KU LEUVEN

Metals for Clean Energy:

Pathways to solving Europe's raw materials challenge

POLICYMAKER SUMMARY

A digital copy of the full report:
Metals for Clean Energy: Pathways to solving Europe's raw materials challenge
(published April 2022) is available via either the QR code above
or the following link: bit.ly/MetalsCleanEnergy

This report has been written by KU Leuven and commissioned by Eurometaux, Europe's metals association. The methodology and conclusions of the report are those of KU Leuven.

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Key Sources
International Energy Agency has provided 2020-2050 technology scenarios for global and EU climate pathways.
Minespans by Mckinsey has provided data on global and EU project pipelines for the metals in scope, as well as other detailed information.

Introduction

Metals will play a central role in successfully building Europe's clean technology value chains and meeting the EU's 2050 climate-neutrality goal. In the wake of supply disruptions from the COVID-19 pandemic and Russia's invasion of Ukraine, Europe's lack of resilience for its growing metals needs has become a strategic concern.

This study evaluates how Europe can fulfil its goal of "achieving resource security" and "reducing strategic dependencies" for its energy transition metals, through a demand, supply, and sustainability assessment of the EU Green Deal and its resource needs .

It concludes that Europe has a window of opportunity to lay the foundation for a higher level of strategic autonomy and sustainability for its strategic metals through optimised recycling, domestic value chain investment, and more active global sourcing. But firm action is needed soon to avoid bottlenecks for several materials that risk being in global short supply at the end of this decade.

The metals intensity of the energy transition

Europe is planning a rapid shift away from today's fossil fuels system towards clean energy technologies.

Europe is planning a rapid shift away from today's fossil fuels system towards clean energy technologies. This energy transition is metals intensive. Electric vehicles, batteries, solar photovoltaic systems, wind turbines, and hydrogen technologies all require significantly more metals than their conventional alternatives to replace fossil fuel needs.

✓ Included in report's base case ● No information on intensities, not quantified in report ○ Included in report's sensitivity analysis

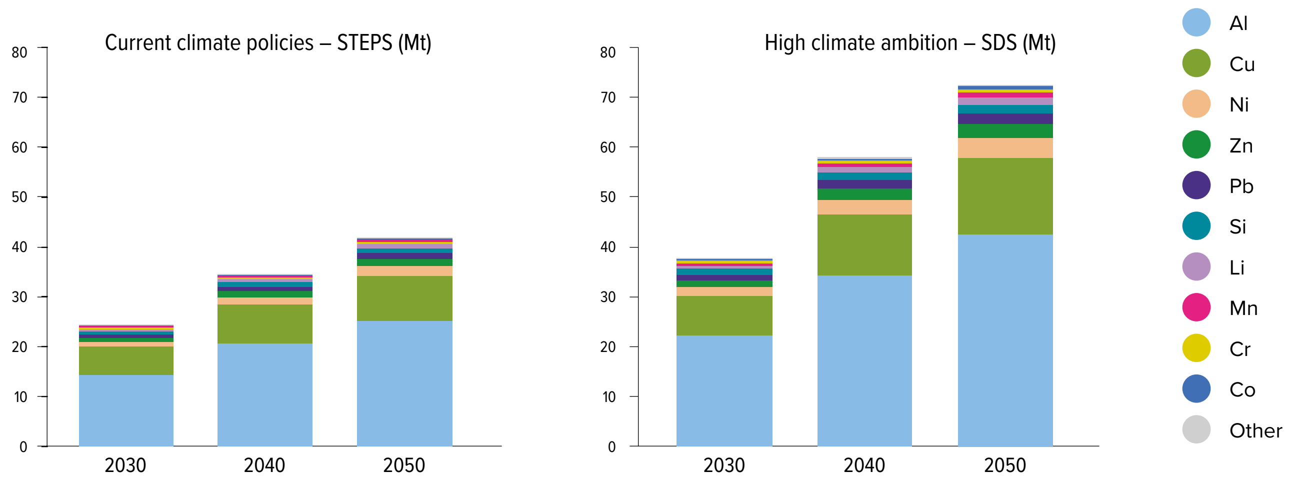
		Renewable power: Solar	Wind	Bio-energy	CSP	Geo-thermal	Hydro	Nuclear	Electricity networks	Battery storage	Electric vehicles	Hydrogen
Base metals & silicon	Al	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Cu	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Zn	✓	✓	✓	✓	✓	✓	✓	✓	○	✓	✓
	Si	✓								○	✓	
Battery raw materials	Li									✓	✓	
	Ni	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
	Co		●	✓	●			●		✓	✓	✓
Rare earth metals	Dy		✓					✓			✓	
	Nd		✓					✓		○	✓	
	Pr		✓							○	✓	
	Ag	✓	●		✓			✓			✓	
	Au	✓									✓	
	B		✓								✓	
	Cd	✓						✓		○		
	Cr		✓		✓	✓	✓	✓				✓
	Ga	✓	●						●		✓	
	Ge	✓									✓	
	In	✓						✓		○	✓	
	Ir											✓
	Mn		✓		✓	✓	✓	✓		✓	✓	✓
	Mo	✓	✓		✓	✓	✓	✓		✓		
	Pb	✓		✓			✓	✓		○	✓	
	Pd									✓		●
	Pt											✓
	Sc											✓
	Sn	✓				✓		✓		○		
	Tb		✓								●	
	Te	✓										
	V						●	✓	●	○	●	●

Steel is also used across clean energy technologies. It is not covered in this study.

According to International Energy Agency scenarios, a world climate trajectory aligned with the Paris Agreement will require almost twice the volume of metals by 2050 as a world continuing with its current climate policies (for context, 75 Mt of required new metals supply compares with today's 1,855 Mt annual global steel consumption and 8,561 Mt coal).

High volume base metals like aluminium and copper dominate in terms of their tonnage used in clean technologies, but several lower volume metals such as lithium, cobalt, and rare earth elements will have an extremely high demand pull from the transition. Once the required metals have been mined once, they can remain in circulation indefinitely if effective recycled systems are established.

Global metal demand by commodity for clean energy technologies in a STEPS and SDS scenario respectively (Mt*)



2050 Metals demand
Current climate policy
45Mt

2050 Metals demand
Ambitious climate policy
75Mt

**Mt = million tonnes, annual (including lithium expressed as metal equivalent)*

% metal required in 2050 for clean energy technologies vs. 2020 overall use (Global SDS ambitious climate scenario).** †

Lithium	2,109%	Silicon	62%
Dysprosium	433%	Terbium	62%
Cobalt	403%	Copper	51%
Tellurium	277%	Aluminium	43%
Scandium	204%	Tin	28%
Nickel	168%	Germanium	24%
Praseodymium	110%	Molybdenum	22%
Gallium	77%	Lead	22%
Neodymium	66%	Indium	17%
Platinum	64%	Zinc	14%
Iridium	63%	Silver	10%

SDS (Sustainable Development Scenario)

The demonstration of a plausible path to concurrently achieve universal energy access (affordable, reliable, sustainable, modern), set a path towards meeting the objectives of the Paris Agreement on climate change and significantly reduce air pollution.

STEPS (Stated Policies Scenario)

A benchmark to assess the potential achievements (and limitations) of recent developments in energy and climate policy. Based on a sector-by-sector assessment of the specific policies that are in place, as well as those that have been announced.

Source: International Energy Agency

** *Commodities with a % lower than 10% not included in list.*

† *The uptake of redox flow batteries is not modelled in detail, but would have a very strong demand pull for vanadium. By 2030, an estimated 117kt of vanadium could be required for vanadium flow batteries, which is equivalent to 110% of today's annual consumption and would make vanadium a key metal in the energy transition.*

Evolution of European metals demand per clean energy technology

Europe’s planned production of clean energy technologies requires a secure metals supply†

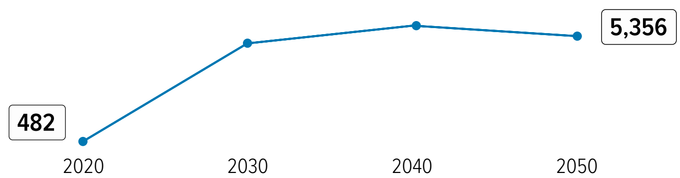
Europe’s 2050 climate-neutrality goal and 2030 mid-term target means it is already accelerating at a faster pace than other world regions, with plans to install most of its new clean energy technology capacity in the next 1-2 decades.

To improve strategic autonomy, Europe and its industries have public plans to grow or establish domestic production of each clean energy technology, at different maturity levels. This study quantifies the metals requirements if all those plans are successful, i.e. assessing Europe's direct metals demand but not the metals in technology imports.

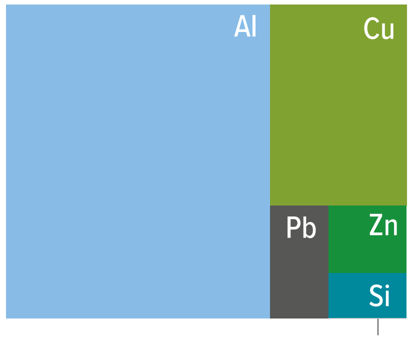
ELECTRIC VEHICLE (excluding battery, permanent magnet)

The European automotive industry is a mature net export market. As electrical vehicles will replace traditional ICE cars, it is assumed that Europe retains its current market position.

