Paving the way to cleaner nickel

Nickel in batteries and how to secure it sustainably

October 2023

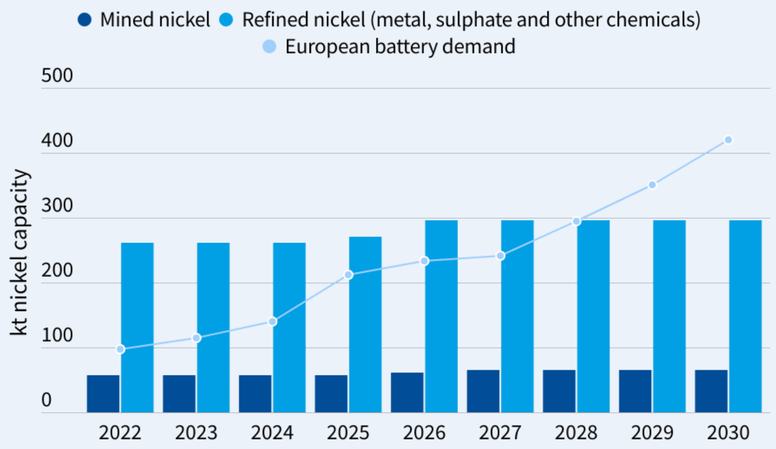
Summary

The green transition will require a substantial supply of raw materials, with nickel emerging as a critical enabler of this transformation. In this paper T&E looks at the current nickel market globally, Europe's potential, and the ways to source nickel sustainably.

Nickel in lithium-ion batteries for electric vehicles provides longer driving ranges and battery chemistries are evolving rapidly. The currently popular high-nickel chemistry (NMC 811) contains around 0.66 kg Ni/kWh, but alternative chemistries with lower content are emerging. In 2030, nickel-containing chemistries are expected to account for around half of the global market.

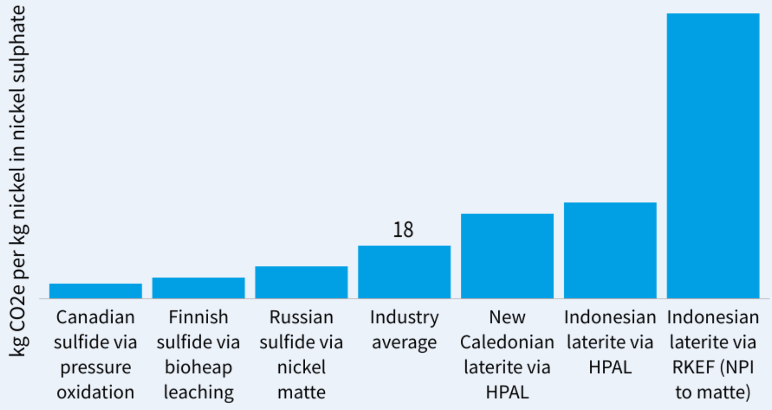
To keep up with the rising demand driven by the widespread adoption of electric vehicles, nickel production will need to expand. A significant portion of the global nickel supply - around 60% of the mined output and 40% of the refined output by 2030 - will originate from Indonesia, which has rapidly grown into a nickel powerhouse in recent years.

In Europe, the nickel mining capacities potentially relevant for the battery sector could reach 66 kt Ni, meeting 16% of the region's demand from electric vehicles and energy storage systems in 2030. Refining capacities of nickel sulphate - the material of choice for these batteries - amount to 63 kt Ni, or 15% of the region's future battery demand, with a potential expansion, albeit uncertain, of 35 kt (8%). Demand coverage would be even higher if some of the metal capacities were diverted to this sector, meeting up to around 70% of the anticipated demand. However, this would not account for other competing applications and remains uncertain.



Source: T&E analysis

Nickel mining and refining comes with a certain carbon footprint, but there are solutions to improve this environmental impact. Greenhouse gas (GHG) emissions vary widely across nickel sulphate production sites, depending on multiple factors including the energy source and production technologies deployed. Analysis by Minviro shows that operations with access to renewable energy and using hydrometallurgical technologies, such as bioheap leaching and pressure oxidation, have the lowest carbon footprint. Specifically, a comparison of six nickel sulphate production routes reveals that emissions levels at the best performing facilities, located in Canada and Finland, are 70% and 63% lower, respectively, than the industry average. At the opposite end, processing laterite ores into nickel pig iron (NPI) to matte to nickel sulphate generates 5 times more emissions than the industry average, while the high pressure acid leaching (HPAL) route, increasingly popular in Indonesia, produces almost twice as much emissions than the industry average.



*Industry average as calculated by the Nickel Institute ("Nickel Sulphate Life Cycle Data")
Source: Minviro, Nickel Institute

Studies show that switching to renewable sources of electricity alone can reduce emissions by up to 40% on average. Other key solutions to mitigate the industry's GHG emissions include using zero-carbon chemicals in the processes, decarbonising mining vehicles, streamline logistics and developing and adopting more efficient ore processing techniques that require less energy, such as bioheap leaching and pressure oxidation for sulphides, as well as heap leaching and atmospheric hydrometallurgical processing for laterites.

However, policies are needed to ensure nickel's production becomes cleaner. These include increasing renewables share in the energy mix, defining cleaner low emission nickel refining and processing routes (e.g. via EU Taxonomy Regulation) to stimulate investments in hydrometallurgy-based technologies, and mandating the use of best available technologies (e.g. for waste management and biodiversity conservation). Globally, applying robust standards such as the Initiative for Responsible Mining Assurance (IRMA) to more mining sites will improve environmental and social stewardship.

In Europe the focus should be on creating a local battery value chain as part of the EU Critical Raw Materials Act, with support for strategic projects that adhere to strict environmental and social standards, and forward looking industrial strategy centred around targeted funding support (e.g. via the EU Innovation Fund). In addition, collaborating with nickel-rich countries, investing in sustainable large-scale projects abroad and sharing expertise will be key for establishing mutually beneficial trade relationships.

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Acronyms

CO2e - carbon dioxide equivalent

CRMA - Critical Raw Materials Act

EIA - Environmental Impact Assessments

ESS - energy storage systems

EV - electric vehicle

FeNi - ferronickel

GHG - Greenhouse gas emissions

GWh - gigawatt-hour

HPAL - high pressure acid leach

IRMA - The Initiative for Responsible Mining Assurance

kt - kilotonnes

kWh - kilowatt-hour

LFP - lithium iron phosphate

Li-ion batteries - lithium-ion batteries

LMFP - lithium manganese iron phosphate

LMR-NMC - lithium-manganese rich nickel manganese cobalt oxide

LNMO - lithium nickel manganese oxide

MHP - mixed hydroxide precipitate

MSP - mixed sulphide precipitate

Mt - million tonnes

Na-ion batteries - sodium-ion batteries

NCA - lithium nickel cobalt aluminium oxide

Ni - nickel

NMC - lithium nickel manganese cobalt oxide

NPI - nickel pig iron

RKEF - rotary kiln-electric furnace

1. Introduction

As a critical raw material for the net zero transition, nickel is found in many clean technologies from electric car batteries to equipment for geothermal power generation and concentrated solar power systems. The metal will experience a continued surge in demand in the coming years, with IEA expecting the demand to increase by 85% by 2035. This growth will intensify the scrutiny on the industry's environmental and social practices, with innovation in technologies and practices making more sustainable nickel production possible.

In this report T&E attempts to provide an analysis of the global and European nickel market and explores some of the challenges and solutions to the issues associated with nickel mining and processing, such as emissions, waste management and biodiversity issues. The report then proposes policy recommendations to scale sustainable nickel manufacturing with the goal of contributing to the acceleration of the green energy transition.

2. The global nickel market

2.1 Demand

Most nickel is used primarily in stainless steel today. Over the next decade, the global nickel demand growth will be driven by the battery sector owing to the rapid global adoption of electric vehicles. While stainless steel will continue to be the main application for nickel, batteries are expected to reach almost 28% market share by 2030, up from 16% in 2022.

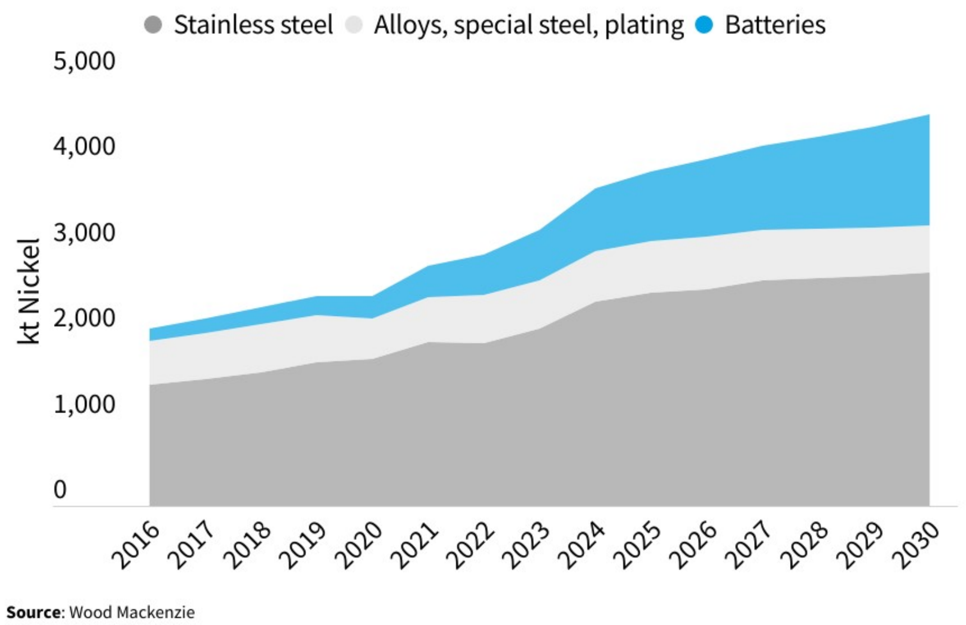


Figure 1: Global nickel demand by application

Nickel is found in battery cathodes, one of the two electrodes responsible for battery energy density and performance. It provides higher energy densities, meaning longer driving ranges, with nickel-rich cathode chemistries such as NMC (lithium nickel manganese cobalt oxide) and NCA (lithium nickel cobalt aluminium oxide) being widely used today, especially outside China.[1]

For the past decade, NMC chemistries have been evolving to cater to consumers' needs for longer driving ranges, which entailed increasing the content of nickel at the expense of cobalt, from NMC 111 with 0.35 kg Ni/kWh to NMC 811 with 0.66 kg Ni/kWh.[2] However, concerns around supply constraints have led to the development of alternative chemistries with lower nickel contents, but which would still provide required range and performance, with nickel being partially substituted by manganese in chemistries such as LMR-NMC (lithium manganese-rich nickel manganese cobalt oxide) and LNMO (lithium nickel manganese oxide). At the same time, the nickel-bearing chemistries have also ramified into alternatives with relatively high nickel content but improved energy densities compared to the standard NMC and NCA, such as the emerging eLNO (enhanced lithium-nickel-oxide), suitable for high end applications.

