The Hague
Centre for
Strategic
Studies

HCSS GEO-ECONOMICS

Securing Critical Materials for Critical Sectors

Policy options for the Netherlands and the European Union

Irina Patrahau, Ankita Singhvi, Michel Rademaker, Hugo van Manen, René Kleijn and Lucia van Geuns

HCSS helps governments, non-governmental organizations and the private sector to understand the fast-changing environment and seeks to anticipate the challenges of the future with practical policy solutions and advice.

Securing Critical Materials for Critical Sectors
Policy options for the Netherlands and the European Union

HCSS Geo-Economics
The Hague Centre for Strategic Studies

ISBN/EAN: 9789492102805

Authors:
HCSS: Irina Patrahau, Michel Rademaker (Project Leader), Hugo van Manen, and Lucia van Geuns
Centrum voor Milieuwetenschappen: Ankita Singhvi and René Kleijn
December 2020

The research for and production of this report have been conducted within the PROGRESS research framework agreement. Responsibility for the contents and for the opinions expressed, rests solely with the authors and does not constitute, nor should be construed as, an endorsement by the Netherlands Ministries of Foreign Affairs and Defense. This project has been completed on behalf of the China Knowledge Network of the Government of the Netherlands.

© *The Hague* Centre for Strategic Studies. All rights reserved. No part of this report may be reproduced and/or published in any form by print, photo print, microfilm or any other means without prior written permission from HCSS.
All images are subject to the licenses of their respective owners.

Design: Mihai Eduard Coliban (layout) and Constantin Nimigean (typesetting).

The Hague Centre for Strategic Studies
info@hcss.nl
hcss.nl

Lange Voorhout 1
2514EA
The Hague
The Netherlands

HCSS GEO-ECONOMICS

Securing Critical Materials for Critical Sectors

Policy options for the Netherlands and the European Union

*Irina Patrahau, Ankita Singhvi, Michel Rademaker,
Hugo van Manen, René Kleijn and Lucia van Geuns*

Table of Contents

Factsheet

Securing critical materials for critical sectors

Policy options for the Netherlands and the European Union

The demand for critical raw materials, on which the Dutch economy is highly dependent, will spike - introducing undesirable dependencies due to China commanding a controlling share of the global supply. What can the Netherlands do to secure its supply of critical materials & technologies?

Critical sectors

NL & the EU are dependent on imported materials, components and technology for meeting their energy, transport and digital ambitions.

Permanent magnets in wind turbines require rare earth elements, mined predominantly in China

Manufacturing of c-Si photovoltaic panels is concentrated in a small number of countries and is led by China

Electric vehicles require batteries, for which China, Japan and Korea are global production leaders

Developing digital technologies, such as semiconductors, requires an ever-increasing range of materials

Strategies to secure critical raw materials (CRM)

Ensuring a resilient CRM-supply chain requires states and companies to make strategic policy choices that enable supply chains to adapt and recover from disruptions.

China's Quasi-Monopoly

China employs a range of strategies to develop each step of domestic supply chains and secure access to strategic resources abroad, with the aim of meeting national ambitions.

Recommendations for the Netherlands & EU

- Develop a long-term national strategy that reflects the needs of industrial actors
- Support small/medium enterprises to collaborate on industrial objectives
- Conduct R&D for innovative waste collection, processing and re-using
- Invest in resource-abundant countries in order to diversify supply
- Encourage capacity-building in technical expertise for policymakers

Interventions to be supported on the EU level

- Expand European Raw Materials Alliance
- Support application of R&D in waste processing & recycling
- Analyse EU stocks and waste flows to map potential of secondary CRM
- Invest in mining expertise within the Union
- Set standards for sustainable & responsible finance and mining practices
- Develop strategic international partnerships

The Hague Centre
for Strategic Studies
Lange Voorhout 1
2514 EA The Hague
The Netherlands
hcss.nl

Management Samenvatting

De geopolitieke ambities van Nederland voor de komende decennia sluiten aan bij de langetermijndoelstellingen van de Europese Unie van klimaatneutraliteit en digitale autonomie. Het behalen van dergelijke doelen is afhankelijk van een gegarandeerde aanvoer van kritische grondstoffen (Critical Raw Materials, CRM) en vervaardigde goederen. Dit is problematisch gezien het feit dat andere landen grote marktmacht hebben in voor Nederland strategische sectoren. China levert 99% van zeldzame aardmetalen aan de EU en controleert 80% van de productie van zeldzame aardmetalen voor permanente magneten die nodig zijn voor windenergie en elektrische voertuigen.[1] Het is daarom niet alleen een gebrek aan binnenlandse mijnbouw die de afhankelijkheden creëert. Nederland en de EU zijn afhankelijk van andere landen van strategische waardeketens voor de meeste intermediaire sectoren (materialen, componenten en producten). Dit rapport beoogt strategieën en beleidsinstrumenten te identificeren die Nederland, in samenwerking met de EU, kan inzetten om de importafhankelijkheid van kritische grondstoffen en bijbehorende technologieën te verminderen.

De drie kritieke sectoren die worden geanalyseerd zijn energie, transport en digitale technologieën. Specifieke technologieën die zijn bekeken, zijn onder meer windturbines, fotovoltaïsche zonne-energie, geothermische energie, infrastructuur voor energienetten, opvang en opslag van koolstof, elektrische voertuigen en halfgeleiders. Op basis van geprojecteerde materiaalvereisten, samen met ontwikkelingen van vestigingsplaats en eigendom van sectoren van toeleveringsketens, is een grote afhankelijkheid aan China vastgesteld voor deze technologieën, hun componenten en grondstoffen.

Het ontwerpen van een overkoepelende strategie om mogelijke verstoringen van de voorziening te beperken, vereist een grondige analyse van de geopolitieke en technische aanpak die doorgaans door landen of bedrijven wordt ingezet om de levering van materialen veilig te stellen. De strategieën die worden ingezet zijn nationalisatie van hulpbronnen (inclusief verticale integratie, voorraadvorming en allerlei restricties), diplomatieke en industriële allianties, diversificatie van leveranciers, standaardisatie, R&D en circulaire economie. Elk van deze strategieën wordt geoperationaliseerd door middel van specifieke beleidsinterventies die Nederland zou kunnen toepassen om de veerkracht van industriële toeleveringsketens te vergroten.

Door een analyse van hoe Nederland, de EU en China genoemde strategieën hebben toegepast, worden verschillende parktijken duidelijk. Terwijl de industrie in Nederland en andere westerse landen onafhankelijk van de regeringen de bevoorrading veiligstelt, volgt China een langetermijnstrategie die grotendeels te danken is aan de grote betrokkenheid van de overheid bij de industriële winning en productie van grondstoffen. China past een breed scala aan strategieën toe om binnenlandse sectoren van toeleveringsketens te ontwikkelen, toegang tot strategische bronnen in het buitenland zeker te stellen en hun grip op complete waardeketens te vergroten.

In dit rapport wordt aanbevolen dat Nederland prioriteit geeft aan de ontwikkeling van een nationale langetermijnstrategie die aansluit bij de behoeften van industriële actoren bij het veiligstellen van hun toeleveringsketens. De overheid zou een leidende rol moeten spelen bij het ontwikkelen van de nationale strategische richting voor het veiligstellen van kritische materialen (CRM) en technologieën. Multilaterale en multi-level programring en beleidscoherentie moeten prioriteit krijgen, zodat zowel publieke als private entiteiten kunnen werken aan dezelfde wederzijds voordelige doelstellingen. Geschikte nationale strategieën omvatten R&D voor innovatieve afvalverwerking, geavanceerde materialen en vervanging ter ondersteuning van de circulaire economie. Dit vereist investeringen. Het ondersteunen van industriële allianties om samenwerking bij het oplossen van problemen te vergemakkelijken is een ander belangrijk instrument. Een van de gebieden waarop industriële allianties kunnen helpen bij het verminderen van gemeenschappelijke kwetsbaarheden van marktspelers, zijn duurzame internationale investeringen in de mijnbouw- en raffinagesector. Verder zou extra capaciteit binnen relevante ministeries in Nederland kunnen bijdragen aan een beter begrip van de kritische grondstoffenindustrieën en daarmee tot effectievere en zinvollere beleidsvorming. Tegelijkertijd moet aanzienlijk worden geïnvesteerd in menselijk kapitaal om de huidige lacune aan expertise en capaciteit op het gebied van mijnbouw, raffinage en andere processen binnen CRM-toeleveringsketens te dichten. Grondstoffendiplomatie en strategische investeringen in buurlanden en ontwikkelingslanden kunnen bijdragen aan de diversificatie van de import en daarmee tot versterking van de voorzieningszekerheid.

Het voortzetten en versterken van de samenwerking tussen private en publieke, nationale en internationale spelers is de meest haalbare manier om de voorgestelde beleidsinterventies toe te passen. Samenwerking op EU-niveau is cruciaal om de afhankelijkheid van niet-EU-spelers zoals China te verminderen door meer hefboomwerking te creëren. Acties die op EU-niveau moeten worden ondersteund, zijn: uitbreiding en versterking van de Europese grondstoffenalliantie; ondersteuning van R&D op het gebied van afvalverwerking, recycling en materiaalvervanging; het aanbod van secundaire CRM uit EU-voorraden en afval in kaart brengen; investeren in mijnexpertise binnen de EU; normen vaststellen voor duurzame financiering en verantwoorde mijnbouwpraktijken; en het ontwikkelen van strategische internationale partnerschappen en allianties.

Kijkend naar specifieke sectoren, voor energie: het ondersteunen van R&D, het stellen van normen en circulaire economie strategieën zullen belangrijk zijn om een sterke markt voor secundaire grondstoffen in NL/ EU te creëren, waardoor de afhankelijkheid van import wordt verminderd. Belangrijke strategieën in de transportsector zijn: het aanmoedigen van diversificatie van leveranciers, meer onderzoek en ontwikkeling en normalisatie. Voortdurend onderzoek naar materiaalvervanging (bijv. Li-Air-batterijen) in samenwerking tussen materiaalwetenschappers en de industrie, en het leren van de beste praktijken in het buitenland, zou kunnen leiden tot een afnemende vraag naar kritische grondstoffen. Ten slotte heeft de EU opgeroepen tot meer 'digitale soevereiniteit', die kan worden bereikt met strategieën zoals: beperking van de toegang tot binnenlandse markten, sterkere diplomatie van hulpbronnen en R&D. Met name is R&D een voordeel gebleken voor Nederland - China heeft het moeilijk gehad om vooruitgang te boeken op het gebied van geavanceerde productie, het meest veeleisende onderdeel van de halfgeleiderproductie.

Het ondersteunen van de inspanningen van de industrie om de voorzieningszekerheid van kritieke technologieën te waarborgen, zou een prioriteit moeten worden voor de relevante ministeries van Nederland. De strategieën en beleidsinstrumenten die in dit rapport worden voorgesteld, zullen waarschijnlijk bijdragen aan de ontwikkeling van veerkrachtige toeleveringsketens, waardoor Nederlandse industrieën klimaat- en digitale doelen kunnen bereiken. Gezien de tijdsdruk om binnenlandse industrieën te ontwikkelen en de huidige quasi-monopolistische positie van China voor CRM's, is het onwaarschijnlijk dat Nederland of de EU op korte en middellange termijn volledig autonoom zullen worden. Nederland zou veeleer moeten streven naar meer veerkracht om maatschappelijke en economische doelen te bereiken. Gediversifieerde en veilige wereldwijde toeleveringsketens zijn essentieel om ervoor te zorgen dat mogelijke verstoringen op een snelle, flexibele en effectieve manier kunnen worden beheerst.

Executive Summary (EN)

The Netherlands' geopolitical ambitions for the following decades align with the European Union's long-term goals of climate neutrality and digital autonomy. The fulfilment of such goals depends on a secure supply of critical raw materials and manufactured goods, which is problematic given that other countries control large market shares in sectors that are strategic to the Netherlands. For instance, in 2019 China controlled 70% of rare earth elements' (REE) mining, 85% of REE oxide refining, 90% of REE metals and 90% of permanent magnets production, needed for wind energy and electric vehicles.[1] Therefore, it is not just a lack of domestic mining that creates dependencies. Rather, the Netherlands and the EU are dependent on other countries for most intermediary sectors of strategic value chains (i.e. materials, components and products). This report aims at identifying strategies and policy instruments that the Netherlands, in collaboration with the EU, can apply in order to reduce import dependence on critical raw materials and associated technologies.

Energy, transport and digital technologies are the three critical sectors analyzed from a dependency perspective. Specific technologies considered include wind turbines, photovoltaic solar power, geothermal, energy grid infrastructure, carbon capture and storage, electric vehicles and semiconductors. Based on projected material demand, together with broad tendencies in terms of location and ownership of different steps of supply chains, high dependence on China is identified for technologies, their components and raw materials.

Designing an adequate overarching strategy to mitigate potential supply disruptions requires a thorough analysis of geopolitical and technical approaches generally employed by countries or companies in order to secure supply of materials. The strategies considered are resource nationalism (including vertical integration, stockpiling and restrictions), diplomatic and industrial alliances, diversification of suppliers, standardization, R&D as well as circular economy. Each of these strategies is operationalized into specific policy interventions that the Netherlands could apply in order to enhance the resilience of industrial supply chains.

From an analysis of how the Netherlands, the EU and China have been applying said strategies, several observations become evident. In the Netherlands and other Western

---

[1] Ryan Castilloux, "Rare Earth Elements: Market Issues and Outlook" (Adamas Intelligence, 2019), 8.

countries, the industry has been securing supplies independently from governments. Contrastingly, China has been pursuing a long-term strategy largely due to the deep involvement of the government in industrial extraction and production of raw materials. China is employing a wide range of strategies to develop stages of domestic supply chains, to secure access to strategic resources abroad as well as to enhance their grip on complete values chains.

This report recommends that the Netherlands prioritizes the development of a long-term national strategy that reflects the needs of industrial actors in securing their supply chains. The government should take on a leading role in developing the national strategic direction for securing critical materials and technologies. Multilateral and multilevel programming and policy coherence should be prioritized so that both public and private entities can work toward the same mutually beneficial objectives. Suitable national strategies include R&D for innovative waste processing, advanced materials and substitution in support of the circular economy. The support for industrial alliances in order to facilitate collaboration in problem-solving is another important recommendation. One area in which industrial alliances could help reduce common vulnerabilities of market players is sustainable international investments in the mining and refining sectors. Further, technical capacity building within relevant ministries in the Netherlands should be conducive to a better understanding of the critical raw materials industries' and, therefore, to more effective and meaningful policymaking. Simultaneously, significant investment in human capital should be made to fill the current gap in expertise and capacity regarding mining, refining and other processes within CRM supply chains. Resource diplomacy and strategic investments in resource-abundant countries could contribute to diversifying imports and hence to strengthening the security of supply.

Continuing and enhancing the collaborative effort between private and public, national and international players is the most feasible way of applying the proposed policy interventions. Cooperation on the EU level is pivotal in reducing dependence on non-EU players such as China. Actions that should be supported on the EU level are: expanding and strengthening the European Raw Materials Alliance; supporting R&D in waste processing, recycling and material substitution; mapping supply of secondary CRM from the EU urban mine in form of stock and wastes; investing in mining expertise within the EU; setting standards for sustainable finance and responsible mining practices; developing strategic international partnerships and alliances; and levelling the (tax) playing field between EU and Chinese technology manufacturers.

Looking at specific sectors, for energy, supporting R&D, setting standards and circular economy strategies will be important to creating a strong market for secondary raw materials in NL/EU, thereby reducing dependency on imports. In the transport sector, important strategies will be: encouraging diversification of suppliers, increasing

R&D and standard-setting efforts. Continuous research into material substitution (e.g. Li-Air batteries) in collaboration with material scientists and industry, as well as learning from best practices abroad, could lead to decreasing critical raw material demand. Finally, the EU has called for greater ‘digital sovereignty’, which can be achieved with strategies such as: restricting access to domestic markets, stronger resource diplomacy and R&D. R&D, in particular, has proven to be an advantage for the Netherlands - China has found it hard to make progress in cutting-edge manufacturing, which is the most demanding part of chipmaking.

Supporting industry efforts to guarantee the security of supply for critical technologies should become a priority for relevant ministries of the Netherlands. The strategies and policy instruments proposed in this report are likely to contribute to the development of resilient supply chains, thus allowing Dutch industries to reach climate and digital goals. Given time constraints to develop domestic industries and China’s current quasi-monopolistic position for CRMs, it is unlikely that the Netherlands or the EU will become completely autonomous on the short and medium term. Rather, the Netherlands should strive for increased resilience to meet societal and economic goals. Diversified and secure global supply chains are key in ensuring that potential disruptions can be managed in a rapid, flexible and effective manner.

1. Introduction

The European Union's (EU) economy is highly dependent on imports of raw materials, semi-manufactured components and end products. The EU is not only the largest economy in the world, but also the largest trading block.[2] It has based its 2019-2024 Industrial Strategy on three pillars – the Green Transition, the Digital Transition and global competitiveness.[3] This Industrial Strategy aligns with longer-term goals of climate neutrality and digital autonomy for the following decades. The fulfilment of climate neutrality goals as well as 'technological sovereignty' depends on a secure supply of critical raw materials (CRM) and manufactured goods.

This is problematic given that other countries control large market shares in sectors that are strategic to the EU. In 2019, China controlled 70% of REE mining, 85% of REE oxide refining, 90% of REE metals and 90% of magnets production, needed for wind energy and electric vehicles.[4] Therefore, it is not just a lack of domestic mining that creates dependencies. Rather, the EU is dependent on other countries for most intermediary stages of strategic value chains (i.e. materials, components and products).

With the stage set for a spike in demand for raw materials and access to the renewable technologies that require these materials, China is in the enviable position of commanding a controlling share of global supply. Post-2025, the steps Beijing is taking today are likely not only to cement China's role as a supplier of raw materials, but also to increase its roles as consumer of said materials and as exporter of the technologies they are used in. From an EU and/ or Dutch perspective, the introduction of this dynamic produces undesirable dependencies. The aim of this report is to explore these dependencies, and reflect on what the Netherlands can do, in collaboration with the European Union, to secure supply of critical materials and technologies.

---

[2] European Commission, "EU Position in World Trade," February 18, 2019, https://ec.europa.eu/trade/policy/eu-position-in-world-trade/.

[3] European Commission, "European Industrial Strategy," Text, European Commission, 2020, https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en.

[4] Ryan Castilloux, "Rare Earth Elements: Market Issues and Outlook" (Adamas Intelligence, 2019), 8.