Evolving metals demand (kt)*



Makeup of metal usage* (%)

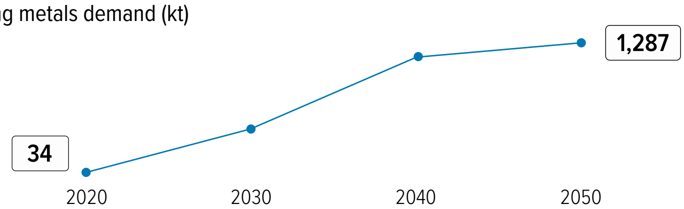


Other includes: B, Ag, Ga, Pt, Au, Ge, In

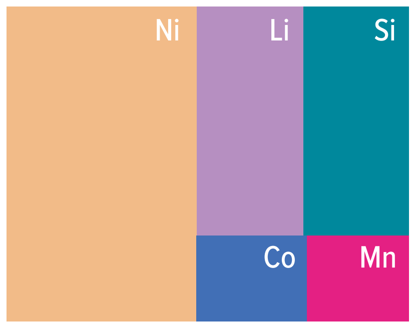
ELECTRIC VEHICLE BATTERIES

Europe has a current project pipeline for 540 GWh of lithium-ion battery capacity per year, equivalent to 5-9 million vehicles. Cathode and anode production - where metals input is required - is ramping up at a slower pace (currently equivalent to 50% of 2030 cell manufacturing plans.

Evolving metals demand (kt)



Makeup of metal usage** (%)

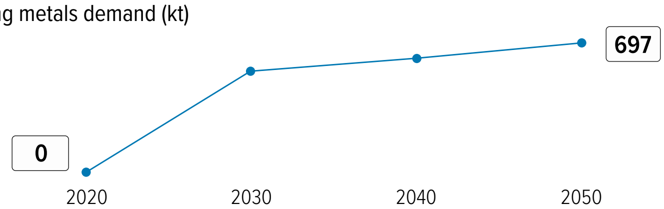


EV batteries also contain aluminium and copper, which are accounted for under electric vehicles above

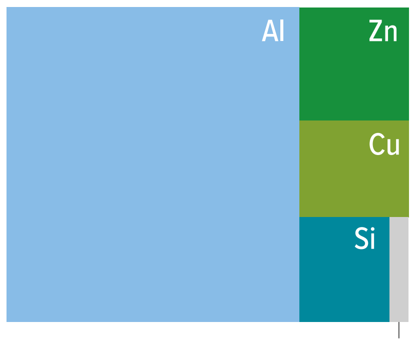
SOLAR PV

The 2021 European Solar Initiative aims at restoring and rescaling the solar PV value chain in Europe after its loss to China, with an initial objective of 20 GW production by 2025.

Evolving metals demand (kt)



Makeup of metal usage (%)

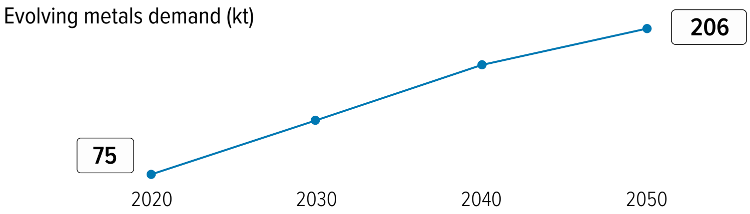


Other includes: Sn, Pb, Ag, Ni, Te, Cd, In, Ga, Ge

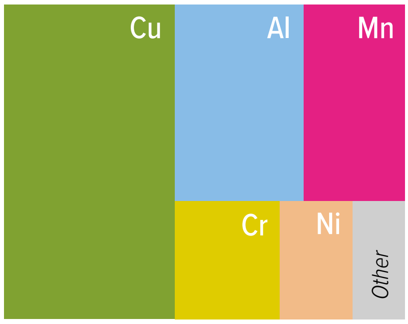
*† Europe = EU, Norway, Iceland, Switzerland, UK. * Steel is not included in charts due to study focus, but used across most technologies*
*** Lithium is expressed in terms of metal content for comparison (not LCE)*

WIND TURBINES

Europe is a significant producer of wind turbines and a net exporter of components, with a current capacity of 15 GW per year. There are ambitions to grow this capacity to meet the demands of the next decade, but without formal targets.



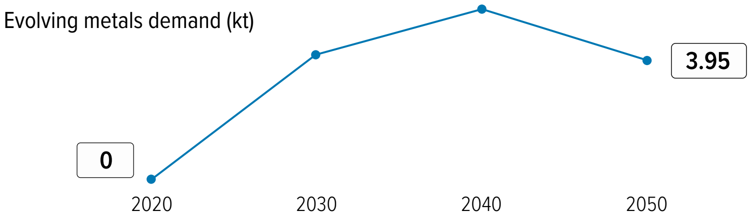
Makeup of metal usage (%)



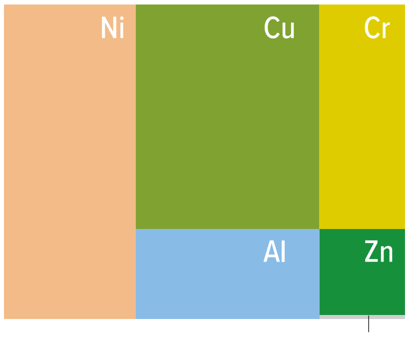
Other includes: Zn, Mo, B

HYDROGEN

The European Clean Hydrogen Alliance plans that Europe takes a leading role in the R&D and production of hydrogen technologies, and there is potential for a considerable share to be produced domestically.



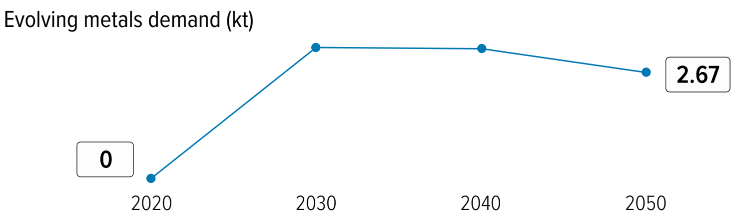
Makeup of metal usage (%)



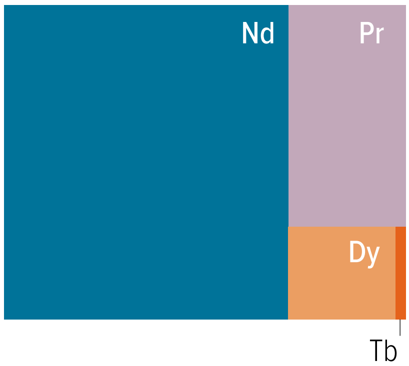
Other includes: Mn, Sc, Co, Ir, Pt

PERMANENT MAGNETS (used in electric vehicles and wind turbines)

The European Raw Materials Alliance has finalised a pipeline for creating a domestic value chain to supply 25% of Europe's permanent magnets needs by 2030, reducing dependence on China.

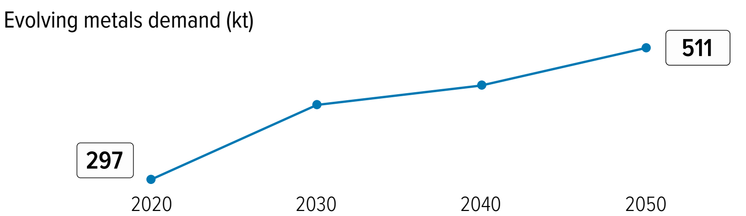


Makeup of metal usage (%)

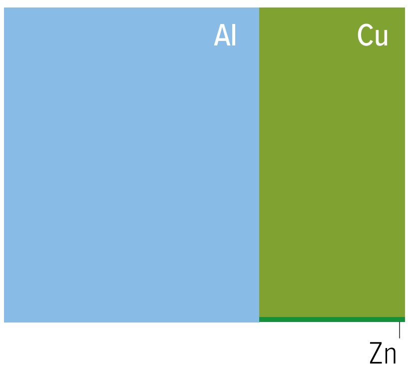


ELECTRICITY NETWORKS †

The components for Europe's electricity networks are produced domestically, and it is assumed that this will remain the case.



Makeup of metal usage (%)



Projections are based on the IEA's SDS technology scenario for Europe, domestic technology production plans, and metals concentration levels
† The figures shown only take into account metals demand for the expansion of electricity networks, not replacement.

Europe's metals needs until 2050 (annual)

Europe's energy transition will be the major growth driver for key metals markets

Europe's plans to establish domestic production for clean energy technologies will directly increase its demand for a wide range of metals. Imported technologies will already include their metals Three groups are focussed on in detail:

BASE METALS AND SILICON

Europe's energy transition will be the major new growth driver in most base metals and silicon markets, which already include widespread uses.

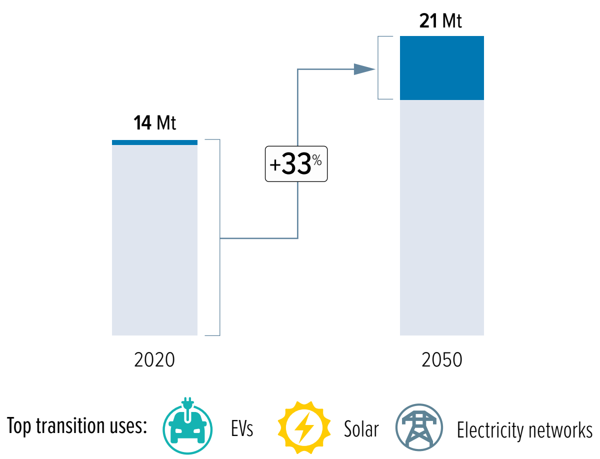
Aluminium and copper have widespread energy transition uses. By 2050, Europe will require new demand equivalent to 30-35% of today's consumption levels for manufacturing of electric vehicles, electricity networks, batteries, wind turbines, and solar panels (plus energy-saving uses in buildings will also drive demand).

Silicon's new demand of over 45% of today's use levels will be required if Europe succeeds in reshoring a level of solar photovoltaics production and establishing battery anodes production (with silicon projected to have a growing use alongside graphite)*.