Overall, nickel-containing chemistries in electric vehicle batteries are projected to make up for around half of the global market in 2030.[3] The rest will come from nickel-free alternatives, such as LFP (lithium iron phosphate), which is particularly favoured in China, and its variation with manganese addition, LMFP (lithium manganese iron phosphate), as well as sodium-ion batteries of the iron-bearing type (i.e. Prussian white).

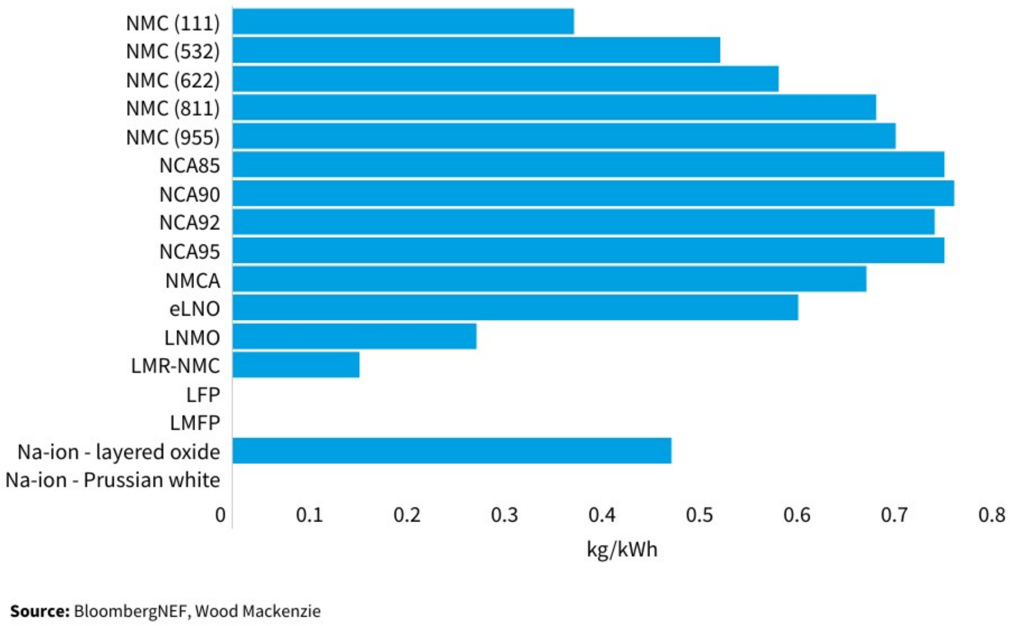


Figure 2: Nickel content in cathode chemistries

[1] Fraunhofer ISI (12.06.2023), "Analysis of global battery production: production locations and quantities of cells with LFP and NMC/NCA cathode material". Link
[2] BloombergNEF (18.08.2023), "Lithium-Ion Batteries: State of the Industry 2023".
[3] Calculated based on data from BloombergNEF.

2.2 Supply

Nickel ore is mined from sulphide and laterite deposits. Exploring and mining nickel sulphides tends to be more difficult and costly since they are typically located deep underground, although nickel sulphide ores are more efficient to process than laterite ores and they can have higher contents of nickel, come with co-products such as copper, cobalt and precious and platinum group elements, and contain sulphur which acts as a fuel source. Sulphide deposits are mainly found in countries like Canada, Finland, Russia, China and Australia.[4] [5]

In contrast, laterite deposits are more abundant than sulphides, constituting approximately 60% of the identified land-based nickel resources globally.[6] They are found near the Earth's surface, making them more cost-effective to explore and mine. However, they contain lower nickel content and tend to be more challenging to process. Laterites typically form in tropical and subtropical regions, with countries like Indonesia, the Philippines, New Caledonia, Australia, Brazil and Cuba being important mining countries. At the same time, Australia boasts both sulphide and laterite ore deposits.[7] [8] Given their prevalence, nickel production from laterites has significantly increased in the last decade.

In terms of reserves, Australia and Indonesia are home to the world's largest nickel reserves, each with 21 million tonnes, followed by Brazil with 16 Mt.[9] Altogether the three countries account for 58% of the known global reserves of nickel.

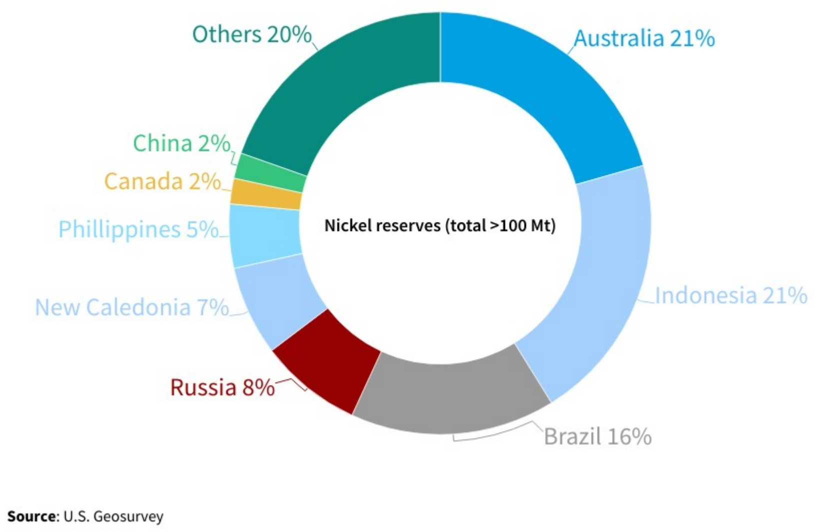


Figure 3: Known global reserves of nickel

[4] Gavin M. Mudd (09.2009), "Nickel Sulfide Versus Laterite: The Hard Sustainability Challenge Remains", Environmental Engineering, Department of Civil Engineering, Monash University, Clayton, Vic, Australia. Link
[5] Nickel Institute, "The life of Ni". Link
[6] U.S. Department of Interior, U.S. Geological Survey (2023), "Mineral Commodity Summaries". Link
[7] Gavin M. Mudd (09.2009), "Nickel Sulfide Versus Laterite: The Hard Sustainability Challenge Remains", Environmental Engineering, Department of Civil Engineering, Monash University, Clayton, Vic, Australia. Link
[8] Nickel Institute, "The life of Ni". Link
[9] U.S. Department of Interior, U.S. Geological Survey (2023), "Mineral Commodity Summaries". Link

INFO BOX: Nickel ore types. Sulphides vs. laterites[10]

Sulphide ores can have higher nickel grades (0.25%-4.0% Ni content) than laterites and contain other metals such as copper, cobalt and platinum group metals. Typically, nickel sulphide concentrate is treated pyrometallurgically using smelting and converted to nickel matte which can be further refined into Class 1 or nickel sulphate, the latter being the preferred material for use in batteries. Alternative routes involve treating the nickel ore or concentrate hydrometallurgically via bioheap leaching (in Finland) or pressure oxidation (in Canada).

Laterite ores are surface deposits and consist of two main types: limonites and saprolites. **Limonites** are closer to the surface, have low nickel (0.9%-1.6% nickel content), low magnesium and high iron contents. They are commonly treated hydrometallurgically via the high pressure acid leach (HPAL) process to produce intermediate products such as mixed hydroxide precipitate (MHP) or mixed sulphide precipitate (MSP) suitable as feedstock for the production of Class 1 nickel, battery grade nickel sulphate or even as directly for precursor cathode active materials in China.

Saprolites are found below the limonite layer, contain higher nickel grades (1.5%-2.5%) than limonites, more magnesium and less iron, and are treated pyrometallurgically via the rotary kiln-electric furnace (RKEF) process to produce Class 2 nickel, such as ferronickel (FeNi) or nickel pig iron (NPI), traditionally for use in stainless steel. Recent market developments, however, made it economically feasible to further convert NPI into matte to produce Class 1 or battery grade nickel sulphate.

INFO BOX: Nickel products classification

Nickel, on a final product-basis, is divided into Class 1 nickel metal and powder, Class 2 nickel and nickel chemicals.[11] **Class 1** nickel is characterised by its high purity, with a minimum purity level of 99%. It is generally deliverable to the London Metals Exchange (LME) and Shanghai Futures Exchange (SHFE), and has been predominantly produced from sulphide ores (and to a lesser extent from limonite ores). Class 1 nickel is used in virtually all nickel applications from stainless steel to high performance alloys through plating and batteries.