2. Research approach

2.1 Research goals

The goal of this report is to provide an overview of the geopolitical activities of the Netherlands, EU and China concerning renewable energy technologies, electric transport and digital technologies; to consider the future material demand of each sector and where the challenges and opportunities lie concerning critical raw materials; to consider technical and political strategies countries employ to meet these challenges; and to recommend interventions that the Netherlands can apply in collaboration with the EU in each sector. This report is built around the following research question:

"What can the Netherlands do, in collaboration with the European Union, to reduce dependencies regarding critical raw materials?"

With particular interest in the:

- Electrification of transport: To what extent are policy options available for securing batteries?
- Digital ICT industry: To what extent are policy options available for securing the microchips related industries?
- Energy transition:
  - Which scenarios do Western organizations take for the introduction of permanent magnets-based wind turbines versus traditional generators? What would be the costs for the exploitation and maintenance during the full life cycle?
  - How do these value chains look like and what are their vulnerabilities?
  - The market for permanent magnets is hardly existing, what applications and technologies will become available and to what extent will these applications reduce future dependencies?

2.2 Methodology

The starting point of this study is the Netherlands' current status and ambitions regarding two important strategic sectors: digital technologies and renewable energy, the latter being sub-divided into energy transition and electric transport. Given China's dominance over global supply chains, Dutch and European goals are compared with Chinese ambitions in the same sectors in order to present the geopolitical context that will dominate the following decades. The context is relevant in determining how to approach potential issues in the supply of critical raw materials.

Achieving Dutch and European ambitions requires a careful analysis of technologies that are likely to play an important role in the following decades. Digital technologies are analyzed holistically in order to provide an overview of material demand. Moreover, this report pinpoints the following essential technologies in the energy transition: wind turbines, photovoltaic solar power, geothermal energy, energy grid infrastructure (transmission networks), as well as carbon capture and storage. Electric vehicles are also awarded special attention due to their relevance to transport electrification ambitions.

As such, product-based assessments are performed in order to determine future material requirements specific to the Netherlands. The next step is a broad analysis of how the supply chains of each type of previously identified technology are organized. While the complexity of even one component's supply chain cannot be captured given the tens of thousands of actors involved (see 2.3 Mapping supply chains), this report nonetheless discusses tendencies associated with these chains, in terms of location or ownership of resources. In doing so, attention is granted to the critical raw materials involved in the production of relevant technologies and to the challenges and opportunities associated with their procurement. A ramification derived from this analysis refers to the need to secure supply of critical raw materials if ambitions for 2050 are to be achieved. Moreover, given its influence over the supply chains of most strategic technologies identified in this report, the People's Republic of China is distinguished as an essential actor in any Dutch or European attempts to ensure resilient supply chains. Special attention is paid to investments that China is making in these supply chains, especially in the Netherlands.

Based on the implication derived from the previous chapters regarding the Netherlands' need to secure supplies of critical raw materials, a comprehensive overview of existing strategies for the maximization of supply chain resilience is constructed. Each strategy is described in turn, based not only on theoretical information, but also on empirical examples. The strategies are: resource nationalism, including vertical integration, stockpiling, and restrictions; resource diplomacy and industrial alliances; diversification of suppliers; standards setting; research and development;

as well as circular economy strategies, including recycling (the urban mine), reusing and reducing. Each strategy is operationalized into policy interventions that could be applicable to the Netherlands.

The next section provides empirical examples of whether and how the previously-discussed strategies have been applied by the Netherlands and the EU on one hand, and by China on the other. It provides an overview of how (pro)active each entity is in securing supply of critical raw materials.

Critical issues, or bottlenecks, have been extrapolated both from the critical sectors analysis in chapter 4 and from the analysis of applied strategies in chapter 6. These aspects are matched with policy instruments that the Netherlands, in collaboration with the EU, can apply in order to reduce import dependence on critical raw materials and technologies. The policy instruments have been selected from the corresponding sections on strategies in chapter 5. Before providing policy recommendations, feasibility checks for the instruments are performed by comparing the proposed interventions with the most recent document put forward by the Dutch government on the critical raw materials issue.[5] In this way, the most politically feasible instruments are selected. This last step is an important building block in achieving this report's goal, that of providing realistic and practical recommendations that will aid the Netherlands in achieving its ambitions.

2.3 Mapping supply chains

Product-based assessments in this report are based on broad tendencies of where and how stages of supply chains are likely to be organized. In this section, critical raw materials' supply chains are defined and discussed, showing that there are tens of thousands of actors involved in a material chain. This is the reason why general trends are discussed in chapter 4 (Critical sectors), rather than specific stages.

Products and services are based on chains of activities of many sorts and qualities. A mineral supply chain can be defined as "the process of bringing a raw mineral to the consumer market".[6] Various actors are involved in this process, which, according to the OECD, broadly consists of the following stages: extraction, transport, handling, trading, processing, smelting, refining and alloying, manufacturing and sale of end product.[7] A supply chain however, can be understood to refer to every activity, stakeholder, organization, technology, resources that is involved in taking the mineral

---

[5] Ministerie van Economische Zaken en Klimaat, "Veerkracht Op Het Gebied van Kritieke Grondstoffen: De Weg Naar Een Grotere Voorzieningszekerheid En Duurzaamheid Uitstippelen," n.d.

[6] OECD, OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas: Third Edition, 3rd ed. (Paris: OECD Publishing, 2016), 14, https://doi.org/10.1787/9789264252479-en.

[7] OECD, 14.

from the upstream to the downstream sector, i.e. from raw material to end-product.[8] A mineral supply chain can be divided into two broad categories, upstream and downstream. The upstream segment of a supply chain refers to every actor and activity involved in the stages between mineral extraction and smelting.[9] The downstream segment, distinctively, connects the stages from smelters to retailers.[10]

Exploration is a precondition allowing mineral extraction to occur. Mineral exploration involves many different stages, its main goal being the discovery of suitable reserves for extraction.[11] While mineral resources are highly abundant geographically, the economically and technically feasible deposits for extraction – the reserves – are more limited.[12] As such, exploration includes activities whereby new reserves are identified, as well as feasibility studies are performed regarding the economic viability and environmental impact of a potential mine.[13] Permits and licenses are additional steps to take within exploration.[14] Depending on the mineral laws of each country, different types of permits are required. Apart from the administrative and environmental protection purposes served by governmental licensing, permits can also be used by governments in order to influence who gets the right to exploit, produce or export a type of resource (see chapter 5.1.3. Restrictions).[15]

Only once the exploration phase has been completed will the construction process of the mine ensue, the duration of this latter stage ranging from several years to a decade.[16] As such, high financial investments and long periods of time are required before extraction from a mine can begin, making the industry unable to respond quickly to market demand.[17] The exploitation of a mineral ore is done post exploration, through extraction from the mine. Other important stages are smelting and refining, which produce crude and refined metal products, respectively, from the raw material.[18]

The different supply chain steps are performed according to each mineral's individual characteristics. Due to the current global nature of supply chains, thousands of actors are involved in the various stages.[19] Determining where and how each step of the

---

[8] OECD, 14.

[9] OECD, 32.

[10] OECD, 33.

[11] Erika Machacek and Niels Fold, "Alternative Value Chains for Rare Earths: The Anglo-Deposit Developers," Resources Policy 42 (December 1, 2014): 54, https://doi.org/10.1016/j.resourpol.2014.09.003.

[12] M. A. de Boer and K. Lammertsma, "Scarcity of Rare Earth Elements," ChemSusChem 6, no. 11 (2013): 2047, https://doi.org/10.1002/cssc.201200794.

[13] Swapan Kumar Haldar, "Chapter 4 - Exploration Geology," in Mineral Exploration (Second Edition), ed. Swapan Kumar Haldar, 2nd ed. (Elsevier, 2018), 69–84, https://doi.org/10.1016/B978-0-12-814022-2.00004-6.

[14] Machacek and Fold, "Alternative Value Chains for Rare Earths," 54.

[15] Nabeel Mancheri, "World Trade in Rare Earths, Chinese Export Restrictions, and Implications," Resources Policy 46 (December 1, 2015): 262, https://doi.org/10.1016/j.resourpol.2015.10.009.

[16] Machacek and Fold, "Alternative Value Chains for Rare Earths," 54.

[17] Machacek and Fold, 54.

[18] Steven B. Young, "Responsible Sourcing of Metals: Certification Approaches for Conflict Minerals and Conflict-Free Metals," The International Journal of Life Cycle Assessment 23, no. 7 (July 1, 2018): 1433, https://doi.org/10/gdtf7f.

[19] Susan van den Brink et al., "Approaches to Responsible Sourcing in Mineral Supply Chains," Resources, Conservation and Recycling 145 (June 1, 2019): 393, https://doi.org/10/gf3t43.

supply chain has been completed becomes a challenge. This is shown by responsible mining and due diligence initiatives who find it extremely difficult trace end-products back to individual actors within the supply chain.[20] Both upstream and downstream sectors are rather opaque and the number of suppliers that an end-user company works with can reach tens of thousands.

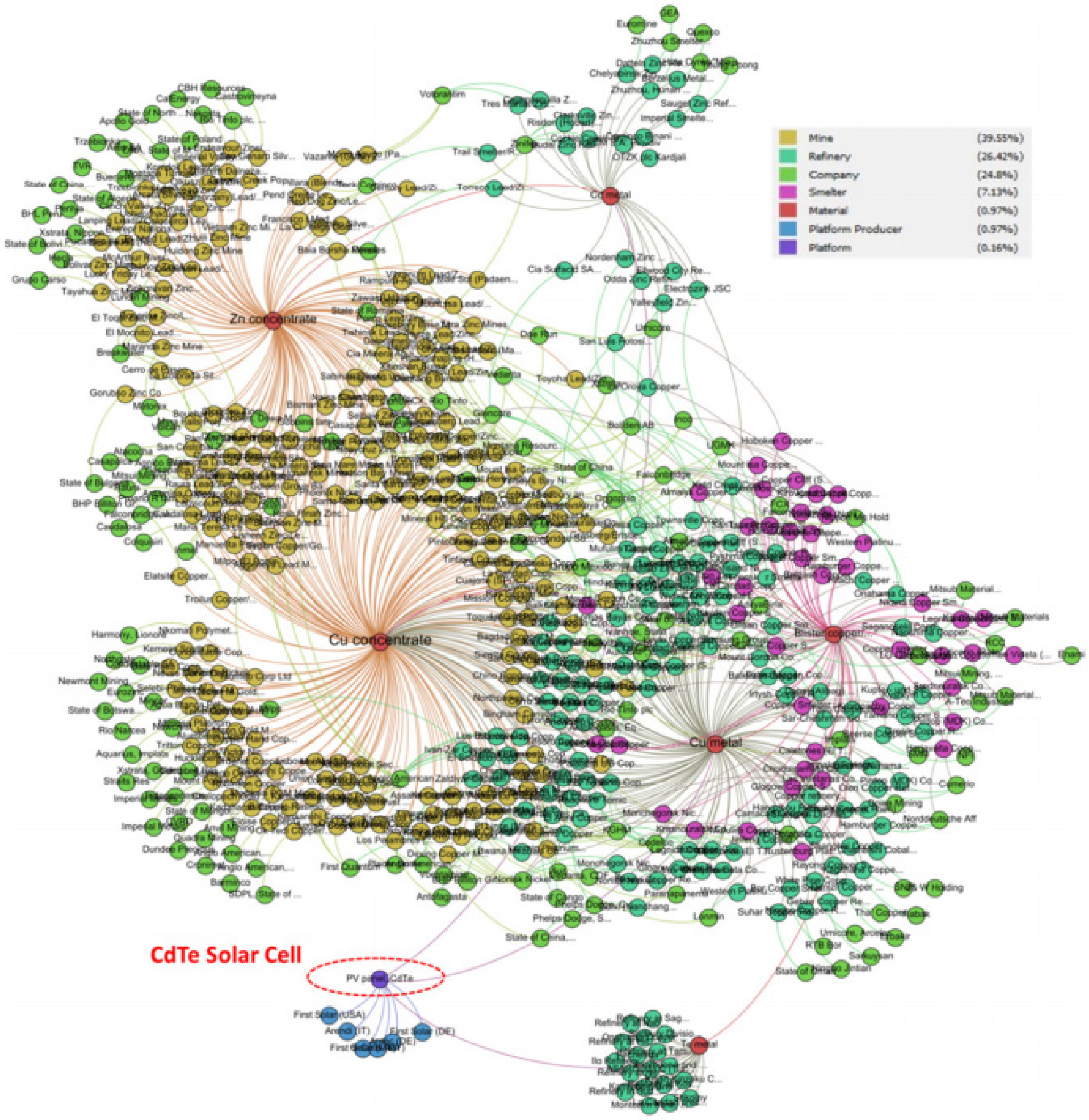


Figure 1. Supply chain of CdTe solar cell[21]

---

[20] van den Brink et al., 393.

[21] Philip Nuss et al., “Mapping Supply Chain Risk by Network Analysis of Product Platforms,” Sustainable Materials and Technologies 10 (December 1, 2016): 14–22, https://doi.org/10/ghbzg4.

Mapping the supply chain of a product requires the identification and aggregation of all companies that produce materials and components and that turn them into final products.[22] A study by Nuss et al. designed a framework of mapping supply chains in which they identified both actors and the connections between them, in the shape of contractual relations and material exchange.[23] They collected data on Cadmium Telluride (CdTe) solar cells, and found a network characterized by 617 actors and 999 connections (see Figure 1).[24] When considering that this is just one component of the final product, it becomes clear that outlining each individual party involved in an end-product's supply chain is a highly complex task. Therefore, this report provides an analysis of general trends and tendencies related to supply chains rather than an in-depth exploration of each supply chain.

---

[22] Nuss et al., 15.
[23] Nuss et al., 14.
[24] Nuss et al., 19.

3. Geopolitical context

This section establishes the circumstances under which the central issue addressed in this report – EU and Dutch import dependency on critical raw materials – has become urgent and problematic. It provides the background against which the geopolitical dynamics surrounding critical materials can be understood. Their relevance for the future of the EU and the Netherlands is emphasized in relation to competing Chinese goals of political and economic leadership. European and Chinese goals specifically tailored for climate and digital technologies are also analyzed in relation to critical materials.

3.1 Ambitions of NL/EU and China

The European Union is the most deeply integrated economic and political union in the world. The Single Market is the first and most successful achievement of the EU, allowing for the free movement of goods, services and people across the borders of its 27 member states.[25] The Single Market has been providing stability for European citizens for more than half a century. Additionally, the single currency – euro – has been a product of the integrated economic area, though not all EU member states have adopted it. Although an economic union at its outset, the EU has been expanding into additional policy areas including climate, justice, migration and external policy. The EU's goals include the promotion of peace and stability as well as the provision of security and justice to its citizens.[26] Moreover, the EU aims at a sustainable and stable development based on economic progress and social inclusion. Scientific and technological progress are additional goals.

Especially the von der Leyen commission, 2019-2024, has been called the geopolitical commission due to the high emphasis on political ambitions for the EU.[27] Other than highlighting the need for expanding and strengthening the Single Market, the von der Leyen commission has also set ambitious goals in areas ranging from digitalization and climate to the promotion of human rights and democratic values.[28] Democratic

---

[25] "The EU in Brief," Text, European Union, June 16, 2016, https://europa.eu/european-union/about-eu/eu-in-brief_en.
[26] "The EU in Brief."
[27] Lili Bayer, "Meet von Der Leyen's 'Geopolitical Commission,'" POLITICO, December 4, 2019, https://www.politico.eu/article/meet-ursula-von-der-leyen-geopolitical-commission/.
[28] "Priorities," Text, European Commission, accessed November 11, 2020, https://ec.europa.eu/info/strategy/priorities-2019-2024_en.

values are at the core of EU institutions and decision-making. The EU places high importance to human rights, equality, rule of law and freedom, values that the union is attempting at furthering both domestically and internationally.[29] As such, on the global scale the EU acts as a normative regulator that safeguards international rule of law and democratic principles.

The von der Leyen commission is aiming at reinforcing and expanding the EU's international influence by becoming the first climate-neutral continent, maintaining its economic power and developing its digital competencies.[30] These objectives should be achieved, according to the most recent industrial strategy, while decreasing import dependency for raw materials and technologies.[31] The objectives are challenging given that they imply both an increase in the demand of certain raw materials that the EU does not possess, and a decrease in imports of said materials.

China is the main source of EU imports of both critical raw materials and components for digital and climate-related technologies. In order to understand how and whether EU goals for the following decades can be achieved, it is important to understand China's geopolitical position as well as domestic goals. China's investments into its supply chains tie into a wider initiative to transform the country into a "manufacturing superpower" by 2025 – something which is clearly encoded in the Chinese Communist Party's (CCP's) 13th five-year plan (FYP), through Made In China 2025 (MIC2025). Introduced in 2015, the MIC2025 outlines the CCP's goal of reducing the Chinese economy's dependence on goods, services, and innovations from outside the country's borders. Virtually all high-tech industries are touched upon, from automotive and aviation to machinery, robotics, high-tech maritime & railway equipment, energy-saving vehicles, and medical and information technologies.

From the CCP's perspective, the goals outlined in the MIC2025 are tailored to catering to domestic audiences on the one hand, and to contributing to the realization of a range of geostrategic international interests on the other. On the domestic front, the MIC2025 can be understood – first and foremost – as catering to the placating of China's growing middle class. China has experienced unprecedented economic development over the course of the past decades. Middle class consumers are significantly more connected and educated (and, by extension, contextually aware) than their low-income counterparts. This reduces their willingness to accept an economic model which incentivizes the exploitation of Chinese human and natural resources by foreign corporations. These factors make China's "cheap labor" model a political and strategic liability to the CCP. Should the Chinese economy fail to transition away

---

[29] "The EU in Brief."

[30] "Priorities."

[31] European Union, "A New Industrial Strategy for Europe," 52020DC0102 § (2020), https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1593086905382&uri=CELEX%3A52020DC0102.

from its current model, the party will have a hard time selling its population on the repressive policies which have, until now, been legitimized by improvements in the country's international status and by the system's ability to produce economic welfare. It will also have a hard time maintaining its strategic autonomy. A China which relies on 3rd countries to develop and deliver cutting-edge technologies and luxury consumer goods is one which is susceptible to international pressures and/or influences.

Of equal relevance are the internationally oriented (geostrategic) considerations surrounding MIC2025. Not only does MIC2025 strive to reduce China's reliance on 3rd countries; it also makes a consecrated effort to increase 3rd countries' reliance on China. Transforming China into an innovation hub capable of developing and exporting breakthrough innovations serves not only to increase the country's international influence and legitimacy, but also to erode the primacy of the United States. Within this context, the MIC2025 can readily be viewed as an opening salvo that provides an early indication of what to expect from the CCP policy as the country works to achieve President Xi's 'qiang zhongguo meng,' or 'strong nation's dream' (hereafter referred to as 'Chinese Dream'), by 2049.[32] At the time of writing, the (international) economic policies associated with the pursuit of the Chinese Dream have been characterized by two high level trends – both of which raise well-founded concerns over China's dependability (and benevolence) as a major trading partner going forward.