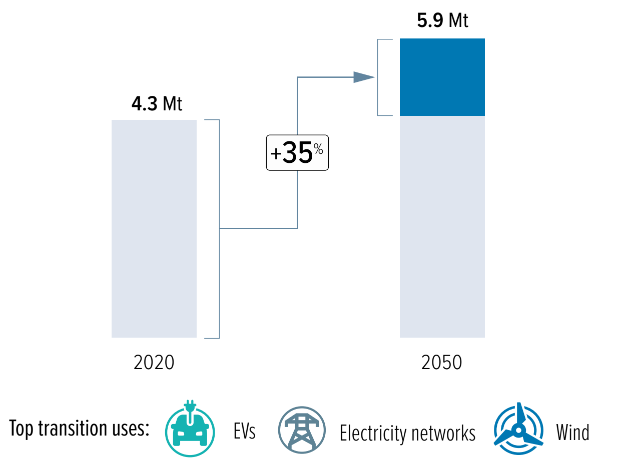
Zinc has several energy transition uses, but not in high enough volumes to meaningfully impact today's consumption levels.

Energy transition uses   Other uses

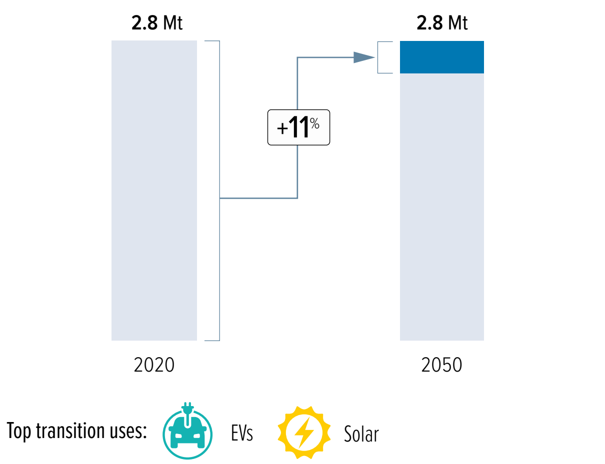
Aluminium (Mt)



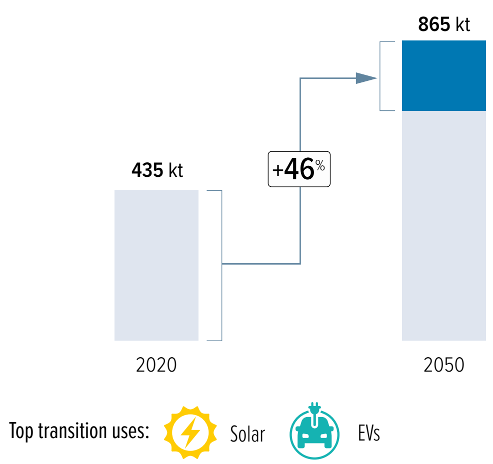
Copper (Mt)



Zinc (Mt)



Silicon (kt)



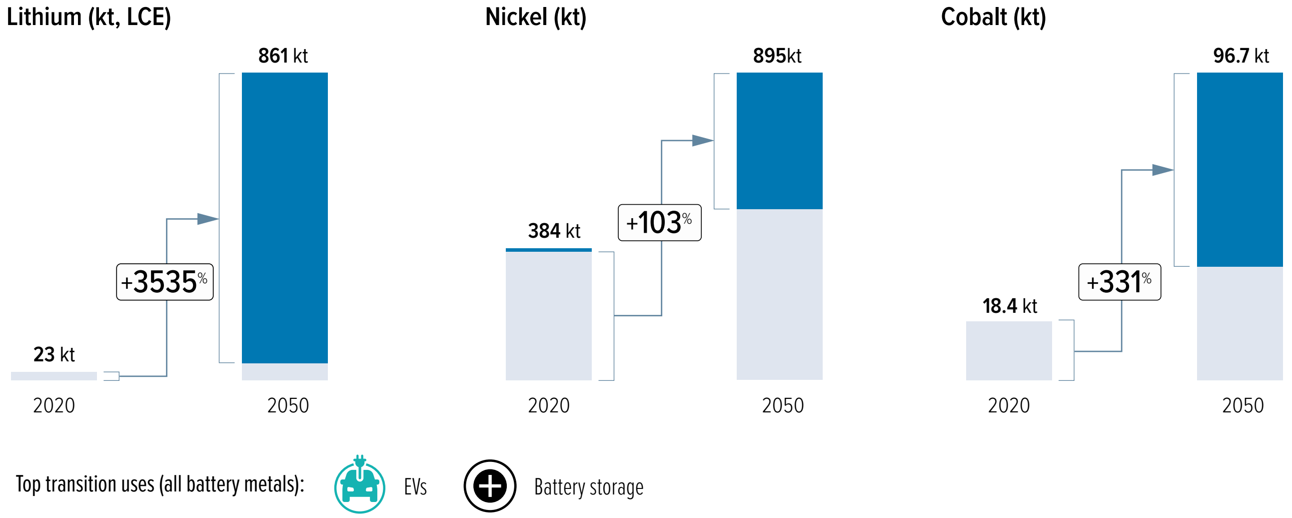
** Silicon is also a used in major aluminium alloys, including in energy transition uses. Only the uses of pure silicon are quantified in this study*

BATTERY METALS

Europe will require significant new supplies of nickel, lithium, and cobalt for its domestic battery cathode manufacturing plans. Of these metals, Europe only has a significant existing market for nickel, which is mainly used in stainless steel.

By 2050, batteries will be Europe's major use for lithium, nickel, and cobalt under all the study's scenarios, with new demand reaching up to 3500% of Europe's lithium consumption today, 330% of cobalt, and more than 100% of nickel.

Uncertain technology developments after 2030 will likely impact these long-term projections. Regular attention is required to the battery market and potential breakthrough technologies.

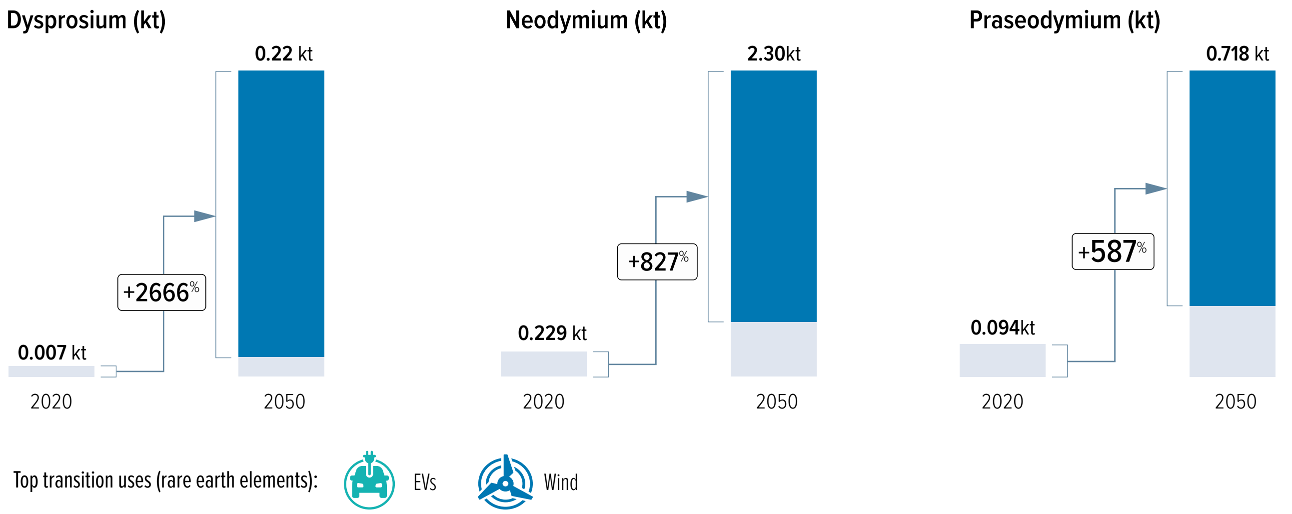


RARE EARTH METALS

Significant volumes of rare earth elements in permanent magnets will be required in Europe's electric vehicles and wind turbines.

But Europe will only require new supplies of rare earth metals if it is successful in building up domestic permanent magnets production – competing against China's near monopoly of the rare earths/permanent magnets market.

Even a moderate level of European domestic magnets production would transform the European rare earths market, requiring between 600% and 2700% extra compared with Europe's consumption today.



OTHER METALS: The energy transition will also significantly impact on several minor metals. Iridium, scandium (hydrogen), and tellurium (solar PV) will have >50% of their 2030 demand from clean energy technologies and major supply pressures. Gallium, germanium, indium and tin are projected to have high combined growth from solar PV and digital applications. The uptake of redox flow batteries for energy storage would have a disruptive demand pull for vanadium.

How Europe can supply its future metals demand

Europe will need to combine long-term recycling growth with new primary metals supply

Europe will need to make choices on how it will supply its accelerating metals demand, to ensure both strategic autonomy and environmental leadership.

In the initial years of the energy transition, Europe will mainly require new primary metals supply from mining and refining, to reach a 2040 baseline. These needs can be supplied through a combination of domestic production capacity and imports.