In contrast, **Class 2** nickel, such as FeNi, NPI, nickel oxide and utility nickel, has a lower level of purity (less than 99%), and is produced from laterite sources for usage in stainless steel production, with NPI being used primarily in China and Indonesia. New options have been explored by the industry to convert NPI into nickel sulphate and Class 1 nickel metal.

[10] Minviro (06.2023), "Nickel's Carbon Challenge. Understanding the relationship between nickel source and carbon intensity". Link

[11] INSG (2023). "INSG World Directory of Nickel Production Facilities - Notes and Definitions".

A third, fast-growing category, is represented by **nickel chemicals**, including nickel sulphate - the nickel product of choice for battery cathodes. They can be produced from sulphide- and laterite-sourced intermediates as well as from Class 1 nickel metal dissolution and Class 2 nickel conversion.

In the last decade, a lack of major sulphide discoveries and underinvestments in the sulphides space due to low prices led to stagnation in higher quality Class 1 nickel output (see info box above). Instead, nickel production growth has come from abundant laterite resources, associated with low-cost mining. In particular Indonesia, supported by Chinese investments, has emerged as a key country whose nickel resources could feed China's increasing appetite initially from the stainless steel sector and more recently from the batteries sector.

The global mined supply is expected to rise to 4.6 Mt by end of the decade, from just 3.4 Mt in 2022, powered by the Indonesian laterite expansion. The country, with some of the world's largest nickel reserves, is poised to account for 60% of the mined output in 2030, while European operations, in contrast, will account for only 1%.

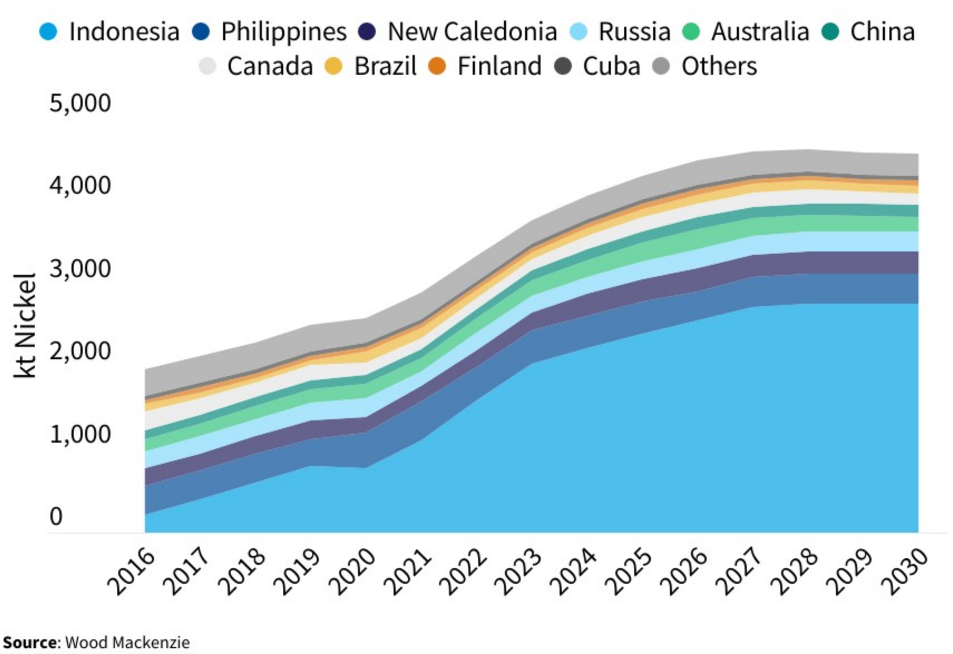
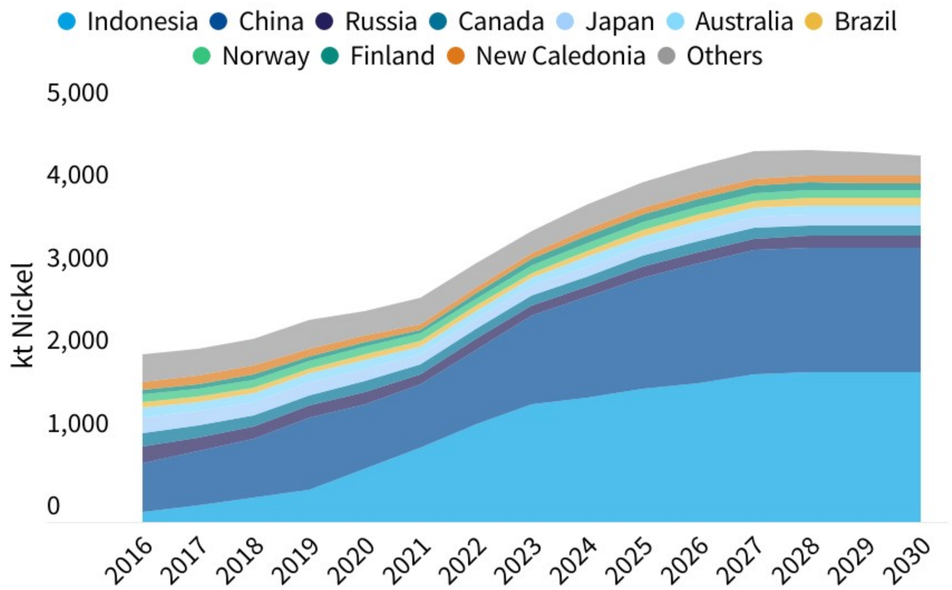


Figure 4: Top 10 nickel mining countries by 2030

The global production of refined nickel - such as nickel metal and powder, nickel chemicals including nickel sulphate, nickel pig iron and ferronickel - will follow the growth in mined output, again driven by Indonesia and China. The main European countries that are refining nickel, Norway and Finland, are expected to maintain a 4% share in the global supply (more details on European operations in Section 3.2).

Indonesia's policy regarding low-grade nickel ore exports, commencing with a ban in 2014, relaxation in 2017 and reinstatement in 2020, which was questioned by some World Trade Organisation member states, has incentivised the development of domestic refining capacities, bolstered by investments from Chinese companies. Since the ban in 2014, Indonesia's refined output increased 50-fold from 24 kt Ni[12] to 1.2 Mt Ni, and more is yet to come.



Source: Wood Mackenzie

Figure 5: Top 10 primary nickel refining countries by 2030

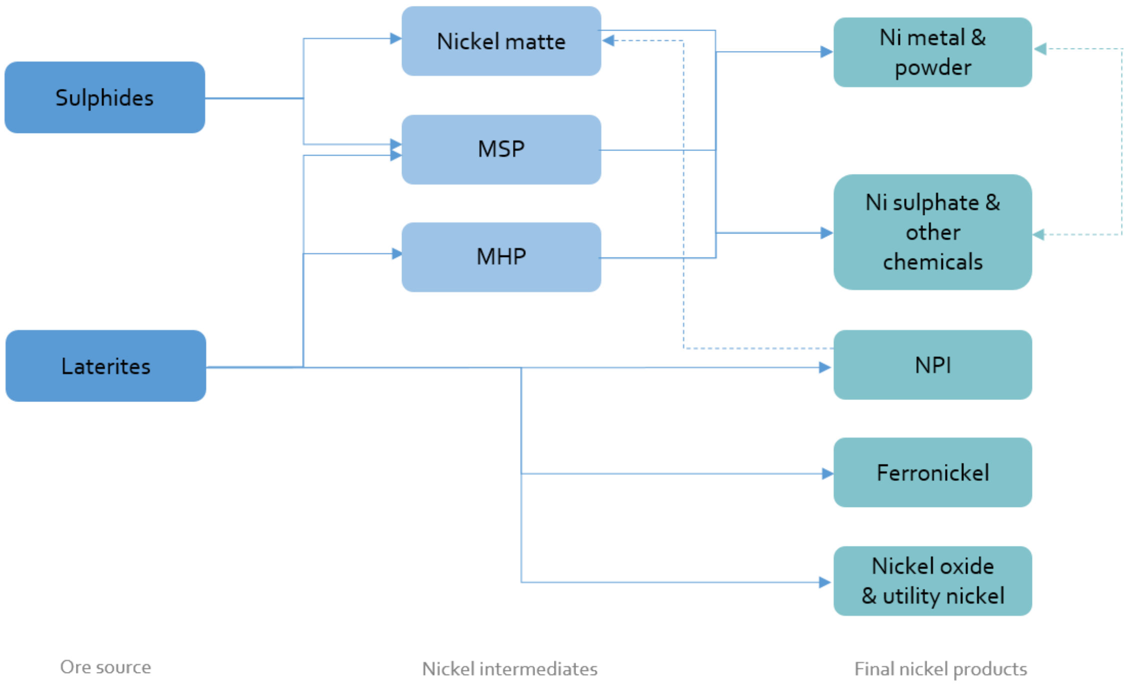
Shortages of nickel sulphate supply, the preferred material for battery cathodes and previously sourced primarily from sulphides (via matte or via Class 1 metal dissolution), prompted market players to explore new alternatives within the abundant laterite deposits. These included processing laterites into intermediate products such as mixed hydroxide precipitate (MHP) or processing nickel pig iron (NPI) to produce nickel sulphate.