China has shown a willingness to leverage its significant economic clout to introduce policies and practices which infringe on WTO commitments and/or clash directly with Western values. Examples of these non-market practices include the state's willingness to finance excess production capacity to facilitate international dumping, laws which force technology transfers from foreign companies,[33] and the Chinese state's role in brokering agreements and facilitating interaction between Chinese-based companies and their Western counterparts. Second, the CCP has systematically engaged in a no-questions-asked approach to securing critical resources through FDI. Clear examples can be observed throughout Africa, where Chinese investors increased their control over mining operations from 10 in 2011 to at least 24 in 2018.[34] Though there is evidence to suggest that the rate at which Beijing has increased its control over African mines has decreased slightly post-2018,[35] the CCP has arguably had easy purchase of these industries as a result of its willingness to finance corruption and

---

[32] Probal Dasgupta, "Xi May Have Lost the Plot on China's Dream of Great Rejuvenation - The Economic Times," The Economic Times, June 29, 2020, https://economictimes.indiatimes.com/news/international/world-news/view-xi-may-have-lost-the-plot-on-chinas-dream-of-great-rejuvenation/articleshow/76679355.cms?from=mdr.

[33] Robert Lighthizer, "How to Set World Trade Straight," Wall Street Journal, August 20, 2020, https://www.wsj.com/articles/how-to-set-world-trade-straight-11597966341.

[34] Bee Chun Boo, "China Aims for Win-Win Partnership with African Mining Sector," Baker McKenzie, January 24, 2020, https://www.bakermckenzie.com/en/insight/publications/2020/01/china-partnership-with-african-mining-sector.

[35] Magnus Ericsson, Olof Lof, and Anton Lof, "Chinese Control over African and Global Mining—Past, Present and Future," Mineral Economics 33 (2020): 153–81, https://doi.org/10/ghkmjp.

contribute to the consolidation of dictators – factors which have both disincentivized Western investments in the past.[36]

Climate

In 2015, the Netherlands and other EU member states became signatory parties to the Paris Climate Agreement, committing to the goal of limiting the increase in temperature to less than 1.5 or 2 degrees Celsius compared to pre-industrial levels.[37] The EU further designed the European Green Deal in order to ensure adherence of its members to the global climate goals outlined in the Paris Agreement.[38] The Green Deal's targets are divided between two main timelines, 2030 and 2050. The 2030 Climate Target Plan requires member states to decrease their greenhouse gas emissions to at least 40% below 1990 levels.[39] However, due to much debate surrounding these non-binding targets being too lenient, the Commission will present a revised version of the 2030 Climate Framework by June 2021.[40] For now, the Netherlands has committed to reducing its emissions by 49% relative to 1990 by 2030, and to a 95% reduction by 2050.[41]

The Chinese Dream, too, places heavy emphasis on renewables. China has committed to ensuring that renewables account for 20% of the country's energy production by 2030,[42] and to achieving carbon neutrality by 2060.[43] The latter goal is based on a speech Xi Jinping held at a UN Conference which received much media attention.[44] Yet so far no official policy documents establishing or detailing this goal have been published.

The current-day concern over China's role in the global energy transition revolves around its emissions – British Petroleum (BP) estimated that the country accounted for 28% of global CO_2 emissions in 2018, more than the US and EU combined. Yet the concern going forward is likely to center around the challenges associated with sourcing raw materials from a country whose energy consumption has increased from 400mn tons oil equivalent (TOE) in 1978 to 3.27bn TOE in 2018.[45] This concern is

---

[36] "More than Minerals," The Economist, March 23, 2013, https://www.economist.com/middle-east-and-africa/2013/03/23/more-than-minerals.

[37] Ministerie van Economische Zaken en Klimaat, "Klimaatakkoord," publicatie (Ministerie van Economische Zaken en Klimaat, June 28, 2019), 5, https://www.klimaatakkoord.nl/documenten/publicaties/2019/06/28/klimaatakkoord.

[38] European Commission, "2030 Climate & Energy Framework," Text, Climate Action - European Commission, November 23, 2016, https://ec.europa.eu/clima/policies/strategies/2030_en.

[39] European Commission.

[40] European Commission, "EU Climate Target Plan 2030: Key Contributors and Policy Tools," Text (European Union, September 17, 2020), 2, https://ec.europa.eu/commission/presscorner/detail/en/fs_20_1610.

[41] https://www.klimaatakkoord.nl/documenten/publicaties/2019/06/28/national-climate-agreement-the-netherlands

[42] X. Jin Yang et al., "China's Renewable Energy Goals by 2050," Environmental Development 20 (November 1, 2016): 84, https://doi.org/10/ghkmjk.

[43] Steven Lee Myers, "China's Pledge to Be Carbon Neutral by 2060: What It Means," The New York Times, September 23, 2020, sec. World, https://www.nytimes.com/2020/09/23/world/asia/china-climate-change.html.

[44] Lili Pike, "Xi Jinping Wants China to Be Carbon Neutral by 2060. These Researchers Have a Plan for That.," Vox, October 15, 2020, https://www.vox.com/2020/10/15/21516537/climate-change-china-xi-jinping-coal-carbon-neutral.

[45] BP 2019 (see the geopolitics of energy transition, p. 76).

grounded in the fact that Beijing has engaged, as outlined in President Xi's Chinese Dream, in an aggressive push effort to ween its energy sector off of fossil fuels. The environmental component of Xi's Chinese Dream will require orders of magnitude more raw materials than the EU, to say nothing of the material requirements of comparable transitions throughout the rest of Asia and Africa.

Demand for materials such as graphite, cobalt, and lithium are expected to increase by as much as 500% of 2018's total production by 2050 as a result of clean energy initiatives alone. Though the severity of shortages brought on by this spike may be slightly mitigated through the introduction of circular economies and by increases in efficiency brought on by technological innovation, the world is on-track to experience significant shortages.[46] The EU, for its part, expects global demand for materials necessary for the construction of wind-turbines and solar panels to outpace global supply by as much as 16% and 21% respectively by 2050.[47]

Digital

Within the information and communication technology (ICT) sector, the concept of technological sovereignty is relevant, implying European autonomy and leadership in the digital sector. European Commission President von der Leyen identified technological sovereignty as a goal of the current Commission's term in office. This ambition was developed as a reaction to global high-tech companies increasingly threatening the cybersecurity of the EU.[48] The main areas of focus are data protection and artificial intelligence.[49] The digital sovereignty ambitions are also relevant from a critical materials perspective. Digital technologies use a wide and increasing range of elements to enable the desired electronic properties needed for chips and devices, and the large number produced each year add up to meaningful volumes of materials, relative to current supply.[50] The EU aims at fostering innovation and competitiveness in the digital sector, while holding companies accountable for ethical issues and security threats.[51] Digital performance is a priority for the Netherlands as well, given that high-tech systems are considered a top sector of the Dutch economy.[52]

---

[46] Kirsten Hund et al., "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition" (World Bank Group, 2020).

[47] https://ec.europa.eu/jrc/en/publication/raw-materials-demand-wind-and-solar-pv-technologies-transition-towards-decarbonised-energy-system

[48] Tambiama Madiega, "Digital Sovereignty for Europe," EPRS Ideas Paper (European Parliament, 2020), 1.

[49] Madiega, 1.

[50] Anthony Y. Ku, "Anticipating Critical Materials Implications from the Internet of Things (IOT): Potential Stress on Future Supply Chains from Emerging Data Storage Technologies," Sustainable Materials and Technologies 15 (April 1, 2018): 27–32, https://doi.org/10/ghgss5.

[51] Madiega, "Digital Sovereignty for Europe," 1.

[52] Ministerie van Economische Zaken, "Encouraging Innovation - Enterprise and Innovation," onderwerp (Ministerie van Algemene Zaken, December 21, 2011), https://www.government.nl/topics/enterprise-and-innovation/encouraging-innovation.

Xi Jinping has also set high objectives in the digital sector to be achieved by 2049, which marks the centenary of the People's Republic of China.[53] The 2049 strategic vision – the Chinese dream – foresees global industrial and technological leadership in strategic sectors.[54] According to the European Commission, the sectors in which China has been gaining important competitive advantages are ICT, machinery and electrical industries.[55] The emergence of tech giants such as Alibaba, Baidu and Xiaomi illustrate the significant progress made by China in the global digital sector.[56] Additionally, the controversy surrounding the adoption of Chinese 5G infrastructure as well as significant FDI in the European high-tech sector shows the proactivity of Chinese companies in trying to establish themselves as global leaders. The government is closely monitoring and supporting the progress of Chinese digital companies so that developments are aligned with the country's strategic ambitions.[57] What is more, the COVID-19 pandemic has provided an additional push to China's digital transformation. Stimulus packages include measures to accelerate the adoption of new technologies such as 5G, as well as to invest more in artificial intelligence and data innovation centers.[58]

3.2 Critical raw materials

The European Commission defines critical raw materials as having high economic value and supply risk.[59] While this chapter refers to critical materials on the EU list, it should be noted that China does not have an equivalent term. The critical materials concept has been translated into Chinese (关键原料) and used only since the EU popularized it. As such, although China has for a long time been attempting to secure a dominant position regarding these raw materials, they are not considered 'critical', perhaps due to large domestic availability.

In the context of the 2050 climate goals, the Commission views critical raw materials as essential resources for the construction of technologies such as wind turbines, permanent magnets and solar panels. A similar definition is adopted by

---

[53] ODI, "Global China 2049 Initiative," ODI, accessed November 11, 2020, https://www.odi.org/projects/china-2049-initiative.

[54] European Commission, "China Is on Track to Achieve Its Objective of Global Industrial and Technological Leadership in Key Sectors by 2049," Text, EU Science Hub - European Commission, July 15, 2019, https://ec.europa.eu/jrc/en/facts4eufuture/china-report-challenges-and-prospects/industrie-innovation-leadership-2049.

[55] European Commission.

[56] Alicia Garcia Herrero and Jianwei Wu, "How Big Is China's Digital Economy?," Working Paper (Bruegel, May 17, 2018), 2, https://www.bruegel.org/wp-content/uploads/2018/05/WP04_Digital-economy_Bruegel.pdf.

[57] European Commission, "China Is on Track to Achieve Its Objective of Global Industrial and Technological Leadership in Key Sectors by 2049."

[58] Rebecca Arcesati, "Competing with China in the Digital Age," in Towards a "Principles First Approach" in Europe's China Policy (MERICS, 2020), 49, https://merics.org/sites/default/files/2020-09/200910_MPOC_EU-China_final_0.pdf.

[59] European Commission, "COM(2020) 474 - Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability" (Brussels, March 9, 2020), 2, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0474.

the U.S. Department of Energy, who views criticality as both relevance for renewable technologies and heightened supply risk.[60] Supply risk can be measured through the vulnerability of a product to disruptions.[61] On one hand, disruptions can be environmental, such as natural disasters on the short term and ore depletion on the long term.[62] On the other hand, political and economic developments can also lead to supply risks through the imposition of trade restrictions.[63] The availability of substitution possibilities[64], strategic importance, price sensitivity and future demand to supply ratio[65] are additional aspects often considered when assessing criticality. Depending on the particularities of each country's technological requirements, different raw materials are deemed critical.[66] The EU, US and Japan are among the main actors who compile critical raw materials lists as a strategy toward ensuring security of supply.[67] The latest critical materials list of the EU from 2020 recognizes 30 CRM.[68]

The critical materials list has been narrowed down based on the 2050 material demand projections for relevant technologies (see chapter 4. Critical sectors). This report focuses on the specific CRMs included in Table 1, together with the relevant technologies in which they are used. The CRMs are further matched with Harmonized System (HS) codes from the UN Comtrade and CBS databases. The Harmonized System is a universal classification of goods and services that can be used to track trade flows across borders.

---

[60] U.S. Department of Energy, "Critical Materials Strategy," 2010, 6, https://www.energy.gov/sites/prod/files/edg/news/documents/criticalmaterialsstrategy.pdf.

[61] Nabeel A. Mancheri et al., "Effect of Chinese Policies on Rare Earth Supply Chain Resilience," Resources, Conservation and Recycling 142 (March 1, 2019): 101, https://doi.org/10.1016/j.resconrec.2018.11.017.

[62] Benjamin Sprecher et al., "Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis," Environmental Science & Technology 49, no. 11 (June 2, 2015): 6746, https://doi.org/10.1021/acs.est.5b00206.

[63] Sprecher et al., 6746.

[64] Artem Golev et al., "Rare Earths Supply Chains: Current Status, Constraints and Opportunities," Resources Policy 41 (September 1, 2014): 53, https://doi.org/10.1016/j.resourpol.2014.03.004.

[65] Christoph Helbig et al., "How to Evaluate Raw Material Vulnerability - An Overview," Resources Policy 48 (June 2016): 7, https://doi.org/10.1016/j.resourpol.2016.02.003.

[66] Gabrielle Gaustad et al., "Circular Economy Strategies for Mitigating Critical Material Supply Issues," Resources, Conservation and Recycling, Sustainable Resource Management and the Circular Economy, 135 (August 1, 2018): 24, https://doi.org/10.1016/j.resconrec.2017.08.002.

[67] Sophia Kalantzakos, "The Race for Critical Minerals in an Era of Geopolitical Realignments," The International Spectator 55, no. 3 (July 2, 2020): 1, https://doi.org/10/gg9fkb.

[68] European Commission, "COM(2020) 474 - Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability," 3.

Critical material		Technology	HS Codes for CRMs[69]
Light Rare Earth Elements	Cerium	Electric vehicles	**2805**
	Lanthanum	Electric vehicles	
	Neodymium	Wind turbines, Electric vehicles, Digital technologies	
	Praseodymium	Wind turbines, Electric vehicles	
	Samarium	Electric vehicles	
Heavy Rare Earth Elements	Dysprosium	Wind turbines, Electric vehicles, Digital technologies	
	Terbium	Wind turbines, Electric vehicles	
Cobalt		Carbon capture and storage, Electric vehicles, Digital technologies	**2605**
Gallium		Solar PV, Electric vehicles, Digital technologies	**8112**
Germanium		Solar PV, Electric vehicles, Digital technologies	**8112**
Graphite		Digital technologies	**2504**
Indium		Solar PV, Electric vehicles, Digital technologies	**8112**
Lithium		Electric vehicles, Digital technologies	**283691**
Niobium		Carbon capture and storage	**2615**
Palladium		Digital technologies	**711021**
Silicon		Solar PV, Digital technologies	**280461**
Tantalum		Digital technologies	**2615**
Titanium		Geo-thermal energy	**2614**
Tungsten		Digital technologies	**2611**
Vanadium		Carbon capture and storage	**2615**

Note: For the description of these HS Codes, see Appendix 2. Overview HS Codes for CRMs. For HS Codes regarding technologies covered in this report, see Appendix 3. Overview HS Codes for relevant technologies.

Table 1. Critical Raw Materials considered in this report and their uses

In short, both the EU and China have set ambitious geopolitical, digital and climate goals for the following decades. From a practical perspective, the achievement of their goals relies heavily on the availability of supplies of critical raw materials, leading to a dramatic projected increase in the global demand of (critical) materials in the near future.[70] The difference between the EU and China is that the latter is largely self-sufficient in terms of raw materials, intermediate and end products, while the EU is highly dependent on imports. Against this backdrop, the remaining of this report seeks to find ways of mitigating challenges that might arise in the EU's procurement of critical materials and technologies.

---

[69] HS Codes are extracted from the UN Comtrade database. This database is compatible with the Netherlands' CBS coding system.

[70] Hund et al., "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition," 11.

4. Critical sectors

4.1 Energy

Important technologies for the energy sector of the future will be wind turbines, solar photovoltaics, geothermal energy, carbon capture and storage, and the grid infrastructure necessary to support the electrification of the energy sector.

4.1.1 Wind turbines

The *Klimaatakkoord* states that in order to reach the GHG emission reduction target, 49 TWh will be produced by offshore wind energy, and 35 TWh by renewables on land by 2030.[71] Assuming a linear growth of installed capacity, this implies that by 2030 there needs to be an installed capacity of 11.7 GW of offshore wind turbines and 7.2 GW of onshore wind turbines.[72] In 2020, the installed capacity is 4.99 GW.[73] The metal demand for increasing Dutch wind energy production in 2030 is significant. It is estimated that the cumulative demand for Neodymium, Praseodymium and Dysprosium will be particularly important. [74]

Material requirements

Wind turbines consist of over 25,000 components, which can be grouped into a few main systems: the tower, nacelle and rotor. The rotor consists of blades, a hub and spinner. The main materials used in the blades are woven glass (or sometimes carbon) fibers infused with epoxy resin. The hub is made of steel, the spinner of glass fiber-reinforced polyester. The rotor is connected to the nacelle, which is attached to the tower. The nacelle is the most complex part of the wind turbine, containing the main shaft, gear box, generator and control systems. The tower is the largest part of the turbine, accounting for a significant proportion of turbine mass. It is primarily manufactured from structural steel, erected onto a concrete and iron foundation, and in case of offshore turbines, a monopile underwater structure.[75]

---

[71] Ministerie van Economische Zaken en Klimaat, “Klimaatakkoord.”

[72] Pieter van Exeter et al., “METAL DEMAND FOR RENEWABLE ELECTRICITY GENERATION IN THE NETHERLANDS” (Metabolic, 2018).

[73] “Statistieken - Windstats.Nl,” accessed October 5, 2020, https://windstats.nl/statistieken/#data_results.

[74] van Exeter et al., “METAL DEMAND FOR RENEWABLE ELECTRICITY GENERATION IN THE NETHERLANDS.”

[75] 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.