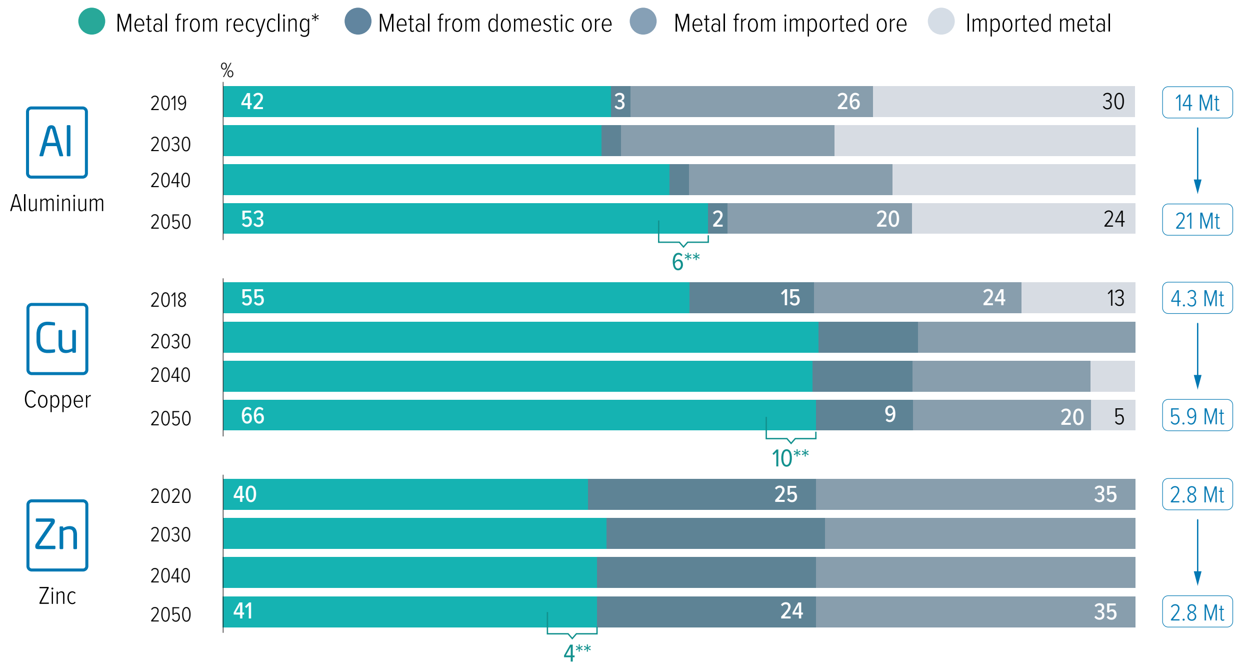
Secondary supply from recycled sources will take a more prominent role as today's clean energy technologies begin reaching their end-of-life. After 2040, recycling could be Europe's major supply source for most transition metals, alongside the continued need for primary metal. This requires major efforts to build new recycling capacity and overcome bottlenecks, furthering Europe's existing global leadership

EUROPE'S RECYCLING POTENTIAL††

Recycling could provide 45-65% of supply by 2050

BASE METALS

Recycling already provides between 40% and 55% of Europe's aluminium, copper, and zinc supply. More metal in stock will become available to recycle by 2050, but future growth will also require improvements to collection and sorting operations, product design, and the prevention of scrap leakage.



Recycling could provide 25% of supply by 2050

SILICON †

Europe will need to develop a new recycling industry for solar PV panels, which will start reaching end-of-life in meaningful volumes after 2035. Pilot plants are currently being set-up.

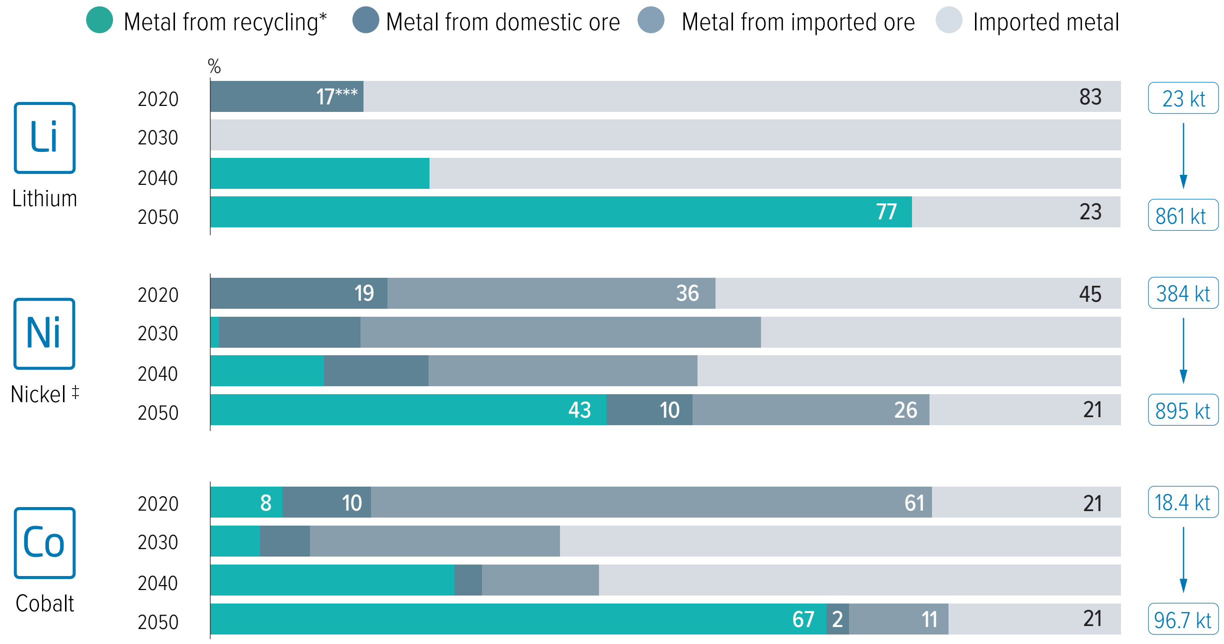
** Recycling estimates include both old and new scrap (or post-consumer/pre-consumer scrap) ** Assumptions on improvements to today's recycling rates (in place from 2030), which are conditional on several frameworks being place, such as improved product design, better collection and sorting systems, and more scrap staying in Europe instead of exported.*

† Today silicon is recycled as part of aluminium alloys but not as pure silicon †† Europe = EU, Norway, Iceland, Switzerland, UK.

BATTERY METALS

Recycling could provide 45-77% of supply by 2050

Europe will need to develop new recycling capacity for electric vehicle batteries. The first generation will start reaching end-of-life in significant volumes after 2035. Until then, recycling volumes will mainly come from process scrap during battery production (not quantified in this study). By 2050, recycling can give Europe a major supply source if batteries reach EU recyclers and new recovery technologies are commercialised.

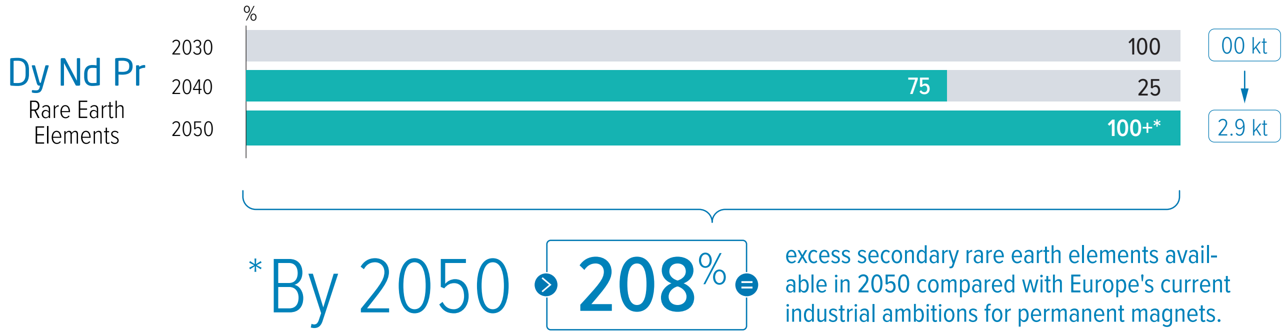


*** This does not represent battery grade lithium, but spodumene destined for the ceramics market
‡ Today nickel is recycled as part of stainless steel but not as pure nickel

RARE EARTH ELEMENTS

Recycling could surpass Europe's needs by 2050

Europe will need to develop new recycling capacity for permanent magnets and overcome economic challenges. Because Europe only aims to produce part of its permanent magnet needs domestically, the volumes of rare earth elements available from magnet recycling could exceed Europe's needs after 2040. Europe should decide in advance whether to expand its domestic ambitions for permanent magnets production, or otherwise to export its excess secondary rare earth elements.



RECYCLING LIMITS: The contribution of recycling to Europe's metals supply is limited by the availability of viable waste streams containing metals, as well as the effectiveness of the recycling system. Metals have a varying lifetime in the economy (e.g. 30 years average for copper), and given historical growth rates there remains a gap between available secondary material and demand.

Disclaimer (for silicon, battery metals, rare earths) - There is high variability on the likely recycling rates for clean energy technologies in the 2030-2040 period due to the high speed of market growth and several unknown conditions (such as their lifetime in use, second life applications, and other factors). Recycling's contribution to meeting direct European metals demand will also depend on Europe's level of technology production. More or less battery cathode, permanent magnets, and solar PV production than modelled would change the percentages listed above.

How much metal could Europe mine and refine domestically?

Europe's energy transition will require high new volumes of primary metal in the next 20 years, especially for battery metals and rare earth metals. The EU is evaluating how to improve its self-sufficiency at both the mining and refining stages. The global significance of Europe's primary metals supply has declined in the last two decades, with mining and refining capacity additions mainly happening in other regions. Firm short-term action would be needed to change this pattern and take pand take some of Europe's limited projects forward in view of high demand in the 2030-2050 period.

MINING

Europe's domestic mining industry supplies 4-30% of the bloc's primary metals needs for aluminium (bauxite), copper, zinc, nickel, and cobalt. Europe does not have mining capacity for battery-grade lithium or rare earth elements. High volumes of ore and concentrates are imported from other regions, mainly South America, Africa, and North America.

Companies have developed a pipeline of potential projects for the next decade which could which could partly help meet Europe's expected demand increase, but also have high levels of uncertainty.

