applications that can be charged thousands of times without degrading[41].

Substituting vanadium is not currently economical or technically easy. Alongside the US and Canada, the European Commission identified and formally registered this metal on the 2017 list of Critical Raw Materials; the list seeks to increase awareness of potential supply risks, inform trade agreements, and stimulate the production of identified resources by steering new mining and recycling activities within the EU.

As previously mentioned, production has been limited by high costs; extraction of additional minerals from vanadium-rich industrial waste products, such as nickel and titanium, has been subsidizing vanadium extraction[42]. Production is largely concentrated in four countries with China owning the majority market share at 62% in 2020, followed by Russia, South Africa and Brazil. However, many mining companies in North America have revealed plans to invest in exploration or reopen closed vanadium mines in the US, Canada and Australia[43].

Graphite: who wants it the most?

68.8m tons (22% of known reserves)
Cumulative demand by 2050

320m tons
Reserves in 2020

<1%[44]
Indicative recycling rates

The main application for graphite is as a refractory material such as in steel making, but it is also essential in the production of lithium-ion batteries used in EVs.

Eurasia Group highlights graphite as a notable example of the risk of country-dominated supply chains: China is the source of more than 60% of the global supply of amorphous graphite, and about two thirds of this is flake graphite (100% of global processing of which occurs in China)[45]. The government has introduced policy controls to restrict new entrants, regionally integrate operations, and grow the percentage of the market touched by state ownership or investment.

The dominance of one country across this chain has the potential to jeopardize other countries' access to the mineral and the economic activity associated with its production and use. However, this may change in the coming years, as an increased global demand for graphite use in batteries has sparked exploration efforts across the globe; Mozambique, Finland and Sweden all have exploration projects underway.

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[38] The promise and limits of urban mining (2020) Fraunhofer ISI.
[39] Methods to increase indium supplies for the manufacture of thin-film solar cells (2015) European Commission; Indium data sheet – mineral commodities summaries (2021) USGS.
[40] Mineral processing and metallurgical treatment of lead vanadate ores (2020) MDPI.
[41] Vanadium: the metal that may soon be powering your neighbourhood (2014) BBC.
[42] Can Vanadium Flow Batteries beat Li-ion for utility-scale storage? (2019) Energy Post EU.
[43] Vanadium Outlook 2021: Strong Chinese Demand Expected, but Uncertainty Remains (2020) Investing News Network.
[44] The success story of graphite as a lithium-ion anode material (2020) Sustainable Energy & Fuels.
[45] Li-Ion Batteries: A Review of a Key Technology for Transport Decarbonization (2020) Energies.

Renewable energy requires 'renewable' inputs

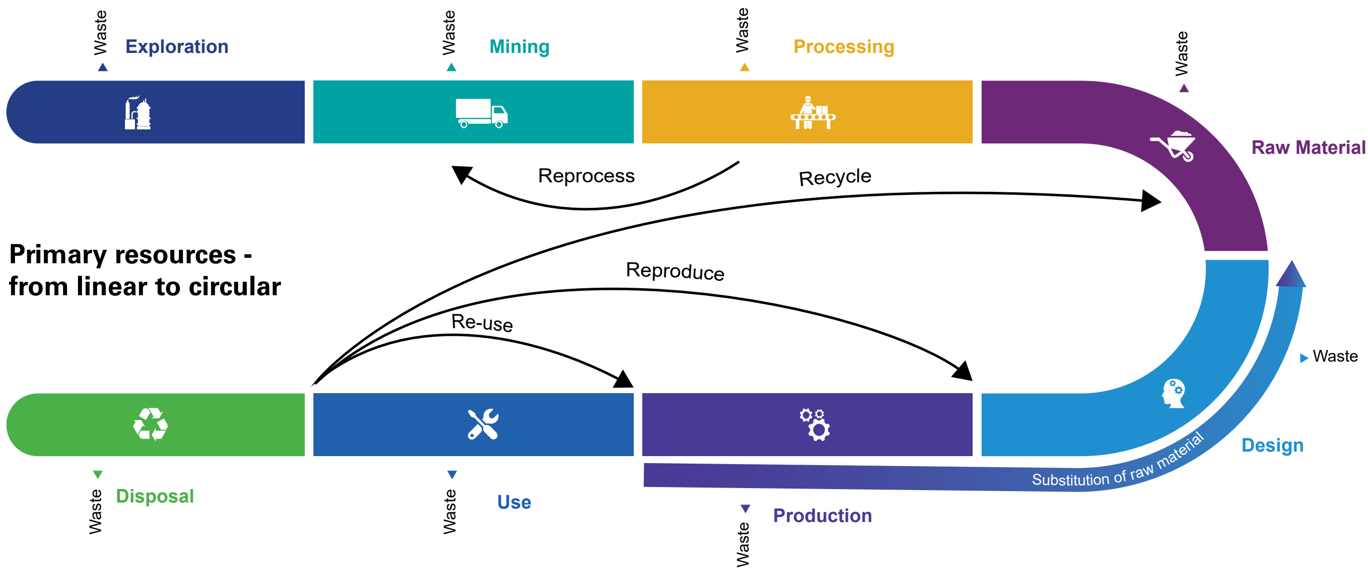
The pace and scale of the energy transition necessary to meet a 2DS scenario requires the widespread deployment of circular economy solutions[46] - and not just in the energy sector.