The type of wind turbine chosen for a site varies depending on size requirements, cost, site conditions, availability and maintenance and operation requirements. The different turbines have different material conditions and supply chains. The following table shows a range of material compositions taking into account four wind turbine types: Direct Drive Electrically Excited Synchronous Generator, Direct Drive Permanent Magnet Synchronous Generator, Gearbox Permanent Magnet Synchronous Generator and Gearbox Double-Fed Induction Generator.[76]

Material	Amount (kg/MW)	Global producers	Notes
Aluminum (Al)	500-1600		
Boron (B)	0-6		
Chromium (Cr)	470-580		
Copper (Cu)	950-5000		The higher estimate is for direct-drive turbines. There is consensus that direct-drive generators can use three times more copper than gearbox configurations.
Dysprosium (Dy)	2-17	Mostly Southern China, some from other Chinese mines and Western Australia	Dysprosium is used in the permanent magnets of the turbine generator, and in magnets for attaching internal fixtures within the turbine tower. The lower estimate is for high- to medium- speed turbines with a gearbox; the higher estimate is for direct-drive turbines.
Iron (cast) (Fe)	18,000 - 20,800		
Manganese (Mn)	780-800		
Molybdenum (Mo)	99-119		
Neodymium (Nd)	12-180	80% of global production in China, some Western Australia and other countries	Neodymium is used in the permanent magnets of the turbine generator, and also in magnets for attaching internal fixtures within the turbine tower. The amount of neodymium in direct-drive turbines is substantially higher. It is estimated at 180 kg/MW, up to 15 times as much as a conventional high-speed drivetrain.
Nickel (Ni)	240-440		
Praseodymium (Pr)	0-35	80% of global production in China, some Western Australia and other countries	Praseodymium is used in the permanent magnet of the turbine generator together with neodymium. The lower estimate is for high- to medium-speed turbines with a gearbox; the higher estimate is for direct-drive turbines.
Terbium	0-7	80% of global production in China, some Western Australia and other countries	Terbium is used in the permanent magnet of the turbine generator where it replaces dysprosium. The lower estimate is for high- to medium-speed turbines with a gearbox; the higher estimate is for direct-drive turbines.

---

[76] Samuel Carrara et al., "Raw Materials Demand for Wind and Solar PV Technologies in the Transition towards a Decarbonised Energy System," 2020, https://ec.europa.eu/jrc/en/publication/raw-materials-demand-wind-and-solar-pv-technologies-transition-towards-decarbonised-energy-system.

Material	Amount (kg/MW)	Global producers	Notes
Zinc (Zn)	5500		
Concrete	243,500-413,000		
Steel	107,000-132,000		
Polymers	4600		
Glass/carbon composites	7700-8400		

In green: Critical raw materials as listed by the European Commission[77]

Table 2. Material composition estimates for direct drive and gearbox wind turbines, aggregated from Carrara et al[78]

Rare earth elements improve the performance of turbines by making the generators more efficient and more grid-compatible, while also reducing the number of moving parts and, thus, maintenance needs. This allows for a reduction in the overall size of the generator and powertrain, and for the use of less structural materials, contributing to a smaller carbon footprint. The amount of rare earth elements used in direct-drive turbines is up to 10 times higher than the amounts used in a conventional drive train.[79]

Supply chain

Tower: The tower consists predominantly out of structural steel. In 2019, steel was produced in large quantities on all continents, the biggest steel producing country being China, accounting for 53.3% of world production.[80] Steel sections are manufactured offsite and assembled on site. The parts are bolted together while the tower is horizontal, and then lifted into position by crane onto a concrete foundation or monopile (offshore). The major global companies manufacturing wind turbine towers include: Trinity Structural Towers Inc. (headquartered in Texas, USA), Valmont Industries Inc. (production facility in Rødekro, Denmark), KGW Schweriner Maschinen- und Anlangenbau GmbH (production facilities in Germany).[81] Denmark and the Netherlands are considered major global wind-tower manufacturing powerhouses, manufacturing towers on a significant scale mostly for export to the U.S. and European markets.[82]

---

[77] European Commission, "COM(2020) 474 - Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability."

[78] Carrara et al.

[79] Garrett and Razdan, "Life Cycle Assessment of Electricity Production from an Onshore V117-3.45 MW Wind Plant."

[80] "Global Crude Steel Output Increases by 3.4% in 2019," 2020, http://www.worldsteel.org/media-centre/press-releases/2020/Global-crude-steel-output-increases-by-3.4--in-2019.html.

[81] ReportLinker, "Wind Turbine Tower Market - Growth, Trends, and Forecast (2019 - 2024)," GlobeNewswire News Room, February 26, 2020, http://www.globenewswire.com/news-release/2020/02/26/1991466/0/en/Wind-Turbine-Tower-Market-Growth-Trends-and-Forecast-2019-2024.html.

[82] "Analyzing the Global Market for Wind-Turbine Towers," Windpower Engineering & Development, 2016, https://www.windpowerengineering.com/analyzing-the-global-market-for-wind-turbine-towers/.

Nacelles: The critical materials in wind turbines are four rare earth elements (REEs): Dysprosium, Neodymium, Praseodymium and Terbium. Rare earth ores are mined and milled into fine particles. Rare earth-containing minerals are then extracted from the particles producing rare earth oxide concentrates. The concentrates, usually containing different types of rare earth elements, are then separated into individual rare earth oxides. The oxides are then either sold to downstream consumers or refined into metals. In 2019, China accounted for 70% of REE mining, 85% of REE oxide refining, 90% of REE metals and 90% of magnets production.[83] Production in China is concentrated in Shandong and Inner Mongolia in the north, Sichuan in the west, and Jiangxi, Guangdong, Fujian, Hunan, and Guangxi in the south. In the 2000s, the central government consolidated production into the hands of state-owned companies, resulting in six state-owned firms now producing around 85% of China's rare earth output. The Bayan Obo mine in Inner Mongolia, operated by state-owned Baotou Iron and Steel, is by far the world's largest, accounting for over half of China's total output.[84]

These rare earth metals are used in the permanent magnets in wind turbines. Japan and China are the two main REE magnet-producing countries, with China having a 90% market share.[85] In Europe, Germany is the largest consumer and manufacturer of permanent magnets.[86] Permanent magnets can be found in all turbines, but only Permanent Magnet Synchronous Generator (PMSG) turbines use them in large quantities. In 2015, it was estimated that about 23% of the global installed capacity consisted of wind turbines using the PMSG technology, and the remaining 77% was using conventional electromagnets generators.[87] The latter are based on electromagnets made from magnetic steel and copper windings (which are not on the critical raw materials list). The wind turbine nacelle market is internationally diverse. Leading vendors include Siemens Gamesa (production centers are in China and Spain, while its manufacturing divisions are in Brazil and India), General Electric (manufacturing in Vietnam, Germany, Brazil and India, and assembly in France, US and China[88]) and MFG.[89]

Blades: Wind turbine blades can be up to 75m long and require a careful and precise manufacturing process. First, fibers are placed in closed and sealed mold. Then, resin is injected into the mold cavity under pressure.[90] After the resin fills all the volume

---

[83] Ryan Castilloux, "Rare Earth Elements: Market Issues and Outlook" (Adamas Intelligence, 2019), 8.

[84] Carlos Aguiar De Medeiros et al., "Transforming Natural Resources into Industrial Advantage: The Case of China's Rare Earths Industry," Brazilian Journal of Political Economy 37, no. 3 (July 2017): 504–26, https://doi.org/10/ggbhwn.

[85] Ryan Castilloux, "Rare Earth Elements: Market Issues and Outlook" (Adamas Intelligence, 2019), 8.

[86] "Permanent Magnets Market Size & Share | Industry Report, 2027."

[87] Claudiu C. Pavel et al., "Substitution Strategies for Reducing the Use of Rare Earths in Wind Turbines," Resources Policy 52 (June 1, 2017): 349–57, https://doi.org/10/gbprkx.

[88] "GE RENEWABLE ENERGY LOCATIONS | GE Renewable Energy," accessed September 2, 2020, https://www.ge.com/renewableenergy/about-us/locations.

[89] "Global Wind Turbine Nacelle Market 2017-2021," Technavio, 2017–21, accessed September 2, 2020, https://www.technavio.com/report/global-wind-turbine-nacelle-market.

[90] Leon Mishnaevsky et al., "Materials for Wind Turbine Blades: An Overview," Materials 10, no. 11 (November 9, 2017), https://doi.org/10/gf8hb4.

between fibers, lasers are used to make sure each blade is properly curved. After that, the blade is coated to protect it from dust particles and water droplets.[91] The blade is transported to the assembly site with enormous convoys. A trend in wind turbine development is the increase in size of blades, motivated by the desire to reduce the leveraged cost of energy.[92] With increasing size, the weight of the rotor blades increases, and with it, the material requirements.

The wind turbine rotor blade market is globally fragmented; there is a large number of manufacturers involved. This includes TPI Composites SA, LM Wind Power (a GE Renewable Energy business), Siemens Gamesa Renewable Energy SA, Vestas Wind Systems A/S, and Enercon GmbH. Some of the major players in the wind turbine industry, like the end-user sector for rotor blades, are also significant players, indicating major vertical integration in the market.[93]

Challenges and opportunities

Development of green production technology: Despite their name, rare earth elements are not so rare. Most of these elements are as abundant as copper or lead, and annual global demand has yet to surpass annual supply. Instead, rare are the places where it is politically acceptable to mine and process them in a cost-effective manner.[94] Countries such as Australia and Russia have rich reserves, however they face challenges in separating the individual rare earths and appropriately disposing of radioactive waste in line with environmental standards. These obstacles prevent large-scale production of rare earth metals outside China.[95] Therefore, it is stated that "nations with abundant rare earth reserves and high wind-power ambition need to strengthen the development of green production technology to establish a responsible and sustainable rare earth supply chain".[96]

Long life-spans: For wind turbines, especially for offshore installations, focusing on a longer lifespan is important: while turbines keep producing electricity, minimal additional material is required.[97] Wind turbines have an expected lifetime in the range of 20 - 25 years, after which decommissioning is expected.[98] There is limited practical experience regarding the decommissioning and recycling of wind turbines,

---

[91] "Innovative Wind Turbine Blade Manufacturing | GE Renewable Energy," accessed September 8, 2020, https://www.ge.com/renewableenergy/stories/lm-castellon-wind-turbine-blade-manufacturing.

[92] Mishnaevsky et al., "Materials for Wind Turbine Blades.

[93] "Wind Turbine Rotor Blade Market | Growth, Trends, and Forecasts (2020 - 2025)," accessed September 2, 2020, https://www.mordorintelligence.com/industry-reports/wind-turbine-rotor-blades-market.

[94] Julie Michelle Klinger, "Rare Earth Elements: Development, Sustainability and Policy Issues," The Extractive Industries and Society 5, no. 1 (January 1, 2018): 1–7, https://doi.org/10.1016/j.exis.2017.12.016.

[95] Jiashuo Li et al., "Critical Rare-Earth Elements Mismatch Global Wind-Power Ambitions," One Earth 3, no. 1 (July 24, 2020): 116–25, https://doi.org/10/ghbzg3.

[96] Li et al.

[97] van Exeter et al., "METAL DEMAND FOR RENEWABLE ELECTRICITY GENERATION IN THE NETHERLANDS."

[98] Jonas Pagh Jensen, "Evaluating the Environmental Impacts of Recycling Wind Turbines," Wind Energy 22, no. 2 (2019): 316–26, https://doi.org/10/ggtbt2.

and 20 years are likely needed before substantial practical experience is gained in this specific field. The Netherlands Enterprise Agency has formulated the *Applicable Law for Offshore Energy*, which requires the permit holder to "dismantle and remove all elements of the wind farm within 2 years at the latest after power generation operations have stopped".[99]

Recycling: Some of the turbine components (such as the tower) are relatively easy to recycle, with an established recycling process. Steel can be recycled with 10% loss.[100] Permanent magnets in wind turbines are relatively easily to dismantle, however recycling technology for rare earths is still in the early stages of development and face a number of difficulties: many devices (not limited to wind turbines) contain less than one gram of valuable rare earths; product design tends to be unfriendly and not suitable for the easy separation of components, which makes the recycling process expensive; there tends to be insufficient information of the REE content of different products.[101] In permanent magnets, efficient metallurgical separation and refining remain the main challenges.[102] Recycling blades remains a challenge; the main difficulties being that the structure of the blade is highly specific and complex, and that it is made from a composite material that cannot be remolded to form new products.[103] Studies on the recyclability of wind turbines vary, and though there is a general lack of consensus on absolute numbers, most studies state that, based on mass, 80 - 90% of the materials in a wind turbine can be recycled.[104] Improvement in recycling technology would lead to a decrease in demand for metals. Improving purity of recovered materials and improving energy consumption related to this recovery are primary areas of improvement in upcoming years.[105]

Permanent magnets: There are two types of turbine drive train concepts using rare earth elements: conventional gearbox drive train and direct-drive (without a gearbox). The amount of rare earth elements used in direct-drive turbines is substantially higher – up to 10 times as much as a generator in a conventional drive train.[106] Permanent magnet generators (PMG) are used because they have a high efficiency (due to the elimination of field loss), and they are smaller and more lightweight in comparison to excited synchronous generators.[107]

---

[99] Jensen.

[100] N. Stavridou, E. Koltsakis, and C. C. Baniotopoulos, "A Comparative Life-Cycle Analysis of Tall Onshore Steel Wind-Turbine Towers," Clean Energy 4, no. 1 (April 4, 2020): 48–57, https://doi.org/10/ggtbvs.

[101] S Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study" (JRC, European Commission, 2020).

[102] Yongxiang Yang et al., "REE Recovery from End-of-Life NdFeB Permanent Magnet Scrap: A Critical Review," Journal of Sustainable Metallurgy 3, no. 1 (March 1, 2017): 122–49, https://doi.org/10/gbvt2r.

[103] Mishnaevsky et al., "Materials for Wind Turbine Blades."

[104] Jensen, "Evaluating the Environmental Impacts of Recycling Wind Turbines."

[105] van Exeter et al., "METAL DEMAND FOR RENEWABLE ELECTRICITY GENERATION IN THE NETHERLANDS."

[106] Garrett and Razdan, "Life Cycle Assessment of Electricity Production from an Onshore V117-3.45 MW Wind Plant."

[107] Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."

About a third of wind turbines installed globally in 2018 incorporated PMGs. This proportion could grow to two-thirds in 10 to 15 years as next generation designs call for more "power per tower".[108] On the other hand, the cost of wind turbines is influenced by metal prices, in particular in the case of turbines that contain rare earth elements, such as PMGs. The European shares along the supply chain are lowest upstream; in the necessary raw materials is 1%, for processed materials it is 12%, 18% for components and 58% for assemblies.[109] Concerns that the supply of rare earths may not be sufficient to meet the growing demand for the global transition to a sustainable energy future have grown considerably since the 'crunch' in 2011 when near-monopolistic China imposed export restrictions (see chapter 5.1. Resource Nationalism).[110] Some major wind turbine manufacturers, e.g. Vesta, choose to use conventional drive train generators to decrease dependency on rare earths, and the associated environmental and labor violations.[111]

Some experts argue the gearbox wind turbine is almost at its maximum efficiency point, while the direct-drive turbines have more possibilities for improvement. The costs of the offshore support structure for direct-drive wind turbines is lower due to its lighter weight. And, while direct drive turbines containing rare earth magnets may cost more than geared turbines, they are also seen as requiring less maintenance, an important factor for offshore wind farms, where maintenance operations are costly. On the other hand, there are many gearbox wind turbines currently available and in use in the market, and there is ongoing R&D to reduce weight and material demand; there has already been a reduction of copper. Therefore, it seems that both technologies sit shoulder-to-shoulder. Looking to the future, either both technologies will continue developing until one prevails, or both types will find sufficient users to coexist in the market. The key determinants of the dominant turbine technology will be manufacturer brand reputation and credibility, total energy yield, cost and reliability, price, availability of scarce materials, manufacturer's warranty and the number of suppliers for components.

4.1.2 Photovoltaic solar power

The *Klimaatakkoord* states that in order to reach the GHG emission reduction target, 35 TWh will be produced by renewable energy sources on land by 2030.[112] Assuming a linear growth of installed capacity, this implies 19.5 GW of photovoltaic solar energy in 2030.[113] The related metal demand depends on the sub-technologies of PV that are installed. Photovoltaic (PV) systems are based on the use of semiconductors that

---

[108] Adamas Intelligence, "FORESIGHT: Wind Industry Prepares for Bottlenecks and Price Hikes," Adamas Intelligence, accessed November 12, 2020, https://www.adamasintel.com/foresight-wind-industry-bottlenecks-price-hikes/.
[109] Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."
[110] Bobba et al.
[111] Garrett and Razdan, "Life Cycle Assessment of Electricity Production from an Onshore V117-3.45 MW Wind Plant."
[112] Ministerie van Economische Zaken en Klimaat, "Klimaatakkoord."
[113] van Exeter et al., "METAL DEMAND FOR RENEWABLE ELECTRICITY GENERATION IN THE NETHERLANDS."

generate electric power when exposed to sunlight.[114] There are several sub-technologies, the most common of which are: wafer-based crystalline silicon (c-Si), cadmium telluride (CdTe), copper indium gallium selenide (CIGS) and amorphous silicon (a-Si).[115] Currently, c-Si technologies hold 95% of the market share, while thin-film technologies hold 4.6% of the market share.[116] Based on previous studies, it is predicted that the future shares of PV sub-technologies will be: 90% c-Si, 5% CdTe and 5% CIGS.[117]

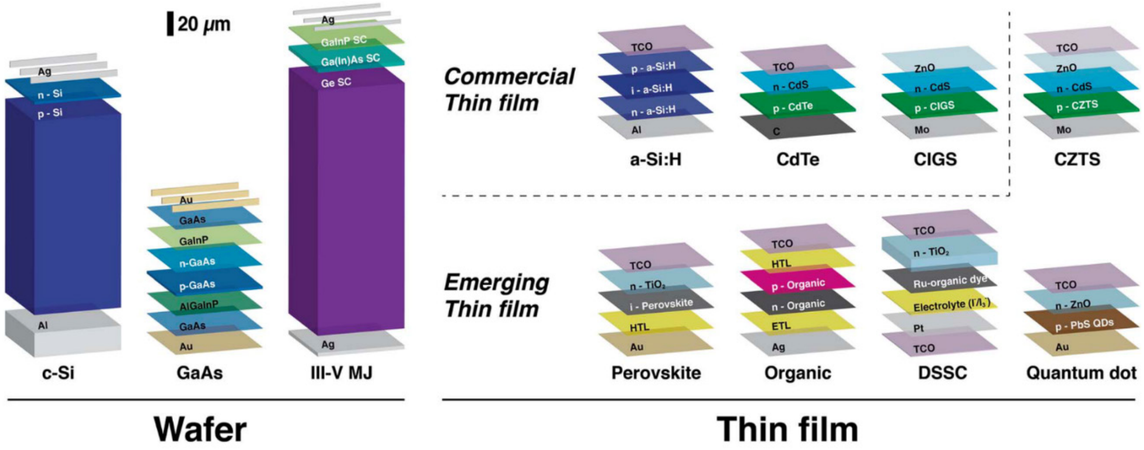


Figure 2. Typical solar PV device structures, divided into wafer-based and thin-film technologies, figure from Jean et al.[118]

Material requirements

Material	Amount (kg/MW)	Global producers	Notes
Aluminum (Al)	7500		Module frames, racking, supports
Cadmium (Cd)	1-85		Lower estimate is for CIGS solar cells; higher estimate is for CdTe photovoltaics
Copper (Cu)	4600		Wiring, cabling, earthing, inverters, transformers of all PV systems, in CIGS: 20-24 kg/MW
Gallium (Ga)	3-7	China (85%) Germany (7%) Kazakhstan (5%)	Dopant in semiconductors or in CIGS technology
Germanium (Ge)	48	China (67%) Finland (11%) Canada (9%) United States (9%)	a-Si, semiconductor materials for multi-junction solar cells[119]

---

[114] Ayman Elshkaki and T. E. Graedel, "Dynamic Analysis of the Global Metals Flows and Stocks in Electricity Generation Technologies," Journal of Cleaner Production 59 (November 15, 2013): 260–73, https://doi.org/10/f5f8zh.