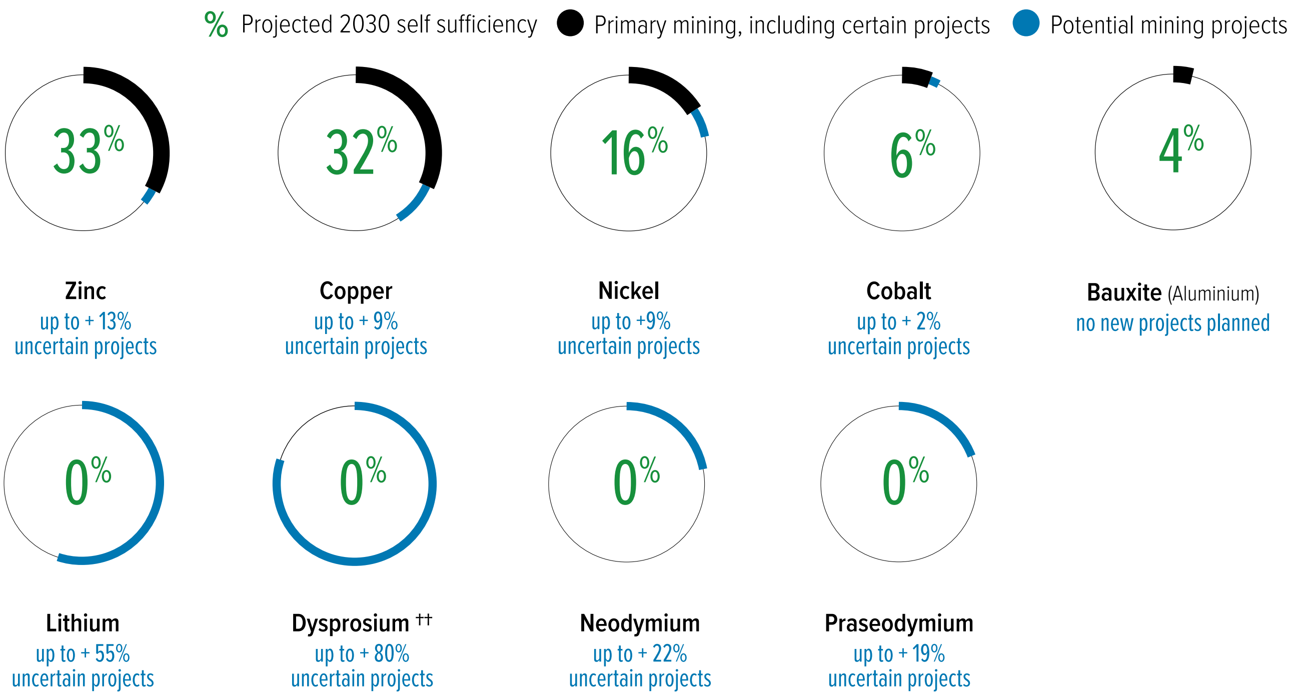
- Europe has a large but uncertain mining project pipeline for lithium and rare earths with potential to provide 25-55% and 20-80% respectively of projected 2030 intra-EU demand
- The project pipeline for copper, zinc, and nickel would mainly compensate for the depletion of existing mines, while supplying an additional 3-9% of 2030 primary needs.
- There are no plans to mine more bauxite domestically, and cobalt mining capacity is minor compared with demand

Most planned new mines in Europe have an uncertain future (and several categorised as unlikely). Projects face a mixture of challenges, including local opposition, permitting delays, less favourable economics, and/or reliance on untested technologies.

Mining projects have long lead times of 10-15 years, meaning there is only a narrow window for Europe to take forward projects in time for the energy transition's 2030 demand spike.

If no new mines are opened, there will be a further depletion of Europe's mining capacity. For example, its copper and zinc output would decline by 50% in the next 20 years.

Europe's self-sufficiency for primary raw material needs (excluding the contribution of secondary supply), 2030 base case, plus the theoretical impact from uncertain new projects*



SELF SUFFICIENCY CONTEXT: The contribution of domestic supply to Europe's primary metals demand (excluding the contribution of secondary supply) depends on production levels down the value chain. For example, Europe today has a theoretical but uncertain lithium mining projects pipeline of 130kt LCE and 165 kt LCE for refining (in Austria, Czech Republic, Finland, Germany, Spain, Portugal). If Europe produces 50% of its cathode needs domestically (in line with current plans), its theoretical lithium mining potential could supply 55% of 2030 demand. But if Europe grows to produce 100% of its cathode needs domestically, its theoretical lithium mining potential could supply 25% of 2030 demand (while less lithium will be imported in products).

REFINING

Europe must also decide in which direction to take its domestic metals refining industry, which processes both domestic and imported ores, as well as being needed for some secondary raw materials (e.g. the output from electric vehicle battery recycling) secondary raw materials (e.g. from electric vehicle batteries).

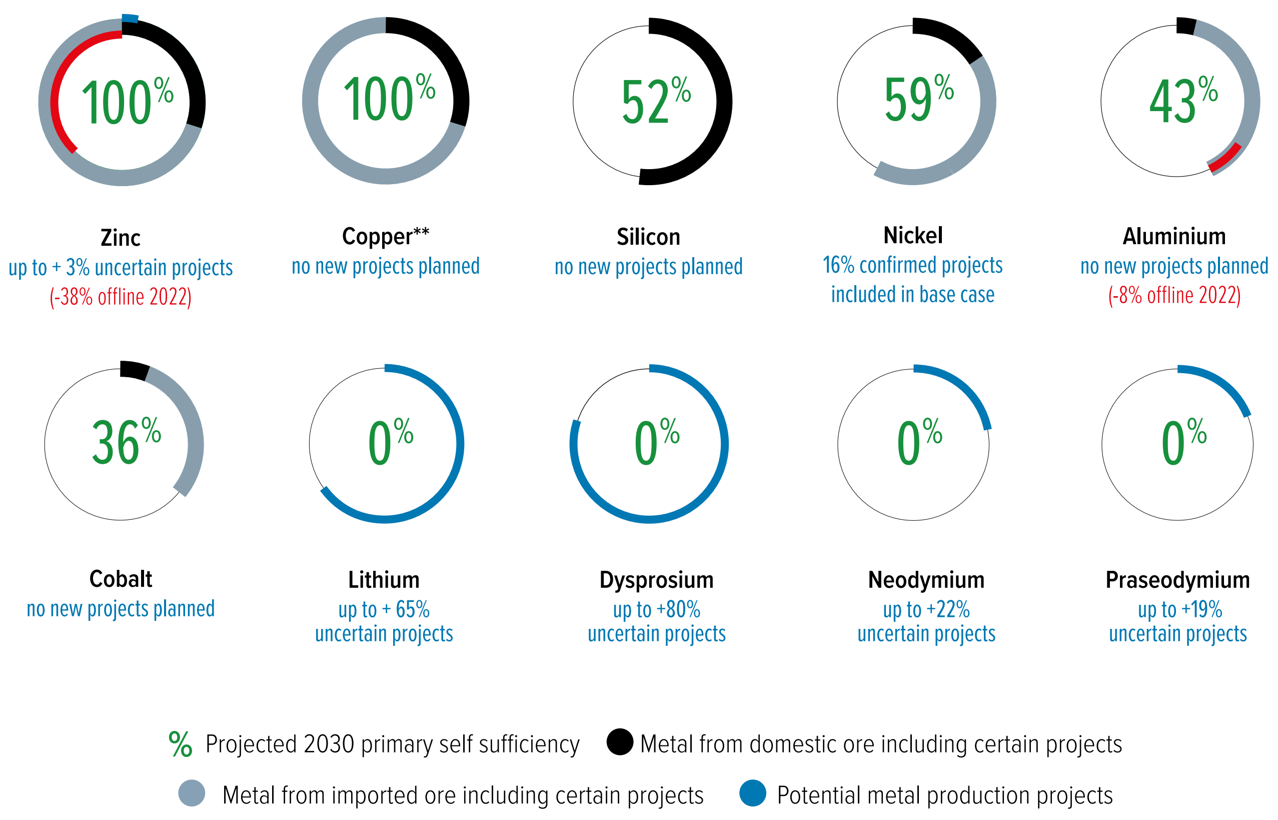
European smelters and refiners supply between 36% and 100% of the bloc's primary metals needs for aluminium, copper, nickel, zinc, and cobalt. Europe does not currently have refining capacity for lithium or rare earth elements. Europe's production capacity has plateaued or declined in the last two decades (including the loss of 1/3 of primary aluminium capacity).

Europe also imports metals, mainly from Russia, Chile, and China. The EU currently has anti-dumping duties in place to safeguard against China's unfair trading practices for aluminium and silicon.

New European lithium and nickel refinery plans have been announced in the last year. But further refining announcements will be necessary for Europe to get an equivalent production base as for its base metals markets.

Europe also faces a legitimate risk of further metals production leakage without more favourable business conditions, particularly affordable clean energy supply. High European power prices had in early 2022 resulted in 10% and 40% of Europe's primary aluminium and zinc capacity being taken temporarily offline, with silicon production also being negatively impacted. Permanent smelter closures or temporary suspension of production facilities are a concern.

Europe's self-sufficiency for its primary metals (excluding the contribution of secondary supply) needs of domestic technology production, 2030 base case, plus the theoretical impact from uncertain new projects*



* Europe = EU, Norway, Iceland, Switzerland, UK.

** Assumes improvement of today's end-of-life recycling rates by 2030. Without improvement, metals self-sufficiency would be 84%.

†† Europe's rare earths demand is also dependent on its success in establishing a permanent magnets production industry. Theoretical self-sufficiency figures are modelled on Europe's current ambition to produce 25% of its permanent magnets domestically, and include projects considered uncertain or unlikely.

