The Hague Centre
for Strategic Studies

Critical raw materials in the Dutch Province of Zuid-Holland

What, why and how?

Irina Patrahau, Lucia van Geuns and Tom Draaijer

March 2024

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This HCSS report was commissioned by the Province of South Holland. The conclusions and recommendations presented in this study are the result of independent research. Responsibility for the content rests with the authors and the authors alone.

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Executive summary

The Netherlands government has published its National Raw Materials Strategy (*Nationale Grondstoffenstrategie*) in 2022 and is currently working on its implementation domestically and abroad. This is taking place in the context of the 2023 European Critical Raw Materials Act (CRMA), which aims to diversify the European Union's (EU) mineral supplier base; as well as invest in mineral domestic capabilities.

Critical raw materials (CRM), a set of 34 minerals and metals considered of high economic importance for the European economy, have been essential to the vital functions of societies and economies for a long time, but now the energy transition is putting pressure on global supply. All the countries undergoing the energy transition need higher quantities of materials to build clean energy technologies and electricity grids. Digital technologies, healthcare and defence applications will continue demanding their share of minerals as well. Moreover, materials are extracted by companies that circumvent environmental, social and governance (ESG) standards, bringing about concerns regarding the global footprint of CRM supply chains.

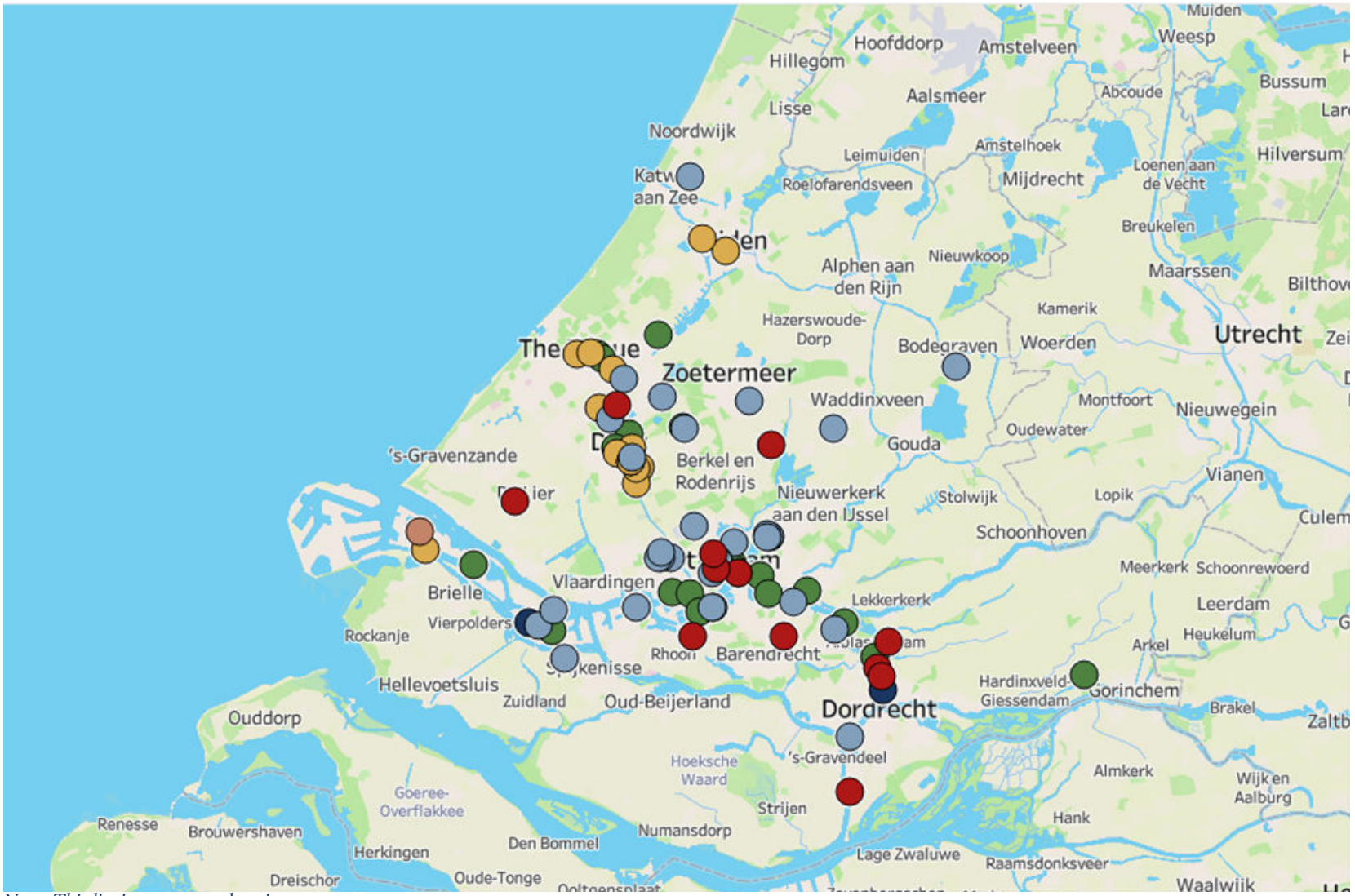
Rising geopolitical tensions are impacting the open trade of CRM. Growing competition between the US and China, increasing pressure on global value chains as a result of the Covid-19 pandemic, and global instability caused by the war in Ukraine and the Israel-Gaza war, have caused a perfect storm for the multilateral order and global trade. Increasingly, countries are divided into geopolitical blocs and are competing for control over technologies that belong to the fourth industrial revolution. CRM are key components of these technologies and key targets in this geopolitical setting.

At the request of the Province of Zuid-Holland and in support of the Netherlands Raw Materials Strategy, this report investigates the potential of the Province of Zuid-Holland to take on a greater role in mineral supply chains, with a focus on refining, urban mining and recycling.

In Zuid-Holland, the most widespread CRM industrial activities as of 2023 are trade and logistics; and recycling pre-treatment (Figure 1). The Netherlands has a notable globally active trade and services industry, centered around the Port of Rotterdam in Zuid-Holland. The Port of Rotterdam is not only Europe's biggest port and a key part of the Western European industrial ecosystem, but it is also the key hub for metals trading in the region. Recycling in Zuid-Holland is largely focused on pre-treatment and scrap, as is the case in the rest of the country, but companies are looking to expand into processing.

Moreover, Zuid-Holland hosts a strong knowledge hub that is closely interlinked with its innovative business environment, leading nationally. World-renowned knowledge institutions are prevalent around the main academic hubs in the Province of Zuid-Holland in Delft and Leiden, as well as in The Hague where the Dutch government is based. This creates a strong entrepreneurial ecosystem that supports innovative and rapidly growing start-ups, which create value through productivity, wellbeing, income and employment opportunities.

Figure 1. Companies and institutions active in mineral and metal supply chains in the Province of Zuid-Holland



Research and Development:
ASML Delft, Biosphere Solar, Blue City, CML Leiden University, Deltares, EAZ Wind, HCSS, IHE Delft, In2Waste Solutions, LeydenJar, M2i, Materials Recycling and Sustainability, TNO, Water-Mining H2020, ZERO BRINE.

Processing:
Climax Molybdenum, Sibelco.

Manufacturing:
Better Future Factory, BOAL, Exasun, Extrusion, Buhlmann Group, Elcee, Rovasta, Eurad, FNsteel, Villares Metals International, Gobinda Mixed Metals, PWT Eurostaal, Krogman Metals.

Recycling (waste collection and pre-treatment of scrap):
7Digits B.V., A&M Recycling, Autosloperij Atlas-Car, Autosloperij Kralingen, Autosloperij Zuid-Holland, Autosloperij Romein, Circular Circuits, DIM, Drake and Farrell, EMR ,Geelhoed, Henk Netten Metaalhandel B.V., Isero B.V., Jansen Recycling Groep, JOBO Metaal, Krommenhoek Metals, Lion Metals Maarten van Rijn Oud Ijzer en Metalen, Metaalhandel & Autosloperij B. Rijsdijk, Metaalhandel W. Ketting, Metalimex, RD Metals, Reconext, Repeat Audio, Rexel, Rijnmond Auto's, SCRAP, Stibat, OPEN, StoredEnergy, TES Battery, Urban Mining Corporation, Uzimet, Van Helvert Metalen, Van Leeuwen Recycling Groep, Van Pelt Recycling, W3E.

Recycling (black mass production and metal recovery):
TES.

Services and Trade:
AccessWorld, Allseas, Arenal Dredging and Mining, Ayaz Auto Inkoop. BM Metals, EPRM, Fugro, Hamwells, Netics, Nouryon Chemicals B.V. Europoort, Optecs, Royal IHC, SGS., Siemens, Gamesa, SkyGeo, Stainalloy, Stedin, Steinweg, Sweco Nederland, Van Essen Instruments, Van Oord WD Trading B.V..

Note: This list is not comprehensive.

If the Province of Zuid-Holland may want to expand its mineral capabilities, notable social, environmental, ethical, economic and political challenges as well as opportunities arise for the society, businesses and authorities. These are summarised in the table below.

	Issue	Explanation
Social	**Negative public opinion**	The negative public perception of heavy industries in the Netherlands and Zuid-Holland make it challenging for companies to make long-term plans and strategies. A part of the negative public opinion is based on challenges surrounding lack of space, as well as lack of awareness about the social and environmental risks and impacts in the Netherlands and abroad. At the same time, there have been several cases in recent history where heavy industrial activity led to environmental and health issues for local communities, which strongly contributed to negative public opinion.
	Lack of physical space	The Netherlands is a small-sized country with a highly advanced economy, relatively large industry and a very dense population. The population is in dire need of housing with limited expansion possibilities in the main cities like Rotterdam and the Hague. At the same time, industrial areas in the Province of Zuid-Holland are filled up. That is challenging considering that clean energy technologies require much more space than fossil fuels.
Environmental	**Environmental risks of heavy industry**	Mineral extraction, processing and recycling are considered heavy industries. They often have a large carbon footprint compared to lighter industries, require a lot of energy and high temperatures, use hazardous chemicals and generate toxic waste. While any industrial activity will bring environmental risks, the extent to which they materialise is heavily dependent on governance and standards. Broadly speaking, risks could be better managed and mitigated in Europe or the US compared to other countries.
Ethical	**The footprint of global supply chains**	Most of the materials used today in wind turbines or electric cars in Europe are sourced under highly problematic environmental, social and governance standards. Risks include forced labour, corruption, child labour, abuses of force by security forces and other human rights violations. This inhibits a just global transition as it outsources negative impacts to places outside of Europe.
Economic	**Skilled labour**	Skilled labour is required for the development of an innovative manufacturing industry in the Province of Zuid-Holland. This can support labour productivity and economic growth provincially and nationally. Zuid-Holland can leverage collaboration platforms with universities, applied sciences schools, and vocational training programs to ensure a skilled workforce.
	Uneven playing field	Differences in legislation, state support, and environmental, social and governance (ESG) standards over time created an uneven playing field for European companies. Now, companies in the Netherlands and Zuid-Holland find it very difficult to compete with their Chinese counterparts, as they have to offer similarly low costs while encountering dramatically different costs.
	Insufficient financial support	Projects in the minerals sector are considered risky due to social and environmental challenges. This makes it difficult for companies to attract private investments in the absence of public interventions that can de-risk investments.
	Energy costs and inadequate green energy infrastructure	Energy prices for industries in the Netherlands are significantly higher than other countries outside of the European Union, primarily due to taxation on fossil fuels. While heavy taxation on fossil fuels is meant to encourage companies to decarbonize, the green energy infrastructure is not yet adequate to allow a shift to low-carbon energy. The electricity grid is congested and costs of green hydrogen remain high.
Political	**Insufficient dialogue between government and industry and lack of trust**	The relationship between the national, provincial and local governments in the Netherlands, and the industry has been suffering over time as a result of a lack of dialogue. On the one hand, the industry is known for trying to maximise its profits, sometimes at the expense of the broader public interest. On the other hand, governments have been passing increasingly strict environmental regulation that at times has unintended negative consequences for industry. The relationship between the government and industry remains characterised by an erosion of trust and pessimism regarding each other's intentions.
	Delayed action and fragmented mandates	A key challenge for companies in the minerals sector in Zuid-Holland is the speed of implementation of new policies. Since 2022 political discourse undertook a major shift regarding the minerals and metals sector. European and national strategies to strengthen this sector have come out. However, concrete policies that are coherent through different levels of government and departments have yet to be developed to support the political claims.
	Cumbersome permitting process	Permitting for minerals and metals industries, which are most often heavy industry, can take quite a long time due to the complex processes that need to be assessed, novelty of some of these processes and sometimes lack of capacity of permitting bodies. Companies in Zuid-Holland and the Netherlands face uncertainty in light of the exact steps they need to undertake, agencies they should talk to, and expectations of the duration of the process.
	Inconsistent or inexistent legislation	Given the novelty of ambitions in the minerals sector, legislation is sometimes not up-to-date or has not yet been developed. This is a challenge faced especially in the recycling sector in Zuid-Holland and the Netherlands, whereby waste streams cannot be easily repurposed by companies as the regulations do not allow it.

Addressing challenges and maximising opportunities associated with CRM supply chains requires close coordination between the local, provincial and national levels of government, as well as industry and knowledge institutions. The recommendations below can support policymakers of the Province of Zuid-Holland in addressing some of the above-mentioned challenges. In implementing the first four recommendations, the Province of Zuid-Holland could play a leading role, while in the case of the other five the Province plays more of a complementary role to other actors.

1. **Awareness and dialogue.** Zuid-Holland should engage in active dialogue with companies and the Port of Rotterdam to better understand the needs of companies in CRM-related sectors and be able to make more informed decisions and policies.

2. **One-stop-shop.** Zuid-Holland should ensure the existence of a 'one-stop-shop' for companies – a specialized service that can offer up-to-date information on demand to companies that look to invest in the Province in CRM-related capabilities.

3. **Network and coalitions.** When deciding whether to invest in mineral capabilities, the Province of Zuid-Holland should ensure coordination and cooperation along the supply chain with other provinces, regions and countries.

4. **Guidance from the Netherlands Government**. The Province of Zuid-Holland should try to obtain clearer guidelines from the national government regarding the future energy system in the Netherlands, with which it can better assess how to design its contribution to national policy.

5. **Innovation and start-ups.** Zuid-Holland should support innovation as well as help create business cases for start-ups in the CRM sector.

6. **Support the business case of industries active in the Netherlands.** Zuid-Holland, together with the central government and the EU and in collaboration with industry, should take steps to support the competitiveness of light but especially heavy industrial sectors.

7. **Public awareness.** Awareness raising campaigns acknowledging existing social, environmental, ethical, economic and political dilemmas should be conducted by Zuid-Holland.

8. **Research.** Zuid-Holland should support the knowledge hub in the region by promoting and funding research on CRM-related topics in academic and applied research centres.

9. **Education.** Zuid-Holland should enhance educational programmes for various skill levels in the CRM sector, starting from basic trainings for entry-level positions to academic education for highly specialised tasks.

1. Introduction

The last few years brought critical raw materials (CRM) to the forefront of the Dutch policy agenda and strategic interests. CRM are minerals and metals necessary for the Netherlands' vital sectors – they are used in healthcare, digital technologies, clean energy applications and the defence industry. To ensure equitable and sustainable value chains and withstand geopolitical tensions, the Netherlands government has published its National Raw Materials Strategy (*Nationale Grondstoffenstrategie*) in December 2022 and its National Technology Strategy (*De Nationale Technologiestrategie)* in January 2024.[1] Both of these highlight the importance of CRM for the Dutch national interest and call for gaining a stronger position in CRM supply chains. This is taking place in the context of the 2023 European Critical Raw Materials Act (CRMA), which aims to diversify the European Union's (EU) CRM supply base as well as invest in mineral domestic capabilities.[2]

The demand for minerals is swiftly increasing but supply chains remain concentrated and problematic from an environmental, social and governance (ESG) perspective. Governments all over the world are moving toward climate neutrality. Renewables require significantly more minerals than the current energy system, driving up demand. At the same time, the supply of raw and processed minerals is concentrated in a few countries and dominated by China. European companies have been taking steps to build CRM-related capabilities in the last couple of years, but their competitive edge is weak compared to China's. Often, materials are extracted by companies that circumvent ESG standards. Dangerous working conditions, air, land and water pollution, and child labour are often associated with the minerals industry.[3] Due to the complexity and opacity of mineral supply chains, it remains difficult for European and Dutch companies to trace the origin of their imports and ensure responsible sourcing.

Geopolitics aggravates the impact of potential imbalances in the supply and demand of minerals, with direct impacts for the Netherlands. The competition between great powers – the United States (US) and China – has been intensifying. As a means of coercion, countries are turning economic interdependencies into weapons. This is already impacting mineral markets. In early 2022, the US government imposed export controls on chip-making technology to China. The US was joined by the Netherlands and Japan in this effort. Soon after, the Chinese government announced measures that could limit the export of gallium, germanium, graphite and rare earths. The Netherlands is affected given the high import dependency on minerals and components used in modern technologies.[4] Moreover, the Netherlands-based ASML is an essential supplier of chip-making technology and a key player in this geopolitical dispute.

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1 Rijksoverheid, 'Grondstoffen Voor de Grote Transities'; Rijksoverheid, 'De Nationale Technologiestrategie: Bouwstenen Voor Strategisch Technologiebeleid', 2024, https://open.overheid.nl/documenten/67b0a9e1-135b-483f-9ed9-3aade270dbce/file.

2 'Critical Raw Materials Act', European Commission, accessed 22 September 2023, https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en.

3 'Critical Minerals Market Review 2023', IEA, accessed 22 September 2023, https://www.iea.org/reports/critical-minerals-market-review-2023/key-market-trends.

4 European Commission et al., 'Study on the Critical Raw Materials for the EU 2023', 2023, https://data.europa.eu/doi/10.2873/725585.

At the request of the Province of Zuid-Holland and in support of the National Raw Materials Strategy, this report investigates the potential of Zuid-Holland to take on a greater role in mineral supply chains, with a focus on refining, urban mining and recycling. It provides recommendations for policymakers in the Province of Zuid-Holland to develop strategies and plans in support of the National Raw Materials Strategy.

While Zuid-Holland has developed ambitions in terms of circularity and the energy transition, so far CRM have not been central to policymaking. Committed to the national goal of achieving a fully circular economy by 2050, with a 50% reduction in the use of primary resources by 2030, the Province recognizes waste as a valuable resource.[5] Urban mining could therefore play a pivotal role in the transition to a circular economy. The Province identifies this as a strategic response to challenges such as resource scarcity and foreign raw material dependence.[6] In this context, the Province's Spatial Planning Strategy recognizes the significant geopolitical opportunity in the considerable volume of e-waste from urban areas.[7] Moreover, the Economic Board of Zuid-Holland underscores the importance of investing in sustainable energy sources and materials to enhance Zuid-Holland's appeal as an international hub.[8]

This provincial initiative by Zuid-Holland aligns with Dutch national ambitions. The Climate and Energy Formation Working Group (*Formatiegroep Klimaat en Energie)* states in its report 'Keuzewijzer Klimaat en Energie' of December 2023 that, especially given the risks to the energy transition, the new cabinet needs to more concretely flesh out the CRMA at a national level.[9] At this moment, national policy action perspectives include circularity, diversification, and European mining and refining.