In 2021, due to limited availability of battery grade nickel supply, attention shifted towards diverting some of the Indonesian NPI, which oversupplied the Class 2 market, to the batteries sector by converting it into matte to be further processed into nickel sulphate. Although not a novel technology, the NPI-to-matte-to-nickel sulphate route emerged as a potential temporary solution in balancing the market in times of shortages.[13] Nonetheless, in response to concerns around the availability of nickel ore in Indonesia and overexploitation of saprolite resources from which NPI is produced, the government announced in 2023 that it would stop issuing new permits for NPI operations and remove the tax incentives for nickel matte production, thus limiting the potential availability of matte from NPI supply.[14]

[12] Center for Strategic & International Studies (08.12.2021), "Indonesia's Nickel Industrial Strategy". Link
[13] Sherritt, "Does Matte Matter? Is nickel pig iron the answer to EV battery demand?". Link
[14] Fastmarkets (04.05.2023), "Indonesia to prioritize domestic MHP production". Link

Instead, Indonesia plans to shift its focus on supporting MHP production from limonite sources that are more abundant.[15] In particular Chinese nickel sulphate producers consider MHP a cost effective product compared to the more traditional route of dissolving high purity metal.[16] In 2022, Indonesia's high pressure acid leach (HPAL) project pipeline included 10 plants, in addition to the 3 plants already operating there, and altogether they were expected to reach a capacity of over 830 kt Ni in MHP by end of the decade.[17]

Overall, in response to the rising demand from the battery sector, nickel sulphate production has diversified to encompass a variety of feedstocks ranging from intermediates derived from sulphide and laterite ores, such as matte, MHP and MSP, as well as Class 1 nickel metal via dissolution and Class 2 nickel via NPI to matte conversion. Additionally, recycling will play a significant role in the future.



Source: T&E analysis, Roskill, Wood Mackenzie

Figure 6: Simplified nickel products flowchart

In the near term, the global nickel market will continue to be well supplied, driven by expansions primarily in Indonesia in Class 2 nickel and nickel sulphate. However, in the long term the rapid adoption of electric vehicles may lead to deficits. Demand reduction measures and product substitution - such as increased usage alternative battery chemistries - can help smoothen potential shortages.

[15] Nikkei Asia (12.06.2023), "Nickel surplus seen widening in 2023 as Indonesian output soars". Link

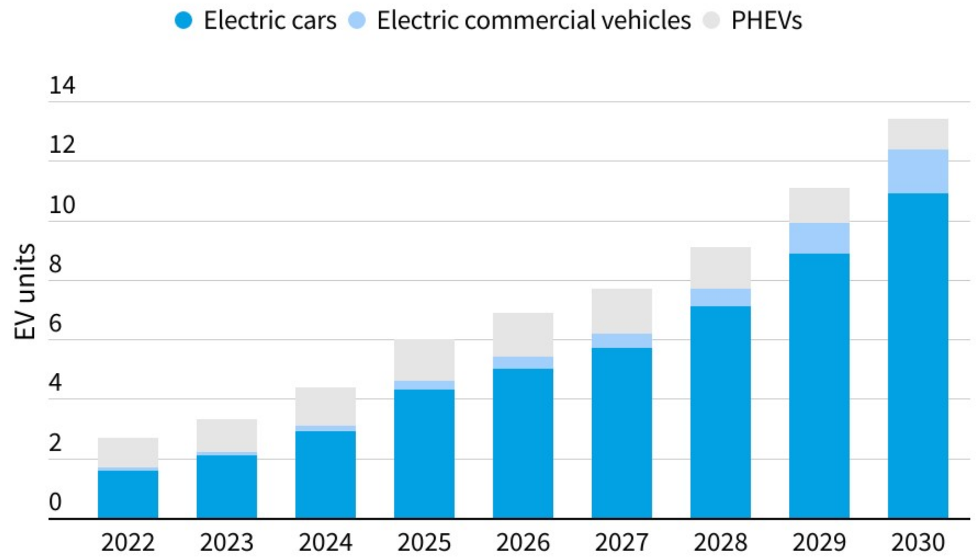
[16] Benchmark Mineral Intelligence (07.07.2023), "Overcoming mining waste issues will be key to Indonesia's nickel ambitions". Link

[17] It is possible that the forecasted volume may have increased since 2022. Source: The Assay, Wood Mackenzie (13.12.2022), "The Rise and Rise of Indonesian HPAL – But Can It Continue?". Link

3. The European nickel market

3.1 Demand from lithium-ion batteries

In Europe, the demand for nickel from lithium-ion batteries is expected to surge, driven by the accelerating trend towards electrification and the implementation of regulations aimed at phasing out internal combustion engine (ICE) cars and vans by 2035. Sales of new battery electric cars and vans are expected to reach 12.1 million units by 2030, while zero-emission commercial vehicles like trucks, buses and coaches, battery- and fuel-cell-based, could reach 0.3 million units.



Note: Electric cars refer to battery-powered cars. Commercial vehicles include vans, trucks, buses and coaches. PHEVs refer to plug-in hybrid electric vehicles.
Source: T&E analysis

Figure 7: European sales of new electric vehicles

These EV sales volumes, along with an increased usage of energy storage systems, would translate into a battery demand of over 1 TWh in 2030, equivalent to 420 kt Ni. This compares to a 145 GWh battery demand in 2022, or 95 kt Ni.[18]

[18] The projections are based on certain assumptions related to electric vehicle battery sizes (sources: LMC Automotive, TNO) and cathode chemistry mix (source: BloombergNEF), which may be subject to revisions in line with technological developments.

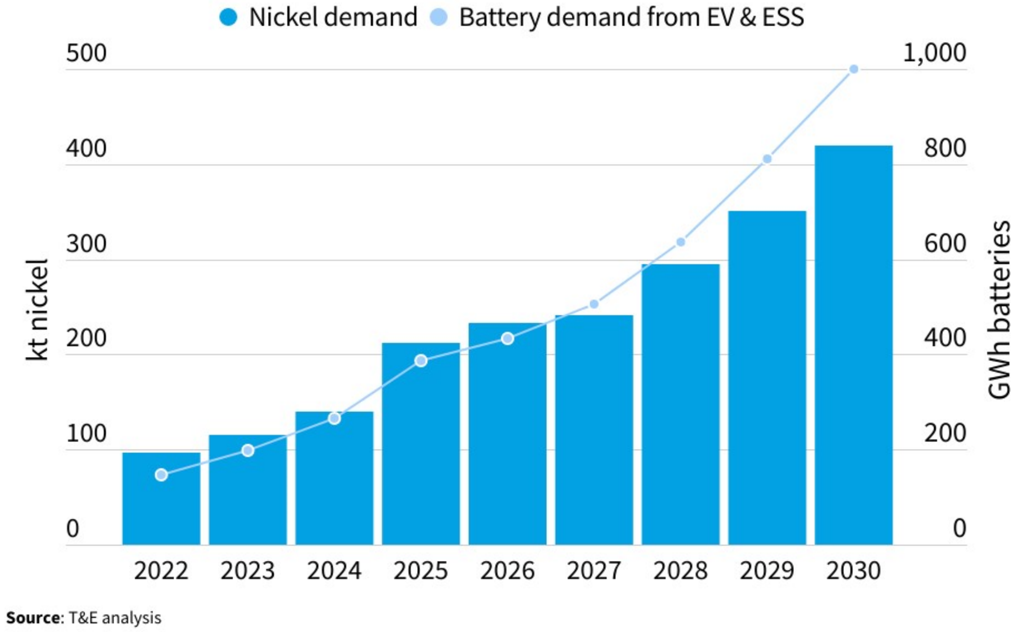


Figure 8: European nickel demand from electric vehicles and energy storage batteries

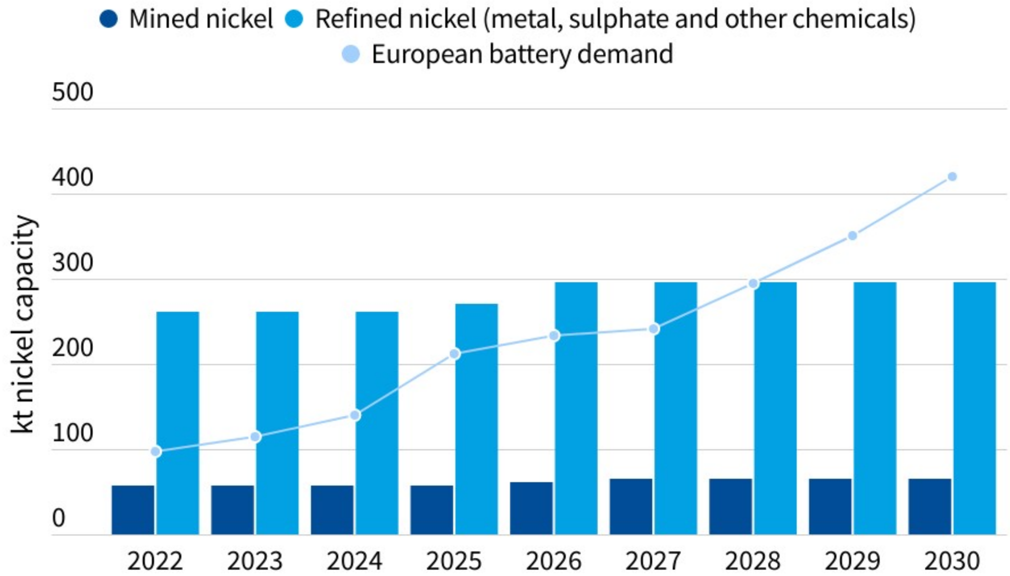
3.2 Supply

Amid surging demand from lithium-ion batteries in the next decade, Europe will have to increase its supply base, via both further imports and local production, alongside similar accelerating recycling.

In Europe nickel is being mined primarily in Finland (from sulphide ores) and in the Balkan region (from laterite ores). The main players in Finland are Terrafame, which recently moved downstream in the processing chain and has now an integrated production process from mining to nickel sulphate production, and Boliden, producing nickel matte which is sold for further refining. Altogether they account for around 58 kt Ni capacity.[19] Further in the south, Greece, Macedonia, Albania and Kosovo have been historically producing ferronickel for the stainless steel sector. However, the plants have recently been on care and maintenance.