Europe's reliance on global markets

Risks of supply constraints

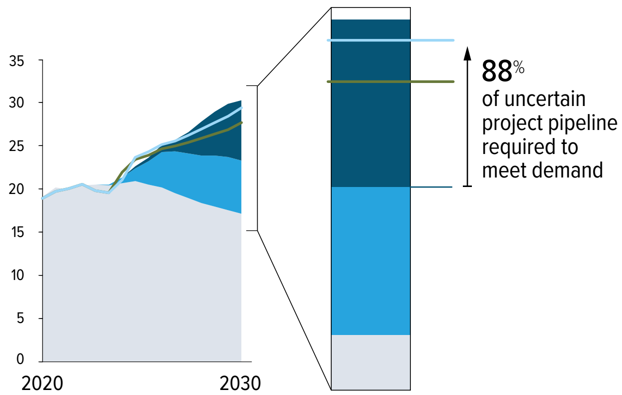
Europe will need to import more lithium, cobalt, rare earth elements, and nickel to supply its energy transition, up to a peak in 2040. If new refineries are opened in Europe, then metal ores will be imported in higher volumes instead of the metals. Opening new mines in Europe will soften demand for imported ores but not replace the demand.

Global metals markets are at risk of supply constraints in this period without an acceleration in mining supply. The rapid global deployment of electric vehicles and renewable energy technologies would result in a disruptive demand pull for five metals - copper, lithium, nickel, cobalt, and rare earths – that will be difficult to meet even if all the currently available project pipeline gets brought online.

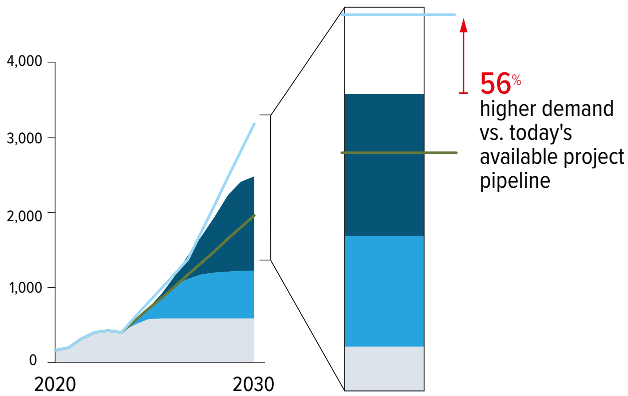
Other markets have different challenges, including pressure on the global silicon and aluminium markets from China over capacities, and uncertainty of where new smelting capacity will be installed given its need for low-cost and ideally low-carbon power sources.

If European industries have not secured long-term domestic or global supply sources for key metals, then they risk supply disruption or cost increases that could slow the pace of the energy transition.

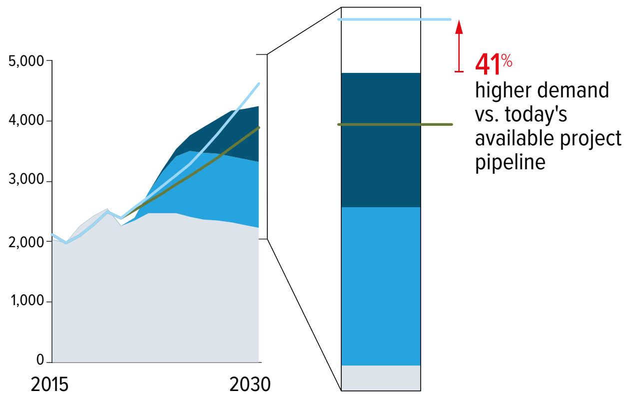
Global copper demand-supply outlook (Mt)



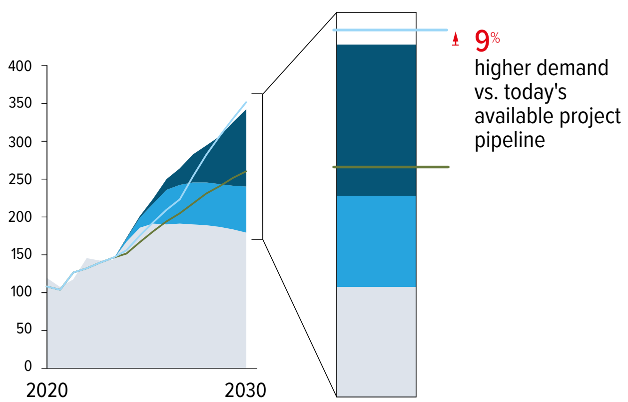
Global lithium demand-supply outlook (kt, LCE)



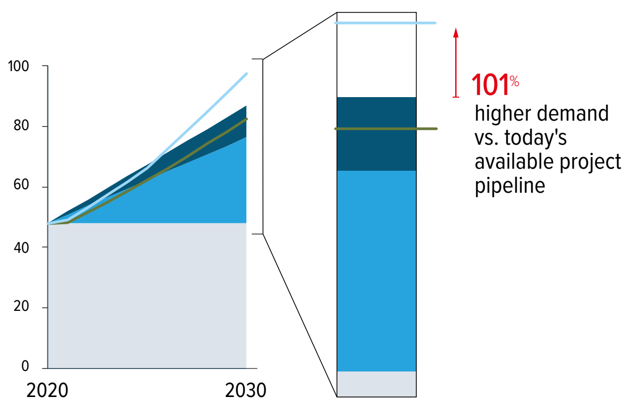
Global nickel demand-supply outlook (kt)



Global cobalt demand-supply outlook (kt)



Global rare earth elements demand-supply outlook (kt)



Operating mines Likely additions Uncertain additions Current climate policies Ambitious climate policies

The potential for global supply constraints is not due to a lack of resources in the ground, but a mismatch between the global mining project pipeline and the speed of the energy transition. Historical trends in reserve and resource development support that there will be enough metal available to meet 2050 energy transition demands.

Shift in global imports profile

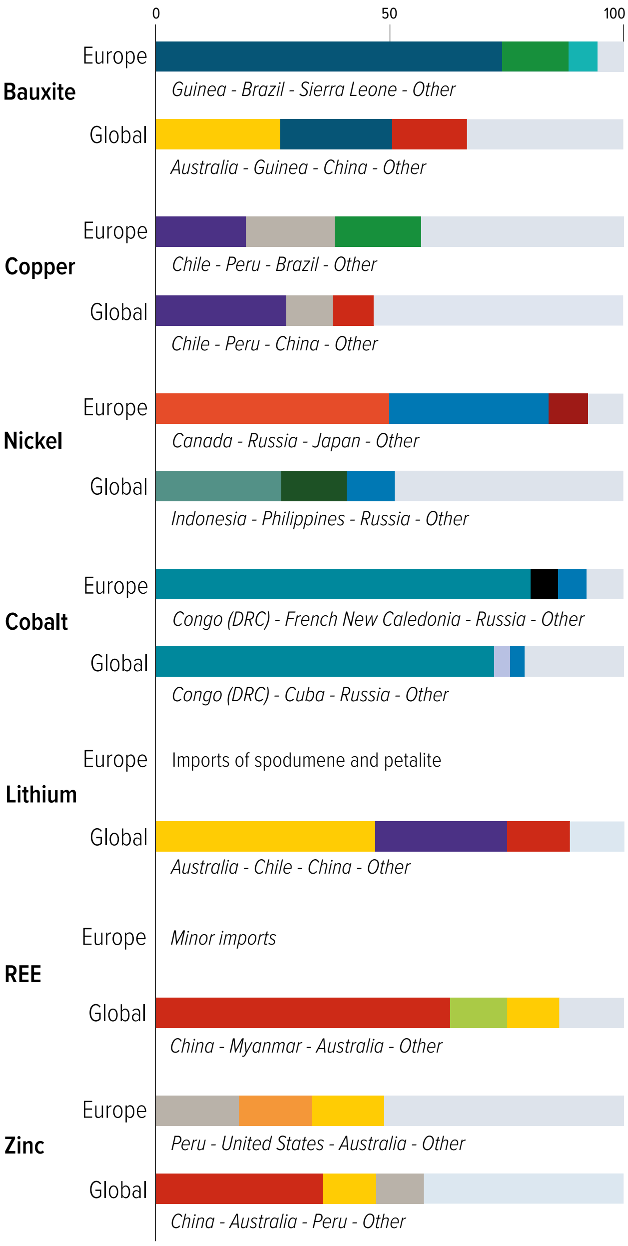
Europe's metals import profile would need to shift in the next decade to meet its energy transition requirements. Active choices will be required, including sustainability considerations.

For example, China is the dominant global refiner of lithium, cobalt, and rare earth elements, and so is positioned to supply more of Europe's growing needs without further diversification. Indonesia will provide most of the world's planned nickel capacity expansion by 2030, largely through China-owned operations. Both regions predominantly produce their metals with coal-fired power and a high carbon footprint (although individual producers vary).