The report answers the following research question: *Why would the Province of Zuid-Holland take on a more active role in the supply chains of critical raw materials, what could this role be and how can this be achieved?*

In order to answer this question, both desk research and primary data collection methods, i.e., interviews and a multi-stakeholder workshop, were employed. Interviews with representatives of provincial authorities, licensing bodies and industry were held about the challenges and opportunities of developing mineral capabilities in Zuid-Holland. The multi-stakeholder workshop informed relevant stakeholders of the initial results of the research and served to validate and verify some of the findings. In addition, the research builds on the findings of the previous HCSS report *"Advancing European mineral security: Insights from Dutch industry",* published in November 2023, which investigated the potential of companies active in the Netherlands to expand their role in global mineral supply chains.[10] That research was based

5 'Omgevingsvisie Zuid-Holland (in Werking per 1 April 2023) - Ruimtelijke Plannen', Provincie Zuid-Holland, 1 April 2023, https://ruimtelijkeplannenzuidholland.nl/omgevingsbeleid/.

6 'Deel 1 van 2 De Hoofdlijnen: Ruimtelijke Strategie Circulair Zuid-Holland' (Rotterdam/The Hague: BVR and Ecorys, December 2022), 2–3, https://circulair.zuid-holland.nl/wp-content/uploads/2021/12/221219-BVR-ECORYS-Ruimtelijke-Strategie-Circulair-Zuid-Holland-Deel-1.pdf.

7 'Deel 2 van 2 De Verdieping: Ruimtelijke Strategie Circulair Zuid-Holland' (Rotterdam/The Hague: BVR and Ecorys, December 2022), 77, https://circulair.zuid-holland.nl/wp-content/uploads/2021/12/221219-BVR-ECORYS-Ruimtelijke-Strategie-Circulair-Zuid-Holland-Deel-2.pdf.

8 'Groeiagenda Zuid-Holland: Samenhangend Investeren in Verdienvermogen, Brede Welvaart En Werkgelegenheid' (Rotterdam/The Hague: Economic Board Zuid-Holland, 2021), 44, https://www.economicboardzuid-holland.nl/wp-content/uploads/sites/14/2021/02/Groeiagenda%20Zuid-Holland%202021.pdf.

9 Noé Van Hulst, 'Keuzewijzer Klimaat En Energie' (Ministerie van Economische Zaken en Klimaat, 4 December 2023), 79–80, https://open.overheid.nl/documenten/be9f1214-2fbf-4104-9edc-a6965cba60c5/file.

10 Irina Patrahau et al., 'Advancing European Mineral Security: Insights from the Dutch Industry' (The Hague Centre For Strategic Studies, 2023), https://hcss.nl/report/advancing-european-mineral-security-insights-from-the-dutch-industry/.

on more than 30 interviews with representatives of companies active in the Dutch minerals and metals industry were conducted. Taking this as the starting point, this report deepens the above-mentioned research by focusing on the specific characteristics of the Province of Zuid-Holland.

Notwithstanding particularities of Zuid-Holland, this report also offers insights into the broader challenges and opportunities that different regions in Europe may face when trying to implement the European Critical Raw Materials Act and work towards open strategic autonomy in the mineral sector.

This report is structured in the following way. Sections two and three introduce the geopolitics and geo-economics of critical minerals and describe the 'why' behind reshoring initiatives in Europe. In the fourth section, an explanation of mineral supply chains is provided as a necessary background to understand existing capabilities and potential opportunities for the Province of Zuid-Holland in the CRM sector. Fifth, the report outlines social, environmental, ethical, economic and political issues associated with expanding mineral capabilities in Zuid-Holland. The report concludes with a set of recommendations that policymakers in the Province of Zuid-Holland may choose to follow when designing CRM-related plans.

2. Why do critical minerals matter for Zuid-Holland?

Critical raw materials

CRM are metals and minerals that are essential to the EU economy and society; and are associated with a high supply risk. The EU conducts assessments every three years and determines which minerals and metals should be included in the 'Critical Raw Materials list'. As of 2023, there are 34 minerals and metals on the CRM list (Table 1). These are normally distinguished from base metals, which are metals that are not considered precious like tin, steel or zinc, and that are not on the EU's CRM list. For the first time in 2023, the EU also defined a list of strategic raw materials, which are specifically linked with technologies in the green, digital, space and defence sectors, rather than associated with the EU economy as a whole like in the case of CRM.[11] Copper and nickel are considered by the EU strategic materials and do not meet the official threshold of CRM. To put this into perspective, in the United States there are 50 materials included in their own version of the CRM list, in Canada 31, in Australia 26.[12]

Table 1. EU list of Critical Raw Materials (CRM) 2023

Bauxite	Coking Coal	Lithium	Phosphorus
Antimony	Feldspar	Light rare earth elements	Scandium
Arsenic	Fluorspar	Magnesium	Silicon metal
Baryte	Gallium	Manganese	Strontium
Beryllium	Germanium	Natural Graphite	Tantalum
Bismuth	Hafnium	Niobium	Titanium metal
Boron/Borate	Helium	Platinum group metals	Tungsten
Cobalt	Heavy rare earth elements	Phosphate Rock	Vanadium
		Copper (strategic raw material)	Nickel (strategic raw material)

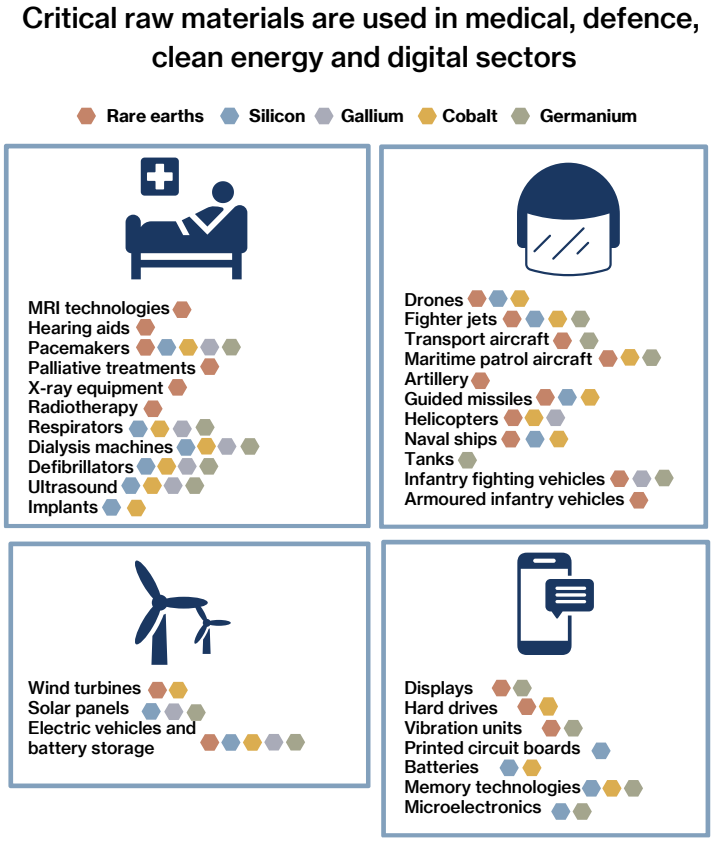
11 'Critical Raw Materials', European Commission, accessed 22 September 2023, https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en.

12 Government of Canada, 'The Canadian Critical Minerals Strategy', 9 December 2022, https://www.canada.ca/en/campaign/critical-minerals-in-canada/canadian-critical-minerals-strategy.html; Australian Government, 'Critical Minerals Strategy 2023–2030', https://www.industry.gov.au/node/92581, 7 July 2023, https://www.industry.gov.au/publications/critical-minerals-strategy-2023-2030; '2022 Final List of Critical Minerals', Federal Register, 24 February 2022, https://www.federalregister.gov/documents/2022/02/24/2022-04027/2022-final-list-of-critical-minerals.

Vital sectors of the Dutch society

Most vital functions of society in the Netherlands and beyond depend on minerals.[13] Smart phones require gallium and germanium, electric cars require lithium, cobalt and graphite; electricity cables require copper and aluminium, and magnetic resonance imaging (MRI) scanners require rare earth elements (see Figure 2).

Figure 2. Critical raw materials use in vital sectors.
Figure adapted from Teer, Bertolini and Girardi, 'Great power competition and social stability in the Netherlands, 2023.



Rising global demand for minerals

Minerals have been essential to vital functions of societies and economies for a long time, but now the energy transition is putting pressure on global supply. The mineral requirements of the energy transition are much higher than those of our current system, meaning that global mineral demand is on the rise. If governments worldwide follow current policy commitments in decarbonizing, global mineral demand is set to rise to around 15 million tonnes (Mt) by 2030, almost doubling the amount of 2022. However, current policy commitments are insufficient to reach the goals of the Paris Agreement. If ambitions are raised accordingly, global mineral

[13] 'Vitale infrastructuur', Nationaal Coördinator Terrorismebestrijding en Veiligheid (Ministerie van Justitie en Veiligheid), accessed 17 April 2023, https://www.nctv.nl/onderwerpen/vitale-infrastructuur.

demand will even increase to 20 Mt by 2030.[14] In addition to the energy transition, minerals are still needed to maintain current sectors. Digital technologies, healthcare and defence applications will continue demanding their share of minerals as well.

While all critical and strategic materials are expected to encounter some supply challenges, the demand for each material depends on its use across technologies and the speed of the energy transition. For instance, copper is used across various technologies in large amounts, whereas neodymium is used mainly in permanent magnets in relatively small amounts. Compared to 2022, the forecasted copper demand in 2030 could increase by 21% in the Stated Policies Scenario (STEPS), by 26% in the more ambitious Announced Pledges Scenario (APS), and by 40% in the Net Zero Scenario (NZE).[15] Neodymium, a rare earth element (REE) used for magnets in wind turbines and electrical vehicles, displays an even larger range in demand by 2030, as these amount to 46%, 64%, and 102% in STEPS, APS and NZE, respectively.[16]

Demand can be fulfilled both through primary supply – i.e., virgin materials – and secondary supply – i.e., recycled materials.[17] Up to at least 2035, a significant increase in primary supply is expected.[18] Depending on the pace at which recycling capacity and rates increase, ore extraction could decline after 2035 with a sharp increase in recycling capacity, or after 2045 if recycling rates increase at a slower pace.[19] Compared to current mining operations that focus primarily on coal, the energy transition will lead to an overall decrease in mining at the global level.[20] According to Krane and Idel, "Even if the world increased 12-fold the annual global production of all rare earths, lithium, cobalt, and even copper, the metals produced would comprise just 3% of 2020 world coal production."[21]

Technological developments still play a decisive role in the expansion of recycling capacity over the next years. For instance, while copper from solar PV and wind turbines can already be recycled with existing technologies, it remains quite difficult to recover minerals from batteries.

Global supply concentration

European domestic capabilities to supply minerals are relatively limited, meaning that the EU is highly import dependent (see Figure 3).[22]

China is the dominant player in CRM markets. A significant amount of minerals is extracted and processed in China. Capabilities for manufacturing clean energy technologies, including

14 'Critical Minerals Market Review 2023', 63.

15 'Critical Minerals Demand Dataset', IEA, July 2023, https://www.iea.org/data-and-statistics/data-product/critical-minerals-demand-dataset. Calculations forecasted total demand increase per scenario: Total copper demand STEPS 2030 (((30848/25502)-1)x100) = 21%), total copper demand APS 2030 (((32070/25502)-1)x100) = 26%), and total copper demand NZE 2030 (((35613/25502)-1)x100) = 40%); Total neodymium demand STEPS 2030 (((73/50)-1)x100) = 46%), total neodymium demand APS 2030 (((82/50)-1)x100) = 64%), and total neodymium demand NZE 2030 (((101/50)-1)x100) = 102%).

16 'Critical Minerals Demand Dataset'.

17 Parliament, 'Strategy for Secondary Raw Materials'.

18 Joey Nijnens et al., 'Energy Transition Will Require Substantially Less Mining than the Current Fossil System', *Joule*, 26 October 2023, https://doi.org/10.1016/j.joule.2023.10.005.

19 Nijnens et al.

20 Nijnens et al.

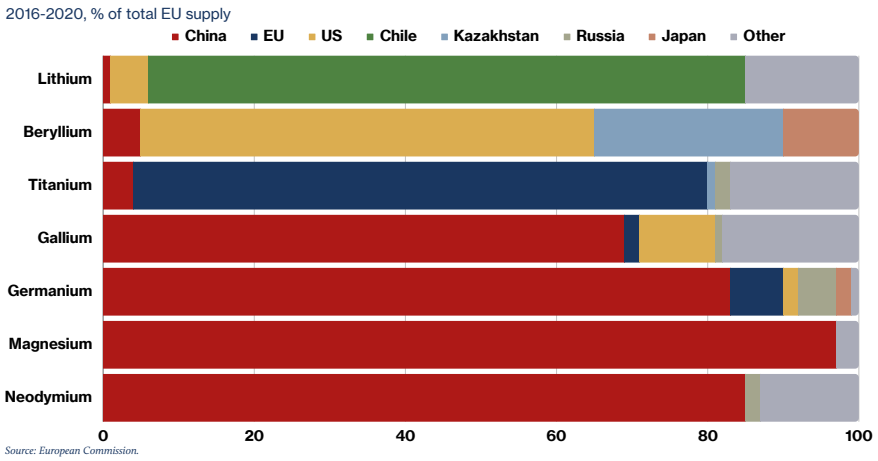
21 Jim Krane and Robert Idel, 'More Transitions, Less Risk: How Renewable Energy Reduces Risks from Mining, Trade and Political Dependence', *Energy Research & Social Science* 82 (1 December 2021): 102311, https://doi.org/10.1016/j.erss.2021.102311.

22 European Commission et al., 'Study on the Critical Raw Materials for the EU 2023'.

lithium-ion batteries, rare earth permanent magnets for wind turbines and solar panels, among others, are also largely based in China. This is the result of a long-term strategy pursued by the Chinese government.[23] Already in the 1990s, the Chinese recognized the importance of certain minerals for strategic sectors: clean energy, health, digital and defence. Through heavy investments in research and development, Chinese companies were able to patent extraction, refining and manufacturing technologies for these products.[24] Heavy subsidisation of state-owned companies allowed for rapid expansion. It also made it easier for companies to offer low prices and become highly competitive in global markets. The reliance on coal as an affordable energy source ensures that industrial processes in China are relatively cheap. As of 2023, 55% of China's total energy consumption depends on coal.[25] Weak environmental standards make operations in China cheaper than in the rest of the world. Weak labour rights and therefore low wages also contribute to low costs for Chinese companies. The combined result of these practices has been a massive development of Chinese domestic capabilities in the sourcing of minerals and manufacturing of strategic technologies.

To complement domestic capabilities, Chinese firms have been active investors in other countries too. In the first half year of 2023, China invested more than $10 billion in materials capabilities, among which lithium, nickel, copper and cobalt.[26] These investments span from South America to Asia and Africa, and cover the entire supply chain of minerals. Chinese companies acquired stakes in a lithium mine in Mali, planned a lithium refining plant in Zimbabwe, and closed an agreement for a copper refining plant in Saudi Arabia.[27]

Figure 3. EU Supply of Processed Critical Raw Materials.
Figure based on data from the European Commission, 2023.[28]



Source: European Commission.

23 Irina Patrahau et al., 'Securing Critical Materials for Critical Sectors: Policy Options for the Netherlands and the European Union' (The Hague: The Hague Centre for Strategic Studies, December 2020), https://hcss.nl/wp-content/uploads/2021/01/Securing-Critical-Materials-for-Critical-Sectors.pdf.

24 Ng, Eric, 'China's War Chest of Rare Earth Patents Give an Insight into Total Domination of the Industry', South China Morning Post, 20 July 2019, https://www.scmp.com/business/companies/article/3019290/chinas-war-chest-rare-earth-patents-give-insight-total.

25 'Statistical Review of World Energy 2023' (Energy Institute, 2023), 8, https://www.energyinst.org/statistical-review/home.

26 Edward White, 'China's Overseas Investment in Metals and Mining Set to Hit Record', *Financial Times*, 31 July 2023, https://www.ft.com/content/dff6b029-43af-46e7-947d-06981cd988ec.

27 Polly Bindman, 'Weekly Data: China Seeks to Extend Its Critical Minerals Dominance with Overseas Investment Surge', *Energy Monitor* (blog), 21 August 2023, https://www.energymonitor.ai/sectors/industry/weekly-data-china-seeks-to-extend-its-critical-minerals-dominance-with-overseas-investment-surge/.

28 European Commission et al.

3. What is the impact of geopolitics on mineral supply chains?

The Netherlands and the EU are heavily dependent on the open trade of CRM, which is heavily impacted by the rising geopolitical tensions. Growing competition between the US and China, increasing pressure on global value chains as a result of the Covid-19 pandemic, and global instability caused by the war in Ukraine and Israel-Gaza war, have caused a perfect storm for the multilateral order and open trade. Increasingly, countries are divided into geopolitical blocs and competing for control over technologies that belong to the fourth industrial revolution, understood as artificial intelligence, quantum computing, big data, as well as clean energy technologies.[29] CRM are key components of these technologies and key targets in this geopolitical setting. These trends are explained below.

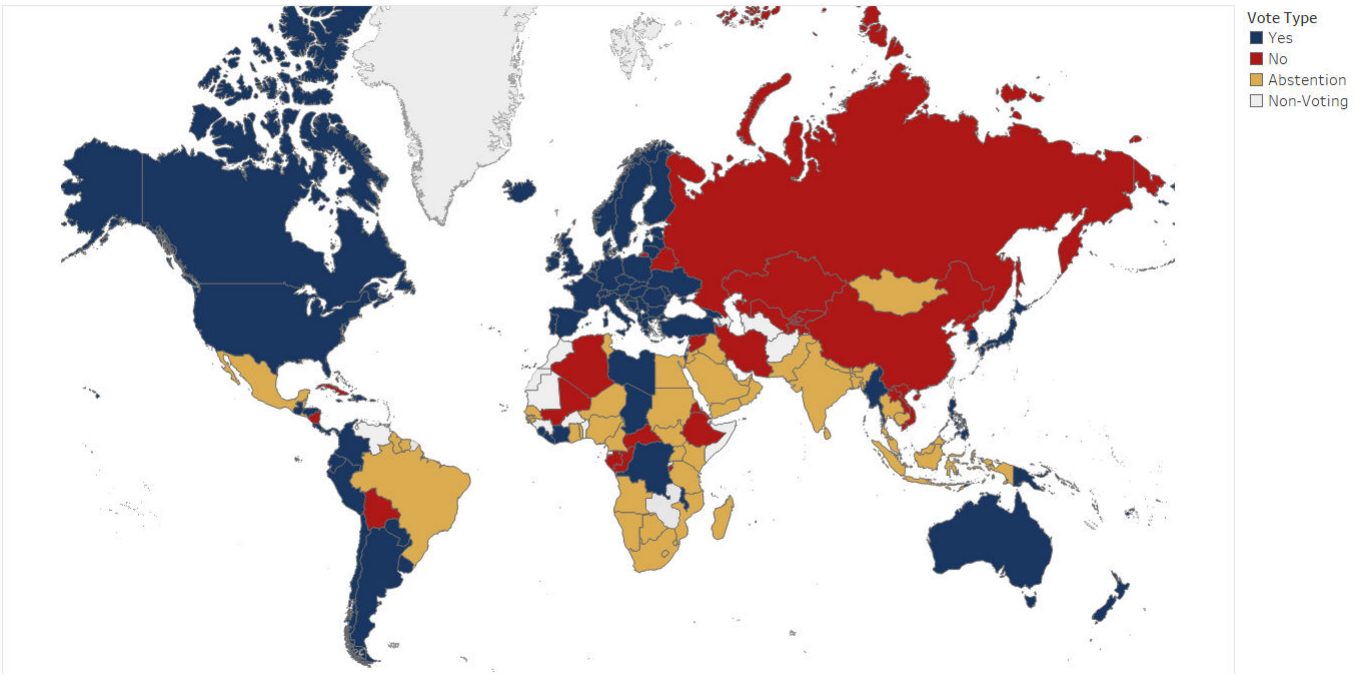
Fragmentation and geopolitical bloc-forming

States are increasingly acting together along similar political, social and economic values. They are acting within so-called geopolitical blocs rather than through multilateral institutions like the United Nations (UN), the World Trade Organisation (WTO) or the Group of 20 (G20). This became particularly noticeable after the Russian invasion of Ukraine. The choice to impose sanctions on Russia as well as to vote on the UN resolution to suspend Russian membership revealed important patterns of geopolitical bloc forming (Figure 4).[30] On the one hand, Western countries imposed numerous sanctions packages on Russian companies, individuals and goods, and were very outspoken condemning the invasion. On the other hand, China, India and some countries in the Middle East continued to import Russian oil and gas and engage in diplomatic exchanges with the Kremlin.