[115] Carrara et al., "Raw Materials Demand for Wind and Solar PV Technologies in the Transition towards a Decarbonised Energy System."

[116] Fraunhofer Institute for Solar Energy Systems, et al., "Photovoltaics Report," 2020, 48.

[117] van Exeter et al., "METAL DEMAND FOR RENEWABLE ELECTRICITY GENERATION IN THE NETHERLANDS."

[118] Joel Jean et al., "Pathways for Solar Photovoltaics," Energy & Environmental Science 8, no. 4 (2015): 1200–1219, https://doi.org/10/gg2wtk.

[119] Bobba et al.

Material	Amount (kg/MW)	Global producers	Notes
Indium (In)	10-27	China (57%) South Korea (15%) Japan (10%)	ITO conductive layer or in CIGS technology
Lead (Pb)	72		c-Si
Molybdenum (Mo)	37		CIGS
Selenium (Se)	22-60		CIGS
Silicon (Si)	150-4000	China (61%) Brazil (9%) Norway (7%) United States (6%) France (5%)	Lower estimate is for a-Si; higher estimate is for c-Si. For a-Si values are often not reported in literature.
Silver (Ag)	5-20		c-Si technologies
Tellurium (Te)	5-95		Lower estimate is for CIGS; higher estimate is for CdTe
Tin (Sn)	6		CIGS
Zinc (Zn)	29		CIGS
Concrete	60,700		System support structures
Steel	67,900		System support structures
Plastic	8600		Environmental protection
Glass	46,400		Substrates, module encapsulation

In green: Critical raw materials as listed by the European Commission[120]

Table 3. Material composition estimates for solar PV panels, aggregated from Carrara et al[121], World Bank Group[122] and Bobba et al[123]

Supply chain

c-Si: The main raw materials used in c-Si photovoltaic systems are silicon, aluminum and copper. High-purity silicon is produced from quartz sand in an arc furnace at very high temperatures. Refining silicon into the required purity of polysilicon is an energy- and cost-intensive process.[124] The United States, Germany and South Korea are the largest exporters of polysilicon, mainly to China and Japan, yet China is still the largest producer[125] with 70% of the global share.[126] Solar-grade polysilicon is manufactured into ingots through a process of: melting, adding dopants, re-crystallizing the melt into ingots, then cropping and sawing into thin wafers. Ingots and wafers are typically produced in the same facility. [127] Wafers are then texturized, doped to form

---

[120] European Commission, "COM(2020) 474 - Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability."

[121] Carrara et al., "Raw Materials Demand for Wind and Solar PV Technologies in the Transition towards a Decarbonised Energy System."

[122] World Bank Group, The Growing Role of Minerals and Metals for a Low Carbon Future (World Bank, 2017), https://doi.org/10.1596/28312.

[123] Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."

[124] GreenMatch, "How Are Solar Panels Made?," 2019, https://www.greenmatch.co.uk/blog/2014/12/how-are-solar-panels-made.

[125] GreenMatch.

[126] Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."

[127] Debra Sandor et al., "BENCHMARKS OF GLOBAL CLEAN ENERGY MANUFACTURING" (NREL, 2017).

the semiconducting p-n junction, and metallized, resulting in a finished PV cell.[128] [129] These solar cells are then soldered together, laminated within encapsulants, and sandwiched between a glass layer and a protective back sheet.[130] Silver is used as contact metallization on the front and rear of the cell.[131] Silver pastes are commonly produced in China, Japan, and South Korea.[132] The entire assembly is then set within an aluminum frame, and a junction box is added, resulting in a complete PV module. To turn the module into a solar panel, the 'Balance of System' is added: this includes an inverter, blocking diode, charge controller, circuit breaker, switch gear, wiring and optionally a battery.[133] The manufacturing of c-Si PV panels is concentrated in a small number of countries (Malaysia, India, Vietnam and South Korea[134]) and is led by China, where the size of the industry far exceeds that of all other countries combined.[135]

In CdTe cells, the main raw materials used are cadmium, zinc and tellurium. In CIGS cells, the main raw materials used are copper, indium, gallium and selenium. Each photovoltaic solar technology has a constraining metal supply; silver for silicon-based technologies, tellurium for CdTe technology, indium for CIGS, and germanium for a-Si.[136]

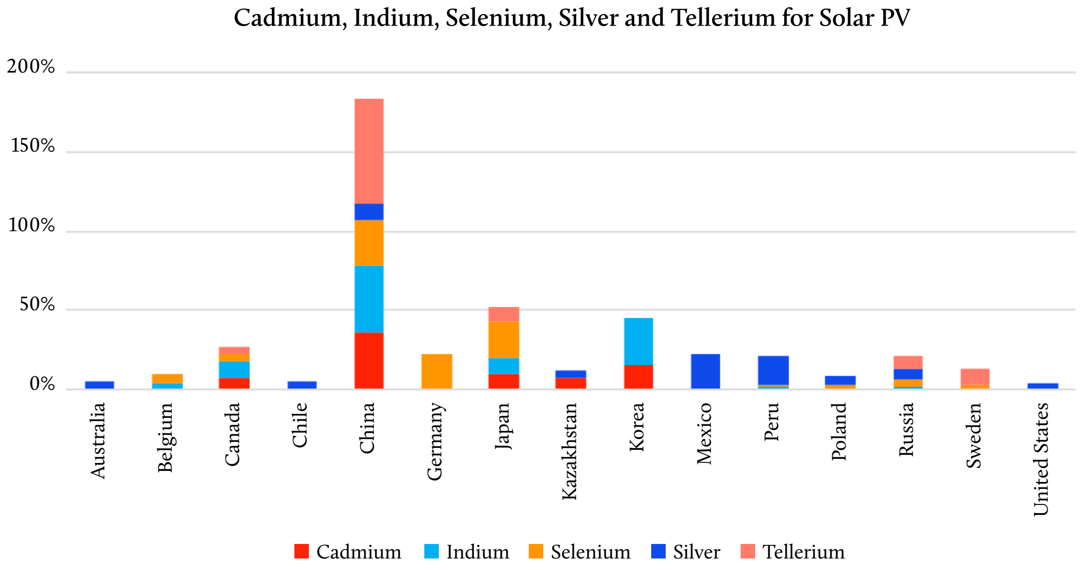


Figure 3. Share of production of metals for PV by country, Source: Dominish et al [137]

---

128 Sandor et al.

129 GreenMatch, "How Are Solar Panels Made?"

130 Sandor et al., "BENCHMARKS OF GLOBAL CLEAN ENERGY MANUFACTURING."

131 Martin A. Green, "Ag Requirements for Silicon Wafer-Based Solar Cells," Progress in Photovoltaics: Research and Applications 19, no. 8 (2011): 911–16, https://doi.org/10/dcf7zm.

132 Sandor et al., "BENCHMARKS OF GLOBAL CLEAN ENERGY MANUFACTURING."

133 Stone & Associates, "Overview of the Solar Energy Industry and Supply Chain," 2011, https://www.bgafoundation.org/wp-content/uploads/2016/08/Solar-Overview-for-BGA-Final-Jan-2011.pdf.

134 Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."

135 Sandor et al., "BENCHMARKS OF GLOBAL CLEAN ENERGY MANUFACTURING."

136 Elshkaki and Graedel, "Dynamic Analysis of the Global Metals Flows and Stocks in Electricity Generation Technologies."

137 Elsa Dominish, Sven Teske, and Nick Florin, "Responsible Minerals Sourcing for Renewable Energy," Report prepared for Earthworks by the Institute for Sustainable Futures, University of Technology Sydney. (Earthworks, 2019), https://www.uts.edu.au/sites/default/files/2019-04/ISFEarthworks_Responsible%20minerals%20sourcing%20for%20renewable%20energy_Report.pdf.

Figure 3 shows the share of production of metals for PV by country. Aside from China, Japan, Korea, Canada and Russia also have significant production levels of metals for PV.[138] In addition, the reliance of the EU on imports of silicon metal is estimated to be 64%. In order to secure access to silicon metal, the EU must look to countries such as the USA, Brazil and Norway.[139] According to Bloomberg, the EU manufacturing capacity for crystalline silicon cells in 2019 accounted for only 0.3%; from Italy, Germany and France.[140] The manufacturing capacity of solar cells is the weakest link of the PV value chain in the EU.[141]

Challenges and opportunities

Recycling: The current volumes of end-of-life panels is too low for recycling to be financially attractive, and where it does occur, it is focused on recovering aluminum, copper and glass.[142] Rare earths are seldom recovered, nor is silver despite it being the most valuable metal in a typical panel (representing nearly 50% of a PV's material value)[143] The extraction of secondary raw materials from end-of-life PV panels could create important value for the PV industry.[144] This could be done by including a recycling strategy in the manufacturing process for PV modules, as it would be important to ensure that (some of) the secondary material flows come back to PV manufacturers so that they can maximize their profits.[145]

Modular design: Recycling is also difficult for technical reasons; most materials in a PV module can barely be separated and therefore not be reused.[146] For example, the encapsulant is designed to last for decades in harsh environments without losing its functional properties. The material used for it cannot be dissolved or melted for recycling without decomposition.[147] This makes recycling PV prone to significant material losses.[148] In order to encourage recycling materials or re-using components, there is an opportunity to focus on modular design. This would improve the purity of recovered materials and reduce energy consumption related to the recovery of materials.[149] The rate of recovery is also dependent on the type of PV: Cadmium and tellurium from CdTe panels can be recovered at around 90% efficiency.[150]

---

[138] Dominish, Teske, and Florin.

[139] Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."

[140] Bobba et al.

[141] Bobba et al.

[142] IRENA and IEA-PVPS, "End-of-Life Management: Solar Photovoltaic Panels" (International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems, 2016).

[143] IRENA and IEA-PVPS.

[144] IRENA, "Future of Solar Photovoltaic: Deployment, Investment, Technology, Grid Integration and Socio-Economic Aspects" (Abu Dhabi: International Renewable Energy Agency, 2019).

[145] Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."

[146] van Exeter et al., "METAL DEMAND FOR RENEWABLE ELECTRICITY GENERATION IN THE NETHERLANDS."

[147] IRENA and IEA-PVPS, "End-of-Life Management: Solar Photovoltaic Panels."

[148] van Exeter et al., "METAL DEMAND FOR RENEWABLE ELECTRICITY GENERATION IN THE NETHERLANDS."

[149] van Exeter et al.

[150] Dominish, Teske, and Florin, "Responsible Minerals Sourcing for Renewable Energy."

Dematerialization: Over time, PV has become thinner and more efficient, allowing for material use to decrease significantly, particularly due to silver and polysilicon (the most expensive materials in c-Si panels).[151] For example, by moving to a back-contact cell design, the use of silicon is cut by half, and energy consumption is reduced by about 30%.[152] There is an opportunity for silver to be replaced on a large-scale basis by a more cost-effective material such as copper, to reduce silver consumption at the cell manufacturing level.[153] But there are trade-offs: replacing silver with copper would make recycling less interesting if the materials to be recovered are less valuable.

4.1.3 Geothermal

Geothermal generates electricity from thermal energy located below the earth's surface, whether in liquid, trapped steam, or rock.[154] In the Netherlands, the ambition is for geothermal energy to meet 5% of the total energy demand for heat in 2030 and 23% in 2050; in other words, 0,27 TWh in 2030 and 55,55 TWh in 2050.[155] On a European level, it is predicted that the main use of geothermal heat will be as direct space and water heating for the residential and commercial sectors, as a replacement for natural gas. Furthermore, it may have moderate use for agriculture (greenhouse heating) and some use in industrial processes (through the electrification of the sector).[156]

Material requirements

Material	Material demand (kg/MW)	Global producers	Notes
Nickel (Ni)	120,155		
Chromium (Cr)	64,405		
Copper (Cu)	3605		
Molybdenum (Mo)	7209		
Manganese (Mn)	4325		
Titanium (Ti)	1634	China (45%) Russia (22%) Japan (22%)	Used to make corrosion-resistant alloys of steel for pipes

In green: Critical raw materials as listed by the European Commission[157]

Table 4 Metal composition estimates for geothermal energy installation, from Hund et al[158] and Moss et al.[159]

---

[151] Dominish, Teske, and Florin.

[152] Bettina Weiss, "International Technology Roadmap for Photovoltaic (ITRPV): 2013 Results" (ITRPV, 2014), https://resources.solarbusinesshub.com/images/reports/37.pdf.

[153] Weiss.

[154] Hund et al., "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition."

[155] Melanie Provoost, Laurien Albeda, and Bas Godschalk, "Geothermal Energy Use, Country Update for The Netherlands," n.d., 8.

[156] Francesco Dalla Longa et al., "Scenarios for Geothermal Energy Deployment in Europe," Energy 206 (September 1, 2020): 118060, https://doi.org/10.1016/j.energy.2020.118060.

[157] European Commission, "COM(2020) 474 - Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability."

[158] Hund et al., "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition," 20.

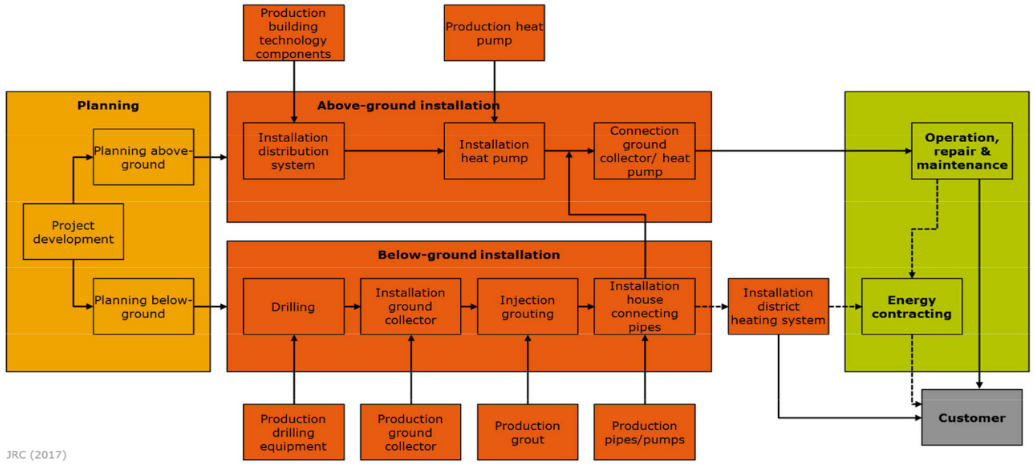
[159] Ray Moss and Evangelos Tzima, "Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector," 2013, https://setis.ec.europa.eu/sites/default/files/reports/JRC-report-Critical-Metals-Energy-Sector.pdf.

Depending on the type of installation, there may also be copper in the heat exchanger and neodymium in the permanent magnet in the generator.[160]

Supply chain

The supply chain of geothermal energy can be divided in four main parts: production of components and materials, planning, installation, and operation & maintenance (Figure 4).[161] The key components of a binary-ORC power plant (geothermal installation with the highest proliferation potential in the EU) are: a turbine/generator, heat exchanger, electrical submersible pump and cooling tower.[162]

The most abundant metal required for a geothermal installation is steel[163] (not shown in Table 4 to avoid double counting). Installations require a very high level of quality steel to be able to cope with the high heat and pressure while carrying reservoirs of steam and hot water for electricity generation. In 2019, the biggest steel producing country was China, accounting for 53.3% of world production.[164] In order to make corrosion-resistant alloys of steel, minerals such as titanium and molybdenum are used.[165] Well piping can consist of alloys that contain chromium, molybdenum, nickel and copper.[166] The demand for these minerals from specific geothermal plants vary from location to location based on the number and depth of wells needed to access the thermal energy.[167]



Source: (Bracke et al., 2008), simplified and adapted

Figure 4: Supply chain for geothermal energy. Image from[168]

---

160 Bram Vonsée, Wina Crijns-Graus, and Wen Liu, "Energy Technology Dependence - A Value Chain Analysis of Geothermal Power in the EU," Energy 178 (July 1, 2019): 419–35, https://doi.org/10/ghgss8.

161 Davide Magnana et al., "Supply Chain of Renewable Energy Technologies in Europe: An Analysis for Wind, Geothermal and Ocean Energy," Text, November 27, 2017, https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/supply-chain-renewable-energy-technologies-europe-analysis-wind-geothermal-and-ocean-energy.

162 Vonsée, Crijns-Graus, and Liu, "Energy Technology Dependence - A Value Chain Analysis of Geothermal Power in the EU."

163 Hund et al., "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition," 20.

164 "Global Crude Steel Output Increases by 3.4% in 2019."

165 Hund et al., "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition."

166 Moss and Tzima, "Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector."

167 Hund et al., "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition."

168 Magnana et al., "Supply Chain of Renewable Energy Technologies in Europe."

For the underground installations (e.g. exploration, drilling, pipes, and pumps), most suppliers of geothermal equipment come from the oil and gas industry. For the above ground installations (e.g. turbines), most suppliers come from the conventional energy sector.[169] Major providers for pumps, valves, and control systems include Schlumberger, Baker & Hughes, GE, ITT/Goulds, Halliburton, Weatherford International, Flowserve (all US), Canadian ESP (Canada), Borets (Russia).[170] Heat exchangers are supplied mainly by Alfa Laval (Sweden), Danfoss (Denmark), Kelvion Holdings (Germany), SPX Corporation (US), Xylem (US), Hamon & Cie, Modine Manufacturing Company (US), SWEP International (Denmark).[171]

Production well drilling and facility construction are responsible for a majority of the costs of a geothermal project. The market for facility construction (balance of plant) is very competitive.[172]

Challenges and Opportunities

Geothermal energy is not heavily dependent on critical materials. However, there are still some challenges in its proliferation. Geothermal power plants often require high capital expenditure arising to drill deep wells in order to reach high-temperature geothermal sources. For this, they are dependent on the oil and gas industry.[173] It would be important, therefore, to facilitate the emergence of a more independent geothermal drilling sector, where rig prices and availability are much less disturbed by changes in oil price and exploration. [174] The EU is a net exporter for all key components of a geothermal installation, except for the cooling equipment, which has a negative trade balance.[175] Policy would need to target providing incentives for the EU's own industry development, such as subsidies for setting up geothermal drilling equipment manufacturers in Europe.