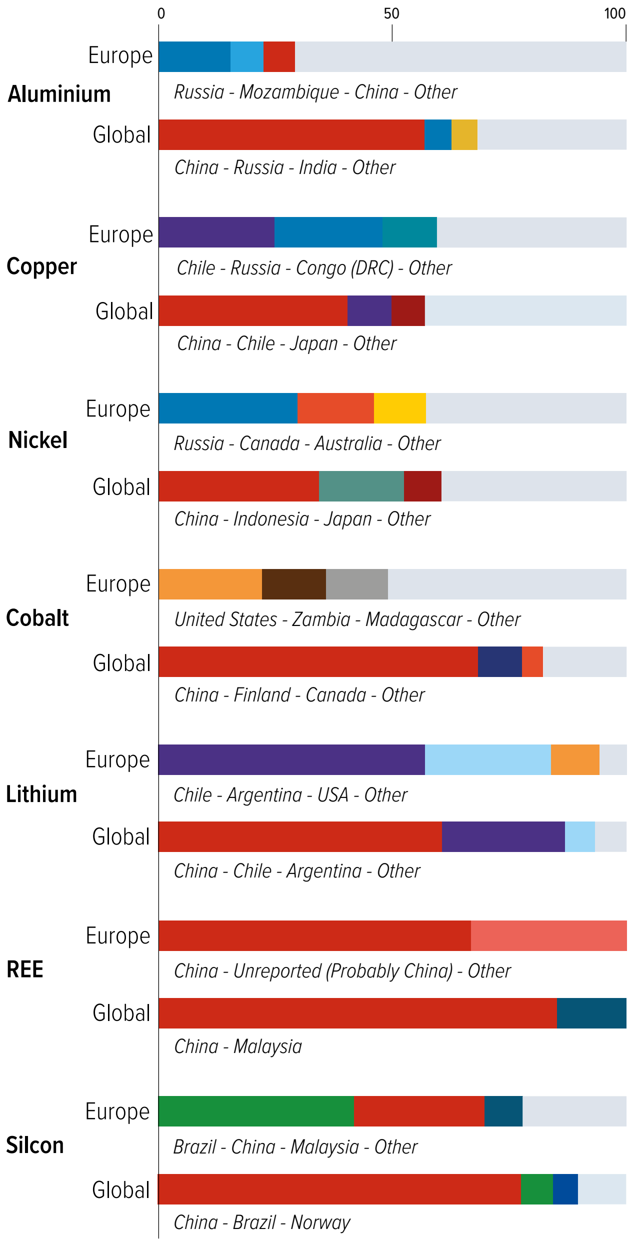
Russia's major share in Europe's alumina/aluminium, Class 1 nickel, and copper import markets also requires assessment. After the 2022 Ukraine invasion, there is a new pressure for Europe to diversify its supply sources.

Lastly, Europe has anti-dumping duties in place for aluminium and silicon to safeguard against proven dumping from Chinese state-funded over capacities. Trade defence will continue to be required to fight documented unlawful trade practices.

Mining/ore - Europe imports and global supply (%)



Refining/metals - Europe imports and global supply (%)



Ensuring sustainability of Europe's metals supply chains

Europe aims that its energy transition will be supplied by sustainable materials and responsible supply chains.

The shift from a fossil fuels system to one powered by metals-based technologies has lifecycle benefits:

- **More material efficient:** The continual burning of fossil fuels is replaced by metals which last the lifetime of a product (for example, an electric car uses an estimated 8x less raw materials input overall than a conventional car)*
- **More circular:** Metals can be indefinitely recycled due to their permanent properties, and so once mined they will be used in multiple lifecycles if effective recycling systems are in place

But to ensure sustainability, Europe must address the potential for adverse environmental and social impacts in the metals production stage.

At a global level, producing the metals in scope currently contributes to around 3% of the world's greenhouse gas emissions. Metals and mining operations impact local biodiversity, create significant waste, and have potential for local pollution. Many metals have an inherent toxicity and exposure must be controlled across the lifecycle. Human rights protections – including for indigenous populations and artisinal miners - must also be secured. Each metal and region has a different ESG profile.**

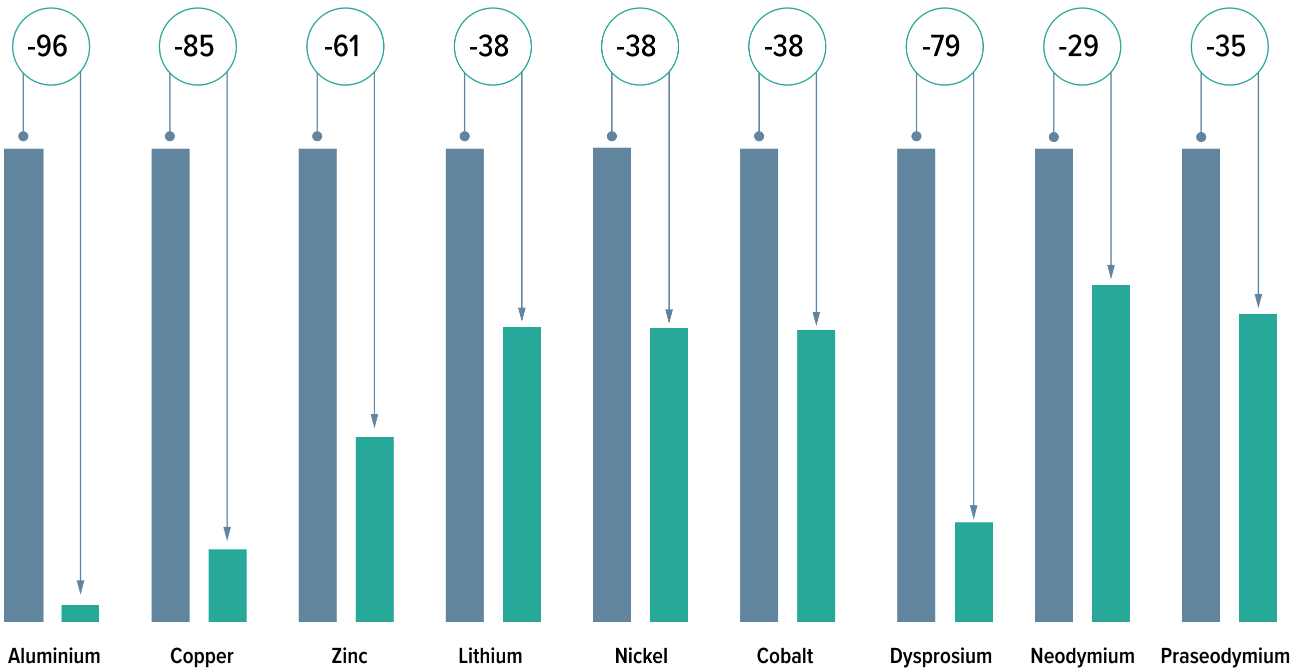
Major metals miners and producers have improved their ESG performance in the last decade. Further action is required for the sector to reduce greenhouse gas emissions in line with the Paris Agreement and to minimise other environmental impacts while ensuring social protections. Europe has several levers to address the sustainability of its metals supply chains.

1. Recycle as much as possible, under the right conditions

Replacing primary metal with secondary metal allows for CO_2 savings of between 29-96%, depending on the waste stream and its complexity. Recycling also prevents the need for new mining, saving resources and avoiding the environmental impacts associated with extraction.

There is a need to ensure that metals recycling also takes place according to high environmental standards. Otherwise, there is potential for pollution and health impacts in certain waste streams – for example informal electronics scrap recycling in the developing world.

CO_2 footprint of secondary supply vs. primary (%)†



** Source: VDI/VDE Innovation + Technik - Raw materials consumption in ICE and BEV (2022) ** See full report for global sustainability profiles*

† The secondary CO_2 footprints for lithium, nickel, and cobalt are based on literature information on electric vehicle battery recycling. Nickel is also widely recycled in stainless steel, with an average CO_2 saving of 89% vs. primary production.

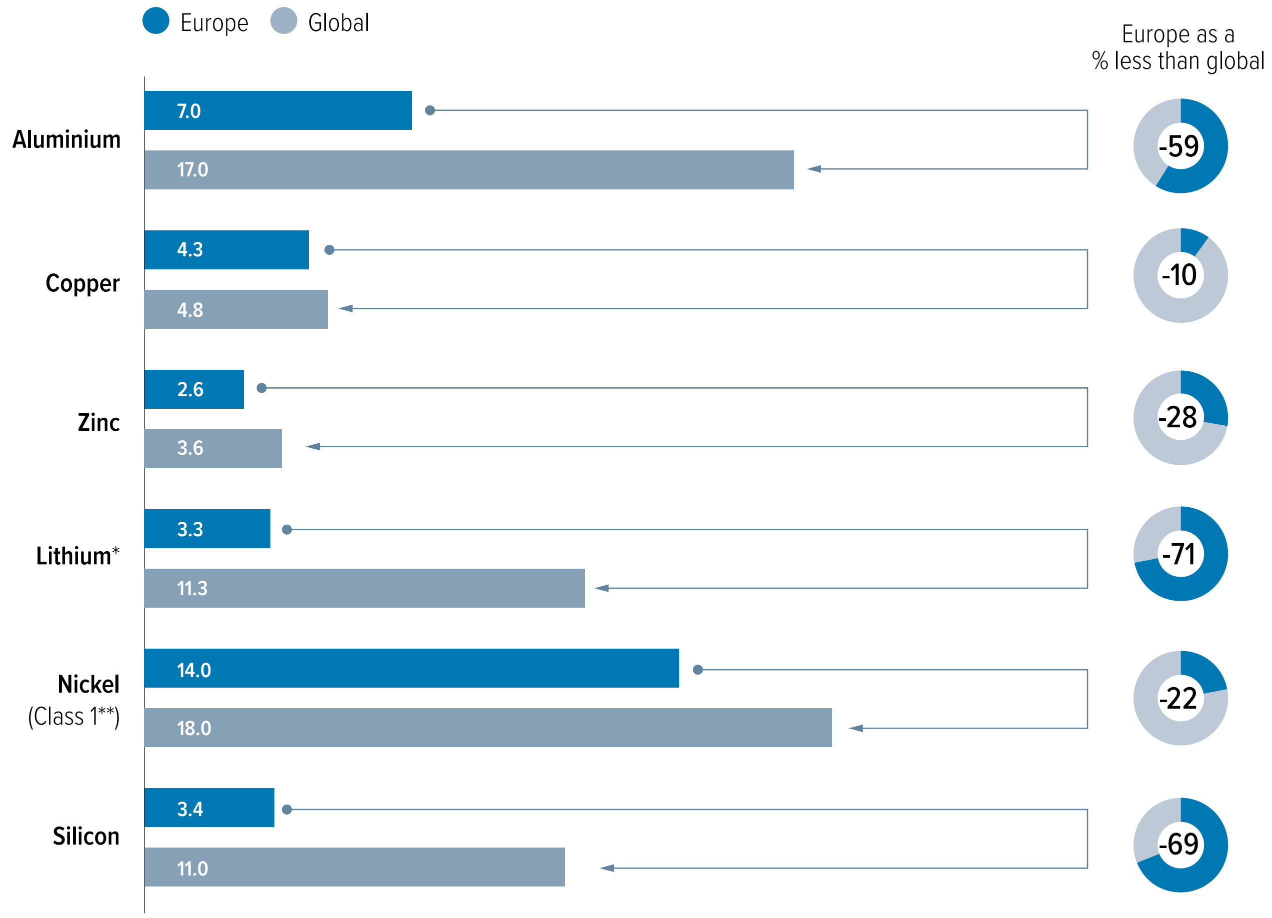
2. Produce what is feasible within Europe, while driving continual improvement

Metals produced in Europe have a lower average CO_2 footprint than the rest of the world, and benefit from Europe's environmental and social protections. The EU's evolving climate and environmental policy framework is a basis for mobilizing the sector's continual improvement.