29 Doshi, 'Prepared Statement before the U.S. Senate Committee on Commerce, Science, and Transportation, Subcommittee on Security "The United States, China, and the Contest for the Fourth Industrial Revolution"'; Schoff and Ito, 'Competing With China on Technology and Innovation'.

30 Rodolfo Campos et al., 'Geopolitical Fragmentation and Trade', CEPR, 31 July 2023, https://cepr.org/voxeu/columns/geopolitical-fragmentation-and-trade.

Figure 4. UN General Assembly vote on the resolution for the "Suspension of the Rights of Membership of the Russian Federation in the Human Rights Council", April 2022 [31]



Source: United Nations Digital Library.

Governments are pursuing similar behaviour across various issues of importance in international politics. On the one hand, the Group of Seven (G7) alliance is committed to: "strongly promote sanctions against Russia and supports for Ukraine"; "reaffirm and strengthen cooperation on the "Free and Open Indo-Pacific."; and "work on issues such as resilient supply chains, non-market policies and practices, and economic coercion".[32] On the other hand, BRICS (Brazil, Russia, India, China, South Africa) is looking to expand toward African, Middle Eastern and South East Asian countries. If Saudi Arabia and Indonesia's applications to join BRICS are accepted, the alliance would account for 44% of the world economy in the next 15 years.[33] The 2023 'Friends of BRICS' summit also included Iran, the United Arab Emirates, Cuba, Democratic Republic of Congo (DRC), Comoros, Gabon, and Kazakhstan, Egypt, Argentina, Bangladesh, and Guinea-Bissau. During this summit, countries called for a BRICS-led "change and the creation of a new international order" after they were "abandoned by wealthy states and global institutions during the COVID-19 pandemic"[34] This points to an alternative set of political and economic beliefs from the ones promoted by G7.

[31] 'Suspension of the Rights of Membership of the Russian Federation in the Human Rights Council : Resolution / Adopted by the General Assembly', United Nations Digital Library, 7 April 2022, https://digitallibrary.un.org/record/3967778.

[32] 'Issues | G7 Hiroshima Summit 2023', G7広島サミット2023, accessed 12 September 2023, https://www.g7hiroshima.go.jp/en/summit/issue/.

[33] Bryce Baschuk, 'How Global Trade Changes With BRICS on the Rise', *Bloomberg*, 23 August 2023, https://www.bloomberg.com/news/newsletters/2023-08-23/supply-chain-latest-how-global-trade-changes-with-saudi-indonesia-in-brics.

[34] Wendell Roelf, 'BRICS Meet with "friends" Seeking Closer Ties amid Push to Expand Bloc', Reuters, June 2023, https://www.reuters.com/world/brics-meet-with-friends-seeking-closer-ties-amid-push-expand-bloc-2023-06-02/.

This is not to say that geopolitical blocs are formalized or cohesive. There are many self-interested countries with a less predictable behaviour, that choose who to support depending on the topic at hand. These are represented in yellow in Figure 4. India, for instance, is not clearly aligned with a bloc. The security partnership between India and the US is growing – e.g. through the Quadrilateral Security Dialogue (commonly known as QUAD) with Japan and Australia. At the same time, India became the largest importer of Russian oil and gas after the invasion of Ukraine, and is an active member of BRICS. India's behaviour in global politics is thus quite unpredictable but essential in determining the direction of strategic competition.

Sanctions and weaponised dependencies

The fragmented political relations are impacting the openness of trade. In order to gain more power relative to their perceived competitors, governments are getting increasingly involved in the market. They use coercive tools like economic sanctions and legal barriers to trade to achieve their goals. Great powers (including the US, China, Russia and the EU) have imposed about 60% of all economic sanctions globally between 2010-2020.[35] When it comes specifically to critical raw materials, export restrictions increased more than tenfold over the last decade, from 2,518 in January 2009 to 13,102 in December 2020.[36] Governments are moving further than imposing economic sanctions toward weaponizing strategic dependencies in order to amplify the coercive effect.[37] A dependency is strategic if interruptions in that good or service would impact the vital interests of a government. In the EU and the Netherlands, strategic dependencies are related to vital sectors: energy supply, communication, transportation, drinking water, defence etc.[38] Russia's weaponisation of natural gas toward Europe after the invasion of Ukraine is a key example. It affected an EU sector of national interest, energy security, and caused more than 1 trillion worth of damage.[39]

The Netherlands is directly involved in and affected by the rising geopolitical tensions, as seen in the trade conflict on chips since 2022 where ASML, the Dutch supplier of chip-making technology, has been a key player (Figure 5).

35 Joris Teer, Mattia Bertolini, and Benedetta Girardi, 'Great Power Competition and Social Stability in the Netherlands: The Risks of Russian Gas, Chinese Materials and Taiwanese Chips to Vital Sectors' (The Hague Centre for Strategic Studies, August 2023), https://hcss.nl/wp-content/uploads/2023/08/Great-power-competition-and-social-stability-in-the-Netherlands-HCSS-2023-V1-1.pdf.

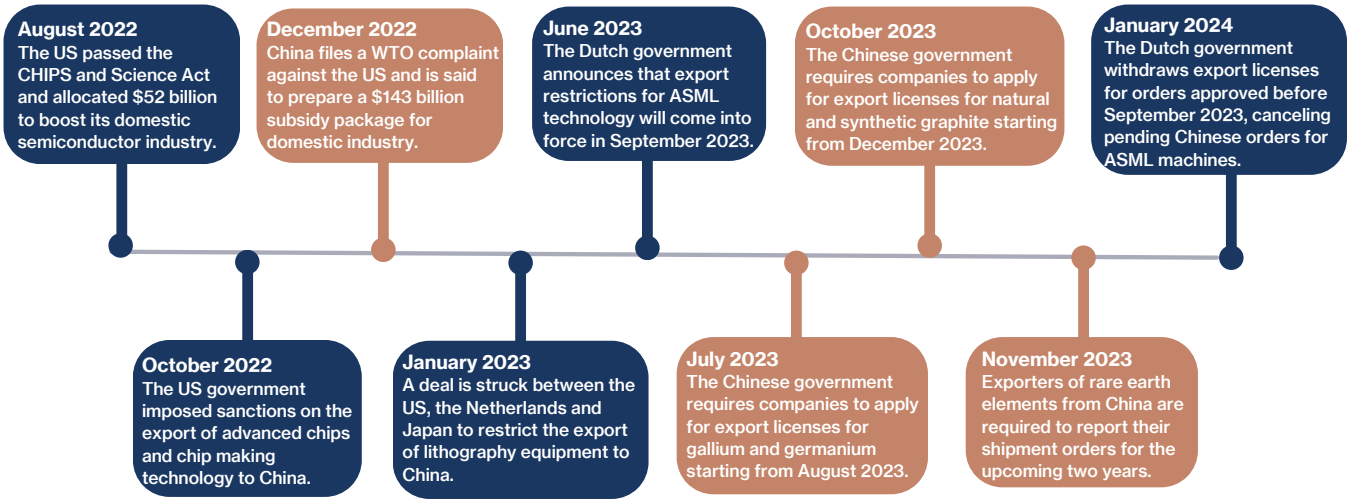
36 Przemyslaw Kowalski and Clarisse Legendre, 'Raw Materials Critical for the Green Transition: Production, International Trade and Export Restrictions', OECD Trade Policy Paper (Paris: OECD, April 2023), https://www.oecd-ilibrary.org/trade/raw-materials-critical-for-the-green-transition_c6bb598b-en.

37 Henry Farrell and Abraham L. Newman, 'Weaponized Interdependence: How Global Economic Networks Shape State Coercion', *International Security* 44, no. 1 (1 July 2019): 42–79, https://doi.org/10.1162/isec_a_00351.

38 'Vitale infrastructuur'.

39 Jeff D. Colgan, Alexander S. Gard-Murray, and Miriam Hinthorn, 'Quantifying the Value of Energy Security: How Russia's Invasion of Ukraine Exploded Europe's Fossil Fuel Costs', *Energy Research & Social Science* 103 (1 September 2023): 103201, https://doi.org/10.1016/j.erss.2023.103201.

Figure 5. Timeline of the trade relations in critical minerals and digital technologies between the US, the Netherlands and China as of January 2024



Reshoring and friendshoring mineral supply chains

The tense geopolitical landscape and the trend toward weaponised dependencies have brought urgency for governments to build open strategic autonomy. While the concept of open strategic autonomy is not universally accepted, it refers to efforts of the EU to become more resilient to disruptions in the supply chains of strategic goods by building domestic capabilities (i.e., reshore) and consolidating partnerships with reliable suppliers (i.e., friend-shore). The EU, US, Japan and South Korea, among others, are engaging in such activities.

The fastest mover has been the US. Overall, the US has dedicated more than 443 billion through the Inflation Reduction Act (IRA) and the Bipartisan Infrastructure Law (BIL) to increase the domestic production capabilities of minerals, clean energy technology and infra-structure.[40] The IRA can offer 'clean vehicle credits' for vehicles that use minerals sourced in the US or in countries that the US has free trade agreements with, that use battery compo-nents manufactured or assembled in North America.[41] As of December 2023, the EU and the US are still negotiating to ensure that EVs using minerals or components manufactured in the EU would also qualify for the credits offered under the IRA.[42]

[40] Adam Barth, Bernice Chan, and Ksenia Kaladiouk, 'The US Bipartisan Infrastructure Law: Funding Clean Energy', McKinsey, 2023, https://www.mckinsey.com/capabilities/sustainability/our-insights/one-year-into-the-bil-catalyzing-us-investments-in-energy; Justin Badlam et al., 'The Inflation Reduction Act: Here's What's in It', McKinsey, 24 October 2022, https://www.mckinsey.com/industries/public-sector/our-insights/the-inflation-reduction-act-heres-whats-in-it.

[41] 'Treasury Releases Proposed Guidance on New Clean Vehicle Credit to Lower Costs for Consumers, Build U.S. Industrial Base, Strengthen Supply Chains', U.S. Department of the Treasury, 31 March 2023, https://home.treasury.gov/news/press-releases/jy1379.

[42] Philip Blenkinsop, 'U.S. Optimistic It Will Reach Critical Minerals Deal with EU', *Reuters*, 2 October 2023, sec. Commodities, https://www.reuters.com/markets/commodities/us-optimistic-it-will-reach-critical-minerals-deal-with-eu-2023-10-02/.

Japan and South Korea have also been active, given their important role in the manufacturing of batteries and digital technologies as well as limited domestic mineral capabilities. Their strategy is focused on investments in upstream facilities – i.e., mining and processing – abroad. Both governments are offering untied loan guarantees to domestic companies that are investing in CRM-related capabilities in mineral-rich countries.[43] Another key pillar of their approach to mineral security is based on diplomatic agreements with suppliers. For instance, Japan, Korea, Italy and Canada entered the Resilient and Inclusive Supply Chain Enhancement (RISE) partnership with the World Bank, committing more than 40 million for emerging and developing countries' mineral sectors.[44] Finally, to strengthen domestic resilience, Japan and South Korea are expanding the size of their national stockpiles.[45]

The EU's approach is to increase domestic capabilities and support their companies' competitiveness while also developing strategic partnerships with reliable suppliers. The EU's central legislation, the Critical Raw Materials Act (CRMA), comprises the following ambitions: by 2030, 10% of the EU's demand of minerals should be extracted domestically; 40% of it processed domestically; and 25% recycled.[46] The final version of the CRMA has been adopted by the EU Parliament at the end of 2023 and awaits formal endorsement of the Council early 2024.[47] Moreover, import dependency on any one supplier should be limited to 65% of EU's annual consumption. The CRMA aims to harmonize and simplify legislation and permitting procedures to accelerate investments and project development. This is coupled with sector-specific pieces of legislation like the Chips Act, which is focused on digital technologies and came into force as of September 2023; and the Net-Zero Industry Act that aims to increase European manufacturing capacity for clean energy technologies and is undergoing final negotiations between the European Parliament and the Council of the EU.[48]

43 'Financial Support for Japanese Companies', JOGMEC: Japan Organization for Metals and Energy Security, accessed 22 September 2023, https://www.jogmec.go.jp/english/stockpiling/metal_10_000003.html; 'Korea Trade Insurance Corporation (K-Sure)', IISD, accessed 22 September 2023, https://www.iisd.org/credit-enhancement-instruments/institution/korea-trade-insurance-corporation-k-sure.

44 'World Bank and Japan to Boost Mineral Investments and Jobs in Clean Energy', World Bank, October 2023, https://doi.org/10/11/world-bank-and-japan-to-boost-mineral-investments-and-jobs.

45 'Financial Support for Japanese Companies'; 'Korea Trade Insurance Corporation (K-Sure)'; 'South Korea to Increase Stockpiles of Rare Metals', Argus Media, 5 August 2021, https://www.argusmedia.com/en//news/2241424-south-korea-to-increase-stockpiles-of-rare-metals; 'Stockpiling', Japan Organization for Metals and Energy Security (JOGMEC), accessed 17 November 2023, https://www.jogmec.go.jp/english/stockpiling/stockpiling_10_000001.html.

46 'An EU Critical Raw Materials Act for the Future of EU Supply Chains', Council of the European Union, 21 November 2023, https://www.consilium.europa.eu/en/infographics/critical-raw-materials/.

47 Guillaume Ragonnaud, 'European Critical Raw Materials Act', Legislative Train Schedule, 15 December 2023, https://www.europarl.europa.eu/legislative-train/theme-a-europe-fit-for-the-digital-age/file-european-critical-raw-material-act.

48 'European Chips Act (Semi-Conductors)', European Parliament, 20 October 2023, https://www.europarl.europa.eu/legislative-train/theme-a-europe-fit-for-the-digital-age/file-european-chips-act-(semiconductors); 'Net Zero Industry Act: Boosting Clean Technologies in Europe', European Parliament, 21 November 2023, https://www.europarl.europa.eu/news/en/headlines/economy/20231031STO08721/net-zero-industry-act-boosting-clean-technologies-in-europe.

CRM initiatives in Europe

Within the EU, governments are taking steps to transpose the EU Critical Raw Materials Act into national strategies and legislation. Below are a few notable examples of national initiatives in the CRM sector.

The Netherlands released its Nationale Grondstoffenstrategie in December 2022, based on five pillars: (1) circular economy; (2) European mining and processing; (3) diversification; (4) sustainable supply chains; and (5) knowledge building and monitoring.[49] Some progress has been made with the National Raw Materials Observatory to start examining value chains, strategic reserves as well as the development of partnerships with resource-rich countries.[50]

France and Germany are particularly busy with financing projects abroad that could provide a secure supply of minerals to their manufacturing industries and subsidizing domestic companies. In 2023, the French government created the Interministerial delegation for the supply of minerals and strategic metals that supports mineral intelligence and R&D, as well as projects in France, Europe and abroad. The French are offering diversified financing tools for projects, including the France 2030 Investment Plan and tax credits for domestic industries, as well as equity investments through private equity firm InfraVia.[51] The German government signalled its commitment to investments in mineral supply chains ever since the 800 million loan agreement for commodity trader Trafigura in October 2022.[52]

Scandinavian countries have been active players in the industry for a long time, as most of Europe's capabilities are concentrated in Sweden and Finland. Finland is highly active in the battery supply chains as they aim to become a leading actor in Europe under its National Battery Strategy.[53] In Sweden, Estonia and the Czech Republic significant investments are being made in the extraction and processing of various minerals.[54]

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49 Rijksoverheid, 'Grondstoffen Voor de Grote Transities'.

50 Ministerie van Economische Zaken en, 'Voortgangsbrief Nationale Grondstoffenstrategie', 22 December 2023, https://open.overheid.nl/documenten/5bb7fb68-971a-47ef-a9b7-4bc907870a11/file.

51 'Investir dans la France de 2030 : remise au gouvernement du rapport Varin sur la sécurisation de l'approvisionnement en matières premières minérales et ouverture d'un appel à projets dédié', Ministères Écologie Énergie Territoires, January 2022, https://www.ecologie.gouv.fr/investir-dans-france-2030-remise-au-gouvernement-du-rapport-varin-sur-securisation; 'InfraVia Launches a Critical Metals Fund with the Backing of the State', Infravia Capital (blog), 11 May 2023, https://infraviacapital.com/infravia-launches-a-critical-metals-fund/.

52 'Trafigura Signs USD800 Million Loan Agreement Guaranteed by the Federal Republic of Germany', Trafigura, 2022, https://www.trafigura.com/press-releases/trafigura-signs-usd800-million-loan-agreement-guaranteed-by-the-federal-republic-of-germany/.

53 Ministry of Economic Affairs and Employment of Finland, 'National Battery Strategy 2025 - Executive Summary', julkaisut.valtioneuvosto.fi (Ministry of Economic Affairs and Employment of Finland, 26 January 2021), https://julkaisut.valtioneuvosto.fi/handle/10024/162685.

54 'Talga's Natural Graphite Mine in Sweden Obtains Environmental Approval', Mining Technology (blog), 6 April 2023, https://www.mining-technology.com/news/talgas-graphite-sweden/; 'Chvaletice Manganese Project', Euro Manganese, accessed 22 November 2023, https://www.mn25.ca/chvaletice-manganese-project; Jiyeong Go, 'Estonia Becomes Unexpected China Rare-Earth Alternative', fDi intelligence, 6 December 2022, https://www.fdiintelligence.com/content/news/estonia-becomes-unexpected-china-rareearth-alternative-81821.