4.1.4 Energy grid infrastructure (Transmission network)

The large-scale introduction of PV and wind into the electricity mix as envisioned in the *Klimaatakkoord* will require substantial changes in electricity grid infrastructure. Roof PV relocate electricity production to the electricity consumers, and it will thereby reduce the transmission load in the network.[176] In contrast, centralized PV and wind power, especially offshore, will relocate and probably increase the infrastructure needed for transmission. [177]

---

[169] Magnana et al.
[170] Magnana et al.
[171] Magnana et al.
[172] Magnana et al.
[173] Vonsée, Crijns-Graus, and Liu, "Energy Technology Dependence - A Value Chain Analysis of Geothermal Power in the EU."
[174] Vonsée, Crijns-Graus, and Liu.
[175] Vonsée, Crijns-Graus, and Liu.
[176] René Kleijn et al., "Metal Requirements of Low-Carbon Power Generation," Energy 36, no. 9 (September 1, 2011): 5640–48, https://doi.org/10/d2nhpp.
[177] Kleijn et al.

Material requirements

Material	Amount (kg/km)	Global producers	Notes
Aluminum (Al)	790-1830		Lower range for high voltage grids and higher range for low and medium voltage grid
Copper (Cu)	1080-6050		Lower range for low and medium voltage grid and higher range for high voltage and offshore
Lead (Pb)	2000		Lead sheathing is used for submarine cables
Steel	550		Found in high voltage overhead cables

Note: No critical raw materials

Table 5. Material composition estimates for energy power lines and cables, aggregated from Moss et al[178], Van Oorschot et al[179] and van der Horst–Verschelling[180]

Currently, 90% of all aluminum and 78% of copper of the Dutch electricity system is found within the cables.[181] Furthermore, there is a significant amount of steel in high voltage cables.

Challenges and Opportunities

Indirect demand for batteries: Transmission network infrastructure is not strongly dependent on the supply of any critical raw materials. Nonetheless, there are indirect consequences for the demand in other metals. A failure to speed up the expansion of the transmission network necessary for integrating fluctuating renewable energies could increase the demand for storage technologies significantly.[182] This would translate to an increase in demand for cobalt, lithium, nickel, manganese and carbon (in the form of natural graphite).

Re-using cables: Re-using a cable is much better than recycling on a material level. In the Netherlands, Enexis has experimented with re-using a cable at end-of-life. However, there are several issues: a retrieved cable needs to be long enough to fit the needs of a new location. [183] Theoretically, short pieces can be connected together using ‘sleeves’ to make one long cable. However, these sleeves are more prone to failure,

---

[178] Moss and Tzima, “Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector.”

[179] Janneke van Oorschot et al., “Voorraden in de Maatschappij: De Grondstoffenbasis Voor Een Circulaire Economiemet Case Studies Op Gebied van Het Elektriciteitssysteem, Elektronica En Voertuigen” (CBS, 2020), https://www.universiteitleiden.nl/binaries/content/assets/science/cml/final-rapportage-voorraden-in-de-maatschappij_edit_23.01.2020.pdf.

[180] Judith van der Horst –Verschelling, “A Circular Economy in 2050: A Look at the Stocks and Flows of Electricity Cables in the Netherlands,” Master thesis (Delft: TU Delft & Leiden Unversity, 2020), http://resolver.tudelft.nl/uuid:00611754-0599-4b9c-9218-1bd8fd9c2111.

[181] van Oorschot et al., “Voorraden in de Maatschappij: De Grondstoffenbasis Voor Een Circulaire Economiemet Case Studies Op Gebied van Het Elektriciteitssysteem, Elektronica En Voertuigen.”

[182] Moss and Tzima, “Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector.”

[183] van der Horst –Verschelling, “A Circular Economy in 2050: A Look at the Stocks and Flows of Electricity Cables in the Netherlands.”

resulting in power-outages. Furthermore, their use is labor-intensive, and man-hours are much more expensive than a new cable, so re-use rarely happens. [184]

Recycling metals from cables: The metals at the end-of-life of cables are generally recycled, as they are profitable enough to be sold to other third parties. However, they are generally not recycled within the cable industry, as new cables are made from virgin aluminum or copper to ensure high enough purity of metal. [185] Furthermore, the stream of secondary materials is not as large as it could be. Above-ground cables are easy to reach, but underground cables tend to be left there. This is because there is a lack of clear data of locations of cables (they reach the end of their life after 50 years), it is expensive to excavate and there is little stakeholder support for excavation. [186]

4.1.5 Carbon capture and storage

The *Klimaatakkoord* envisions a thriving, circular manufacturing industry where greenhouse gas (GHG) emissions are almost zero by 2050.[187] In order to achieve this, 19.4 Mt of GHG emissions need to be reduced by 2030. [188] This will require a combination of different interventions, including the capture and storage of carbon. Carbon capture and storage (CCS) is the capture and compression of the CO_2 emitted in industrial processes and its transport to a storage location creating a geological formation onshore or offshore. Storage can take place in deep saline aquifers, deep coal bed methane (enhanced), and in depleted oil/gas reservoirs amongst others. The cement, iron and steel industry are particularly interested in CCS technology.[189]

Material requirements

Material	Amount (kg/MW)	Global producers	Notes
Aluminum (Al)			
Chromium (Cr)	326		
Cobalt (Co)	7.5	Democratic Republic of Congo (64%) China (5%) Canada (5%)	
Copper (Cu)	692		
Manganese (Mn)	3761		
Molybdenum (Mo)	7.5		
Nickel (Ni)	1145		

---

[184] van der Horst –Verschelling.
[185] van der Horst –Verschelling.
[186] van der Horst –Verschelling.
[187] Ministerie van Economische Zaken en Klimaat, "*Klimaatakkoord*."
[188] Ministerie van Economische Zaken en Klimaat.
[189] Moss and Tzima, "Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector."

Material	Amount (kg/MW)	Global producers	Notes
Niobium (Nb)	100	Brazil (90%) Canada (10%)	
Steel			
Vanadium (V)	100	China (53%) South Africa (25%) Russia (20%) Source of EU Supply: The Netherlands (2%, based on oil refineries)	

In green: Critical raw materials as listed by the European Commission[190]

Note: Ta, Hf, Re and Y may also be required but demand is uncertain.

Table 6. Material composition estimates for carbon capture and storage installations, aggregated from Moss et al[191]

Challenges and Opportunities

Widespread commercial-scale CCS has yet to emerge and there is great uncertainty over how large a role it will play in climate change mitigation. The International Energy Agency (IEA) sees an increasing role for this technology in conjunction with coal plants, stating that 350 GW of coal plants will operate with CCS.[192] On the other hand, IRENA does not include CCS in their scenarios at all. There is a number of factors that will affect the scale at which CCS is deployed: the height of the carbon price, which is vital for ensuring that CCS is commercially viable; regulatory and legal factors relating to the storage of carbon and any liabilities that may result from this process; and availability of suitable geological formations to store the CO_2 underground. [193] Until now, these factors have caused a slow acceptance of CCS; in 2019 there were 51 large-scale facilities at various stages of operation, with 19 operating commercially.[194]

The *Klimaatakkoord* sees a role for CCS in the Netherlands under a number of restrictions. They state that subsidization of CCS must occur in a manner that there is sufficient budget for sustainable technologies, and that to this end "CCS will be limited both in time and in scope."[195] They focus on industry rather than the energy production sector for the deployment of CCS. CCS will be subsidized for a maximum of 7.2 Mt of the total 14.3 Mt of emissions reductions in the industry sector by 2030.[196] The critical material demand from CCS is therefore unlikely to be an important source of dependency.

---

[190] European Commission, "COM(2020) 474 - Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability."
[191] Moss and Tzima.
[192] Hund et al., "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition."
[193] Hund et al.
[194] GCSSI, "Global Status of CCS 2019," 2019, https://www.globalccsinstitute.com/resources/global-status-report/.
[195] Ministerie van Economische Zaken en Klimaat, "*Klimaatakkoord*."
[196] Ministerie van Economische Zaken en Klimaat.

4.2 Transport

The Netherlands aims for zero-emission mobility for everyone by 2050, for which they encourage electric mobility.[197] Electric vehicles emit less GHG than conventional diesel vehicles.[198] The *Klimaatakkoord* predicts that by 2025, electric passenger cars will become price competitive, and there will be rapid growth of electric vans, public transport buses and light lorries. The ambition is that by 2030, 100% of new cars sold will be emissions-free.[199] More specifically, this means targets of ±600,000 electric cars by 2025 and ±2,000,000 cars by 2030, and a corresponding increase in charging points.[200]

Material requirements

Material	Amount (kg/vehicle)	Global producers	Notes
Boron (B)	0.01 - 0.09		
Cerium (Ce)	0 - 1.03	China (86%) Australia (6%) United States (2%)	Catalytic converters
Cobalt (Co)	0 - 13.91	Democratic Republic of Congo (64%) China (5%) Canada (5%)	
Copper (Cu)	0 - 71.08		
Dysprosium (Dy)	0.0005 – 0 .43	China (86%) Australia (6%) United States (2%)	Electric motor
Gallium (Ga)	0.004 – 0 .001	China (80%) Germany (8%) Ukraine (5%)	
Germanium (Ge)	0.00003 – 0 .00005	China (80%) Finland (10%) Russia (5%)	
Gold (Au)	0.00016 – 0 .0002		
Graphite		China (69%) India (12%) Brazil (8%)	
Indium (In)	0.00003 – 0 .00005	China (48%) Korea, Rep. (21%) Japan (8%)	
Lanthanum (La)	0 - 1.16	China (86%) Australia (6%) United States (2%)	Used in optics

---

[197] Ministerie van Economische Zaken en Klimaat.

[198] “Electric Vehicle Life Cycle Analysis and Raw Material Availability | Transport & Environment,” accessed September 30, 2020, https://www.transportenvironment.org/publications/electric-vehicle-life-cycle-analysis-and-raw-material-availability.

[199] Ministerie van Economische Zaken en Klimaat, “*Klimaatakkoord*.”

[200] Sybren Bosch et al., “Metal Demand for Electric Vehicles” (Metabolic, 2019), https://www.metabolic.nl/publications/metal-demand-for-electric-vehicles/.

Material	Amount (kg/vehicle)	Global producers	Notes
Lead (Pb)	8 - 12		
Lithium (Li)	0.09 - 12.7	Chile (44%) China (39%) Argentina (13%)	
Manganese (Mn)	0 - 91.5		
Neodymium (Nd)	0.0062 - 2.91	China (86%) Australia (6%) United States (2%)	Electric motor
Nickel (Ni)	0 - 46.5		
Palladium (Pd)	**0.00064- 0.0008**	**Russia (40%)**	
Praseodymium (Pr)	**0 - 0.08**	**China (86%)** **Australia (6%)** **United States (2%)**	**Electric motor**
Samarium (Sm)	**0 - 0.08**	**China (86%)** **Australia (6%)** **United States (2%)**	**Used in magnetic materials**
Silver (Ag)	0.005 - 0.007		
Terbium (Tb)	0.009 - 0.021	China (86%) Australia (6%) United States (2%)	
Titanium (Ti)	0 - 38.78		

In green: Critical raw materials as listed by the European Commission[201]

Table 7. Material composition estimates for electric vehicle (including Lithium-ion battery), aggregated from World Bank Group[202] and Bobba et al[203]

The main components of an electric vehicle containing critical metals are the battery and the motor. Batteries are the key differentiator between electric vehicle manufacturers. The amount of energy stored in the battery determines the range of the vehicle, which is a major limiting factor for electric vehicle sales.[204] Important materials in a Li-ion battery are: cobalt, lithium, nickel, manganese and carbon (in the form of natural graphite).[205] In the motor, important materials are neodymium, dysprosium and praseodymium.[206]

Looking at the expected future demand, the supply of lithium is expected not to be a major issue for the battery supply chain in the short or medium term despite recent fears of shortages and price spikes. [207] This is expected to be the case for most of the

---

[201] European Commission, "COM(2020) 474 - Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability."

[202] World Bank Group, The Growing Role of Minerals and Metals for a Low Carbon Future.

[203] Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."

[204] David Coffin and Jeff Horowitz, "The Supply Chain for Electric Vehicle Batteries," 2018, 21.

[205] Dominic A. Notter et al., "Contribution of Li-Ion Batteries to the Environmental Impact of Electric Vehicles," Environmental Science & Technology 44, no. 17 (September 1, 2010): 6550–56, https://doi.org/10/c58rcv.

[206] James D. Widmer, Richard Martin, and Mohammed Kimiabeigi, "Electric Vehicle Traction Motors without Rare Earth Magnets," Sustainable Materials and Technologies 3 (April 1, 2015): 7–13, https://doi.org/10/ghgss6.

[207] Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."

key materials: manganese, nickel, and natural graphite will have sufficient supply to meet the anticipated increase in demand for Li-ion batteries.[208] However, there are risks associated with the geopolitical concentrations of lithium and cobalt.[209]

Supply chain electric vehicle motor

Electric vehicles have an electric motor instead of an internal combustion engine. Not every electric vehicle uses the same motor. Tesla, for example, uses copper-based induction motors in its Model S, but uses neodymium-magnetic motors in its Model 3.[210] Neodymium-magnet based electric motors tend to have a greater efficiency but use a large quantity of rare earth metals.[211] In contrast to batteries, the quantity of critical metals does not depend on the car's characteristics.[212] It is important to note that parts of an EV may use rare earths to *produce*, such as aluminum. But a traditional (non-electric) car is just as likely to be full of all the same components, e.g.: steel, plastics, epoxies, circuit boards, carbon fiber, glass, nickel, copper, lead acid battery, etc.[213]

As discussed in 4.1.1, China accounts for 90% of REE metals.[214] China dominates the production of NdFeB magnets by 85–90%, the rest being produced in Japan (10%) and in other countries in the EU and the USA.[215] Recently, manufacture of NdFeB magnets have been continuing to move to China where access to REEs remains cheapest and more secure. A few European players are found at different stages of the REEs value chain, including a few alloy makers and magnets manufacturers that operate mainly from imported processed materials.[216] The prominent players in the electric vehicle motor market include Continental AG (Germany), Hitachi Automotive Systems, Ltd. (Japan), Tesla, Inc. (U.S.), BYD Auto Co., Ltd. (China), Denso Corporation (Japan), Metric Mind Corporation (U.S.), Mitsubishi Electric Corporation (Japan), Allied Motion Technologies Inc. (U.S.), Robert Bosch GmbH (Germany) and Siemens AG (Germany).[217] Production of fully assembled electric motors is dominated by Asian companies, in particular from Japan.[218]

---

[208] Elsa A. Olivetti et al., "Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals," Joule 1, no. 2 (October 11, 2017): 229–43, https://doi.org/10/gg9q58.

[209] Olivetti et al.

[210] Bosch et al., "Metal Demand for Electric Vehicles."

[211] Bosch et al.

[212] Bosch et al.

[213] "Do We Have Enough Rare Earth Metals for EVs?," Leading The Charge, accessed October 12, 2020, https://www.leadingthecharge.org.nz/do_we_have_enough_rare_earth_metals_for_evs.

[214] Ryan Castilloux, "Rare Earth Elements: Market Issues and Outlook" (Adamas Intelligence, 2019), 8.

[215] Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."

[216] Bobba et al.

[217] "Electric Vehicle Motor Market | Industry Size, Share Analysis Report 2019-2023," accessed October 12, 2020, https://www.marketresearchfuture.com/reports/electric-vehicle-motor-market-5385.

[218] Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."

Supply chain Li-ion battery

The smallest, but most important, component of the Li-ion batteries is the electrochemical cell, which consists of three major parts: a cathode and an anode separated physically but connected electrically by an electrolyte. [219] The anode is typically made of graphite, while the electrolyte generally consists of organic carbonate solvents with dissolved lithium salts. The cathode has the most variation in its different forms: can include cobalt, manganese and/or nickel.[220]

Cobalt is predominantly mined in the Democratic Republic of Congo and refined in China.[221] Lithium is largely mined in Australia and refined in China and Chile.[222] Nickel is sourced from a diverse number of countries, with Philippines as an important source for mining, and China as an important refiner.[223] Manganese is largely mined in South Africa, and refined in China.[224] Natural graphite is also concentrated in China.[225] The EU produces 1% of all battery raw materials overall.[226]

---

[219] Coffin and Horowitz, “The Supply Chain for Electric Vehicle Batteries.”

[220] Coffin and Horowitz.

[221] Natalia Lebedeva, Franco DI PERSIO, and Lois BRETT, “Lithium Ion Battery Value Chain and Related Opportunities for Europe,” Text, December 19, 2016, https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/lithium-ion-battery-value-chain-and-related-opportunities-europe.