In the future, the nickel mined output could increase by some 8 kt Ni based on the known project pipeline, i.e. Anglo American in Sweden and Eurobattery Minerals in Finland and Spain. The combined mined nickel capacity in Finland, Sweden and Spain would account for 16% of the European nickel demand from EV and ESS batteries in 2030 (not accounting for other sectors), of which only 2% would come from new projects.

[19] It must be noted that capacity and production (or supply) are distinct concepts. Often, plants operate below their nameplate capacities, meaning that the actual output may be lower than the maximum potential capacity.



Source: T&E analysis

Figure 9: European capacities of mined and refined nickel

In the area of nickel refining, today Europe is home to several refineries that produce nickel in various forms with combined capacities of almost 130 kt Ni in the EU and some additional 132 kt Ni in Norway and the UK. The major players are:

- Nornickel (Finland), producing nickel metal, nickel powder and nickel sulphate;
- Terrafame (Finland), with integrated production process from mine to nickel sulphate;
- Hellenic Minerals (Cyprus), producing nickel sulphate from imported intermediates;
- Sibanye Stillwater (France), producing nickel metal and nickel chemicals;
- Glencore (Norway), producing nickel metal;
- Vale (UK), producing nickel metal and powder.

Looking ahead, the known project pipeline indicates a potential, albeit uncertain, expansion of 35 kt Ni in nickel sulphate by 2030, coming from the Russian-owned Nornickel plant in Finland. This is equivalent to 8% of Europe's anticipated nickel demand in 2030 from batteries only. However, without this expansion materialising, Europe's nickel sulphate capacity of around 63 kt Ni would cover only 15% of this demand. At the same time, if other nickel capacities, such as metal and other chemicals, from operations in the EU, UK and Norway would be redirected to this sector, they would meet some further 47% of the future European demand. Altogether, all capacities could theoretically cover over 70% of the future battery demand or 62% excluding the expansions, not accounting for other applications.

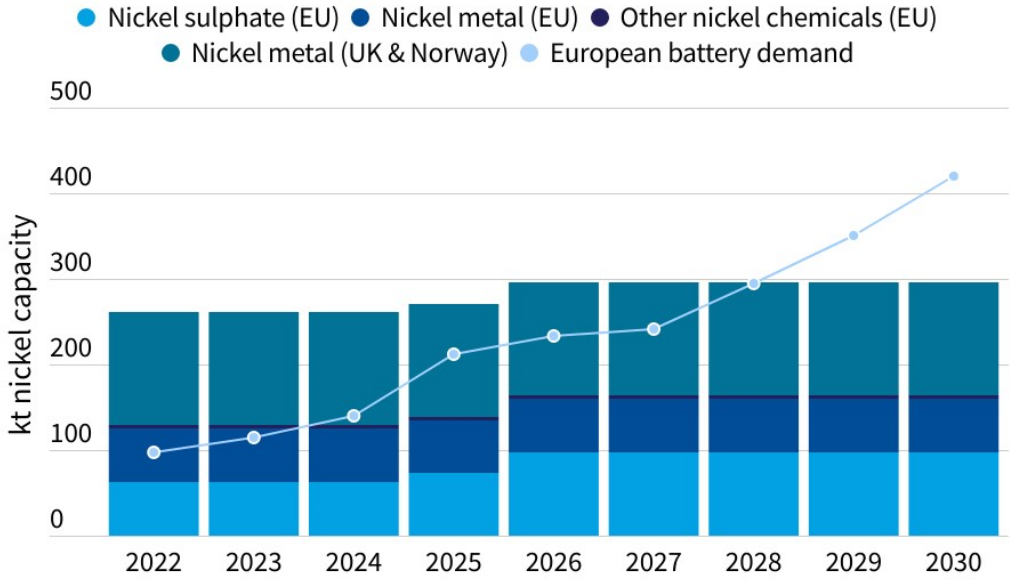


Figure 10: European capacities of refined nickel

Generally, it is technically feasible to convert nickel metal into nickel sulphate - although some nickel metal forms are preferred over others - by installing additional dissolution equipment by the producer or the customer (e.g. battery cathode precursor maker). But from a supply chain point of view, this would also mean that European producers, traditionally serving non-battery sectors, would change their established customer bases.

Right now, however, Europe is missing an essential midstream link following nickel refining in the battery value chain - the manufacturers of battery cathodes (and their precursors), who represent the direct customers of such refineries and therefore key offtakers. The next few years will be critical for Europe to establish an integrated battery ecosystem if it wants to break the dependence from countries such as China.

3.3 Trade flows

In order to meet its demand from various sectors, in 2022 the EU imported around 208 kt of refined nickel in various forms and qualities from around 242 kt apparent demand (or 86% of demand),[20] [21] of which:

- 164 kt of high purity nickel metal, typically used in stainless steel, alloys, special steel, plating and batteries sectors;
- 44 kt Ni in ferronickel, used in stainless steel production;

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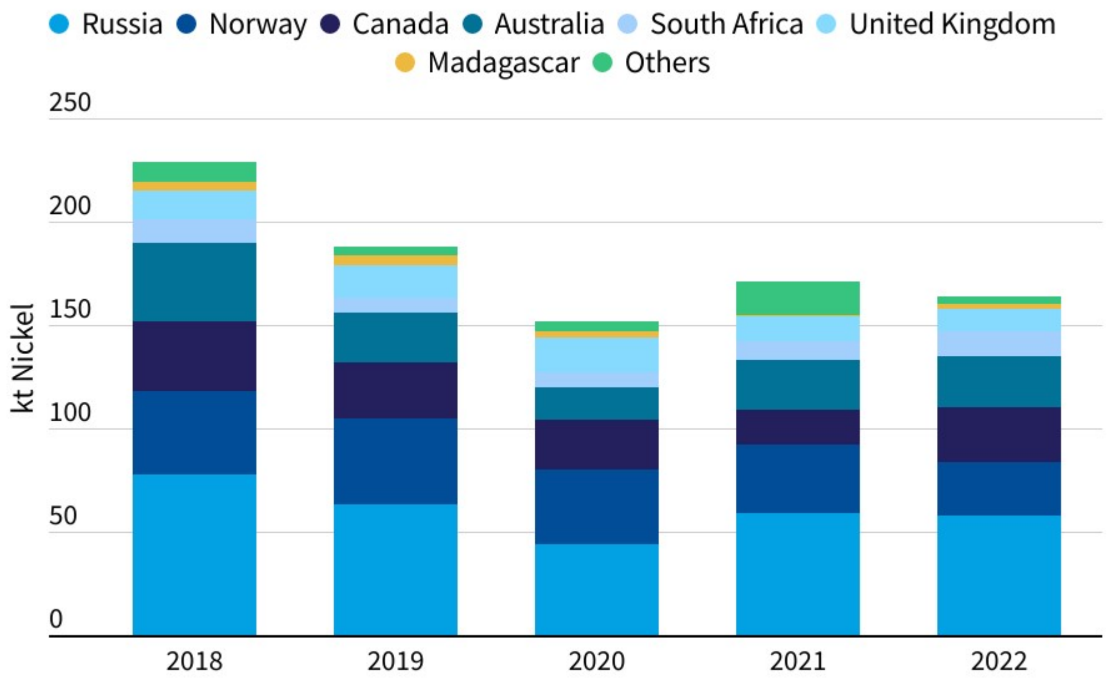
[20] Trade volumes calculated based on data from Acces2Markets (link). The following Harmonized System codes for nickel were used: 75021000 (nickel metal), 75021000 (nickel powder), 28332400 (nickel sulphate, with a nickel content of 22%), 28332400 (ferronickel, with an assumed average nickel content of 23%).
[21] Apparent consumption calculated as: production + imports - exports.

- And some very small volumes of nickel sulphate (0.3 kt Ni content), used in the batteries and plating sectors, along with nickel powder (0.07 kt Ni) which has applications in batteries, alloys, powder metallurgy, etc.

Russia, home to Nornickel, Norway with Glencore, Canada with Vale and Sherritt, and Australia with BHP and Glencore, were the main exporting countries of nickel metal to the EU, representing altogether 82% of the imports. While in absolute terms the nickel metal imports declined in the past 5 years, these countries maintained relatively similar shares during this period.



Source: T&E analysis of data from Access2Markets/European Commission

Figure 11: EU imports of nickel metal by country of origin

In terms of ferronickel imports for the stainless steel sector, the EU's largest suppliers of ferronickel are located in Latin American countries such as Brazil (Anglo American and Vale), Colombia (South32), Dominican Republic (Falcondo) as well as in New Caledonia (Eramet and Glencore), accounting for 78% of the imports.

The EU has also exported some volumes of nickel in 2022 (~42 kt Ni content), primarily in the form of nickel metal to the US, South Korea, UK and China along with some volumes of nickel sulphate and nickel powder.

Overall, on a net basis, the EU was a net importer of nickel metal (134 kt Ni), a net importer of ferronickel (43 kt Ni), a net exporter of nickel sulphate (6 kt Ni) and a net exporter of nickel powder (5 kt Ni).