So how do you manage supply chain risks where geographic diversification of sources is limited and inputs may not be able to be substituted?

The circular economy. As more clean technologies are required to meet lower temperature targets, greater quantities of these minerals will be needed. Reducing the need to extract from terrestrial and ocean sites, and still grow available materials in the market, will require existing material to be utilized in new, circular ways.

What is the circular economy[47]?

A circular economy is a 'regenerative' model that looks to retain the value of 'circulating' resources, products, parts and materials. It seeks to design out waste and pollution, keep products and materials in use, increase productivity and regenerate natural systems.

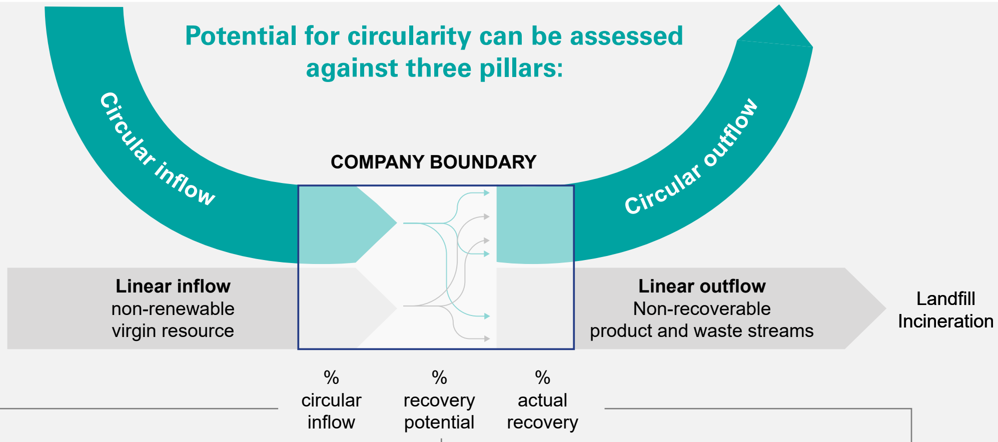


In recent years, the circular economy has gained increasing momentum as a concept among business, policymakers and consumers, as the urgency to act against climate change intensifies. However, political pressure to eliminate the use of fossil fuels and increase the share of renewable energy has focused R&D predominantly on more cost-effective generation and transportation of renewable energy, with less focus on the need for circularity within the energy sector.

Redesign, recycling, reusing and repurposing across the resource lifecycle will play a key role addressing geopolitical and geographic constraints - mitigating potential price volatility and supply shortages, particularly for resources unable to be substituted (like vanadium), and reducing the need for the extraction and emissions. Surety of supply has already been improved by existing circular economy strategies; for example, Japan and South Korea have made significant investments into the recycling of indium[48].