One of the main challenges that European industries face is the uneven playing field compared to non-European companies who experience lower energy taxes, environmental standards and workforce costs, and who receive significant subsidies from their governments. To combat this, the EU has introduced the Carbon Border Adjustment Mechanism (CBAM), an instrument that aims to tackle carbon leakage, i.e., the circumvention of strict EU CO_2 emissions limitations by moving production to non-EU countries with weaker regulations.[55] In other words, it aims to level the playing field between goods produced inside and outside of Europe, by increasing the price of imported goods with a high environmental footprint. In the trial period between 2023-2026, two metals industries – iron and steel, and aluminum – have been selected to report direct greenhouse gas emissions (i.e., emissions from the production process).[56] By 2030, the goal is to expand the CBAM to all sectors covered in the EU Emissions Trading System, including all metals.[57]

At the same time, the EU is actively pursuing partnerships with mineral suppliers. Through the Global Gateway Initiative, the EU is investing in mineral value chain development across South America and Sub-Saharan Africa. The Commission pledged investments of 45 billion during the summit of the EU and the Community of Latin American and Caribbean States (CELAC) in July 2023.[58] In October 2023, the EU signed Memoranda of Understanding (MoU) with the DRC and Zambia to develop sustainable mineral supply chains.[59] In addition, the EU, DRC and Zambia partnered with Angola, the US, the African Development Bank and Africa Finance Cooperation, to develop the Lobito Corridor, a transportation route connecting the DRC with the Port of Lobito in Angola.[60]

Finally, the EU has introduced the Corporate Sustainability Due Diligence Directive (CSDDD) to urge large companies to reduce their negative impact on human rights and the environment. These are companies with more than 500 employees and a global net turnover of more than €150 million. Non-EU companies are also covered by the CSDD if they achieve net sales of more than €150 million in the EU within three years of its entry into force. The CSDDD applies to the entire value chain of these companies and companies must demonstrate that their business operations are in line with the Paris Agreement. Furthermore, public contracts and concession agreements are only awarded to companies that comply with the CSDDD.[61]

55 'Regulation (EU) 2023/956 of the European Parliament and of the Council of 10 May 2023 Establishing a Carbon Border Adjustment Mechanism', 10 May 2023, https://eur-lex.europa.eu/eli/reg/2023/956/oj.

56 'Regulation (EU) 2023/956 of the European Parliament and of the Council of 10 May 2023 Establishing a Carbon Border Adjustment Mechanism'.

57 Elena Belletti, Nuomin Han, and Ivan Perez, 'Playing by New Rules: How the CBAM Will Change the World', Wood Mackenzie, 21 September 2023, https://www.woodmac.com/horizons/how-the-cbam-will-change-the-world/; 'Regulation (EU) 2023/956 of the European Parliament and of the Council of 10 May 2023 Establishing a Carbon Border Adjustment Mechanism'.

58 Philip Blenkinsop and Andrew Gray, 'EU Aims to Be "partner of Choice" for Latam, Caribbean in Pivot from China, Russia', *Reuters*, 18 July 2023, sec. World, https://www.reuters.com/world/eu-seeks-revive-latam-caribbean-ties-it-turns-away-china-russia-2023-07-17/.

59 'EU Signs Strategic Partnerships with DRC and Zambia', European Commission, October 2023, https://ec.europa.eu/commission/presscorner/detail/en/ip_23_5303.

60 'EU Signs Strategic Partnerships with DRC and Zambia'.

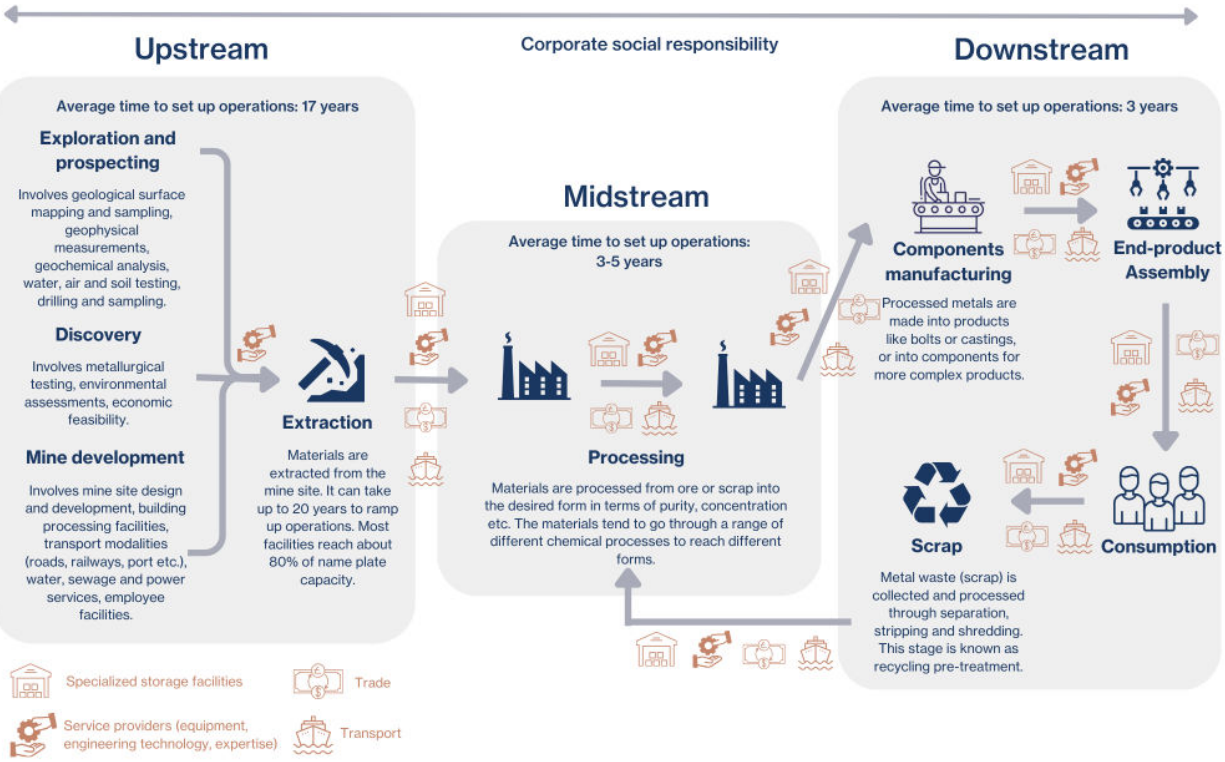
61 'Corporate Sustainability Due Diligence: Council and Parliament Strike Deal to Protect Environment and Human Rights', European Council, 14 December 2023, https://www.consilium.europa.eu/en/press/press-releases/2023/12/14/corporate-sustainability-due-diligence-council-and-parliament-strike-deal-to-protect-environment-and-human-rights/; Miguel de Groot, 'De CSDDD heeft niet alleen gevolgen voor grote ondernemingen', Baker Tilly, 14 January 2024, https://www.bakertilly.nl/inzichten/kennisartikel/eu-parlement-en-eu-raad-bereiken-op-hoofdlijnen-akkoord-over-klimaatrichtlijn-csddd.

4. What role can Zuid-Holland play in mineral supply chains?

Every mineral supply chain is different

A mineral supply chain consists of all the processes involved from extracting the raw material to the consumer market (Figure 6). Most minerals involve very different industrial processes along their supply chains. Depending on the mineral, it may require a particular mining technique and highly specialised chemical processing, manufacturing, and recycling. This also means that many processes are not directly replicable, so (almost) every CRM needs its own supply chain to be developed. This section provides insights into the heterogeneity and diversity of processes in minerals supply chains. Appendix 2 explains each supply chain segment in more detail.

Figure 6. Simplified mineral supply chain



Extraction

The upstream involves extraction (or mining) and all the various activities that are required before extraction can happen, including exploration and prospecting, discovery and mine development. Four of the most widely known industrial mining techniques are surface mining, underground mining, solution mining, and deep-sea mining. Artisanal mining, despite social and environmental challenges, remains a widespread practice in many countries.

- Open-pit mining is the most popular mining method, given the lower costs of establishing the operation at surface level, lack of restrictions regarding the size of equipment and ease of transportation.[62] Copper, nickel and cobalt are often mined in open-pits.

- Underground mining is often employed when the mineral ore is located deeper in the ground and is sufficiently concentrated to make the operation economically feasible. The Kiruna iron ore mine in Sweden is the largest such iron mine in the world and uses advanced remote-controlled equipment and technology.[63]

- Solution, or in-situ, mining is based on the dissolving of the metal in the ore and pumping it to the surface. This is a major lithium extraction method. This process requires significant amounts of water, which is becoming a challenge in dry areas.[64]

- Deep-sea mining seeks to extract materials from the seabed, which could occur at depths of several hundred or thousand meters. While governments are allowed to license companies for deep-mining in their own Exclusive Economic Zone (EEZ), as of 2023 this remains prohibited in international waters.[65] Whether deep-sea mining will take off depends on the decision of the International Seabed Authority (ISA), the institution granted the exclusive competence on permits for commercial mining in international waters.

- In addition to large scale industrial mining, small scale and artisanal mining (ASM) is a widespread activity. An estimated 15 million people are employed in ASM in India, 9 million in China and 3.6 million in Indonesia.[66] Given that this is an informal industry, working conditions are hazardous and environmental impacts major.

62 'Open-Pit Mining Definition', AngloAmerican, accessed 23 November 2023, https://www.angloamerican.com/futuresmart/stories/our-industry/mining-explained/mining-terms-explained-a-to-z/open-pit-mining-definition.

63 'Kiruna Iron Ore Mine, Sweden', *Mining Technology* (blog), 2020, https://www.mining-technology.com/projects/kiruna/.

64 Maeve Campbell, 'South America's "lithium Fields" Reveal the Dark Side of Electric Cars', euronews, 1 February 2022, https://www.euronews.com/green/2022/02/01/south-america-s-lithium-fields-reveal-the-dark-side-of-our-electric-future; María L. Vera et al., 'Environmental Impact of Direct Lithium Extraction from Brines', *Nature Reviews Earth & Environment* 4, no. 3 (March 2023): 149–65, https://doi.org/10.1038/s43017-022-00387-5.

65 Oliver Ashford et al., 'What We Know About Deep-Sea Mining — And What We Don't', World Resources Institue, 19 July 2023, https://www.wri.org/insights/deep-sea-mining-explained.

66 Harry Dempsey, 'Artisanal Mining: The Struggle to Clean up a Murky Industry', *Financial Times*, 2023, https://www.ft.com/cobalt1.

Processing

Once the material has been extracted, it typically goes through a series of processes to reach the desired characteristics in terms of purity and concentration. Both primary materials (ores) and secondary materials (scrap) have to undergo this process in order to be fit-for-purpose for various end-products. When it comes to high-tech and clean tech applications, processing is a very important stage as materials need to have particularly high purity levels in order to be suitable for use in component manufacturing.[67] See appendix 2 for case studies of how battery materials are processed, with a focus on aluminium, nickel, copper, manganese, lithium, and natural graphite.

Manufacturing

After the materials have been extracted and have undergone complex processing to be brought to the required purity and characteristics, the materials are used in manufacturing components and, later, end-products. The manufacturing process is highly complex and spread over several countries and continents. For instance, one wind turbine consists of about 25,000 components.[68] Every one of the minerals in the components has a supply chain with hundreds of actors involved in extraction, processing, transport, trade, storage and the provision of other services. It is estimated that minerals used in batteries travel more than 50.000 nautical miles from origin to the manufacturing site.[69]

Recycling

Recycling consists of a series of processes, broadly divided into the pre-treatment and treatment phases. Pre-treatment involves the collection of metal waste, known as scrap, and its processing through separation, stripping and shredding.[70] Scrap comes from a variety of sources, ranging from large structures such as buildings and vehicles to smaller products such as phones and laptops.[71] The resulting metal streams are typically sold to smelters and processing plants, where they are (re)processed for use in the production of new goods.[72] The most widely used and conventional approaches are pyrometallurgy and hydrometallurgy, also used for primary materials and ores, but emerging approaches like direct recycling and biotechnological methods are starting to take shape as well.[73] See appendix 2 for an overview of these methods.

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67 Coco Zhang, Ewa Manthey, and Rico Luman, 'Tightening Supply Shakes up Battery Metal Dynamics', ING Think, 2023, https://think.ing.com/articles/tightening-supply-shakes-up-battery-metals/.

68 Peter Garrett and Priyanka Razdan, 'Life Cycle Assessment of Electricity Production from an Onshore V117-3.45 MW Wind Plant', 2017, https://www.vestas.com/~/media/vestas/about/sustainability/pdfs/v1363%2045mw_mk3a_iso_lca_final_31072017.pdf.

69 'Written Testimony of JB Straubel CEO Redwood Materials Before the U.S. Senate Committee on Energy and Natural Resources: The Scope and Scale of Critical Mineral Demand and Recycling of Critical Minerals', 2022, https://www.energy.senate.gov/services/files/43143C20-B0B4-4BC7-A5E2-5B2CB2CDE4D2.

70 'Samenvatting branche informatie metaalrecycling', Kenniscentrum InfoMil, accessed 30 January 2024, https://www.infomil.nl/onderwerpen/integrale/activiteitenbesluit/branches/metaalrecycling/samenvatting/.

71 'Metaalrecycling', Recycling Magazine Benelux, accessed 30 January 2024, https://www.recyclingmagazine.nl/metaalrecycling/.

72 'Metaalrecycling'.

73 Luigi Toro et al., 'A Systematic Review of Battery Recycling Technologies: Advances, Challenges, and Future Prospects', *Energies* 16, no. 18 (January 2023): 6571, https://doi.org/10.3390/en16186571.

Urban mining

Urban mining refers to the retrieval of materials from the anthropogenic stock, which encompasses all materials present in products used or stored by society.[74] As such, urban mining involves the recovery, recycling or reuse of materials. Urban mining begins with the identification of urban mines. An urban mine is a concentrated hotspot with secondary raw materials in various products or components. Logistics is essential in facilitating urban mining. Waste generation hotspots need to be connected to recycling industries, involving the establishment of waste collection and classification techniques, and drop-off / pick-up systems. A key challenge of urban mining is the identification of valuable materials across various products like buildings as well as their potential for reuse. Moreover, waste is often downcycled as materials lose value and are re-used in different sectors. Nonetheless, there is great potential for urban mining to contribute more substantially to a circular economy.[75]

Services: trade, storage, transport, equipment, technology

Service providers make every step of the supply chain possible. Transport, specialised storage and trade is required between each process – between extraction and refining; refining and component manufacturers; component and product manufacturers and so on. Service providers also supply technology and equipment, both in terms of hardware and software. Further, they are essential in the provision of support in environmental and technical assessments, but also in project development through engineering and technology.

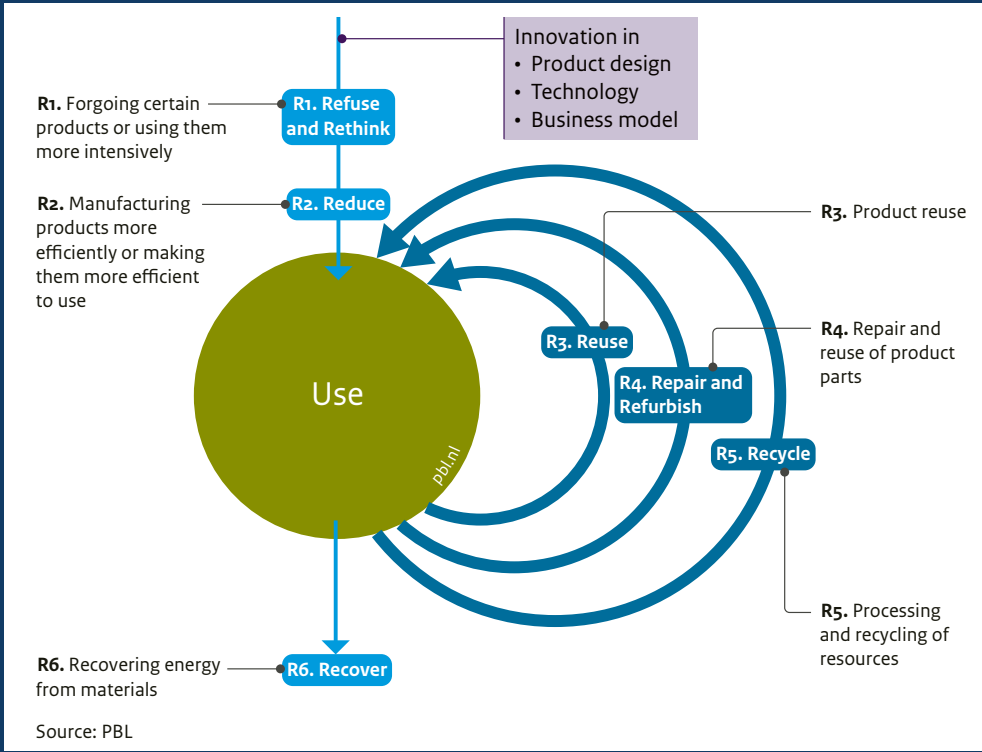
74 Luis A. Tercero Espinoza et al., 'The Promise and Limits of Urban Mining' (Karlsruhe: Frauenhofer-Gesellschaft, 2020), 8, https://publica.fraunhofer.de/handle/publica/300566.

75 Merlijn Blok, 'Urban Mining and Circular Construction – What, Why and How It Works', *Metabolic* (blog), 2021, https://www.metabolic.nl/news/urban-mining-and-circular-construction/.

Circular economy and the R-ladder

A key way of achieving climate neutrality is the transition from a linear "take-make-use-dispose" model to a regenerative one that ensures that products and resources are maintained in the economy for as long as possible, and that waste is minimized.[76] Circular economy strategies can be defined with the help of the "R-ladder", which highlights six approaches of reducing raw material use. R1 ensures the least use of primary materials (see Figure 7).[77] The same R-ladder is used to monitor the Netherlands National Circular Economy Programme.

Figure 7. Circular economy strategies according to the R-ladder. Figure from PBL Netherlands Environmental Assessment Agency.[78]



76 'Circular Economy', European Commission, accessed 8 January 2024, https://environment.ec.europa.eu/topics/circular-economy_en.

77 'R-ladder - Strategieën van circulariteit', RVO, accessed 8 January 2024, https://www.rvo.nl/onderwerpen/r-ladder.

78 Trudy Rood and Maikel Kishna, 'Outline of the Circular Economy' (PBL Netherlands Enviornmental Assessment Agency, 2019), https://circulareconomy.europa.eu/platform/sites/default/files/pbl-2019-outline-of-the-circular-economy-3633.pdf.

Mineral capabilities in Zuid-Holland

As of 2023, industrial activity involving CRM is limited in the Netherlands. The extraction/mining currently taking place in the Netherlands is outside of the Province of Zuid-Holland. Mining of salt and sand is the most prevalent. Salt and sand are important materials but not under the official definition of 'criticality' of the EU as of 2023. The exception is silica sand, the material used to produce silicon, but operations are relatively small. The Netherlands also has a strong portfolio when it comes to deep sea mining equipment and operations, but this cannot take off before the approval of the International Seabed Authority. Moreover, companies are primarily active in the processing and recycling of base metals, which are metals that are not considered precious like steel or zinc. The capabilities of the Netherlands have been outlined in the HCSS report *"Advancing European mineral security: Insights from Dutch industry",* published in November 2023.[79]

In Zuid-Holland, the most widespread CRM industrial activities are trade and logistics; and recycling pre-treatment. The Netherlands has a notable globally active trade and services industry, centered around the Port of Rotterdam in Zuid-Holland. Figure 8 shows the concentration of metals trade and service providers, recycling companies and manufacturing sites around the Port of Rotterdam. The Port of Rotterdam is not only Europe's biggest port and a key part of the Western European industrial ecosystem, but it is also the key hub for metals trading in the region. A significant amount of the critical minerals coming through the Port of Rotterdam are transported directly to the German industry.[80] Rotterdam is also a hub for delivery of minerals from different European mineral suppliers to the North American market given its existing logistics network. The digitalized and efficient customs processes are additional advantages of the Netherlands in comparison to other countries within and outside of Europe. This makes it advantageous for traders to store materials in the Port of Rotterdam as they can reach various locations with relative ease and can therefore react to shifts in global supply and demand.[81]

The interconnectedness with the ARA trade hub (Amsterdam-Rotterdam-Antwerp) and ARRRA chemical cluster (Antwerp-Rotterdam-Rhine-Ruhr-Area) furthermore make transport to, from and via Rotterdam highly efficient.[82] The ARRRA area accounts for 40% of EU production of petrochemicals and it is a closely integrated industrial cluster that allows for a degree of interdependence and mutually beneficial arrangements.[83] For instance, a company's excess heat, by-products or even waste may be another's energy source or feedstock. ARRRA companies are connected through pipelines.