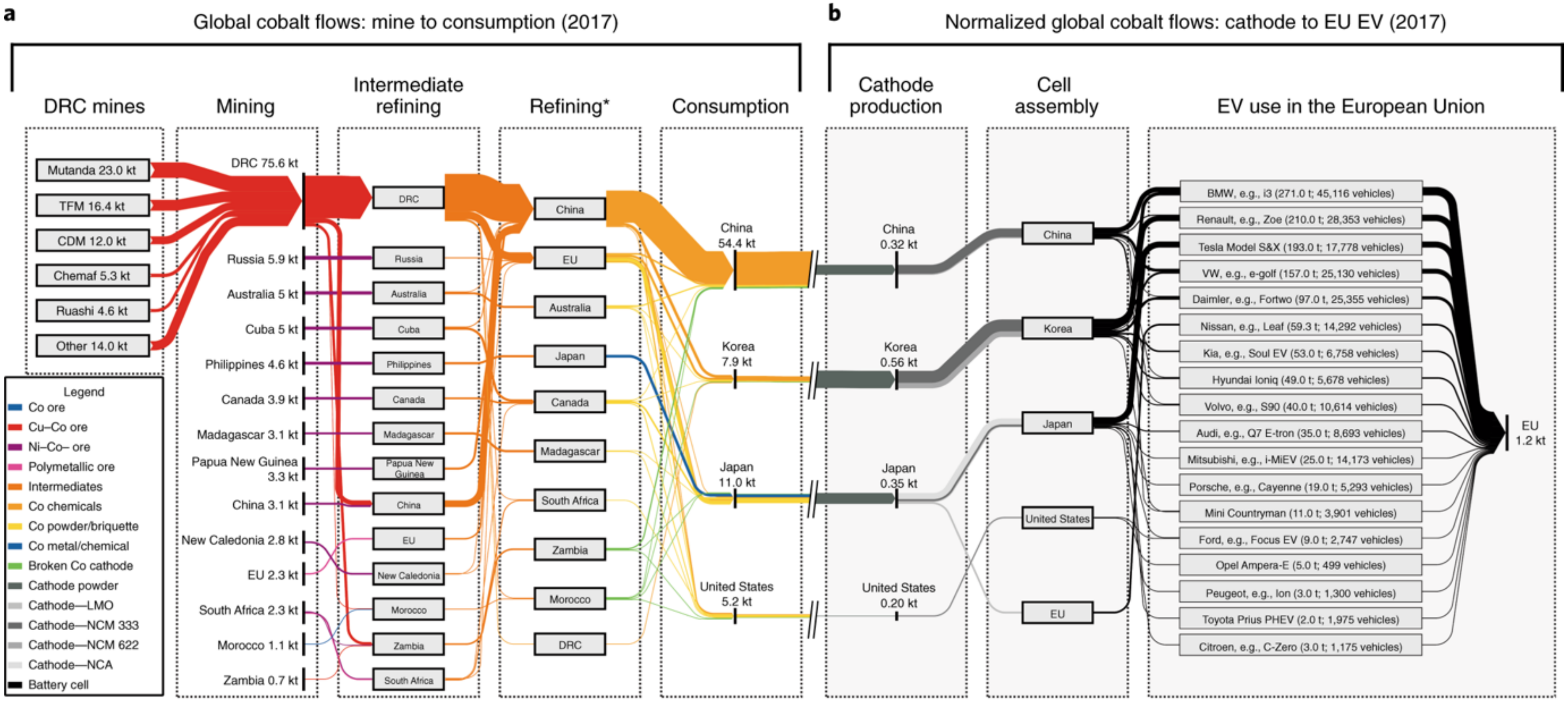
[222] Xin Sun et al., “Supply Risks of Lithium-Ion Battery Materials: An Entire Supply Chain Estimation,” Materials Today Energy 14 (December 1, 2019): 100347, https://doi.org/10/ghgss7.

[223] Sun et al.

[224] Sun et al.

[225] Olivetti et al., “Lithium-Ion Battery Supply Chain Considerations.”

[226] Bobba et al., “Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study.”



*Cobalt refining suitable for battery production

Cobalt flows 2017 from mine to refined material suitable for battery production.[227]

---

[227] Joris Baars et al., "Circular Economy Strategies for Electric Vehicle Batteries Reduce Reliance on Raw Materials," Nature Sustainability, September 7, 2020, 1–9, https://doi.org/10/ghgss4.

The electrochemical cells are cased together and attached with terminals to produce a module. The number of cells per module varies by manufacturer and cell type. The modules are then assembled with electrical connections and cooling equipment to make the battery pack. Most modules are made in the same facility as the battery pack.[228]

Today, China controls production of 77% of the world's cell capacity and 60% of the world's component (i.e. battery pack) manufacturing.[229] Japan and Korea rank number two and three respectively; they are leaders in battery and components manufacturing but do not have the same influence in raw materials refining and mining as China does.[230] However, what Japan and Korea lack in the control of the raw materials supply chain, they make-up for in higher environmental and RII (regulations, innovation & infrastructure) scores compared to China.[231] Looking to the future, cells are likely to continue to be internationally traded as they are more easily imported/exported over longer distances. Conversely, due to the higher cost of transporting battery packs, international trade in EV battery packs is likely to remain low compared to trade in battery cells.[232] Vehicle manufacturers' decisions about where to produce EVs (and in what quantities) are likely to be the primary determinants in Li-ion battery module and pack production locations.[233] China and the United States are expected to be the largest suppliers of lithium-ion battery cells, with competition from Japan and South Korea.[234]

In terms of vehicles, China is currently leading the global EV market.[235] In 2019, it represented more than half of the world's electric car market, with nearly 1.2 million electric cars sold.[236] It projected to produce around 10 million battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) in 2022, more than any other nation worldwide. China's estimated production level is also anticipated to exceed the combined output of other large markets, such as the United States, Germany, and Japan.[237] This capacity is much larger than current demand levels (even without factoring in any likely market contraction as a consequence of the Covid-19 pandemic).[238]

---

[228] Coffin and Horowitz, "The Supply Chain for Electric Vehicle Batteries."

[229] "China Dominates the Lithium-Ion Battery Supply Chain, but Europe Is on the Rise," BloombergNEF (blog), September 16, 2020, https://about.bnef.com/blog/china-dominates-the-lithium-ion-battery-supply-chain-but-europe-is-on-the-rise/.

[230] "China Dominates the Lithium-Ion Battery Supply Chain, but Europe Is on the Rise."

[231] "China Dominates the Lithium-Ion Battery Supply Chain, but Europe Is on the Rise."

[232] Coffin and Horowitz, "The Supply Chain for Electric Vehicle Batteries."

[233] Coffin and Horowitz.

[234] Coffin and Horowitz.

[235] IEA, "Global EV Outlook 2020," 2020.

[236] "How China's Electric Vehicle (EV) Policies Have Shaped the EV Market – Sustainalytics," July 31, 2020, https://www.sustainalytics.com/esg-blog/how-chinas-electric-vehicle-policies-have-shaped-the-ev-market/.

[237] "Production of Electric Vehicles: Selected Countries," Statista, accessed October 12, 2020, https://www.statista.com/statistics/270537/forecast-for-electric-car-production-in-selected-countries/.

[238] IEA, "Global EV Outlook 2020."

Challenges and Opportunities

Dematerialization: On a material level, metal demand is expected to decline as batteries become more energy dense.[239] On a component level, having smaller vehicles with shorter ranges could lead to a reduction in demand for metals. However, the metal demand for the electric motor will remain, which means the effectiveness of this option is limited to those metals required for batteries.[240] On a system level, making more effective use of our vehicles (e.g. car sharing), the number of vehicles could be reduced significantly. This is by far the most effective solution for reducing metals demand, but the most complex in socio-political terms.[241]

Substitution: The consumption of rare earth elements in the electric vehicle industry is unsustainable under current market conditions.[242] The elements neodymium, dysprosium and praseodymium – which are needed for the motors in electric cars – are also needed to produce wind turbines. The scarcity of these elements will create tensions between different sustainable technologies.[243] The dependence on some metals could be mitigated by substituting critical metals with other metals. This appears to be the easiest solution from a societal perspective but it is technically challenging as it could reduce performance and efficiency.[244]

There is also discussion of whether hydrogen-propelled cars will substitute the battery-driven electric car. The most important arguments in favor of the hydrogen car are the rapid technological advances in fuel cells, the energy density and the speed with which it can be filled. The main arguments against it are that it consumes more energy per kilometer than a battery-propelled car, and the absence of a transport infrastructure for hydrogen. In fact, both hydrogen-driven and battery-driven cars are currently propelled mainly by fossil energy: hydrogen is currently recovered mainly from natural gas ('grey' hydrogen), and electric cars are often charged with fossil-based electricity.[245]

Recycling: Although end-of-life collection of vehicles is rather well organized in the EU, recycling as a source of secondary materials at an industrial level is not sufficiently developed to consistently answer the market demand.[246] However, effort is needed in this area to avoid leakages in collection and recycling. The recycling rate of lithium

---

[239] Coffin and Horowitz, "The Supply Chain for Electric Vehicle Batteries."
[240] Bosch et al., "Metal Demand for Electric Vehicles."
[241] Bosch et al.
[242] Benjamin Ballinger et al., "The Vulnerability of Electric-Vehicle and Wind-Turbine Supply Chains to the Supply of Rare-Earth Elements in a 2-Degree Scenario," Sustainable Production and Consumption 22 (April 1, 2020): 68–76, https://doi.org/10/gg9chm.
[243] Bosch et al., "Metal Demand for Electric Vehicles."
[244] Bosch et al.
[245] Bosch et al.
[246] Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."

from end-of-life products, including batteries, is currently below 1% in the EU.[247] Recycling of Li-ion batteries is a complex and expensive process due to the wide variety of chemistries and battery formats. Additional complexities arise from the need for dismantling and pre-treatment of large electric vehicle batteries to reach sizes compatible with recycling process. [248] At present the main focus in recycling of Li-ion batteries is the recovery of cobalt since this metal has a high economic value and is a critical raw material for the EU.[249] In Europe, companies such as Umicore (BE) and Recupyl (FR) have been active for several years in the battery recycling sector, and have developed their own processes.[250]

Research and development: Significant research effort is dedicated world-wide to the development of several future cell chemistries which have the potential to outperform contemporary Li-ion cells.[251] Chemistries which have been identified as capable of advancing battery technology to beyond the Li-ion include: a) Lithium metal (Li-metal) batteries b) Solid State batteries (SSB) c) Lithium-sulphur (Li-S) batteries and d) Lithium-air (Li-air) batteries.[252] These technologies look promising for increasing the energy density of batteries, and hence reducing their metal demand. However, they are only expected to enter the mainstream by 2030, once their performance has been proven in automotive applications. Li-ion technology is therefore expected to remain as the dominant deployed technology at least until 2025 -2030.[253]

Traction motors: The compact size and high performance of permanent magnets makes them the favored technology for traction motors. Forecasts of raw materials consumption for traction motors in electric vehicles shows major consumption spikes for borates and rare earth elements. Several mines and processing facilities for REEs are now slowly ramping up their production after long delays, and there is potential for REE mining in Europe: in Sweden, Finland, Germany, Spain, Norway and Greenland. [254] Developing capacity in processing of REEs and manufacturing of PMs will be important for the EU since these stages might influence later stages of the value chain (e.g. motor and vehicle design). The collection, dismantling and reuse of materials from smaller electric motors can be enhanced since currently the majority of these ‘scrap’ flows are exported to Asia. [255] The development of innovative cost-effective processing, separation and recycling methods for REEs could improve supply security for the EU. Further research and development into substitutes and “low cost magnets” is necessary. This may be achieved through putting ecodesign requirements into place for fostering higher

---

[247] Lebedeva, DI PERSIO, and BRETT, “Lithium Ion Battery Value Chain and Related Opportunities for Europe.”
[248] Lebedeva, DI PERSIO, and BRETT.
[249] Bosch et al., “Metal Demand for Electric Vehicles.”
[250] Bosch et al.
[251] Lebedeva, DI PERSIO, and BRETT, “Lithium Ion Battery Value Chain and Related Opportunities for Europe.”
[252] Lebedeva, DI PERSIO, and BRETT.
[253] Bosch et al., “Metal Demand for Electric Vehicles.”
[254] Bobba et al., “Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study.”
[255] Bobba et al.

levels of reuse, remanufacturing and recycling, including the increased use of recycled content in new products to lower environmental and raw material footprints. [256]

4.3 Digital technologies

Europe's reliance on foreign components and technology is increasing, as it falls behind on the production of key digital information and communication technologies. In 2017, the EU's overall trade deficit for high-tech products stood at 23 billion euro – largely due to sizeable Chinese imports.[257] Over the next decades, digital data services are expected to grow: with increasing per capita use, emerging applications such as Internet of Things and consequent infrastructure such as data centers.[258] This industry is interesting from a critical materials perspective because 1) it uses a wide and increasing range of elements to enable the desired electronic, magnetic, optical, or mechanical properties needed for chips and devices; 2) the large number of chips and devices that are produced each year amount to meaningful volumes of material relative to current supply; and 3) the speed of technology introduction cycles can be faster than the time scales associated with other aspects of the supply chain.[259]

Material	Uses	Global producers
Boron	In semi-conductors and HDD permanent magnets	
Chromium	In stainless steels, for plating and coatings of electronic components, pigments	
Cobalt	In HDDS, semi-conductors and integrated circuits	Democratic Republic of Congo (64%) China (5%) Canada (5%)
Copper	Main conductor in electronics, connectors, printed circuits, wiring, contacts, ics, semi-conductors, etc.	
Dysprosium	In NdFeB permanent magnets to increase the resistance of the magnet to high temperatures	China (86%) Australia (6%) United States (2%)
Gallium	Semiconductors for Integrated Circuits. In particular, Ga is used in Power Amplifiers (pas) used in cell phones to amplify signals, both voice and data. The more advanced the generation used (3G, 4G, 5G), the more pas needed.	China (85%) Germany (7%) Kazakhstan (5%)
Germanium	Glass for fiber-optic Ge cables, infrared optics (night-vision), in semiconductors	China (67%) Finland (11%) Canada (9%) United States (9%)

---

[256] Bobba et al.

[257] European Political Strategy Centre, "Rethinking Strategic Autonomy in the Digital Age.," Website (Publications Office of the European Union, November 21, 2019), http://op.europa.eu/en/publication-detail/-/publication/889dd7b7-0cde-11ea-8c1f-01aa75ed71a1/language-en/format-PDF.

[258] Ku, "Anticipating Critical Materials Implications from the Internet of Things (IOT)."

[259] Ku.

Material	Uses	Global producers
Graphite	For production of graphene, electrically and thermally conductive material destined for many applications	China (69%) India (12%) Brazil (8%)
Gold	Connectors, switches, relay contacts, solder joints, connection wires and strips, memory chips and circuit boards	
Indium	In screens as indium-tin- oxide	China (48%) Korea, Rep. (21%) Japan (8%)
Lithium	Primary batteries	Chile (44%) China (39%) Argentina (13%)
Manganese	In memory storage technologies and batteries	
Neodymium	For NdFeB permanent magnets used in hard drives	80% of global production in China, some in Western Australia
Palladium	Printed circuit boards and in multi-layered ceramic capacitators (in mobile phones)	Russia (40%)
Silver	Soldering and brazing alloys, electrical contacts and printed circuit boards	
Silicon	Electronics grade silicon in Si semiconductors, SSDs and microelectronics	China (61%) Brazil (9%) Norway (7%) United States (6%) France (5%)
Tantalum	Special capacitators, characterised by high capacity, small size and high performance. Thin layers of tantalum are also used in integrated circuits.	Congo, DR (33%) Rwanda (28%) Brazil (9%)
Tellurium	Phase-change memory	
Tungsten	Heat resistant in ics, dielectric materials and transistors. In light bulbs and vacuum tube filaments	China (69%) Vietnam (7%) United States (6%) Austria (1%) Germany (1%)

In green: Critical raw materials as listed by the European Commission[260]

Table 5. Key materials in digital technologies, aggregated from Ku, 2018[261] and Bobba, 2020[262]

Supply chains

Although Europe is successful in several niche areas such as embedded electronics, sensor systems or power electronics, there is considerable underrepresentation of European manufacturers in others.[263] For stand-alone electronic equipment, such as personal computers or smartphones and other telecommunication devices, the EU's

---

[260] European Commission, "COM(2020) 474 - Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability."

[261] Ku.

[262] Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."

[263] European Political Strategy Centre, "Rethinking Strategic Autonomy in the Digital Age."

share is only 6%.[264] American and Asian companies dominate in this global market. In fact, about 70% of the world's smartphones are assembled in one region of China.[265] Another sub-region accounts for half of global laptop production. When it comes to the production of electronic boards – the basis for complex electronic devices – EU production accounts for a mere 10%, while almost two thirds of production capacity is in Asia and less than 15% in the US.[266]

Semiconductors have particularly complex, geographically widespread supply chains. For example, one U.S. semiconductor company has over 16,000 suppliers worldwide. More than 7,300 of its suppliers are based in 46 different American states and more than 8,500 of its suppliers are located outside of the United States.[267] They require silicon metal and gallium, both of which are sourced predominantly from China.[268] Canada, European countries, and the United States specialize in semiconductor design, along with high-end manufacturing. Japan, the United States, and some European countries specialize in supplying equipment and raw materials. China, Malaysia and other Asian countries tend to specialize in manufacturing, assembling, testing and packaging.[269] In the production of semiconductors and microprocessors, Europe has experienced a constant decline in its worldwide share, today accounting for just 9% of global sales, while the production capacity in Asia (mainly in South Korea and Japan) has surged.[270] This industry has undergone an unprecedented market concentration due to a number of mergers and acquisitions.[271]

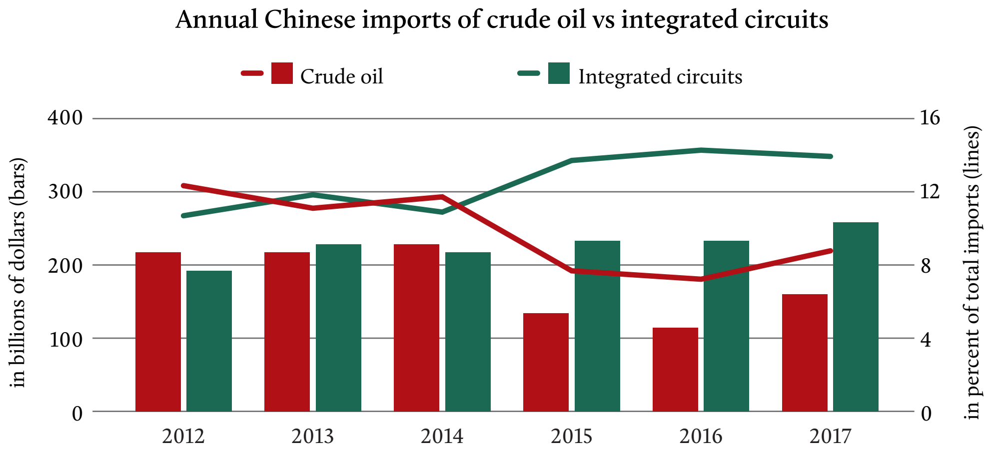


Figure 5. Semiconductors top oil as China's number one import, source Natixis, CEIC

---

[264] European Political Strategy Centre.

[265] "China's Smartphone Production Falls Under 70% for the First Time in 2019," Counterpoint Research (blog), March 23, 2020, https://www.counterpointresearch.com/chinas-smartphone-production-falls-70-first-time-2019/.

[266] European Political Strategy Centre, "Rethinking Strategic Autonomy in the Digital Age."

[267] SIA, "BEYOND BORDERS: THE GLOBAL SEMICONDUCTOR VALUE CHAIN," 2016, https://www.semiconductors.org/wp-content/uploads/2018/06/SIA-Beyond-Borders-Report-FINAL-June-7.pdf.

[268] Moss and Tzima, "Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector."

[269] SIA, "BEYOND BORDERS: THE GLOBAL SEMICONDUCTOR VALUE CHAIN."

[270] European Political Strategy Centre, "Rethinking Strategic Autonomy in the Digital Age."

[271] European Political Strategy Centre.