But existing recycling efforts will not be enough. Ironically, **the more ambitious our climate ambitions, the greater the potential reliance on 'non-renewable' mined materials,** possibly negating the positive environmental impact of manufacturing these green technologies in the first place.

[46] Circular Economy: A Key Lever in Bridging the Emissions Gap to a 1.5°C Pathway (2016) Circle Economy.
[47] 'Circular Transition Indicators' Framework (2021) WBCSD, powered by KPMG.
[48] Indium data sheet (2020) USGS.



Inflow, or movement towards secondary resources and substitution of 'critical' resources with non-critical alternatives; this could be constrained by the availability of secondary feedstock and suitable substitutes for virgin critical resources.

Recovery potential: improved design to focus on modularity, disassembly and recyclability (such as the use of mono-materials), which will rely on new forms of technological innovation.

Actual recovery: addressing current collection constraints through new business models (incentivizing recovery through product-as-a-service and buy-back schemes), more mature return logistics (to enhance collection), and innovation in new recycling technologies (to improve recycling yield, which may be constrained due to the limited amounts of resources able to be harvested).

Source: WBCSD; KPMG.

Super-charging circular economy solutions will be essential to addressing the geographic, geopolitical and economic constraints of the future, ensuring a smoother short-term supply-demand equilibrium and the longer-term viability of the energy transition. This can only be achieved if global and national climate and energy transition policy goes hand-in-hand with circular economy strategies to reduce critical metal risks and dependence[49].

A couple of caveats: some level of new resource extraction will be a given, as existing levels of some of these resources already in circulation cannot meet future demand on their own. Challenges to the expansion of these circular economy strategies also remain, including costs, design and technical issues[50]. These limitations (such as the thermodynamic manufacturing process of these products, the design for recyclability constraints and alignment across stakeholders in the value chain) will need to be addressed.

Lithium prices in China are experiencing significant volatility as a result of demand for energy storage solutions. Coming close to $25,000 a tonne in 2018 and in steady decline since, the midpoint price for battery grade lithium carbonate has now increased by over 40% compared to January 2020[51].

Despite being almost fully recyclable, only 5% of lithium batteries are recycled[52]. Why? Battery design – challenges around the separation of the metal component parts currently limits recycling opportunities.

Governments, investors, mineral producers, corporates and end users each have a part to play as part of a holistic response to the shift in energy mix and resource availability:

#1 Consumers

End users and civil society have so far proven to be one of the **strongest agents of change for sustainable and responsible sourcing of critical minerals.** The public's imagination has been captured by the idea of their ostensibly 'green' products like EVs causing hidden and untold harm to the environment and to communities. This gives such public interest groups the opportunity to continue to apply pressure and exert scrutiny on mining practices to ensure fair and equitable outcomes. However, it also comes with a responsibility to accept and work within the constraints posed by technology and policy factors which limit the 'art of the possible' for the producers and processors of these minerals.

[49] Linear Risks (2018) WBCSD in partnership with KPMG.
[50] World Bank Report (2020).
[51] Lithium price in China surges 40% to 18-month high (2021) Mining.com
[52] The battery paradox: how the electric vehicle boom is draining communities and the planet (2020) SOMO.

#2 Governments

Being 'open for business' is a far cry from the proactive risk assessment and mitigation required to develop resource supply chains in a highly competitive global environment. Governments have a multifaceted obligation to address each of the issues highlighted previously, and promote these resources as a permanent material to maximize their use in a future circular economy.

First and foremost, **greater clarity on climate ambition and energy mix expectations will be required to drive market signals** – for example, 'in a 2DS decarbonization pathway, global demand for relevant minerals in electric storage batteries is expected to increase by over 1,000 percent'. Detailed pathways on the embedded costs in clean tech will allow governments to bolster their policy frameworks to drive investment, secure against supply risks, and achieve their policy ambitions with critical minerals at the heart of industrial, trade, environment, natural resource, and security policy.

Governments may also consider incentivizing urban mining from used products (such as e-waste), particularly in Europe. Europe is almost completely dependent on supply of critical metals from outside of its borders, although the continent has some reserves. Mining in Europe will be confronted with hurdles, but high-tech solutions and circular focused incentives can help overcome these.