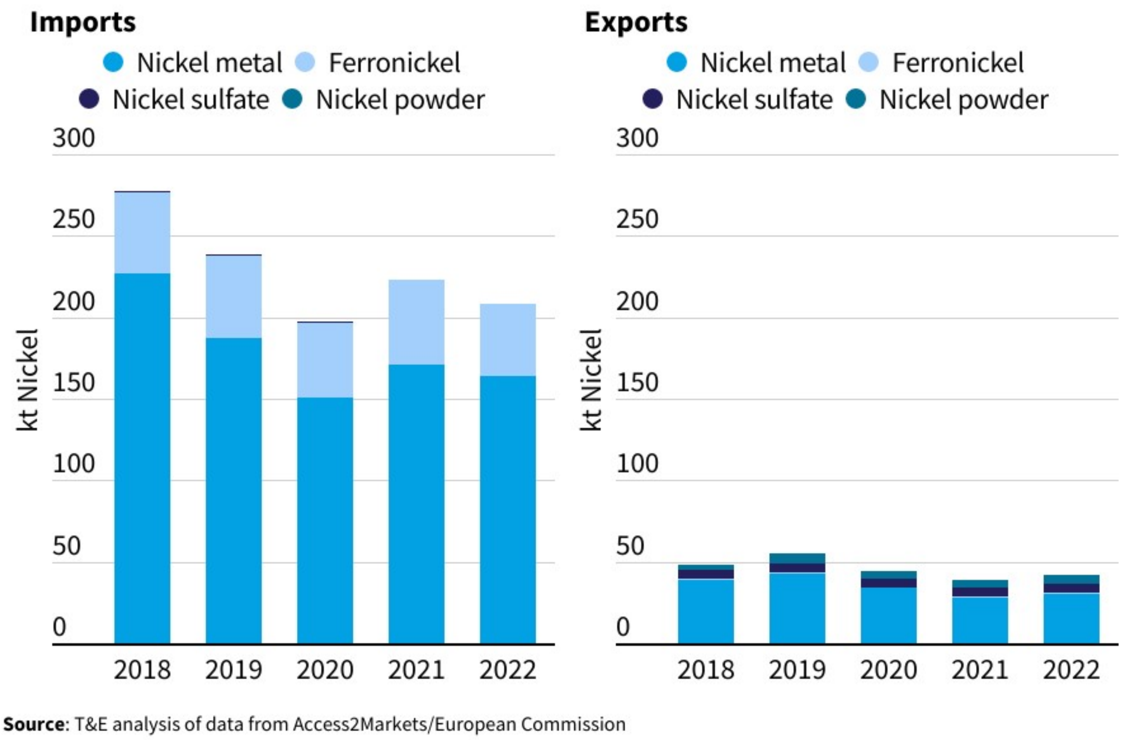


Figure 12: EU trade flows of nickel by nickel product

Considering the limited nickel project pipeline so far, unless more effort is made on the demand or battery technology substitution side, Europe will continue to rely on imports from countries that are better endowed with resources in the years to come, such as Australia, Indonesia or Brazil.

4. Environmental aspects

4.1. GHG emissions management

The production of nickel is generally energy intensive and associated with high levels of greenhouse gas emissions (GHG). However, GHG emissions can vary significantly across production sites, depending on the ore source (sulphide or laterite), production technology, location and energy source (fossil-based or renewable).[22]

Nickel produced from sulphide ores tends to have a lower GHG intensity than nickel from laterites, owing to the higher nickel content and their natural sulphur content acting as a fuel source, requiring less energy to process.[23] In contrast, laterite deposits are easier to explore and mine, but necessitate more

[22] Minviro (06.2023), "Nickel's Carbon Challenge. Understanding the relationship between nickel source and carbon intensity". Link

[23] Minviro (06.2023), "Nickel's Carbon Challenge. Understanding the relationship between nickel source and carbon intensity". Link

energy (and chemicals) to be processed into the required purity intermediate and end products, resulting in higher GHG emissions.[24] [25]

Further, pyrometallurgical processes such as smelting - used for treating sulphide concentrate or saprolite ore - consume substantial energy and rely on thermal and electrical inputs. On the other hand, certain hydrometallurgical processes, while less energy-intense, may require chemicals, which come with embodied GHG emissions impacts and can pose difficulties in managing waste.[26]

Assessments of GHG emissions are particularly important for nickel sulphate since it can be produced via a variety of feedstocks each with its own environmental credentials. In this section a comparison of six production routes for evaluating GHG emissions associated with nickel sulphate is presented.[27] These routes cover both sulphide and laterite sources and employ diverse pyrometallurgical and/or hydrometallurgical processes, with some being innovative, some poised for growth in the near future, and others presenting potential risks.

Sulphide processing via pressure oxidation: In this process, sulphide ore is upgraded into an intermediate product, nickel concentrate, which is then processed hydrometallurgically under high pressure and further refined into nickel metal. Finally, the nickel metal is dissolved with sulphuric acid into nickel sulphate.

Sulphide processing via bioheap leaching: Sulphide ore stacked in heaps is irrigated with an acidic solution containing naturally occurring bacteria, which help break down the sulphide minerals and separate the metals from the ore. The solution containing nickel and other metals, is collected and separated, with the intermediate product mixed sulphide precipitate being further treated via pressure oxidation and then refined into nickel sulphate. Bioheap leaching is time consuming (e.g. the first stage of bioheap leaching takes 15 months and the second and final stage around 5 years), but has reduced environmental impact compared to other processes due lower energy consumption and reduced usage of harmful chemicals and less landscape damage.[28] In addition, it is also considered an effective method for recovering nickel from ores previously considered uneconomical to exploit.[29]

Sulphide processing via nickel matte: Sulphide ore is upgraded into nickel concentrate, which is processed via pyrometallurgical smelting into matte and then hydrometallurgical refining into nickel sulphate (and metal) at a separate location.

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[24] Gavin M. Mudd (09.2009), "Nickel Sulfide Versus Laterite : The Hard Sustainability Challenge Remains", Environmental Engineering, Department of Civil Engineering, Monash University, Clayton, Vic, Australia. Link

[25] The Assay, "The Great Laterite Challenge: Why Scaling Class 1 Nickel Production Won't Be Easy, Cheap, or Environmentally Friendly". Link

[26] Minviro (10.2021), "Shifting the Lens: The Growing Importance of Life Cycle Impact Data in the Battery Material Supply Chain". Link

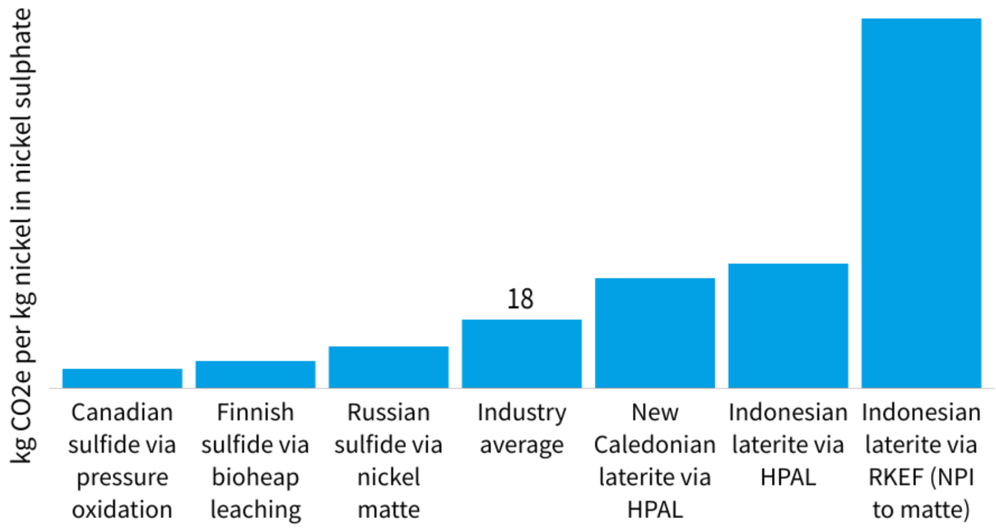
[27] Based on LCA data from Minviro.

[28] Terrafame (06.2021), "Sustainability Review - Creating Responsible Battery Value Chain", Link

[29] Terrafame(06.2022), "Bioleaching - A Core Technology For Treatment Of Low-Grade Metal Containing Tailings". Link

Laterite processing via high pressure acid leaching (HPAL): This hydrometallurgical route is the main method for the extraction of nickel from limonite ores to produce an intermediate product such as MHP and MSP (as well as refined nickel metal and powder). The process utilises sulphuric acid under high pressure and temperature conditions to dissolve the nickel contained in the ore. Additionally, purification with sulphuric acid is employed to further refine the intermediate product into nickel sulphate. The HPAL process tends to score higher in emissions than its peers utilising sulphide ores due to usage of coal-based energy.

Laterite processing via Rotary Kiln-Electric Furnace (RKEF), or NPI to matte: This route pyrometallurgically processes saprolite ores using RKEF into NPI, which in turn is processed into an intermediate product, matte. The matte is further refined into battery grade nickel sulphate (as well as nickel metal). This route, used by the giant Chinese nickel and stainless steel producer Tsingshan, carries the highest GHG footprint as it requires a significant amount of energy derived from coal-burning for the smelting as well as for the additional steps needed to convert NPI into nickel suitable for batteries.



*Industry average as calculated by the Nickel Institute ("Nickel Sulphate Life Cycle Data")
Source: Minviro, Nickel Institute

Figure 13: GHG emissions from nickel sulphate production for selected routes

Among the six production routes compared, the lowest carbon emitting operations are located in Canada and Finland, with emissions that are 70% and 63% lower, respectively, than what is considered the industry average.[30]

The Canadian site using pressure oxidation scores the best in the ranking due to several factors, including a higher nickel content in the ore and higher recoveries of valuable byproducts (such as cobalt), but also usage of renewable energy and usage of hydrometallurgical processes as opposed to energy-intensive

[30] Industry average calculated by the Nickel Institute (2021), "Nickel Sulphate Life Cycle Data". Link

pyrometallurgy (or smelting). Bioheap leaching scores the second best in this ranking in terms of emissions due to lower energy consumption since it does not use smelting processes. The sulphide to matte route presented here, combining pyro- and hydrometallurgical processes and a relatively higher share of non-renewables in total electricity and fuel consumption, result in higher emissions, but still below the routes processing laterite ores and the industry average.