79 Patrahau et al., 'Advancing European Mineral Security'.

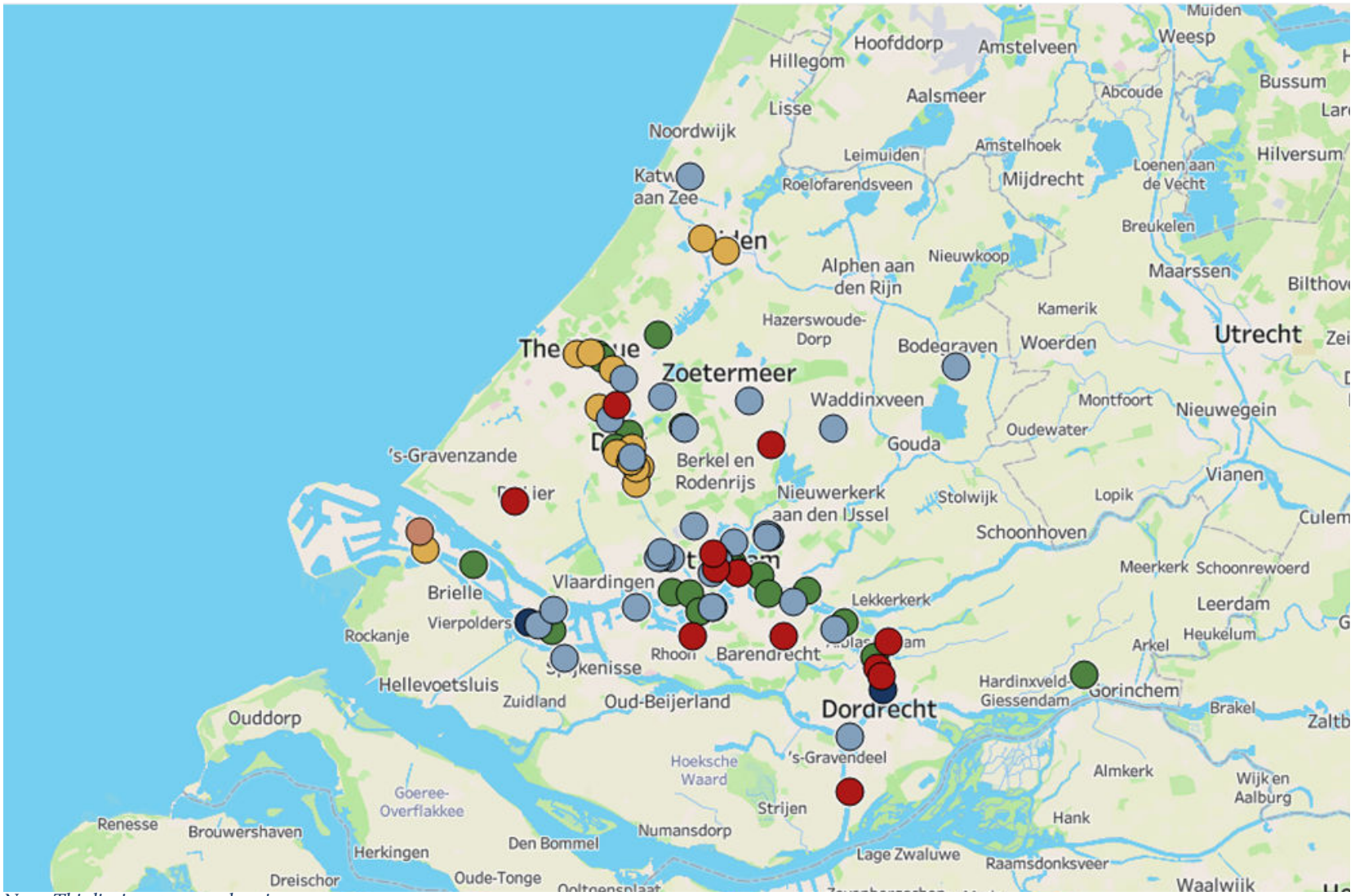
80 HCSS interview, 2023.

81 Patrahau et al., 'Advancing European Mineral Security'.

82 Port of Rotterdam, 'Refining and Chemicals', accessed 8 January 2024, https://www.portofrotterdam.com/en/setting/industry-port/refining-and-chemicals; Irina Patrahau, Lucia Van Geuns, and Michel Rademaker, 'Energy Trade in the Netherlands | Past, Present and Future', HCSS, January 2023, https://hcss.nl/report/energy-trade-in-the-netherlands/.

83 Port of Rotterdam, 'Refining and Chemicals'.

Figure 8. Companies and institutions active in mineral and metal supply chains in the Province of Zuid-Holland



Research and Development:
ASML Delft, Biosphere Solar, Blue City, CML Leiden University, Deltares, EAZ Wind, HCSS, IHE Delft, In2Waste Solutions, LeydenJar, M2i, Materials Recycling and Sustainability, TNO, Water-Mining H2020, ZERO BRINE.

Processing:
Climax Molybdenum, Sibelco.

Manufacturing:
Better Future Factory, BOAL, Exasun, Extrusion, Buhlmann Group, Elcee, Rovasta, Eurad, FNsteel, Villares Metals International, Gobinda Mixed Metals, PWT Eurostaal, Krogman Metals.

Recycling (waste collection and pre-treatment of scrap):
7Digits B.V., A&M Recycling, Autosloperij Atlas-Car, Autosloperij Kralingen, Autosloperij Zuid-Holland, Autosloperij Romein, Circular Circuits, DIM, Drake and Farrell, EMR ,Geelhoed, Henk Netten Metaalhandel B.V., Isero B.V., Jansen Recycling Groep, JOBO Metaal, Krommenhoek Metals, Lion Metals Maarten van Rijn Oud Ijzer en Metalen, Metaalhandel & Autosloperij B. Rijsdijk, Metaalhandel W. Ketting, Metalimex, RD Metals, Reconext, Repeat Audio, Rexel, Rijnmond Auto's, SCRAP, Stibat, OPEN, StoredEnergy, TES Battery, Urban Mining Corporation, Uzimet, Van Helvert Metalen, Van Leeuwen Recycling Groep, Van Pelt Recycling, W3E.

Recycling (black mass production and metal recovery):
TES.

Services and Trade:
AccessWorld, Allseas, Arenal Dredging and Mining, Ayaz Auto Inkoop. BM Metals, EPRM, Fugro, Hamwells, Netics, Nouryon Chemicals B.V. Europoort, Optecs, Royal IHC, SGS., Siemens, Gamesa, SkyGeo, Stainalloy, Stedin, Steinweg, Sweco Nederland, Van Essen Instruments, Van Oord WD Trading B.V..

Note: This list is not comprehensive.

The Dutch metal recycling sector focuses on recycling pre-treatment.[84] This involves companies collecting metal waste, known as scrap, and processing it through separation, stripping and shredding.[85] Dutch metal recyclers particularly focus on recycling steel, aluminium, nonferrous metals, cables, and batteries.[86] The resulting metal streams are typically sold to smelters, where they are remelted for reuse in the production of new goods.[87] It is important to note that Dutch metal recycling companies do not engage in the recovery of raw materials through pyrometallurgy, hydrometallurgy, and direct recycling, as well as the subsequent refining.[88] This stage takes place abroad.[89] As a result, these recycling treatments and the refining of raw materials is currently lacking in the Netherlands. The recycling and refining of CRM remains challenging due to high costs associated with recovering small amounts of material, often making the secondary supply more expensive than buying primary materials. At the same time, there is a mismatch between legal definitions of waste and the ability of Dutch companies to reprocess it into secondary materials, especially when it comes to lithium-ion batteries.[90]

Moreover, knowledge institutions are prevalent around the main academic hubs in the Province of Zuid-Holland in Delft, Leiden, and Rotterdam, as well as in the Hague where the Dutch government is based. Delft hosts the majority of research and development facilities due to the prominence of the Technical University. In addition to the cluster in Delft, Leiden University's Institute for Environmental Sciences (CML) is active in metals research. The Hague hosts institutions with applied research capabilities like TNO and strategic geopolitical research activities like HCSS. The knowledge institutions in Zuid-Holland sometimes cooperate with recycling companies that are trying to expand toward the field of CRM but perhaps lack all the information regarding the technology or feasibility.

The knowledge ecosystem in Zuid-Holland is closely linked to the region's innovative business environment in high-tech industry and sustainable energy.[91] The Entrepreneurial Ecosystem Index of Utrecht University and Birch place Delft and Westland on top of the national ranking.[92] A strong entrepreneurial ecosystem is built with the help of legislation, physical infrastructure, culture, but also talent, finance and knowledge development.[93] This ecosystem supports innovative and rapidly growing start-ups, which create value through productivity, wellbeing, income and employment opportunities.[94] For instance, ASML has a research office

84 Beant Dijkstra and Jeroen Bartels, 'Verkenning Batterijen Circulariteit: De Realisatie van Een Circulaire Batterijenketen in Nederland' (KplusV, 1 December 2023), 12–13, https://open.overheid.nl/documenten/dpc-00e92cb719270594a987c14cb98083561fc02d21/pdf.

85 'Samenvatting branche informatie metaalrecycling'.

86 'Samenvatting branche informatie metaalrecycling'.

87 'Metaalrecycling'.

88 Jessica de Koning and Marijn Bijleveld, 'CO2-Besparing Door Recycling van in Nederland Verhandeld Ferro- En Non Ferroschroot' (Delft: CE Delft, October 2021), 17–18, https://cedelft.eu/wp-content/uploads/sites/2/2021/12/CE_Delft_210150_CO2-besparing_recycling_in_NL_verhandeld_ferro-_en_non-ferroschroot.pdf; Dijkstra and Bartels, 'Verkenning Batterijen Circulariteit: De Realisatie van Een Circulaire Batterijenketen in Nederland', 31.

89 de Koning and Bijleveld, 'CO2-Besparing Door Recycling van in Nederland Verhandeld Ferro- En Non Ferroschroot', 17–18; Dijkstra and Bartels, 'Verkenning Batterijen Circulariteit: De Realisatie van Een Circulaire Batterijenketen in Nederland', 31.

90 Ross Yeo, 'European Battery Regulations to Restrict Black Mass Exports to Secure Raw Materials', *Fastmarkets* (blog), 6 July 2023, https://www.fastmarkets.com/insights/european-battery-regulations-to-restrict-black-mass-exports/.

91 'Infographics – 10 Reasons Why the Greater Rotterdam – The Hague Area Is the Hotspot For', InnovationQuarter, accessed 8 January 2024, https://www.innovationquarter.nl/en/infographics/.

92 Hendricksen et al., 'Entrepreneurial Ecosystem Index 2023: Regionale en nationale ontwikkelingen in internationaal perspectief'.

93 Hendricksen et al.

94 Hendricksen et al.

in Delft, praising the importance of being present in this key knowledge ecosystem for building a network and attracting young talent.[95] InnovationQuarter, the regional economic development agency of Zuid-Holland, supports the innovative ecosystem in the Province.[96]

Opportunities for Zuid-Holland in mineral supply chains

The Province of Zuid-Holland finds itself in a unique position to expand capabilities in CRM supply chains considering both the existing mineral capabilities outlined in the previous section, as well as other related industrial capabilities that can feed into the mineral sector. These opportunities refer to (1) logistics, trade and specialised storage; (2) mineral processing / recycling; (3) high-tech products; (4) innovation and knowledge development.

1. **Logistics, trade and specialised storage of minerals** bring significant benefits for the Dutch and European mineral security. The Port of Rotterdam is a hub for metals trade and is in prime position to further expand this capability as part of the ARA (Amsterdam-Rotterdam-Antwerp) trade hub, a highly integrated industrial cluster that decreases the cost and transport time for companies located there. Enhancing the trade function would benefit not only Dutch but also European companies that use CRM in their products. A physical trade hub is characterised by constant availability of products and the circumvention of transport time, costs and emissions.[97] Traders will likely choose to have stock-level presence in a hub that is conveniently located and allows for quick logistics when the products need to be shipped. Moreover, as the products are already there, companies located in the proximity do not have to pay and wait for transport. They also have a lower dependence on the openness of global trade routes and maritime chokepoints. The limited transport also reduces the carbon footprint of a product. Finally, a larger role for Rotterdam in global metals trade would also bring geopolitical advantages for the Netherlands and the EU as they would be more difficult to replace in supply chains and bypass by other players.

2. **Mineral processing / recycling.** The Province's existing industrial capabilities, its contribution as an integral part of the ARRRA industrial chemical cluster and the innovative entrepreneurial ecosystem can support the expansion of capabilities in mineral processing.[98] In the CRM sector, there are advantages of placing processing facilities in the vicinity of companies that manufacture high-technologies, knowledge institutions and a skilled workforce.

   In the Province of Zuid-Holland there are no processing facilities for CRM, which means that neither primary nor secondary materials can be processed here. The Dutch metal

95 Ester Janssen, 'ASML Blijft in Delft Vanwege Goed Ondernemersklimaat', Delft op Zondag, 19 February 2022, https://www.delftopzondag.nl/nieuws/algemeen/95902/asml-blijft-in-delft-vanwege-goed-ondernemersklimaat.

96 'Invest & Innovate in the Greater Rotterdam – The Hague Area', InnovationQuarter, accessed 8 January 2024, https://www.innovationquarter.nl/en/.

97 Patrahau, Van Geuns, and Rademaker, 'Energy Trade in the Netherlands | Past, Present and Future'.

98 Irina Patrahau et al., 'European Tank Storage in Global Supply Chains: Outlook to 2030', HCSS, April 2022, https://hcss.nl/report/european-tank-storage-in-global-supply-chains-outlook-to-2030/; Patrahau, Van Geuns, and Rademaker, 'Energy Trade in the Netherlands | Past, Present and Future'.

recycling sector focuses on recycling pre-treatment, after which the streams of scrap are exported to other countries for re-processing.[99]

Mineral processing is a major bottleneck in global supply chains that the Province of Zuid-Holland could address. While global mining projects are increasingly more diversified, the geographical concentration of processing has grown since 2020.[100] China is the world's largest refining hub as well as a key destination of investments to further develop its capacity.[101] In other words, even if the extraction of raw materials becomes more spread out geographically in the coming years, China will remain the key producer and exporter of refined materials in the absence of more investments in other countries. Even when recycling will become an important source of materials, having to ship the scrap to Asia and import it later will mean that the Netherlands will not necessarily become more self-sufficient.

Companies that want to expand toward CRM processing / recycling in the Netherlands face various obstacles. First, it is more expensive to recover secondary materials than to buy new (primary) ones, making the business case for recycling companies difficult. Second, information about the precise location of CRM in many household application lacks, making it difficult for recycling companies to identify and recover them. Third, many materials get exported from the Netherlands in the form of waste or for second-hand use, meaning that the materials cannot be recycled and reused in the Netherlands.

Still, investing in capabilities early on could set up the Province of Zuid-Holland as an important source of secondary raw materials after 2035. Given that most minerals require distinct processing capabilities, the choice should be based on existing or planned manufacturing capabilities in the Netherlands or in other European countries. This would guarantee that there is a consumer for the refined materials and create an attractive business case for the processing plant. This would also contribute to open strategic autonomy, ensuring that materials refined in the Netherlands can be used to manufacture strategic goods within European borders. Moreover, the environmental and social footprint of mineral processing in the Netherlands is likely to be much smaller than in countries with weaker institutional capabilities.

3. **High-tech products.** Apart from investigating ways to strengthen the resilience of mineral supply chains, attention should be paid to expanding manufacturing capabilities for strategic components in the field of energy, digital technologies, defence or healthcare. Research has shown that the Netherlands dependence on CRM is largely translated into imported half-fabricates.[102] Dutch companies are more highly dependent on the import of components that contain CRM and have been produced elsewhere, than on raw or processed CRM. As seen through the example of ASML, manufacturing of a high-tech product like lithography machines for advanced microchips can be an advantage in global supply chains.[103]

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99 Dijkstra and Bartels, 'Verkenning Batterijen Circulariteit: De Realisatie van Een Circulaire Batterijenketen in Nederland', 12–13.

100 'Critical Minerals Market Review 2023'.

101 'Critical Minerals Market Review 2023'.

102 'China grootste leverancier van producten met kritieke grondstoffen', webpagina, Centraal Bureau voor de Statistiek, 27 November 2023, https://www.cbs.nl/nl-nl/nieuws/2023/48/china-grootste-leverancier-van-producten-met-kritieke-grondstoffen?trk=feed_main-feed-card_feed-article-content.

103 Joris Teer and Mattia Bertolini, 'Reaching Breaking Point: The Semiconductor and Critical Raw Material Ecosystem at a Time of Great Power Rivalry' (HCSS, 2023).

4. **Innovation and knowledge development.** In order to enhance the role of the Province of Zuid-Holland and, thus, the Netherlands, in strategic technologies supply chains, it is essential to continue investing in education, innovation and start-ups. Institutions of higher education – Leiden University and TU Delft – are global leaders in fields like industrial ecology, applied earth sciences, chemical engineering, among others. They can support innovation and cutting-edge research into more environmentally friendly and efficient mineral processing and recycling capabilities, product design and material substitution. InnovationQuarter (IQ) can take on a more proactive role in the CRM sector. IQ can join forces with academic and applied knowledge institutions to identify prospective innovative firms that support the Dutch open strategic autonomy.

   Moreover, the National Growth Fund offers opportunities for investment in CRM projects, as the topic of critical raw materials and energy is a key assessment criterion when submitting an application at the autumn 2024-early 2025 submission deadline. With the National Growth Fund's focus on strategic autonomy, money can be invested in the CRM sector, provided there is substantiated evidence of an unwanted dependency and there is a public interest in making more knowledge, technology, or resources available for this purpose.[104]

[104] 'Handreikingen Nationaal Groeifonds: Ten Behoeve van de Indieningsmomenten Najaar 2024 - Voorjaar 2025' (Nationaal Groeifonds, October 2023), https://www.nationaalgroeifonds.nl/binaries/nationaalgroeifonds/documenten/richtlijnen/2023/10/11/handreikingen-nationaal-groeifonds-2024-2025/77070+-+EZ-K+-+Handreikingen+NGF+2023_TG_PDFA.pdf.

5. Challenges and opportunities of expanding mineral capabilities in Zuid-Holland

If the Province of Zuid-Holland may want to expand its mineral capabilities, notable social, environmental, ethical, economic and political challenges as well as opportunities arise for the society, businesses and authorities. These are summarised in Table 2 below and discussed in turn.