#3 Investors

Divestment will remain the easy way out for investors looking to safeguard against ESG-related risks. However, to ensure the stable access of global markets to critical mineral inputs and to enable the industrial transformation required for a smooth energy transition, **a holistic approach to portfolio management, with a better understanding the risks and opportunities of mining, sourcing, using, and recycling these materials, will be required.**

Central to this effort is focusing on what certain value chain players can do to improve metal use efficiency (for example, product designers and producers with respect to ease of metal separation), as well as the geopolitical pinch points covered here, when they are expected to manifest, and the degree to which government policy hedges may solve for them.

What about financing?

There are several funding challenges specific to investment in critical resource projects, including:

01 Technology & process: the new or commercially unproven technology and processes required to produce minerals increase the risk of cost overruns or production being below expectations.

02 Markets & pricing: it can be more difficult to assess market supply and demand and pricing is not as transparent as other more established commodities.

03 Customers & offtake: it can be challenging to identify and engage with end user customers and then progress to offtake agreements with terms required to obtain debt financing.

04 Equity & sponsors: equity requirements to fund construction can be significant for smaller development companies and difficult to attract the investor type preferred by debt financiers.

05 Infrastructure & supply chain: remote locations and limited suppliers / processing means a credible strategy to ensure long term access to infrastructure and supply chains is needed.

These challenges make it more difficult to attract debt funding at required volume and on appropriate terms. Governments around the world have responded to these challenges with various grants and loan programs in order to "crowd in" other commercial sources of finance. However, more could be done to fill market gaps and encourage commercial sources of capital to fund the investment needed.

#4 Resource producers

The value chain of critical metals is extremely complex[53]. In light of aforementioned challenges, **producers of critical minerals will be facing scarcity and therefore increasing price and price volatility, at the same time as consumers are looking for more circular and sustainable practices.**

As a first step, mining is often associated with significant environmental and social negative impacts; getting a grip on the company's 'ESG footprint' and level of the 'circular transition' is necessary to map a baseline. Limiting the carbon footprint of minerals needed for the clean energy transition may offer

"Metals are essentially circular, therefore an early adopter of a no-waste circular manufacturing process will likely gain strong competitive advantage and shorten the path to their net-zero goals."
– Ugo Platania, Global Head of Steel and Metals

[53]Critical Raw Materials (2014) KPMG.

double wins, helping to boost economic growth and reduce environmental risks in resource-rich developing countries. It will also enable the transition to a 2DS in line with the Paris Agreement, Sustainable Development Goal (SDG) 7 "access to affordable, reliable, sustainable and modern energy for all", and SDG 13, taking "urgent action to combat climate change and its impacts".

The supply chain will only become more complex when factoring in recovered metals and their reintegration into the value chain; this will likely need to be integrated into pricing and investment decisions for producers. There are a number of new and expanded business models that can be explored, including retention of ownership to enable urban mining.

> "Every mining company understands the unique complexity and challenges to consistently find, mine and deliver product to market. A society keen to accelerate the energy transition must now prioritize working with the sector to help it deliver."
>
> —Trevor Hart, Global Head of Mining

#5 Corporates

Across the three pillars of circularity, businesses across exposed industries, in particular industrial manufacturing, will have a range of options to help enable a circular transition. For example:

1. **Inflow:** companies across a range of sectors could look to reduce critical metal use by increasing alternative efforts to produce clean energy or other products with a smaller need for critical metals. Substitution alone is not enough and might shift this burden to other metals.

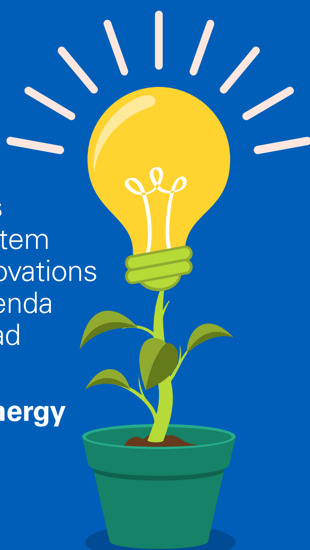
> The recycling potential of ITO scrap is a proven way of returning a significant amount of indium to the global market, with efficient technology and a fast process time; the world's secondary refined indium production resulted almost exclusively from the recycling of manufacturing scrap rather than recovery from end-of-life. However, this only represents a very small amount of total indium currently used, due to lack of recycling infrastructures and volatile prices of the metal.