The EU has implemented a package of environmental policies that control impacts from its domestic mining and refining operations. Rules are in place to limit air and water emissions, to manage extractive waste, to safeguard biodiversity, and to restore mining sites post-closure. Social standards are also high.

Some Member State frameworks differ from each other, for example when it comes to mining codes. There are ongoing discussions about where/how rules should be improved, which are outside the scope of this report. But overall, producing metal within Europe reduces the environmental and social risks that are mapped in certain other jurisdictions.

CO_2 footprint per ton of primary metal production (mining and refining)



* *The European carbon footprint is based on the estimated 2030 CO_2 footprints of announced European projects. The number is hence uncertain and subject to the realization of the ambitions. This is compared to the global average footprint for lithium brine operations that produce lithium carbonate have a footprint of 3.5t CO_2/t LCE, producing lithium hydroxide runs op to 8.2 t CO_2/t LCE. Hard rock operations are more energy intense and produce lithium at an average carbon footprint of 18-22.5 tCO_2/t LCE (for hydroxide and carbonate respectively).*

** *Class 2 Nickel has a far higher global average carbon footprint of 70tCO_2/t.*

3. Import from responsible sources, with robust certification

The EU's proposed due diligence rules will make it a legal requirement for all big European suppliers to ensure environmental and social risks are controlled in their supply chains. This is necessary to mitigate the potential for adverse impacts from Europe's imported metals supply.

Europe has partnered with other countries, such as Canada, which already have equivalent environmental and social protections established in law. And there are individual operators across all regions who have invested into controlling their impacts and supporting communities (and those who have not).

Proven responsible operators should be favoured for Europe's clean energy technology supply chains, in parallel to efforts for addressing the root causes of some impacts (e.g. the Fair Cobalt Alliance's work to improve artisanal and small-scale mining conditions in the Democratic Republic of Congo).

Numerous industry certification schemes allow companies to audit their environmental and social performance. These are based on international frameworks such as the UN Guiding Principles on Business and Human Rights and OECD Guidelines and are the basis for demonstrating due diligence. Each has a different scope and comprehensiveness. Further rationalisation and strengthening is expected in the next decade.

	Metals in scope	Coverage	Content*	Governance
Initiative for Responsible Mining Assurance	All	Mining	ESG	Multi-stakeholder
Towards Sustainable Mining	All	Mining	E & S	Multi-stakeholder
International Council on Metals & Mining	All	Mining	ESG	Industry
Environmental, Social & Governance (ESG) Standard for Mineral Supply Chains	All	Smelter and refiner	ESG	Third-party auditors
Global Responsible Sourcing Due Diligence Standard for Mineral Supply Chains	All	Smelter and refiner	OECD Due Diligence risks	Third-party auditors
Aluminium Stewardship Initiative	Aluminium	Value chain	ESG	Multi-stakeholder
Cobalt Industry Responsible Assessment Framework	Cobalt	Smelter and Refiner	E & S	Industry
Cobalt Refiner Supply Chain Due Diligence Standard	Cobalt	Smelter and refiner	OECD Due diligence risks	Third-party auditors
The Copper Mark	Copper	Value chain	ESG	Multi-stakeholder
Joint Due Diligence Standard for Copper, Lead, Nickel and Zinc	Copper, Zinc, Nickel, Lead	Smelter and refiner	OECD Due diligence risks	Multi-stakeholder
*Nickel, Zinc and Molybdenum Mark***	*Zinc, Nickel, Molybdenum*	*Value chain*	*ESG*	*TBD*
*Certification of raw materials***	*All*	*Value chain*	*ESG*	*TBD*

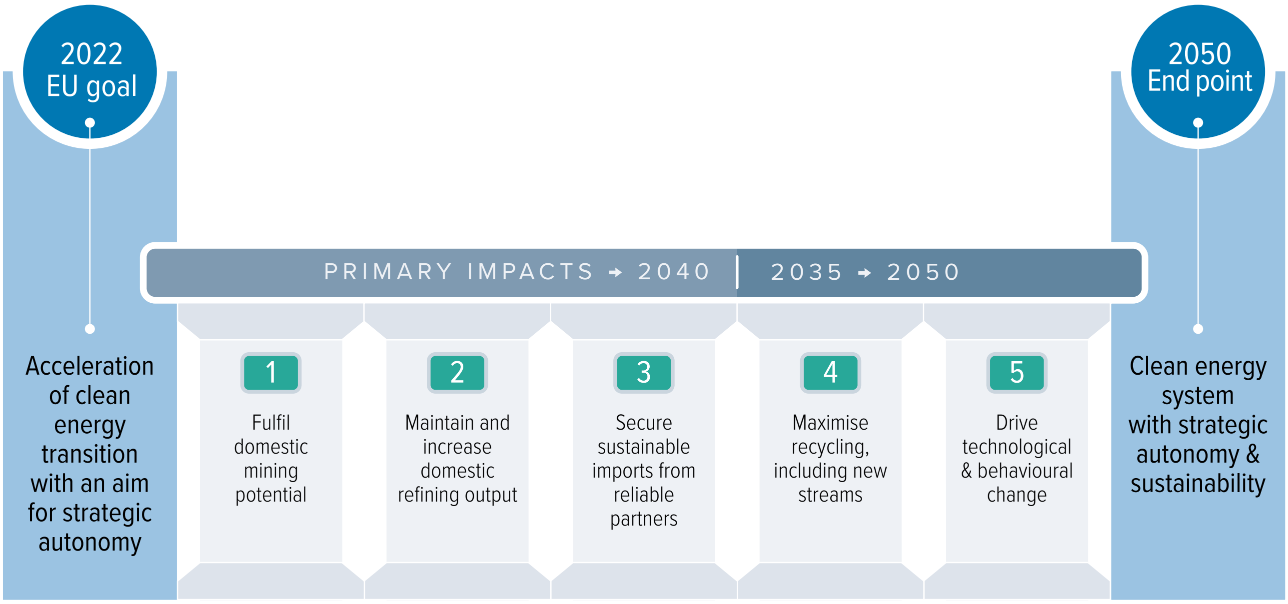
** There is not consistent information on the differing comprehensiveness of schemes. The IGF has made a quantitative comparison of selected schemes, available here: bit.ly/3E7x8yo*

*** Not yet launched*

Innovation and behavioural change: Europe's metals consumption will also be optimised through technological innovation and some substitution from downstream industries. A shared economy could also make a real difference, particularly in the transport sector which represents 60% of analysed metals demand (whereas renewable energies, electricity networks cannot be much reduced). The study does not model this impact due to a lack of robust scenarios. It is assumed that bigger societal demand shifts would happen only after 2030.

Conclusion: Achieving Europe's goal for energy transition metals resilience

The EU can improve the strategic autonomy of its clean energy system and avoid repeating its current fossil fuel dependencies through five pillars of action between now and 2050:



Europe's clean energy system will be based on permanent metals which can remain indefinitely in a circular economy. Recycling is Europe's main opportunity to improve its long-term self-sufficiency and could provide 45-65% of Europe's base metals needs by 2050, up to 77% for battery metals, and a a rare earth elements surplus.

But for the next 20 years, new primary metal will be pivotal to kickstart Europe's clean energy shift. Recycling will not provide Europe with meaningful supply for many metals until after 2040 when high volumes of clean energy technologies start reaching their end-of-life.

Europe faces supply vulnerabilities around 2030 without secure inputs of primary metal. The global energy transition is progressing faster than the mining project pipeline, with copper, cobalt, lithium, nickel, and rare earths all at risk of a disruptive demand pull between now and 2035.

Europe has a narrow window to take forward any of its domestic and refining projects to soften some of the medium-term supply risk. But a paradigm shift would be needed given their uncertainty today.

Mining projects across Europe are challenged by local opposition, permitting delays, and technical uncertainties. Power-intensive refineries are struggling to survive in a period of high energy prices.

Europe's relatively limited additional domestic potential means that imports will also need to be secured from responsible partners under fair trade conditions. To manage environmental and social risks, Europe must diversify its trade partners, implement its new due diligence law linked with industry certification schemes, and decide whether to support investment in external mines and drive ESG standards directly.

Long-term technological and behavioural change will also have an impact on Europe's metal needs, through innovation, substitution, and potential future shifts towards a shared economy.

None of these actions in isolation provides a silver bullet. Europe must act across all five identified pillars to support its strategic autonomy goal.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