Nickel sulphate production via HPAL, which will increase significantly in the coming years in Indonesia, generates almost twice as much emissions than the industry average and 5 to 6 times higher emissions than the lowest scoring peer.

Finally, at the opposite end are operations in Indonesia, processing laterite ores into NPI to matte to nickel sulphate, using coal-based power generation. This route produces 5 times more emissions than the industry average and a whopping 18 times higher emissions than the lowest peer. As the NPI supply continues to expand in Indonesia to feed the local and Chinese stainless steel industry, some volumes may be diverted for use in batteries, which would pose serious risks for the sustainability of the battery value chain.

Overall, the energy requirement of the various nickel sulphate production routes has a significant contribution to GHG emissions. Sulphide processing, benefiting from its inherent heat production due to sulphur content, is less energy intensive than laterite processing. However, while geology cannot be controlled, operations do have control over the energy source. Laterite processing routes generate some of the highest GHG emissions as they have large energy requirements and, on top, this requirement is often sourced from polluting, coal-based sources. To reduce this environmental impact, transitioning to renewable energy sources can be a promising step forward.

A study published by the Nickel Institute, covering 100% of the nickel sulphate production in 2017 via various routes, shows that the emissions from nickel sulphate production amount on average to around 4 kg CO_2e/kg nickel sulphate, or 18 kg CO_2e/kg nickel in nickel sulphate. Electricity, both generated onsite and purchased, accounts for around 40% of the emissions.[31] This suggests that if nickel operations would switch to 100% renewable electricity sources, the emissions could be cut by as much. Input materials such as chemicals and raw materials have a contribution of 17% to the GHG emissions on average; if these inputs were produced with renewables, total emissions would further decline accordingly. Transport-related emissions account for 7% of total industry average emissions and streamlining logistics could potentially have a further impact in reducing overall emissions.

Another recent study carried out by the International Finance Corporation, which discusses various interventions to minimise GHG emissions in nickel mining and refining, indicates that deployment of renewables could reduce emissions by 20% for HPAL plants. Shifting from fossil fuel-based heat sources to electric ones could further contribute to 33% reduction, while the usage of zero-carbon chemicals has the potential to decrease total emissions by 37%. With regards to mining fleet electrification,

[31] Nickel Institute, Sphera (01.2023), "Life cycle data - Executive Summary". Link

battery-powered vehicles would bring a 3% reduction in emissions. The report also highlights the importance of setting emission reduction targets with a final goal of over 90% emission reduction by 2050.[32] According to T&E's calculations based on the report's assumptions, a 35% to 50% reduction target by 2030 for the entire nickel industry would lead to emissions of around 10 to 13 kg CO_2e/kg nickel (in all forms), while a 70% to 80% reduction between 2030 and 2040 would bring emissions down to 4 to 6 kg CO_2e/kg nickel. Finally, a 90% reduction by 2050 would result in 2 kg CO_2e/kg nickel.

At technology level, the hydrometallurgical methods of pressure oxidation and bioheap leaching are considered to be the most energy efficient among the compared routes here. Apart from Vale in Canada, Kabanga Nickel plans to employ pressure oxidation at its Lifezone Project in Tanzania starting in 2025-2026.[33] [34] Bioheap leaching is currently used by Terrafame in Finland.

In the laterite realm, heap leaching - a process similar to bioheap leaching but without involving microbial activity - has been commissioned by Hellenic Minerals in Cyprus and is being tested by Brazilian Nickel at its Piauí Nickel Project in Brazil.[35] [36] [37] Atmospheric hydrometallurgical processing of various types of laterites (or atmospheric leaching) is also emerging as an alternative to the currently popular HPAL route. This includes the Direct Nickel Process DNi™, using recycled nitric acid (instead of conventional sulphuric acid), developed by the Altilium Group and to be used by Queensland Pacific Metals at its TECH Project in Australia in the future.[38] [39] Another atmospheric leaching technology is the STAL Technology™ developed by PT Hydrotech Metal Indonesia. [40]

Reducing GHG emissions associated with nickel production will be essential for mitigating the environmental impact of the nickel industry and reducing even further the battery's carbon footprint. Below are the key solutions to reduce greenhouse gas emissions:

- Develop and adopt more efficient ore processing techniques that require less energy. For example, hydrometallurgical treatment of sulphide ores via bioheap leaching or pressure oxidation eliminates the energy intensive smelting stage. For laterites, alternatives to the HPAL process can include heap leaching or atmospheric leaching, such as the patented DNi™ Process.
- Use renewable energy sources such as solar, wind or hydropower to replace fossil fuels. As shown in this section, the source of energy represents a critical component in the

[32] International Finance Corporation, World Bank Group (01.2023), "Net Zero Roadmap for Copper and Nickel - Technical Report". Link, link
[33] Innovation News Network (21.02.2022), "Tanzania: Tomorrow's source of clean nickel for the world". Link
[34] S&P Global (06.05.2022), "Kabanga Nickel 'not waiting' to complete feasibility, expects surging demand". Link
[35] Emmanouil N. Zevgolis et al. (24.01.2022), "The Nickel Production Methods from Laterites and the Greek Ferronickel Production among Them", Materials Proceedings, vol. 5, issue 1. Link
[36] Brazilian Nickel website
[37] Anne Oxley et al. (15.03.2016), "Why heap leach nickel laterites?", Minerals Engineering, vol. 88. Link
[38] Altilium website
[39] Innovation News Network (18.07.2023), "TECH Project high-grade nickel is primed to fuel the global green transition". Link
[40] STAL Technology website

assessment of GHG emissions and renewables can significantly reduce emissions from electricity generation, i.e. up to around 40% on average.

- Use zero-carbon chemicals, produced with renewable energy, during processing stages, which can decrease emissions by up to 17% on average or more for HPAL plants.
- Decarbonise mining vehicles to replace diesel powered vehicles with battery powered ones (e.g. 3% emissions reduction in HPAL plants).
- Streamline logistics, including optimising transportation routes and modes, and collaborate with partners with lower emissions intensity through near-shoring to reduce transportation emissions (e.g. up to 7% emissions reduction on average).

4.2. Waste management

Apart from emissions, another environmental concern related to nickel mining - just like any extraction, also that of fossil fuels - is the disposal and storage of tailings, or extractive waste. With nickel supply continuing to expand in the coming years, the amount of mine tailings is also expected to accelerate. If not designed, managed and monitored in a responsible manner, tailings can pose risks to the environment such as water and soil pollution as well risks to livelihoods, human health and safety.

In particular, HPAL processing of laterite ores, using sulfuric acid to recover nickel and cobalt at high temperatures, produces large amounts of waste that can be challenging to dispose of. Around 1.4-1.6 tonnes of waste are generated for every tonne of nickel produced via the HPAL process, according to Wood Mackenzie estimates. By the middle of decade, Indonesian HPAL plants could produce over 830 kt Ni in MHP by the middle of decade, from less than 100 kt in 2022, resulting in over 130 Mt of waste.[41]

When the first HPAL plants were announced in Indonesia back in 2018, a debate around the disposal method of tailings emerged. The plant operators initially intended to dispose of tailings deep sea, which involves discharging a mixture of precipitated chemicals from the dissolution of the limonite ore in acid and subsequent purification stages into the sea through pipes.[42] However, in 2021 the Indonesian government decided to stop issuing new permits for this method, putting a de facto moratorium on the practice.[43] [44]

Deep sea tailings storage is cheap, but poorly understood and could pose threats to marine biodiversity and local communities.[45] For example, the Initiative for Responsible Mining Assurance (IRMA), which sets principles and best practices for social and environmental performance at mine sites, does not certify

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[41] Wood Mackenzie (04.04.2023), "The rise and rise of Indonesian HPAL – can it continue?". Link
[42] The original sentence referring to HPAL tailings as residual pulverised rock was revised following expert feedback to accurately describe the nature of these tailings.
[43] Reuters (05.02.2021), "Facing green pressure, Indonesia halts deep-sea mining disposal". Link
[44] Reuters (11.10.2019), "EXPLAINER-How do miners dispose of their waste in the sea?". Link
[45] EarthWorks (09.02.2021), "Indonesia's Move Away from Ocean Mine Waste Dumping Sets Example for Norway, Papua New Guinea". Link

mine sites using aqueous disposal of mine waste materials. The only nickel mine globally using the deep sea tailings disposal is Ramu NiCo operated by Metallurgical Corporation of China in Papua New Guinea.[46]

Instead, mining companies in Indonesia now need to store tailings on land, with options including dry stacking of filtered tailings or building conventional tailings dams. Conventional tailings dams tend to have stability issues risking failure due to their higher water content and have been banned in several countries (e.g. Chile, Peru, Brazil, Ecuador). Just recently in 2022, the Goro nickel mine located in New Caledonia experienced leaks from its tailings dam following heavy rains, resulting in a "limited release of salt-laden liquid". [47] These issues of conventional tailings storage are further compounded by the limited space for large dams as well as limited availability of hard rock in Indonesia to secure the dam walls.[48]

In contrast, dry stacking is considered one of the safest forms of tailings storage and disposal and a best practice. The method involves filtering and drying tailings that can be then compacted and deposited into a freestanding and stable structure, thus reducing the risks of groundwater contamination.[49] Since Indonesia's wet climate and high seismicity can pose challenges to dry stacking, its implementation should be done with caution and using best practice technologies and third party independent oversight as well as regular management.[50] While dry stacking adds to operating costs in the short term compared to the other options, it represents a competitive solution when considering the entire lifetime of the mine including the associated closure and post-closure costs, speed of getting environmental and construction permits and potentially higher acceptance by the local communities.[51] As more and more companies use this technology, the scale and economies of scale will reduce the costs.