2. **Recovery potential:** the automotive and energy sector could look to increase circular product design and closed loop efforts by including circular design principles in the production of energy assets such as wind turbines and PV panels, but also EVs to enable future reuse of components and materials after the technical use cycle. For example, the first solar panels are nearing the end of their lifespan (approximately 25 years) and, with investment into necessary infrastructure, could theoretically become a source of many valuable materials, including silicone, silver, glass and aluminum.

3. **Actual recovery:** those in the industrial manufacturing value chain can financially incentivize metal reuse through leasing and refurbishment contracts, effectively tagging a financial benefit to keep metals in use and allowing, for example, for the collection and recycling of precious metals from discarded batteries and electronics.

By analyzing the risks and opportunities of new business models and better circular metrics associated with the lifecycle of resources, businesses will not only be able to avoid potential supply chokepoints and realize cost savings, but also capture new opportunities, as consumers, employees and private and public financial stakeholders gravitate towards industry leaders in this space.

> In implementing the Paris Agreement, global efforts by government and the private sector are needed to move towards a renewable energy system. Closing the loop will not be easy - development of these circular economy strategies may encounter legal, financial, organizational and operational barriers, that require collaboration between different stakeholders, and potentially new skills (technological, environmental and economic) to overcome.
>
> However, as technology advances, opportunities to embrace circular economy principles will only increase, and their application to the resources required for this energy system and other technological innovations should be higher on the agenda of businesses across a broad spectrum of sectors.
>
> **Moving to a renewable energy system and the transition towards a more circular economy are part of the same agenda.**



About the KPMG and Eurasia Group Alliance

KPMG International has formed an alliance with Eurasia Group, one of the world's leading global political risk research and consulting firms, to develop solutions that help businesses deal with geopolitical challenges. Through our alliance, KPMG professionals can bring the political insights of Eurasia Group's analysts across 100+ countries and territories together with KPMG firms' nuts and bolts understanding of your business covering the macro to the most granular of analysis.

About KPMG IMPACT

KPMG firms are working with clients across the world to support them in decarbonizing their businesses and supply chains, and embedding ESG in everything they do. KPMG IMPACT brings together KPMG firms' expertise in supporting clients to address the biggest challenges facing our planet, with the aim of delivering growth with purpose and achieving progress against the United Nations Sustainable Development Goals (SDGs).

Authors

Sophie Heading
Global Geopolitics Lead
KPMG
E: sophie.heading@kpmg.co.uk

Rohitesh Dhawan
Macro Strategist and Head of Partnerships
Eurasia Group
E: dhawan@eurasiagroup.net

Arnoud Walrecht
Circular Economy Lead
KPMG in the Netherlands
E: Walrecht.Arnoud@kpmg.nl

Josh Hasdell
ESG Strategy
KPMG in the UK
E: josh.hasdell@kpmg.co.uk

Contacts

Trevor Hart
Global Head of Mining, KPMG
E: thart@kpmg.com.au

Mike Hayes
Global Head of Climate Change & Decarbonization, KPMG
E: michael.hayes@kpmg.ie

Ugo Platania
Global Head of Steel and Metals, KPMG
E: Ugo.PLATANIA@kpmg.lu

With thanks to:

Abdul Hassan (KPMG in the UK); **Coleman Sabbithi** (KPMG in India); **Craig Jones** (KPMG in Australia); **Dan Ginger** (KPMG in Australia)**; George Mowles-Van Der Gaag** (KPMG in the UK)**; Riya Aneja** (KPMG in India); **Rohit Sabharwal** (KPMG in India); **Suzanne Kuiper** (KPMG in the Netherlands).

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