Table 2. Challenges and opportunities of expanding mineral capabilities in Zuid-Holland

	Issue	Explanation
Social	**Negative public opinion**	The negative public perception of heavy industries in the Netherlands and Zuid-Holland make it challenging for companies to make long-term plans and strategies. A part of the negative public opinion is based on challenges surrounding lack of space, as well as lack of awareness about the social and environmental risks and impacts in the Netherlands and abroad. At the same time, there have been several cases in recent history where heavy industrial activity led to environmental and health issues for local communities, which strongly contributed to negative public opinion.
	Lack of physical space	The Netherlands is a small-sized country with a highly advanced economy, relatively large industry and a very dense population. The population is in dire need of housing with limited expansion possibilities in the main cities like Rotterdam and the Hague. At the same time, industrial areas in the Province of Zuid-Holland are filled up. That is challenging considering that clean energy technologies require much more space than fossil fuels.
Environmental	**Environmental risks of heavy industry**	Mineral extraction, processing and recycling are considered heavy industries. They often have a large carbon footprint compared to lighter industries, require a lot of energy and high temperatures, use hazardous chemicals and generate toxic waste. While any industrial activity will bring environmental risks, the extent to which they materialise is heavily dependent on governance and standards. Broadly speaking, risks could be better managed and mitigated in Europe or the US compared to other countries.
Ethical	**The footprint of global supply chains**	Most of the materials used today in wind turbines or electric cars in Europe are sourced under highly problematic environmental, social and governance standards. Risks include forced labour, corruption, child labour, abuses of force by security forces and other human rights violations. This inhibits a just global transition as it outsources negative impacts to places outside of Europe.

Table 2. Challenges and opportunities of expanding mineral capabilities in Zuid-Holland (continued)

	Issue	Explanation
Economic	**Skilled labour**	Skilled labour is required for the development of an innovative manufacturing industry in the Province of Zuid-Holland. This can support labour productivity and economic growth provincially and nationally. Zuid-Holland can leverage collaboration platforms with universities, applied sciences schools, and vocational training programs to ensure a skilled workforce.
	Uneven playing field	Differences in legislation, state support, and environmental, social and governance (ESG) standards over time created an uneven playing field for European companies. Now, companies in the Netherlands and Zuid-Holland find it very difficult to compete with their Chinese counterparts, as they have to offer similarly low costs while encountering dramatically different costs.
	Insufficient financial support	Projects in the minerals sector are considered risky due to social and environmental challenges. This makes it difficult for companies to attract private investments in the absence of public interventions that can de-risk investments.
	Energy costs and inadequate green energy infrastructure	Energy prices for industries in the Netherlands are significantly higher than other countries outside of the European Union, primarily due to taxation on fossil fuels. While heavy taxation on fossil fuels is meant to encourage companies to decarbonize, the green energy infrastructure is not yet adequate to allow a shift to low-carbon energy. The electricity grid is congested and costs of green hydrogen remain high.
Political	**Insufficient dialogue between government and industry and lack of trust**	The relationship between the national, provincial and local governments in the Netherlands, and the industry has been suffering over time as a result of a lack of dialogue. On the one hand, the industry is known for trying to maximise its profits, sometimes at the expense of the broader public interest. On the other hand, governments have been passing increasingly strict environmental regulation that at times has unintended negative consequences for industry. The relationship between the government and industry remains characterised by an erosion of trust and pessimism regarding each other's intentions.
	Delayed action and fragmented mandates	A key challenge for companies in the minerals sector in Zuid-Holland is the speed of implementation of new policies. Since 2022 political discourse undertook a major shift regarding the minerals and metals sector. European and national strategies to strengthen this sector have come out. However, concrete policies that are coherent through different levels of government and departments have yet to be developed to support the political claims.
	Cumbersome permitting process	Permitting for minerals and metals industries, which are most often heavy industry, can take quite a long time due to the complex processes that need to be assessed, novelty of some of these processes and sometimes lack of capacity of permitting bodies. Companies in Zuid-Holland and the Netherlands face uncertainty in light of the exact steps they need to undertake, agencies they should talk to, and expectations of the duration of the process.
	Inconsistent or inexistent legislation	Given the novelty of ambitions in the minerals sector, legislation is sometimes not up-to-date or has not yet been developed. This is a challenge faced especially in the recycling sector in Zuid-Holland and the Netherlands, whereby waste streams cannot be easily repurposed by companies as the regulations do not allow it.

Social issues

- **Negative public opinion.** The negative perception of the public in relation to heavy industries in the Netherlands and Zuid-Holland make it challenging for companies even in strategic sectors to make long-term plans and strategies. Local groups oppose having industrial activity in their proximity due to environmental or social consequences. This is known as the 'Not In My Back Yard' (NIMBY) movement. A part of the negative public opinion is based on societal considerations such as lack of space and environmental risks, while another part can be explained through lack of awareness about the global footprint of CRM supply chains. These factors are discussed below. At the same time, there have been several cases in recent history where heavy industrial activity led to environmental and health issues for local communities, which strongly contributed to the negative public opinion.

- **Lack of physical space.** The Netherlands' social, economic and physical features are growing in contradiction with one another, which is a difficult dilemma for local, provincial and national policymakers. The Netherlands is a small-sized country with a highly advanced economy, relatively large industry and a very dense population. This means that

many socio-economic functions must compete for space. The population is in dire need of housing with limited expansion possibilities in the main cities – Rotterdam, Amsterdam or the Hague. As of 2023, the housing shortage amounts to 390.000 houses, and to match the growing population in the Netherlands, there are 980.000 new houses needed by 2030.[105]

At the same time, industrial areas in the Province of Zuid-Holland are filled up, but clean energy technologies require much more space than fossil fuels. Especially in the coming years, two energy systems must operate to fulfil the vital needs of the country – both the fossil fuel system; and the emerging low-carbon one, which requires a lot of space for storage and production. Green hydrogen, a key pillar of the Dutch energy transition, requires roughly 3 times more volume than oil or natural gas in order to fulfil the same function.[106] Apart from hydrogen, the transition also requires the construction of offshore wind and solar panels. To support this system, the electricity grid, consisting mainly of cables and transformer stations, must be significantly expanded. Last but not least, there is also a push to reshore mineral capabilities to ensure that all of the above-mentioned technologies can be manufactured.

Environmental risks

Mineral extraction, processing and recycling are considered heavy industries. They often have a large carbon footprint compared to lighter industries, require a lot of energy and high temperatures, use hazardous chemicals and generate toxic waste.[107]

The environmental risks and impacts associated with CRM supply chains depends on the physical characteristics of each material, mining method, and governance indicators.[108] Some minerals like cobalt or chromium are inherently toxic and carcinogenic. Others, like rare earths, are found in the same rocks with heavy metals or radioactive substances, heightening environmental risks during extraction. The chosen mining and processing technology can furthermore make a difference in terms of possible risks. Some techniques require more toxic reagents and chemicals than others. Moreover, despite recent advancements in the efficiency of recovering critical materials through both pyrometallurgical and hydrometallurgical processes, most CRM recycling methods are energy-inefficient, environmentally harmful, and resource-intensive.[109]

The extent to which these risks materialize is heavily dependent on governance. Unfortunately, most extraction and refining activities take place in regions with poor environmental performance (Figure 9).

105 'Woningtekort stijgt fors naar 390.000, pas vanaf 2028 minder krapte', NOS, 12 July 2023, https://nos.nl/artikel/2482485-woningtekort-stijgt-fors-naar-390-000-pas-vanaf-2028-minder-krapte.

106 Ahmed I. Osman et al., 'Hydrogen Production, Storage, Utilisation and Environmental Impacts: A Review', *Environmental Chemistry Letters* 20, no. 1 (1 February 2022): 155, https://doi.org/10.1007/s10311-021-01322-8.

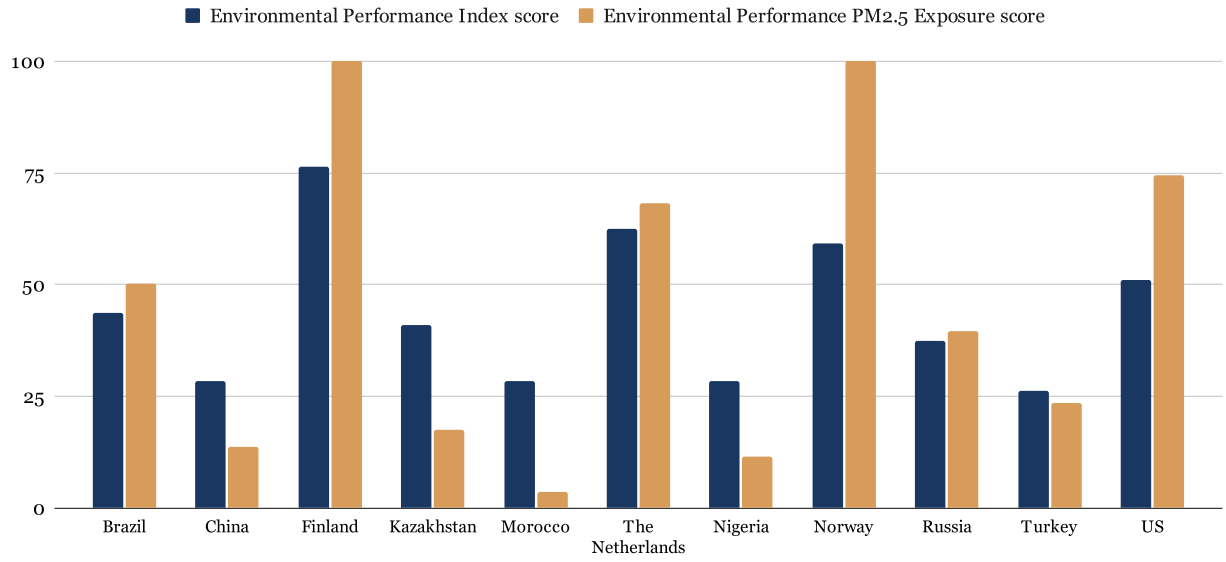
107 'The Challenge of Reaching Zero Emissions in Heavy Industry', IEA, accessed 21 December 2023, https://www.iea.org/articles/the-challenge-of-reaching-zero-emissions-in-heavy-industry.'Light Industry', IEA, 11 July 2023, https://www.iea.org/energy-system/industry/light-industry.

108 John Bachér et al., 'Environmental Aspects Related to the Use of Critical Raw Materials in Priority Sectors and Value Chains' (European Topic Centre Waste and Materials in a Green Economy, 2020), https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-wmge-reports/environmental-aspects-related-to-the-use-of-critical-raw-materials-in-priority-sectors-and-value-chains.

109 Darren H. S. Tan, Panpan Xu, and Zheng Chen, 'Enabling Sustainable Critical Materials for Battery Storage through Efficient Recycling and Improved Design: A Perspective', *MRS Energy & Sustainability* 7 (January 2020): 9, https://doi.org/10.1557/mre.2020.31.

Figure 9. Large suppliers of CRM to the EU and their Environmental Performance Index and PM2.5 Exposure scores.

Figure based on data from John Bachér et al., 'Environmental Aspects Related to the Use of Critical Raw Materials in Priority Sectors and Value Chains'.[110]



Industries in Europe and the US often obey significantly higher standards than most companies that produce minerals elsewhere. Figure 9 shows a comparison between the very high environmental performance scores in the US, Finland and Norway compared to China, Russia, Kazakhstan or Turkey. Moreover, Sweden's mines are some of the most advanced in the world, with highly automated remote processes and limited impact for the surrounding environment.[111] Processing and recycling activities are often fully electrified and powered by green electricity, and use advanced technology to limit the amount of toxic or hazardous waste. Within the EU CRM Act, investments are being made in the research and development of refining techniques to make them more eco-friendly and more energy efficient.[112] Within this context, the Netherlands non-paper on the external dimensions of the Critical Raw Materials Act supports the reduction of the environmental footprint in the extractive and processing segments of CRM supply chains.[113]

[110] Bachér et al., 'Environmental Aspects Related to the Use of Critical Raw Materials in Priority Sectors and Value Chains'.

[111] 'Kiruna Iron Ore Mine, Sweden'.

[112] 'Safety, Sustainability and Security for Europe's Mineral Processing Industry', CORDIS | European Commission, accessed 21 December 2023, https://cordis.europa.eu/article/id/436347-safety-sustainability-and-security-for-europe-s-mineral-processing-industry; 'Green, Efficient Approach Transforms Metal Extraction', CORDIS | European Commission, 10 October 2023, https://cordis.europa.eu/article/id/446790-green-efficient-approach-transforms-metal-extraction.

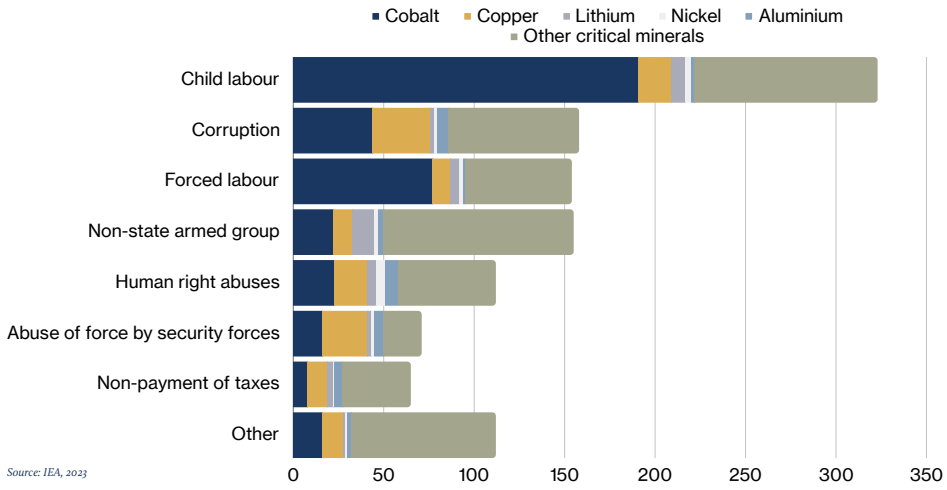
[113] Ministerie van Buitenlandse Zaken, 'Non-paper externe dimensies Critical Raw Materials Act', Rijksoverheid (Ministerie van Algemene Zaken, 22 May 2023), 3, https://www.rijksoverheid.nl/documenten/publicaties/2023/05/22/non-paper-externe-dimensies-critical-raw-materials-act.

Ethical issues

Most of the materials used today in wind turbines or electric cars in Europe are sourced under highly problematic social standards (Figure 10).[114] Cobalt is mined in DRC with limited environmental standards and often involving child labour and hazardous conditions for workers. There is limited accountability when it comes to processing activities in China, the global processing hub. In the central hub for rare earths in Baotou, China, the pollution has severely affected water, soil and air.[115] Outside of the city there is a lake of radioactive material produced through rare earths refining.[116] People are getting sick and have to move around to find new areas to settle in.

While limiting industrial capabilities can reduce Dutch domestic GHG emissions, it may have the opposite effect globally. The social and environmental implications of Europe's and the Netherlands' import dependencies are significant. In the energy transition, the demand for minerals will grow. Choosing to rely on imported materials rather than expand domestic capabilities inhibits a just global transition as it outsources the negative impacts to places outside of Europe. A decrease in domestic industrial capability can only have a positive impact if domestic consumption is proportionally reduced.

Figure 10. Public reports of risks along mineral supply chains.
Figure based on IEA data from 2023.[117]



114 K.C. Michaels, Louis Marechal, and Benjamin Katz, 'Public Reports of Governance-Related Risks by Mineral Supply Chain, 2017-2019', IEA, 2022, https://www.iea.org/data-and-statistics/charts/public-reports-of-governance-related-risks-by-mineral-supply-chain-2017-2019.

115 Tom Cheshire, 'Clean Energy's Dirty Secret: How Push for Modern Technology Has Made Chinese Pond Toxic', Sky News, 2022, https://news.sky.com/story/clean-energys-dirty-secret-pond-filled-with-toxic-material-in-northern-china-is-by-product-of-rare-earth-processing-12592342.

116 Cheshire.

117 Michaels, Marechal, and Katz, 'Public Reports of Governance-Related Risks by Mineral Supply Chain, 2017-2019'.

Economic issues

- **Skilled labour.** The development of an innovative manufacturing industry in the Province of Zuid-Holland can support labour productivity and economic growth provincially and nationally. The stagnant labour productivity in Zuid-Holland, growing only 0.4% annually from 2015 to 2021, aligns with broader challenges facing European economies. According to the Economic Board Zuid Holland, a strategic response lies in fostering an innovative manufacturing industry, offering a dual benefit of enhancing Dutch prosperity and reducing reliance on Asian manufacturers amid geopolitical power competition.[118] Zuid-Holland, boasting the highest number of industrial companies in the Netherlands, 15.620 in 2023, is well-positioned to lead in this initiative.[119] The transition to a circular economy promises substantial benefits for various sectors, including metal recycling, metal upgrading (copper, aluminium, steel), wholesale and retail trade, motor vehicle repair, and renewable energy production.[120] Despite displacing traditional jobs in the fossil fuel sector, prevalent in the Port of Rotterdam, circular interventions could positively impact overall employment.[121] Smart and circular resource utilization is critical for Zuid-Holland's Spatial Planning Strategy and the envisioned high-tech, circular, and energy-transitioned manufacturing industry by 2050.[122] Nationally, the goal is to establish the region around the Port of Rotterdam as a global centre for refining and recycling critical minerals.[123]

  Critical raw material refineries and recycling plants, due to their complexity, require specialized skills in logistics engineering and metallurgy, creating technical job opportunities.[124] The recycling sector provides a spectrum of job opportunities, spanning various skill levels. Entry-level positions, designated as Skill Level 1 by CBS, involve basic tasks like manual sorting and disassembly. Intermediate roles (Skill Level 2) encompass machine operation and maintenance, with skilled electric installers exemplifying this category. Progressing further, individuals at Skill Level 3 undertake complex technical tasks, including supervisory roles, while Skill Level 4 entails highly specialized positions demanding academic or applied sciences expertise. Professions in this top tier involve the development of constructions, machines, and manufacturing processes.[125] The Netherlands National Technology Strategy highlights the need for highly skilled technical personnel at both university (WO), higher vocational (HBO), and intermediate vocational (MBO) levels.[126] Widespread shortages of technical personnel are not only prevalent in the Netherlands but also in other countries.

118 Economic Board Zuid-Holland, 'Economische Monitor Zuid-Holland in Een Onstuimige Wereld', 2022, https://www.economicboardzuidholland.nl/wp-content/uploads/sites/14/2022/11/Economische_Monitor_Zuid-Holland_definitief-1.pdf.

119 'Vestigingen van bedrijven; bedrijfstak, gemeente', CBS, 27 March 2023, https://opendata.cbs.nl/#/CBS/nl/dataset/81575NED/table.

120 Mohammed Chahim et al., 'De Gevolgen van de Transitie Naar Een Circulaire Economie Op de Werkgelegenheid in de Provincie Zuid Holland' (TNO, 2019), 28–29, https://www.cirkelregio-utrecht.nl/wp-content/uploads/2021/11/Gevolgen-van-de-transitie-naar-CE-op-de-werkgelegenheid-in-Zuid-Holland_TNO_2019.pdf.

121 'Zuid-Holland als economische motor', Elsevier Weekblad, 2022, https://www.ewmagazine.nl/partners/toplocaties-2022/zuid-holland-als-economische-motor/; Carlos Romero, Sofia Brizuela, and Gustavo Ferro, 'Measuring the Effects of Increasing Circularity in the Economy Through Recycling', *Circular Economy and Sustainability*, 15 August 2023, 2, https://doi.org/10.1007/s43615-023-00299-6.

122 'Atelier Ruimtelijke Strategie Circulair Zuid-Holland: Seizoen 1 "Gronden"' (Rotterdam: BVR and Ecorys, December 2021), 42, https://circulair.zuid-holland.nl/wp-content/uploads/2021/12/Ruimtelijke-Strategie-Circulair-Zuid-Holland.pdf.

123 Ministerie van Buitenlandse Zaken, 'Speech by minister Schreinemacher at the faculty of Geo-Information Science and Earth Observation in Enschede', Government of the Netherlands (Ministerie van Algemene Zaken, 25 October 2023), https://doi.org/10/25/speech-liesje-schreinemacher-enschede.