In Indonesia, currently there are three HPAL plants operating, all using the dry stacking method, although at least one is considering building a dam.[52] [53] France-based Eramet, with an NPI plant at Weda Bay and an upcoming HPAL project, made an early commitment in 2020 to implement dry stack tailings.[54] As more plants are expected to be launched in the near future, it will be crucial for the nickel industry to prioritise environmental considerations over short-term cost savings.

4.3. Biodiversity conservation

Alongside mitigating GHG emissions and managing extractive waste, one of the biggest challenges linked to the nickel mining industry is land use and its direct impact on biodiversity. Without adequate

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[46] Reuters (05.02.2021), "Facing green pressure, Indonesia halts deep-sea mining disposal". Link
[47] Bloomberg (15.11.2022), "Tesla-Backed Nickel Miner Cuts Output After Waste Dam Leak". Link
[48] Wood Mackenzie (04.04.2023), "The rise and rise of Indonesian HPAL – can it continue?". Link
[49] Tailings.info website
[50] S&P Global (17.04.2023), "Indonesia's nickel processing boom raises questions over tailings disposal". Link
[51] C. Cacciuttolo et al. (2022), "An Alternative Technology to Obtain Dewatered Mine Tailings: Safe and Control Environmental Management of Filtered and Thickened Copper Mine Tailings in Chile", Minerals, vol. 12, issue 19. Link
[52] Benchmark Mineral Intelligence (07.07.2023), "Overcoming mining waste issues will be key to Indonesia's nickel ambitions". Link
[53] PT Trimegah Bangun Persada Tbk (2023) "Leading the Charge". Link
[54] Eramet (09.2022), "Eramet in Indonesia. A landmark for the EV industry". Link

safeguards, nickel mining can lead to habitat destruction, loss of species, disruption of ecological services and community conflicts.

Preventing and mitigating the adverse impacts of mining on biodiversity is especially important given that most of the nickel supply expansion is to come from Indonesia, home to a wealth of biodiversity and unique ecosystems, including tropical rainforests and coral reefs, such as in the islands of Sulawesi and North Maluku. Moreover, due to the ore's characteristics, the main mining method used in the country is open-pit mining - which involves clearing lands for mining and tailings storage - that directly leads to deforestation.

Research by Benchmark Mineral Intelligence shows that, in the nickel, cobalt and lithium space, only one-third of operating companies disclose their implementation of biodiversity monitoring measures. In Indonesia specifically, only 16% of the refined nickel producers are tracking their impact on biodiversity, while Australia and Canada score better in this area (60%), although there is room for improvement.[55]

Companies should adhere to the mitigation hierarchy of avoiding, minimising, restoring and offsetting their negative impacts on biodiversity, and follow best practices as, for example, indicated in the International Finance Corporation (IFC) Performance Standard 6.[56] The IFC Standard recognizes that protecting and conserving biodiversity, maintaining ecosystem services and managing living natural resources adequately are fundamental to sustainable development and core to companies' practices. The industry should develop and integrate a so-called "High Carbon Stock Approach" (HCSA) and a "High Conservation Value" (HCV) approach into their operations. These methodologies - that are peer-reviewed and eventually disclosed - are developed for companies to evaluate potential biodiversity impacts, enabling them to determine which areas are more suitable for their operations and which eventually should be off-limits, such as rich biodiversity areas. Equally, it is important that the industry works together and in regular consultation with stakeholders such as environmental NGOs, communities and of course governments.

Mining companies must therefore ramp up their efforts in terms of avoiding, reducing and managing biodiversity impacts. This can be done with concrete solutions and learnings from the agricultural sector such as the palm oil industry, who have adopted and implemented deforestation and human rights policies that cover more than 83% of the sector, leading to significant declines in deforestation across South-East Asia. Beyond this, mining companies should also implement habitat restoration and reforestation programs and establish compensation budgets to finance these.

Buyers such as carmakers must also play their part in working with their suppliers. As seen in the palm oil business, such as supply chain monitoring via the use of satellites or third parties, and publishing exact

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[55] Benchmark Mineral Intelligence (22.05.2023), "Mining companies need to look at new ways to reduce biodiversity impacts". Link

[56] International Finance Corporation (01.01.2012), "Performance Standard 6. Biodiversity Conservation and Sustainable Management of Living Natural Resources". Link

locations and establishing also clear policies to ban deforestation and destruction of peatlands can significantly improve the impact on biodiversity.

5. Conclusions & policy recommendations

While Europe won't be 100% self-sufficient in nickel, potential to enter the refining and midstream of this metal key to the battery value chain exists. A set of industrial, financial and research support will be necessary. At the same time, stricter standards and regulations will be necessary to ensure nickel is mined, refined and processed with the least impact on the environmental and local communities. Below are T&E's recommendations to achieve these two objectives of onshoring and sustainability.

To enhance strategic autonomy and bolster the resilience of critical raw materials supply chains, Europe must pursue a diversification strategy accompanied by strong environmental and social safeguards. This would entail creating a local value chain where raw materials are mined and processed in a sustainable and responsible manner, and complementarily setting up trade partnerships with other global regions to secure access to raw materials and transfer technology and know-how. Strategic projects both in the EU and abroad should benefit from leaner and more effective permitting rules, while adhering to the strict environmental and social standards.

- **Strategic projects:** The EU should pursue Strategic Projects in the area of nickel refining and processing in particular, as proposed in the EU Critical Raw Materials Act. These should benefit from much simpler permitting than today and financial support, while adhering to strictest environmental and social standards and with local communities on board. Global projects in particular benefiting from public funding could in the future undergo IRMA audits, which are widely recognized for their thoroughness and multi-stakeholder approach, as a means to assess and verify compliance effectively.
- **Trade partnerships**: Even if the end game is circularity, Europe will rely on global imports for a long time. Given that Europe will be unable to meet a substantial amount of its primary nickel demand, Europe's critical metals strategy should push for transparent and diverse nickel markets, as well as create a framework for the public and private investments into nickel projects abroad provided high environmental and social criteria are guaranteed (regardless of the strictness of the rules in the foreign country in question). This can be done as part of the many third country partnerships that are now in development (e.g. with Canada, Indonesia, etc.). Regional collaboration, investments at scale and exchange of expertise will be key for mutually beneficial trade relationships. Particularly for countries in the Global South, trade agreements can fuel economic development and facilitate know-how transfer to extract better social and economic value from their resources.
- Expansion of **domestic nickel processing capacities**: Given its potential and existing nickel refining expertise, Europe should prioritise expanding its capacities for refining nickel. This can be done through investment incentives (e.g. via the EU Innovation Fund), infrastructure development and the attraction of a skilled workforce. Specifically on building an industrial talent pool, Europe should develop and fund educational programs tailored to the needs of industry, i.e. in process engineering, metallurgy, environmental management, process automation, etc.;

encourage partnerships between companies and educational institutions to offer traineeships; provide funding for upskilling professionals; and establish innovation hubs bringing together companies, researchers and startups that collaborate on developing innovative techniques and sustainable practices.

- Provide financial support for the development of innovative nickel processing technologies that have less impact on the environment, fostering **research and development**.
- **Demand substitution/reduction**: The EU should reward critical raw material substitution and the scaling up of manufacturing of battery chemistries less intense in critical raw materials such as lithium manganese iron phosphate (LMFP), lithium nickel manganese oxide (LNMO), sodium-ion batteries and other post-lithium batteries. This can be done by providing support to accelerate R&D and industrial production of emerging alternative battery chemistries. Chemistry innovation can decrease Europe's cumulative nickel demand by 7% between 2022 and 2030 and by 20% between 2022 and 2050. For additional insights, T&E recently delved into the topic of demand reduction.

On the **climate and environment** side, policymakers should:

- In order to increase the share of renewables in the nickel industry, countries with nickel production operations should prioritise grid decarbonisation by **investing in renewables infrastructure** such as solar, wind and hydroelectric power; develop and enforce regulations that set emission reduction targets for the extractive sector; and mandate the use of renewable energy sources in mining, refining and all manner of extractive operations.
- In Europe, the upcoming taxonomy requirements should correctly define the cleaner low-emission nickel refining and processing routes to stimulate investments and commercialisation of hydrometallurgy-based technologies. T&E research shows that setting a maximum threshold of 10 kg CO_2e/kg nickel by 2030 could define nickel as "low emissions".
- Require the implementation of **best tailings management practices**, such as ensuring the facilities are designed to withstand the most severe meteorological and seismic events possible at a specific location as well as mandate the use of best available practices and best available technologies, such as dry stacking (of filtered tailings). The Standard for Responsible Mining created by the Initiative for Responsible Mining Assurance (IRMA), the industry's truly multi-stakeholder certifying organisation, and the Safety First guidelines developed by scientists, community groups and NGOs including Earthworks and MiningWatch Canada set principles and good practices for social and environmental performance at mine sites.
- **Biodiversity conservation**: Governments and mining companies should collaborate to conduct baseline biodiversity assessments to establish the current state of biodiversity in order to accurately monitor and mitigate the impacts of mining projects. In addition, policymakers should require companies to implement habitat restoration and reforestation programs in areas affected by mining activities throughout the life cycle of the mines. Furthermore, they should establish a well-funded compensation budget to finance these rehabilitation activities.

And finally, more broadly policymakers should also:

- Incentivise regulatory **transparency** and good governance practices, by encouraging public participation in the regulatory decision-making process and making permits, environmental impact assessments (EIA) and compliance reports publicly accessible.

Further information

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