124 'Which Jobs and Profiles Will Demand the Future Battery Industry?', cicenergigune, 14 September 2021, https://cicenergigune.com/en/blog/jobs-profiles-future-battery-industry.

125 Chahim et al., 'De Gevolgen van de Transitie Naar Een Circulaire Economie Op de Werkgelegenheid in de Provincie Zuid Holland', 55–56.

126 Rijksoverheid, 'De Nationale Technologiestrategie: Bouwstenen Voor Strategisch Technologiebeleid'.

Therefore, the focus should be on fostering the development of Dutch technical talent at all levels, while simultaneously attracting and retaining international expertise.[127]

This evolving job landscape underscores the circular economy's integration with education and research centres. Zuid-Holland can leverage collaboration platforms with universities, applied sciences schools, and vocational training programs to ensure a skilled workforce. The TU Delft Campus is poised to play a pivotal role in advancing the circular economy by contributing to necessary technologies and supporting startup growth both on and off campus.[128] Nevertheless, a change in the Dutch research landscape could improve its performance as materials science is fragmented due to the compartmentalization across various disciplines such as physics, chemistry, and mechanical engineering.[129] This stands in contrast to countries like the United States and Switzerland, where materials science has been offered as a dedicated field of study for decades.[130]

- **Uneven playing field.** Strengthening domestic European industry is a challenge given that the internationalisation of value chains and outsourcing of production to the most efficient player have contributed to the development of industries outside of Europe over the last 15-20 years. Differences in legislation, state support, and environmental, social and governance (ESG) standards created an uneven playing field for European companies. Looking at profit margins, it made more sense for companies to buy refined materials or even semi-finished goods at low costs from, for instance, China. Now, companies in the Netherlands and Zuid-Holland find it almost impossible to compete with their Chinese counterparts, as they have to offer similarly low costs while encountering dramatically different costs. Still, European policy instruments like CBAM or the CSDDD bring opportunities to address some of these challenges. As these policies remain in their infancy as of 2024, they may be gamechangers for European companies if implemented carefully in such a way that negative externalities like protectionist initiatives are mitigated.

- **Insufficient financial support.** Whereas in the United States, France, Germany or Finland significant national funds have been allocated to the minerals sector, companies in the Netherlands and Zuid-Holland are not experiencing the same. Projects in the minerals sector are considered risky due to the above-mentioned social and environmental challenges. This makes it difficult for companies to attract private investments in the absence of public interventions that can de-risk investments.

- **Energy costs and inadequate green energy infrastructure.** Energy prices for industries in the Netherlands are significantly higher than other countries outside of the European Union, primarily due to taxation on fossil fuels. China, India and Indonesia, for instance, rely heavily on coal for their industrial processes and offer subsidies for companies to reduce their expenses. The United States is a world leader in the production of natural gas and oil, meaning that domestic costs are structurally low. The industrial retail price for natural gas in the US is less than half the price in the Netherlands.[131] While heavy taxation on fossil fuels is meant to encourage companies to decarbonize, the green energy infrastructure is not yet adequate to allow a shift to low-carbon energy. The electricity grid is heavily congested and costs of green hydrogen remain high. As such, the high taxation on fossil fuels combined with the limited decarbonization possibilities bring challenges for industry in the Netherlands and Zuid-Holland.

127 Rijksoverheid.

128 'Zuid-Holland als economische motor'.

129 Rijksoverheid, 'De Nationale Technologiestrategie: Bouwstenen Voor Strategisch Technologiebeleid'.

130 Rijksoverheid.

131 'Dashboard for Energy Prices in the EU and Main Trading Partners', European Commission, accessed 22 September 2023, https://energy.ec.europa.eu/data-and-analysis/energy-prices-and-costs-europe/dashboard-energy-prices-eu-and-main-trading-partners_en.

Political issues

- **Insufficient dialogue with the government and lack of trust.** The relationship between the government and the industry has been suffering over time as a result of lack of dialogue. This is applicable at all levels of government in the Netherlands – national, provincial, and local. In the last decades increasingly strict legislation has made it more challenging and expensive for European companies to continue their industrial operations. Some of them were able to modernise and continue activities, some outsourced operations outside of Europe, while others were forced to close down. Simultaneously, the industry is known for trying to maximise its profits, sometimes at the expense of the broader public interest. The relationship between the government and industry remains characterised by an erosion of trust and pessimism regarding each other's intentions.

- **Delayed action and fragmented mandates.** A key challenge for companies in the minerals sector in Zuid-Holland is the speed of implementation of new policies. Since 2022 political discourse undertook a major shift regarding the minerals and metals sector. European and national strategies to strengthen this sector have come out. However, concrete policies that are coherent through departments have yet to be developed to support the political claims. The implementation of the *Nationale Grondstoffenstrategie* remains slow. In the cases where policies are being developed, they are not coherent across departments and agencies. There is often fragmentation between local, provincial and national policies and within departments inside local, provincial and national government. This makes it difficult and requires a lot of time and effort for companies to understand the latest developments.

- **Cumbersome permitting process.** Permitting for minerals and metals industries, which are most often heavy industry, can take quite a long time due to the complex processes that need to be assessed, novelty of some of these processes and sometimes lack of capacity of permitting bodies. Companies in Zuid-Holland and the Netherlands face uncertainty in light of the exact steps they need to undertake, agencies they should talk to, and expectations of the duration of the process. This is an issue considering climate and CRM goals for 2030. The EU CRMA set benchmarks of maximum timelines for permitting selected strategic projects in the minerals sector – 24 months for extraction and 12 months for processing and recycling. This is now meant to be transposed in national legislation.

- **Inconsistent or inexistent legislation.** Given the novelty of ambitions in the minerals sector, legislation is sometimes not up-to-date or has not yet been developed. This is a challenge faced especially in the recycling sector in Zuid-Holland and the Netherlands, whereby waste streams cannot be easily repurposed by companies as the regulations do not allow it. This, combined with the lack of capacity in processing and material recovery plants for lithium-ion batteries, among others, leads to material leakage outside of Europe. Inadequate legislation is also partly the reason why a new wave of criminal activity has emerged in the Netherlands and in Europe regarding illegal trade of e-waste (waste electrical and electronic equipment).[132] This has both positive and negative impacts on the developing countries where the e-waste is sent, and addressing the issue requires an inclusive strategy that takes into account affected communities.[133]

[132] Hester Brink et al., 'Potential Effects of Dutch Circular Economy Strategies on Low- and Middle-Income Countries' (PBL Netherlands Environmental Assessment Agency, 2021), https://www.pbl.nl/sites/default/files/downloads/pbl-2021-potential-effects-of-dutch-circular-economy-strategies-on_low-and-middle-income-countries_4312.pdf.

[133] Brink et al.

6. How to move forward: Policy recommendations

The Province of Zuid-Holland has notable opportunities to invest in domestic CRM supply chains. Addressing challenges and maximising opportunities associated with CRM supply chains requires close coordination between the local, provincial and national levels of government, as well as industry and knowledge institutions. The recommendations below can support policymakers at the Province of Zuid-Holland in addressing some of the above-mentioned challenges. In implementing the first four recommendations, the Province of Zuid-Holland plays a leading role, while in the case of the other five the Province plays more of a complementary role to other actors.

Recommendations for the Province of Zuid-Holland whereby they play a leading role

1. **Awareness and dialogue.** The Province should gain a better understanding of minerals and metals activities within the borders of the Province, and try to establish dialogue with companies.

    1.1 **Dialogue with companies**. Policymakers would better understand the needs of companies and would be able to make more informed decisions and policies. Moreover, the Port of Rotterdam and Rotterdam Municipality are large European and international players in mineral supply chains, and their efforts should be supported by Zuid-Holland whenever possible. Efforts to gain political or economic advantages at the national or European levels should be coordinated among the port, municipality and province.

    1.2 **In-depth research into specific material supply chains.** The Province should support further research into the specific materials that are of importance for local and regional industry. Each material has a specific supply chain. The amount of minerals that is consumed depends on end-users in the Province of Zuid-Holland, the rest of the Netherlands, and the hinterland. In order to determine which materials are of utmost importance for the Province and which parts of the supply chain could be established in Zuid-Holland, the Province should support in-depth research in specific material supply chains. A part of this could be realized through the National Growth Fund proposal for 'Circular Critical Raw Materials'.[134]

[134] 'Government invests 4 billion euros in 18 projects for sustainable economic growth and future prosperity', Rijksoverheid (Ministerie van Economische Zaken en Klimaat, 5 July 2023), https://www.nationaalgroeifonds.nl/english/government-allocates/government-invests-4-billion-euros-in-18-projects-for-sustainable-economic-growth-and-future-prosperity.

2. **One-stop-shop.** Zuid-Holland should ensure the existence of a 'one-stop-shop' for companies active in the minerals and metals sector within the Province. This would be a specialized service that can offer up-to-date information on demand to companies that look to invest in CRM-related capabilities in the Province: providing situational awareness of existing activities in Zuid-Holland, helping to identify investment opportunities, supporting the permitting process, looking for collaboration with other companies, and so on.

   2.1 **Permitting.** Permitting should be streamlined and accelerated where possible, while still holding companies accountable for their activities according to the legislation.

   - Knowledge and capacity building programmes within permitting organisations should be encouraged by the Province of Zuid-Holland.
   - Permitting processes should become clearer and more simplified so that companies know the duration and requirements until they may start operating from the beginning.

   2.2 **Spatial planning.** In its spatial planning activities, Zuid-Holland should take ambitions regarding the development of CRM capabilities into consideration and determine whether and where space for CRM activities can be spared. Physical space in Zuid-Holland is limited and many societal functions compete with each other – from housing to large scale food storage and energy production. At the moment, there is no remaining space in the Province for energy intensive industries, which includes processing and recycling of minerals. If CRM capabilities are desired in the Province, spatial planning should be adapted to ensure the realisation of these ambitions. This should be discussed and coordinated with the municipalities in Zuid-Holland and the national government.

3. **Network and coalitions.** When deciding whether to invest in mineral capabilities, the Province of Zuid-Holland should ensure coordination and cooperation along the supply chain. This would support knowledge exchange and ensure that efforts are complementary.

   3.1 **Inter-provincial network**. Zuid-Holland should be a frontrunner in inter-provincial dialogue when it comes to CRM. Within the Netherlands, Zuid-Holland is already one of the most active Provinces in this respect. Yet other provinces like North Holland (Port of Amsterdam) or Overijssel (salt mining) host certain activities in mineral supply chains as well. Inter-provincial cooperation through the IPO (*Interprovinciaal Overleg*) whenever feasible and possible is essential in ensuring smart investments and informed policymaking.

   3.2 **National network.** Zuid-Holland should harmonise its cooperation with the various Dutch ministries. On environmental and infrastructure issues, the Province of Zuid-Holland is primarily in touch with the Ministry of Infrastructure and Water (IenW). However, the Ministry of Economic Affairs (EZK) is responsible for CRM activities. Given the international nature of mineral supply chains, the Ministry of Foreign Affairs (BZ) has also been very active in developing international partnerships and facilitating exchanges for Dutch companies. As such, it would be beneficial for the Province to expand its reach toward EZK and BZ as well when it comes to CRM issues. This would also help the national government in its policymaking and European and international exchanges.

3.3 **Regional network.** There are several port-industrial areas in North-Western Europe that are looking to expand mineral capabilities, but each of them has distinct characteristics and capabilities. An assessment of relative competitive advantage should be conducted to determine a good 'division of labour' between regions and countries.

4. **Guidance from the Netherlands Government**. The Province of Zuid-Holland should try to obtain clearer guidelines from the national government regarding the future energy system in the Netherlands. Various national climate ambitions are now being set, ranging from becoming a green hydrogen hub, to advanced and synthetic fuels, to critical raw materials. It is challenging for provincial and local levels of government to take action towards these ambitions when the long-term national vision is blurry. The report "Keuzewijzer Klimaat en Energie" highlights the importance of making concrete choices in order to accelerate the transition. The provincial and local governments can assess their own strengths and potential, thereby supporting the national government in making choices about where energy transition capabilities should be located in the Netherlands.

Recommendations for the Province of Zuid-Holland whereby it can play an active role in cooperation with other stakeholders

5. **Innovation and start-ups.** Zuid-Holland should support innovation as well as help create business cases for start-ups in the CRM sector. In this way, the Province and support the development of innovative technologies and software to optimise material use, increase energy efficiency and maximise material recovery from end-of-life products.

5.1 **Financing criteria.** By collaborating with InnovationQuarter, TNO and universities in the region, the Province of Zuid-Holland can develop criteria for funding that support the scale-up of new ideas and technologies that can support resilience in mineral supply chains.

5.2 **Public procurement** can be used as an instrument to support companies that use more sustainably or locally sourced minerals.

6. **Support the business case of industries active in the Netherlands.** The global uneven playing field is causing issues for companies in the Netherlands to remain competitive in relation to their counterparts. For that reason, the Province of Zuid-Holland together with the national government and the EU, in collaboration with industry, can take steps to support the competitiveness of companies active in light and especially heavy industrial sectors.

6.1 **De-risking.** The Province and/or the other levels of government can play a role in funding new large-scale industrial activities through de-risking investments. In order to attract private funds for the development of energy transition-related industries, such as CRM, public actors can offer to bear a share of the financial risk through debt, guarantees or tax-breaks.

6.2 **Champion environmental practices.** The Province should support the uptake of product passports and other tools that allow for the inclusion of information about the socio-environmental footprint of the product along its supply chain. This can also lead to the integration of socio-environmental costs in the price of primary materials.

6.3 **CBAM.** The Carbon Border Adjustment Mechanism (CBAM) can be a useful tool in this regard. The Province could investigate the opportunities and limitations of this instrument in the metals industry in the Netherlands, as CBAM will be extended to include more and more industries up to 2030.

6.4 **CSDDD.** The EU Corporate Sustainability Due Diligence Directive (CSDDD) can also support the competitiveness of Dutch companies that employ sustainable technologies and practices in their operations domestically and abroad. The Province of Zuid-Holland should try to implement the CSDDD directive in a way that strengthens the business case of sustainable industry.

6.5 **E-waste.** The Province should collaborate with municipalities, other provinces and the national government to address illegal e-waste streams. In dialogue with industry, the police and other authorities, the Province should find ways of updating legislation to support the domestic recycling industry and limit illegal waste streams. At the same time, unintended negative impacts on communities that until now were the destination of illegal waste streams should be accounted for.

7. **Public awareness.** The Province of Zuid-Holland together with the national government and the industry should support and carry out awareness raising campaigns acknowledging existing social, environmental, ethical, economic and political challenges. This would ensure that public debates are conducted based on factual information and a better understanding of the issues at hand in the energy transition.

8. **Research.** Zuid-Holland should support the knowledge hub in the region by promoting and funding research on CRM-related cutting-edge technologies and social, environmental, ethical, economic and political dilemmas in academic and applied research centres. This can be done by (co-)funding long-term research programmes and the work of PhD candidates on the topic.

9. **Education.** Zuid-Holland should enhance educational programmes for various skill levels in the CRM sector, starting from basic trainings for entry-level positions to academic education for highly specialised tasks. The emerging capabilities in the energy transition bring attractive and future-oriented jobs to Zuid-Holland.

Appendix 1. **Companies active in minerals and metals industries in the Province of Zuid-Holland**

Company	Supply chain activity	Location
Better Future Factory	Manufacturing	Rotterdam
BOAL Extrusion	Manufacturing	Naaldwijk
Buhlmann Group	Manufacturing	Dordrecht
Elcee	Manufacturing	Dordrecht
Eurad	Manufacturing	Rotterdam
Exasun	Manufacturing	Den Haag
FNsteel	Manufacturing	Ablasserdam
Gobinda Mixed Metals	Manufacturing	Ridderkerk
Krogman Metals	Manufacturing	Rotterdam
PWT Eurostaal	Manufacturing	Ablasserdam
Rovasta	Manufacturing	Bleiswijk
Villares Metals International	Manufacturing	Rotterdam
7Digits B.V.	Recycling	Pijnacker
A&M Recycling	Recycling	Rotterdam
Autosloperij Atlas-Car	Recycling	Rotterdam
Autosloperij Kralingen	Recycling	Rotterdam
Autosloperij Zuid-Holland	Recycling	Rotterdam
Autoslopertij Romein	Recycling	Rotterdam
Circular Circuits	Recycling	Delft
DIM	Recycling	Spijkenisse
EMR	Recycling	Rotterdam
Geelhoed	Recycling	Nootdorp
Henk Netten Metaalhandel B.V.	Recycling	Stellendam

Company	Supply chain activity	Location
Isero B.V.	Recycling	Waddinxveen
Jansen Recycling Groep	Recycling	Dordrecht
JOBO Metaal	Recycling	Den Haag
Krommenhoek Metals	Recycling	Rotterdam
Lion Metals	Recycling	Rotterdam
Maarten van Rijn Oud Ijzer en Metalen	Recycling	Noordwijk
Metaalhandel & Autosloperij B. Rijsdijk	Recycling	Rotterdam
Metaalhandel W. Ketting	Recycling	Pernis
Metalimex	Recycling	Rotterdam
Repeat Audio	Recycling	Rotterdam
Rexel Nederland Hoofdkantoor	Recycling	Zoetermeer
Rijnmond Auto's	Recycling	Rotterdam
SCRAP	Recycling	Rotterdam
SCRAP XL	Recycling	Rotterdam
StoredEnergy	Recycling	Schiedam
TES Battery	Recycling	Rotterdam
Uzimet	Recycling	Delft
Van Helvert Metalen	Recycling	Schiedam
Van Leeuwen Groep	Recycling	Rotterdam
Van Leeuwen Recycling Groep	Recycling	Rotterdam
Van Pelt Recycling	Recycling	Ridderkerk
W3E	Recycling	Bodegraven
Climax Molybdenum	Processing	Rotterdam
Sibelco	Processing	Papendrecht
ASML Delft	Research & Development	Delft
Biosphere Solar	Research & Development	Delft
BlueCity	Research & Development	Rotterdam
CML Leiden University	Research & Development	Leiden
Deltares	Research & Development	Delft
EAZ Wind	Research & Development	Rijswijk
HCSS	Research & Development	Den Haag
IHE Delft	Research & Development	Delft
In2Waste Solutions	Research & Development	Rotterdam
LeydenJar	Research & Development	Leiden
Materials Innovation Institute (M2i)	Research & Development	Delft
Materials Recycling and Sustainability	Research & Development	Den Haag
TNO	Research & Development	Den Haag
TU Delft	Research & Development	Delft
Water-Mining H2020 (TU Delft)	Research & Development	Delft

Company	Supply chain activity	Location
ZERO BRINE (TU Delft)	Research & Development	Delft
AccessWorld	Services and Trade	Rotterdam
Allseas	Services and Trade	Delft
Arenal Dredging and Mining	Services and Trade	Pijnacker
Ayaz Auto Inkoop	Services and Trade	Rotterdam
BM Metals	Services and Trade	Rotterdam
European Partnership for Responsible Minerals (EPRM)	Services and Trade	Den Haag
Fugro	Services and Trade	Leidschendam
Hamwells	Services and Trade	Rotterdam
Netics	Services and Trade	Ablasserdam
Nouryon Chemicals B.V. Europoort	Services and Trade	Rotterdam
Optecs	Services and Trade	Rotterdam
Royal IHC	Services and Trade	Kinderdijk
SGS Nederland BV	Services and Trade	Rotterdam
Siemens Gamesa	Services and Trade	Den Haag
SkyGeo Netherlands	Services and Trade	Delft
Stainalloy	Services and Trade	Schelluingen
Stedin	Services and Trade	Rotterdam
Steinweg	Services and Trade	Rotterdam
Sweco Nederland	Services and Trade	Rotterdam
Van Essen Instruments	Services and Trade	Delft
Van Oord	Services and Trade	Rotterdam
WD Trading B.V.	Services and Trade	Krimpen aan den Ijssel

Appendix 2. **Mineral supply chains explained**

Extraction

The extraction of minerals can involve very different processes. The chosen extraction technique depends primarily on the location and characteristics of the mineral ore, but also on the degree of technological advancement. Four of the most known types of mining are discussed below: surface mining, underground mining, solution mining, and deep-sea mining. Finally, artisanal mining is discussed as well, as it remains a widespread practice in many countries.

Industrial large-scale mining is most often done through open-pit mining given the lower costs of establishing the operation at surface level, the lack of restrictions regarding the size of equipment and ease of transportation.[135] Copper, nickel laterite deposits and cobalt – often a by-product of copper and nickel – are typically exploited using open-pit techniques.[136] Open-pit methods involve the excavation of stepped benches progressively dug deeper, de-watering bores into the pit walls to relieve water pressure, and a haul road used to transport material.[137] Once the mine infrastructure is completed, holes drilled into hard rock, explosives inserted for blasting and the material is excavated.[138] An open-pit mine can have negative impacts on the soil and water due to the waste and tailings collected over time. However, ensuring no discharge into the environment throughout the mine operational life and undertaking rehabilitation, a series of processes meant to re-establish sustainable ecosystems for the long term, after mine closure, can ensure minimal negative impacts.[139]

Underground mining is often employed when the mineral ore is located deeper in the ground and is concentrated enough to make the operation economically feasible. The Kiruna iron ore mine in Sweden is the largest such iron mine in the world and uses advanced remote-controlled equipment and technology.[140] Access to an underground ore is done primarily through

135 'Open-Pit Mining Definition'.

136 Vladimir Basov, 'The World's Top 10 Highest-Grade Copper Mines', *MINING.COM* (blog), 20 February 2017, https://www.mining.com/the-worlds-top-10-highest-grade-copper-mines/; 'Mining Methods', Copper Development Association, accessed 23 November 2023, https://copper.org/education/copper-production/2.html; P Alves Dias et al., 'Cobalt: Demand-Supply Balances in the Transition to Electric Mobility' (JRC, 2018), https://publications.jrc.ec.europa.eu/repository/bitstream/JRC112285/jrc112285_cobalt.pdf; 'The Ultimate Guide to Nickel Mining Process', Mining Pedia, 2022, https://www.miningpedia.cn/mining/ultimate-guide-to-nickel-mining-process.html.

137 'Open-Pit Mining Definition'.

138 'Open-Pit Mining Definition'.

139 'Mine Rehabilitation: Leading Practice Sustainable Development Program for the Mining Industry' (Australian Government, 2016), https://www.industry.gov.au/sites/default/files/2019-04/lpsdp-mine-rehabilitation-handbook-english.pdf; Jari Väätäinen, 'Aitik Mine, Sweden', *Mine Closure* (blog), accessed 23 November 2023, https://mineclosure.gtk.fi/aitik-mine-sweden/.

140 'Kiruna Iron Ore Mine, Sweden'.

a shaft, which is a vertical excavation to the lowest point of the mining area, and drifts, which are horizontal openings dug from the shaft toward the ore.[141] This type of activity is more expensive given that access is more limited and equipment needs to be smaller in size to fit underground, which in some cases decreases productivity.[142] Underground mining also requires additional safety measures for workers. Ventilation is necessary to constantly provide fresh air, especially to dilute exhaust emissions or explosive gases. These risks are minimized by using advanced technologies and autonomous electrified processes.

Solution, or in-situ, mining is based on the dissolving of the metal in the ore and pumping it to the surface. This is a major lithium extraction method. Liquid reservoirs beneath salt flats are accessed through drilling, and the brine undergoes an evaporation process in ponds, followed by lithium extraction in a lithium recovery facility. This process requires significant amounts of water, which is becoming a challenge in dry areas, especially when local communities need to compete for scarce freshwater sources.[143] In absence of strict guidelines and legislation, these extraction sites also contribute to pollution and contamination of the environment.

Deep-sea mining seeks to extract materials from the seabed, which could occur at depth of several hundreds or thousands of meters. The minerals in the deep sea are mostly enclosed in various types of deposits, of which the polymetallic nodules, roughly the size of a tennis ball, are at present the main focus for deep-sea mining.[144] First, remotely operated vehicles are sent underwater to gather samples and locate mining sites on the seabed. To collect the polymetallic nodules, vehicles dredge the seafloor, where both the nodules and layers of sediment are uncovered. Hydraulic pumps will then bring the gathered material up to a surface vessel, where the materials are processed and the waste will be pumped back in the water, causing sediment plumes.[145] While governments are allowed to license companies for deep mining in their own Exclusive Economic Zone (EEZ), as of 2023 it remains prohibited in international waters.[146] Whether this will take off depends on the decision of the International Seabed Authority (ISA), the institution granted the exclusive competence on permits for commercial mining in international waters by the Convention on Nations Convention on the Law of the Sea (UNCLOS). The challenge stems from the ecological consequences for marine life and the environmental consequences of a potential disruption of the carbon cycle of the ocean. The deadline to develop a legal framework for these activities expired in July 2023, with various eventual outcomes being possible.[147] For now, the new deadline on a decision is set early 2025.[148]

In addition to large scale industrial mining, small scale and artisanal mining (ASM) is a widespread activity. An estimated 15 million people are employed in ASM in India, 9 million in China

141 'Mining - Underground, Safety, Techniques', Britannica, accessed 23 November 2023, https://www.britannica.com/technology/mining/Underground-mining.

142 'Mining - Underground, Safety, Techniques'.

143 Campbell, 'South America's "lithium Fields" Reveal the Dark Side of Electric Cars'; Vera et al., 'Environmental Impact of Direct Lithium Extraction from Brines'.

144 The other two types are sulphide deposits, which have a larger scale and develop around hydrothermal vents; the ferromanganese crusts, which are part of seamounts, also referred to as underwater mountains. Ashford et al., 'What We Know About Deep-Sea Mining — And What We Don't'; U. S. Government Accountability Office, 'Science & Tech Spotlight: Deep-Sea Mining', US Government Accountability Office, 16 December 2021, https://www.gao.gov/products/gao-22-105507.

145 Office, 'Science & Tech Spotlight'.

146 Ashford et al., 'What We Know About Deep-Sea Mining — And What We Don't'.

147 Jeff Amrish Ritoe, 'El Confidencial | Amrish Ritoe on Deep-Sea Mining', HCSS, 20 July 2023, https://hcss.nl/news/el-confidencial-amrish-ritoe-on-deep-sea-mining/.

148 Ashford et al., 'What We Know About Deep-Sea Mining — And What We Don't'.

and 3.6 million in Indonesia.[149] In the DRC, 2 million people engage in such activities, which account for an estimated 20% of DRC's cobalt production.[150] Given that this is an informal industry, working conditions are hazardous and environmental impacts major. Workers are in danger due to the improper working conditions and lack of protective equipment.[151] Child labour is widespread when it comes to artisanal mining. According to the International Labour Organisation, more than 1 million children are involved in mining activity globally.[152] Child labour is conducive of risks including traumatic injuries or death, joint and bone deformities, neurological damage, or injury from beatings and abuse.[153]

Processing

In order to illustrate the wide variety of conversion processes that materials undertake before they are sent to manufacturing plants, this section uses the case study of battery materials, including aluminium, nickel, copper, manganese, lithium, and natural graphite.[154]

Nickel and copper are produced simultaneously from sulphidic or latherite ores. Sulphidic ores are subjected to the pyrometallurgical method.[155] The first step is ore beneficiation, also known as ore concentration, whereby the material without commercial value is removed from the ore. This economically irrelevant material is called gangue. The next step is smelting, which results in the production of an intermediate product known as matte.[156] Matte is further refined to obtain pure metals. Unlike sulphidic ores, laterite ores are processed using hydro-metallurgical methods.[157] This involves ore preparation, leaching, solvent extraction, and electrowinning, finally resulting in the production of pure metals.[158] It is important to note that nickel products fall into two categories: Class I and Class II. Class I nickel, often referred to as nickel metal, contains over 99.8% nickel, and is the purity required for battery production.[159] Class II has lower nickel content and cannot be used in batteries without further processing.[160]

Battery-grade lithium can be produced through three distinct methods. Firstly, mining and acid leaching from spodumene ores involve mining solid rock ore, primarily pegmatite deposits, which is then treated through crushing, dense media separation, and flotation to produce a concentrate. Spodumene, the dominant lithium ore mineral, is further refined at conversion

149 Dempsey, 'Artisanal Mining: The Struggle to Clean up a Murky Industry'.

150 'Cobalt Value Chain Mapping', *Cobalt Institute* (blog), 2022, https://www.cobaltinstitute.org/responsible-sourcing/cobalt-value-chain-mapping/.

151 'Cobalt Mining in the Democratic Republic of Congo', *Cobalt Institute* (blog), accessed 26 September 2022, https://www.cobaltinstitute.org/cobalt-mining-in-the-democratic-republic-of-congo/.

152 International Labour Organisation, 'Child Labour in Mining and Global Supply Chains', 2019, https://www.ilo.org/wcmsp5/groups/public/---asia/---ro-bangkok/---ilo-manila/documents/publication/wcms_720743.pdf.

153 International Labour Organisation.

154 Nelson Bunyui Manjong et al., 'Life Cycle Modelling of Extraction and Processing of Battery Minerals—A Parametric Approach', *Batteries* 7, no. 3 (September 2021): 5, https://doi.org/10.3390/batteries7030057.

155 Manjong et al., 'Life Cycle Modelling of Extraction and Processing of Battery Minerals—A Parametric Approach'; 'About Nickel', Nickel 28, accessed 31 October 2023, https://www.nickel28.com/media/about-nickel/.

156 Manjong et al., 'Life Cycle Modelling of Extraction and Processing of Battery Minerals—A Parametric Approach'; 'About Nickel'.

157 Manjong et al., 'Life Cycle Modelling of Extraction and Processing of Battery Minerals—A Parametric Approach'; 'About Nickel'.

158 Manjong et al., 'Life Cycle Modelling of Extraction and Processing of Battery Minerals—A Parametric Approach'; 'About Nickel'.

159 Zhang, Manthey, and Luman, 'Tightening Supply Shakes up Battery Metal Dynamics'.

160 Zhang, Manthey, and Luman.

plants, involving varying temperatures, sulfuric acid, and sodium carbonate to yield lithium carbonate. The second method, concentration and precipitation from brines, relies on solar evaporation to extract lithium from salt-rich subterranean reservoirs. Over months, lithium concentration increases, and potassium is also extracted, while impurities like boron and magnesium are removed at a recovery plant. The solution is treated with sodium carbonate to generate lithium carbonate, which can be further processed into lithium hydroxide. Lastly, the Direct Lithium Extraction (DLE) approach absorbs lithium from saline water sources onto an ion exchange material or bead, followed by washing with hydrochloric acid to produce dilute lithium chloride with impurities. DLE suits lithium resources with higher hardness in areas where evaporation ponds are unfeasible.[161]

Natural flake graphite, a variant of graphite, is favoured by the lithium-ion industry. The most widely employed method for processing flake graphite requires substantial modification to meet the strict purity requirements of battery anodes, which demand a minimum purity level of 99.9%.[162] This process involves transforming graphite ore into flake concentrate through flotation. The flake concentrate then undergoes chemical treatment with hydrofluoric acid (HF) to enhance its purity. Subsequently, micronization reduces the flake graphite to very small particles (10-20 micron). The micronized material undergoes further chemical purification, commonly utilizing hydrofluoric and sulfuric acids for their effectiveness in eliminating impurities that could impact battery performance. However, it's worth noting that other methods that significantly reduce the use of harmful acids, reduce energy intensity and increase recovery rates are being developed.[163]

Recycling

Recycling consists of the physical and chemical processes that enable material recovery. In general, the recycling of CRM remains challenging due to high costs associated with recovering small amounts of material, often making the secondary supply more expensive than just buying primary materials. Moreover, product design can hinder component separation, which is why recycling considerations should be included early in the manufacturing process. Finally, recycling facilities are quite energy intensive and can also pose pollution and environmental challenges.[164]

The most widely used and conventional approaches are pyrometallurgy and hydrometallurgy, but emerging approaches like direct recycling and biotechnological methods are starting to take shape as well.[165]

Pyrometallurgy relies on high temperatures and chemical reducing agents to extract and purify the metal. In the context of lithium ion batteries, the pyrometallurgical method involves pre-treatment methods like incineration, pyrolysis or roasting, whereby lithium metal oxides

161 Dolf Gielen and Martina Lyons, 'Critical Raw Materials for the Energy Transition: Lithium' (Abu Dhabi: International Renewable Energy Agency, January 2022); 'Lithium Extraction and Refining', Saltworks Technologies, accessed 31 October 2023, https://www.saltworkstech.com/applications/lithium-extraction-and-refining/.

162 Jeff Amrish Ritoe, Irina Patrahau, and Michel Rademaker, 'Graphite: Supply Chain Challenges & Recommendations for a Critical Mineral' (HCSS, March 2022), 11, https://hcss.nl/wp-content/uploads/2022/03/Graphite-Challenges-and-Recommendations-HCSS-2022.pdf.

163 Ritoe, Patrahau, and Rademaker, 15–16.

164 Tercero Espinoza et al., 'The Promise and Limits of Urban Mining', 9.

165 Toro et al., 'A Systematic Review of Battery Recycling Technologies'.

are turned into simpler compounds.[166] Then, the battery scrap undergoes high-temperature smelting, breaking down battery components into a molten mixture of slag, containing aluminium, manganese and lithium; and metal alloys, including copper, nickel, cobalt, and iron.[167] While materials from the alloy can be recovered, those contained in slag – lithium and manganese – are often lost during the process.[168]

Hydrometallurgical processes involve leaching and solution concentration and purification for metal recovery, bypassing high-temperature roasting. Acid leaching typically uses sulfuric acid (H2SO4) to dissolve the lithium, cobalt, nickel, manganese, and copper.[169] Alkaline leaching uses ammonia based solutions like ammonium carbonate are conventionally used for the dissolution of lithium, nickel and cobalt.[170] Then, the liquid solution must be concentrated through processes like chemical precipitation or solvent extraction, depending on the specific metal. Typically, reagents like sodium hydroxide are used for the selective removal of the material from undesired components, enabling the recovery of critical materials.[171]

Despite its high efficiency for large scale recycling, pyrometallurgy presents challenges. These include the production of toxic gases, necessitating capture or remediation, its economic unfeasibility for low-grade ore concentrations, and the need for hydrometallurgical post-processing.[172] Combining hydrometallurgical and electrometallurgical techniques is a common practice for recovering metals from low-grade ore, with specific approaches depending on material recovery preferences and concentration levels.[173] In contrast to pyrometallurgy, hydrometallurgical processes are more selective in metal recovery, with fewer risks, environmental hazards, and energy consumption.

Direct recycling and biotechnological methods are emerging approaches aiming to address some of the challenges of pyro- and hydrometallurgy. Direct recycling looks at restoring the battery components without decomposing them into metals. In this way, processing steps are avoided, reducing waste, material losses and costs. This technology has the potential of restoring 80-90% of the initial capacity of the battery. However, it remains difficult to implement due to dependence on battery health, handling difficulties of metal oxides, and sensitivity to contamination—especially by metals like aluminium, impacting the electrochemical performance of cathode coatings.[174] Bio-technological methods use microorganisms like bacteria, fungi or algae, to extract metals. The method has proven successful in various studies, but it requires additional research for its implementation at an industrial scale.[175]

166 Toro et al.

167 Tan, Xu, and Chen, 'Enabling Sustainable Critical Materials for Battery Storage through Efficient Recycling and Improved Design', 7.

168 Toro et al., 'A Systematic Review of Battery Recycling Technologies'.

169 Toro et al.

170 '23.3: Hydrometallurgy', Chemistry LibreTexts, 29 August 2017, https://chem.libretexts.org/Courses/University_of_Missouri/MU%3A__1330H_(Keller)/23%3A_Metals_and_Metallurgy/23.3%3A_Hydrometallurgy.

171 Tan, Xu, and Chen, 'Enabling Sustainable Critical Materials for Battery Storage through Efficient Recycling and Improved Design', 8.

172 Lisa Brückner, Julia Frank, and Tobias Elwert, 'Industrial Recycling of Lithium-Ion Batteries—A Critical Review of Metallurgical Process Routes', *Metals* 10, no. 8 (August 2020): 7, https://doi.org/10.3390/met10081107.

173 Lúcia Helena Xavier, Marianna Ottoni, and Leonardo Picanço Peixoto Abreu, 'A Comprehensive Review of Urban Mining and the Value Recovery from E-Waste Materials', *Resources, Conservation and Recycling* 190 (1 March 2023): 10, https://doi.org/10.1016/j.resconrec.2022.106840; Brückner, Frank, and Elwert, 'Industrial Recycling of Lithium-Ion Batteries—A Critical Review of Metallurgical Process Routes', 8–18.

174 Gavin Harper et al., 'Recycling Lithium-Ion Batteries from Electric Vehicles', *Nature* 575, no. 7781 (November 2019): 75–86, https://doi.org/10.1038/s41586-019-1682-5; Toro et al., 'A Systematic Review of Battery Recycling Technologies'.

175 Harper et al., 'Recycling Lithium-Ion Batteries from Electric Vehicles'.

Trade

The metals market is quite complex, as some metals are traded in the open market primarily through the London Metal Exchange (LME), though the majority is still traded in bilateral closed deals, known as 'over the counter'. The LME is an important actor as it provides the regulatory cadre and environment for trading, impacting the operation of the market. Highlighting its importance in the metals market, LME was bought in 2012 by the Hong Kong stock exchange at a price equating 180 times LME's 2011 earnings.[176] To support market transparency and stabilise prices, LME authorises warehouses that store metals traded via the LME and influences the amount of stock released each day. This follows a 2015 US Senate committee investigation into the aluminium market, with major users alleging price manipulation up to $6 billion annually by hoarding of banks, traders, and warehouses. Glencore-owned Pacorini played a key role in the 'LME storage wars' as it used its storage capacity in Vlissingen to hoard nearly a million tonnes of aluminium in 2012.[177]

[176] Jack Farchy and Robert Cookson, 'HKEx Agrees to Buy LME for £1.4bn', Financial Times, 2012, https://www.ft.com/content/6fdca33c-b54a-11e1-ad93-00144feabdc0.

[177] Karl West, 'London Metal Exchange Urged to Act Swiftly over "broken" Aluminium Market', *The Guardian*, 19 March 2015, sec. Business, https://www.theguardian.com/business/2015/mar/19/london-metals-exchange-urged-to-act-swiftly-over-broken-aluminum-market; Maytaal Angel and Melanie Burton, 'Glencore Profits from Metals Backlog in Dutch Port', *Reuters*, 27 April 2012, sec. Business, https://www.reuters.comarticle/idUSBRE83Q0KP/; Andy Home, 'Column: LME Warehouse Wars Rumble on in the Malaysian Jungle', *Reuters*, 27 August 2020, sec. Stocks, https://www.reuters.comarticle/idUSKBN25N1NZ/.

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