Challenges and Opportunities

Alternate sources: Clear indications of structural changes in demand are usually needed to justify the costs and time needed to expand mining or refining capacity. Robust analysis of technology adoption trends may allow producers to recognize these changes earlier. In addition, extended periods of high prices can also prompt innovation that can bring on new sources of supply. For example, coal has recently attracted attention as a non-traditional source of raw materials.[272] Partly in response to the rare earth crisis of the early 2010s, the US is sponsoring research into rare earth element recovery from coal.[273] Other materials might also be available from mining or energy by-products; germanium may also be produced from coal. Although significant work would be needed to develop the extraction and purification processes needed to create a supply chain, alternate supply is a possibility if the market creates a sustained demand.[274]

Recycling: The major use of gallium is in semiconductors, which require the refined material to have a very low concentration of impurities. Only 15% of a GaAs ingot is actually used during electronics manufacture, and the remaining 85% can be recycled.[275] The leading role of the EU concerning collection and management of Waste Electric and Electronic Equipment and in standardisation (also concerning material efficiency of electric equipment) could be an asset to reduce supply risk of raw materials for digital technologies.[276]

Data storage: When it comes to data storage, neodymium and PGM supply chains are important to HDD production. If certain types of phase-change memory or resistive random-access memory technologies take off, significant stress could develop on the germanium, tellurium, or hafnium supply chains within the next decade.[277] In general, the material demand associated with data storage is not too alarming. Clear market signals are expected, particularly as specific data storage technologies win dominant shares of data storage. It is not at all clear that storage will be the most pressing material issue related to ICT scale-up. Data processing and data transmission will also require substantial amounts of material, and careful consideration of the critical materials implications associated with these aspects is needed to fully determine the where the greatest materials risks lie.[278]

---

[272] Ku, “Anticipating Critical Materials Implications from the Internet of Things (IOT).”
[273] Ku.
[274] Ku.
[275] Moss and Tzima, “Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector.”
[276] Bobba et al., “Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study.”
[277] Ku, “Anticipating Critical Materials Implications from the Internet of Things (IOT).”
[278] Ku.

Foreign direct investment: China is critically dependent on foreign technology for semiconductors. [279] China is trying to grow its chip industry, namely through acquisitions abroad, prompting countries such as South Korea to implement policies to restrict Chinese purchases of domestic semiconductor producers as well as intellectual property flows into China. [280] Some of the largest Chinese direct investment transactions in the Netherlands have occurred in the high-tech sector.[281] Over the past decade Philips divested itself of most of its activities as part of its strategy to focus exclusively on health technology. For instance, in 2006 Philips spun off its semi-conductor division under the name NXP Semiconductors. In 2015, Jianguang Asset Management (JAC Capital) purchased a part of NXP named 'RF Power'. After acquiring RF Power (2,000 employees) JAC renamed it Ampleon and turned it into a separate company based in the Netherlands. The largest instance of FDI from China in the Netherlands to date is the EUR 2.45 billion acquisition of another part of NXP, its Standard Products division, by a Chinese consortium consisting of JAC Capital and Wise Road Capital. The former NXP division is now a stand-alone firm named Nexperia based in the Netherlands. It has 11,000 employees working mostly in factories outside the Netherlands and produces semiconductors for the automotive industry, among other sectors. These acquisitions support the Chinese government's 'Made in China 2025' strategy that is aimed at moving China's manufacturing capacity up the global value chain.[282]

---

[279] European Political Strategy Centre, "Rethinking Strategic Autonomy in the Digital Age."

[280] European Political Strategy Centre.

[281] Frans-Paul van der Putten, "Chinese Direct Investment in the Netherlands: Patterns, Reception and Political Significance" (Clingendael, 2017), https://www.clingendael.org/sites/default/files/2017-12/PB_Chinese_Investment_Netherlands.pdf.

[282] van der Putten.

5. Strategies to secure supply

In the context of this report, strategies are technical and political approaches employed by countries or companies in order to secure supply of materials. Ensuring a resilient supply chain requires governments to make strategic policy choices that support supply chains in adapting and recovering from disruptions. For a discussion on the concept of resilience, see Appendix 4. Technical approaches, specifically, are discussed not only in terms of their direct consequences, but also from a geopolitical point of view, in terms of their potential indirect consequences. At the end of each section, the strategies are operationalized into policy interventions that could be applicable to the Netherlands.

5.1 Resource Nationalism

Resource nationalism is a political strategy that tends to be used by governments as a justification not only for controlling domestic resource extraction, but also for passing restrictive measures against foreign companies.[283] Through legal instruments, governments ensure that resources are used for achieving national goals.[284] Without protectionist regulations to ensure that this is the case, resources would be divided according to global trade mechanisms and potentially used elsewhere.[285] Such politically motivated policies are different from resource liberalist ones that would be primarily dictated by the market.[286] For this reason, consumer countries and companies are generally opposed to resource nationalism.[287]

There are three goals that governments might want to achieve through resource nationalistic policies: maximizing state gains; establishing state control over strategic sectors; and facilitating developmental spillovers in other sectors.[288] Examples of

---

[283] Natalie Koch and Tom Perreault, "Resource Nationalism," Progress in Human Geography 43, no. 4 (August 2019): 612, https://doi.org/10/gfc952.

[284] Jeffrey D. Wilson, "Resource Nationalism or Resource Liberalism? Explaining Australia's Approach to Chinese Investment in Its Minerals Sector," Australian Journal of International Affairs 65, no. 3 (June 2011): 285, https://doi.org/10/bxw4jk.

[285] Wilson, 285.

[286] Wilson, 285.

[287] Wilson, 285.

[288] Paul A Haslam and Pablo Heidrich, "From Neoliberalism to Resource Nationalism. States, Firms and Development," in Political Economy of Natural Resources and Development. From Neoliberalism to Resource Nationalism, Routledge Studies in Development Economics (Routledge, 2016), 1, https://www.researchgate.net/publication/340680811_Political_Economy_of_Natural_Resources_and_Development_From_neoliberalism_to_resource_nationalism.

policies include heavy taxation on foreign companies, forcing foreign companies to collaborate with state-owned enterprises, nationalizing companies with important market shares.[289] In other words, governments want to ensure – to the extent possible – monopolistic control over domestic resources, as well as establish state mechanisms that optimize this monopoly. Any type of state constraint that is designed to conserve reserves for domestic use and decrease access of foreign competitors can be considered a resource nationalistic policy.[290]

In the case of a (quasi-)monopoly, a company or country dominates either a sector of an industry – upstream, midstream or downstream – or, in more rare occasions, an entire supply chain.[291] Even though some critical raw materials are abundant geographically, the amount that can be economically mined is limited.[292] Opening a functional mine requires high investments and long periods of time before it can become economically feasible.[293] Thus, once a company or a country achieves economies of scale in a raw materials' industry, it can easily monopolize this entire stage of the supply chain.[294]

Within resource nationalism, this report will consider the following strategies: vertical integration, stockpiling, export restrictions and licensing.

5.1.1 Vertical integration

With vertical integration, companies ensure that they control many stages of a supply chain in order to not have to rely on independent contractors whose self-interested behavior they cannot control.[295] It is a supply chain management strategy with the purpose of minimizing transaction costs within an industry.[296] Vertical integration strategies can be employed by transferring ownership through mergers and acquisitions.[297] From a technical and transactional point of view, such integration reduces the time and finances spent on managing contracts with independent parties. Once all stages of a supply chain are integrated within the same company, no resources need to be spent on, for example, researching prices offered by alternative suppliers, ensuring quality consistency between company branches or negotiating contracts.[298]

---

[289] Haslam and Heidrich, 2.

[290] Sam Pryke, "Explaining Resource Nationalism," Global Policy 8, no. 4 (2017): 476, https://doi.org/10/ghbzg5.

[291] Jim Chappelow, "Natural Monopoly," Investopedia, August 29, 2019, https://www.investopedia.com/terms/n/natural_monopoly.asp.

[292] de Boer and Lammertsma, "Scarcity of Rare Earth Elements," 2047.

[293] de Boer and Lammertsma, 2047.

[294] Chappelow, "Natural Monopoly."

[295] Guan and Rehme, 188.

[296] Wei Guan and Jakob Rehme, "Vertical Integration in Supply Chains: Driving Forces and Consequences for a Manufacturer's Downstream Integration," Supply Chain Management: An International Journal 17, no. 2 (March 9, 2012): 187, https://doi.org/10/f2zr4z.

[297] Guan and Rehme, 188.

[298] Guan and Rehme, 189.

Strategically, vertical integration plays an important role.[299] Vertically integrated companies can acquire a monopolistic position and create entry barriers for junior companies. Moreover, information asymmetry becomes an issue between vertically integrated and unbundled companies, leading to the non-price discrimination of the latter by the former.[300] In other words, vertical integration can be said to offer a company knowledge about all stages of the value chain, which is an important advantage over those without access to such information.[301]

In the critical raw materials industry, vertical integration is specific to Chinese companies. China controls not only upstream REE sectors, but also downstream ones due to high investments in research and development of capabilities over time.[302] Moreover, Chinese vertical integration of lithium processing companies – Tianqi Lithium and Jiangxi Ganfeng Lithium – is more prominent than in the case of Australian companies, for example.[303] Australia, the world's largest lithium producer in the world, is nonetheless making efforts to move up the lithium-ion battery value chain.[304] Investing in the development of the lithium downstream sector – not only processing of lithium, but also lithium-ion battery technologies – is included in Australia's National Critical Minerals Strategy.[305]

Box 1. Vertical integration policy interventions

Policy interventions for the Netherlands:

- Invest in mergers and acquisitions to nationalize organizations in order to ensure a degree of control remains in NL/EU
- Subsidize domestic companies and invest in company shares in order to provide a competitive advantage to NL/EU companies
- Provide VAT tax returns for NL/EU companies that import raw materials rather than finished products in order to create a level playing field between NL/EU and Chinese manufacturers and encourage domestic production
- Create laws that prevent Chinese investments in Western mining capacity in order to maintain autonomy over domestic resources

---

[299] Guan and Rehme, 189.
[300] Vigen Nikogosian and Tobias Veith, "Vertical Integration, Separation and Non-Price Discrimination: An Empirical Analysis of German Electricity Markets for Residential Customers," SSRN Electronic Journal, 2011, 1, https://doi.org/10/gg9fm6.
[301] Nikogosian and Veith, 1.
[302] Eva Barteková and René Kemp, "National Strategies for Securing a Stable Supply of Rare Earths in Different World Regions," Resources Policy 49 (September 2016): 156, https://doi.org/10.1016/j.resourpol.2016.05.003.
[303] Kalantzakos, "The Race for Critical Minerals in an Era of Geopolitical Realignments," 9.
[304] Commonwealth of Australia, "Australia's Critical Minerals Strategy" (Australian Government, 2019), 3.
[305] Commonwealth of Australia, 8.

The Belt and Road Initiative (BRI) is the most significant addition to international logistical networks, involving 65 countries.306 Considering the importance of logistical facilities in establishing vertically integrated industries and China's dominance over the supply of critical raw materials to the EU307, the BRI could be seen as an attempt at further securing dominance within critical raw materials sectors.

5.1.2 Stockpiling

Stockpiling is a strategy aimed at strengthening security of supply. By accumulating a strategic stock of a certain asset, countries and companies become less vulnerable to short term disruptions in the market.[308] Thus, unexpected fluctuations in the price and supply of CRMs no longer influence an industry's supply chain significantly. Due to the strategic nature of CRMs, countries such as the US, Japan and China tend to not disclose the amounts stored, creating further uncertainty on the market.[309] Stockpiling can be considered a resource nationalistic strategy, as it aims at creating domestic leverage at the expense of other countries.[310] While strategic stockpiling is a widespread practice among countries, it is also often done by companies to secure their supply.[311]

Stockpiling can also lead to additional disturbances in the market. When certain countries increase their stockpiles, market demand surges and prices rise.[312] Stockpiling thus has the unintended consequence of influencing price volatility, as was illustrated by the cobalt crisis in the 1970s. A small-scale conflict in the Democratic Republic of Congo led to an interruption in the mining of cobalt and therefore to a global supply shortage.[313] Simultaneously, the US decided to increase stockpiles of cobalt, which further decreased the global availability of the material.[314] The result was a spike of 380% in the global price of cobalt between 1977 and 1979.[315]

---

306 Ye Jing and Hans Dietrich Haasis, "Impacts of the BRI on International Logistics Network," in Dynamics in Logistics, 2018, 250, https://doi.org/10.1007/978-3-319-74225-0_34.

307 EU Commission, "Critical Raw Materials," Text, Internal Market, Industry, Entrepreneurship and SMEs - European Commission, July 5, 2016, https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en.

308 Sprecher et al., "Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis," June 2, 2015, 6745.

309 Polina Klossek, Jakob Kullik, and Karl Gerald van den Boogaart, "A Systemic Approach to the Problems of the Rare Earth Market," Resources Policy 50 (December 1, 2016): 135, https://doi.org/10.1016/j.resourpol.2016.09.005.

310 Klossek, Kullik, and van den Boogaart, 134.

311 Sprecher et al., "Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis," June 2, 2015, 6745.

312 Benjamin Sprecher et al., "Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis," Environmental Science & Technology 49, no. 11 (June 2, 2015): 6745, https://doi.org/10/f7f8bf.

313 Elisa Alonso et al., "Material Availability and the Supply Chain: Risks, Effects, and Responses," Environmental Science & Technology 41, no. 19 (October 1, 2007): 6650, https://doi.org/10/fh7k45.(2

314 Alonso et al., 6650.(2

315 Alonso et al., 6649.(2

Box 2. Stockpiling policy interventions

Policy interventions for the Netherlands:

- Create an EU investment fund for responsible EU mining exploration and exploitation in order to decrease investment risks of companies
- Invest in mining exploration and exploitation in EU countries in order to gain autonomy over raw materials and prevent EU resources from being controlled by foreign powers
- Create national/EU bonds for mining investments in EU countries in order to encourage domestic investments

5.1.3 Restrictions

Resource nationalism is commonly materializes in the form of restrictions such as export quotas, export taxes, obligatory minimum export prices as well as licensing.[316] Resource nationalism commonly materializes in the form of restrictions such as export quotas, export taxes, obligatory minimum export prices as well as licensing.[317] Export quotas are quantitative restrictions on the total amount of a specific good that can be exported.[318] Two types of export taxes can be distinguished – either as a part of the good's value or as an amount to be paid per quantity of product.[319] Under the World Trade Organization rules, trade restrictions are only allowed if they conform with exceptions laid out in Article XX.[320] Although countries justify their restrictions on the basis of Article XX grounds, such as environmental causes, the WTO Dispute Settlement mechanism often declares them unlawful. Other reasons, primarily geopolitical, are believed to be the cause of many restrictions, showing how export restrictions can be used as a strategy to influence both domestic and global security of supply.

Although such restrictions might be beneficial for the exporting country, they tend to impact world trade significantly. Export restrictions can lead to an increase in the global price of the exported product and therefore to an improvement in terms of trade for the exporting country.[321] Moreover, imposing restrictions can decrease domestic prices of the exported product.[322] This is advantageous on one hand for

---

[316] Horizon Scanning Program, "Resource Nationalism" (HM Government, December 2014), 6, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/389085/Horizon_Scanning_-_Resource_Nationalism_report.pdf.

[317] Horizon Scanning Program, "Resource Nationalism" (HM Government, December 2014), 6, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/389085/Horizon_Scanning_-_Resource_Nationalism_report.pdf.

[318] Jane Korinek and Jeonghoi Kim, "Export Restrictions on Strategic Raw Materials and Their Impact on Trade and Global Supply," in The Economic Impact of Export Restrictions on Raw Materials, OECD Trade Policy Studies (OECD Publishing, 2010), 109, https://read.oecd-ilibrary.org/trade/the-economic-impact-of-export-restrictions-on-raw-materials_9789264096448-en.

[319] Korinek and Kim, 109.

[320] Yuzhou Shen, Ruthann Moomy, and Roderick G. Eggert, "China's Public Policies toward Rare Earths, 1975–2018," Mineral Economics 33, no. 1–2 (July 2020): 137, https://doi.org/10.1007/s13563-019-00214-2.

[321] Mancheri, "World Trade in Rare Earths, Chinese Export Restrictions, and Implications," 262.

[322] Mancheri, 262.

domestic consumers involved in the manufacturing of semi-processed goods, as they can produce cheaper final products, and on the other hand for consumers of the final commodity.[323] Lastly, export restrictions can also increase national public revenue.[324]

Generally, quantitative export restrictions are prohibited by Article XI of the General Agreement on Tariffs and Trade (GATT).[325] The exception laid out in Article XX allows export restrictions in cases of "conservation of exhaustible natural resources"[326], provided that they are met with similar domestic restrictions on production and consumption.[327] However, examples of trade restrictions are abundant. For example, in 2015 the American government prohibited sales of high-tech chips from Intel, the second-largest semiconductor producer in the world, to Chinese labs.[328] The unintended consequence of such trade restrictions is that they reduce interdependencies by encouraging the other side to become increasingly self-sufficient. In other words, the Intel ban ultimately strengthened Chinese capabilities in high-tech chips, which became more advanced than the ones from Intel were.[329]

Box 3. Restrictive policy interventions

Policy interventions for the Netherlands:

- Institute licensing requirements in order to maintain control over domestic markets:
  - Only allow maximum % of foreign investment
  - Require domestic presence in the company after investment
  - Discourage possibilities for acquisitions & mergers led by foreign companies in order to protect and restore intellectual property
- Take legal action with support of WTO against unbalanced subsidization by monopolists, in order to establish a level playing field
- Impose legal obligations for reporting on EU/NL level in order to increase transparency
- Establish a European minerals and metals exchange excluding monopolists in order to create a trading facility/an investment platform for metals and minerals
- Require Chinese investors to be listed on Western Exchanges when investing in CRM value chains
- Create enhanced legal restrictions such as the Dodd Frank act and equivalent EU legislation in order to decrease investment risks of companies

---

[323] Mancheri, 262.

[324] Mancheri, 263.

[325] Korinek and Kim, "Export Restrictions on Strategic Raw Materials and Their Impact on Trade and Global Supply," 104.

[326] "The General Agreement on Tariffs and Trade," § Article XX (1947), https://www.wto.org/english/docs_e/legal_e/gatt47_01_e.htm.

[327] Korinek and Kim, "Export Restrictions on Strategic Raw Materials and Their Impact on Trade and Global Supply," 104.

[328] The Economist, "The Chips Are down - The Semiconductor Industry and the Power of Globalisation," The Economist, December 2018, https://www.economist.com/briefing/2018/12/01/the-semiconductor-industry-and-the-power-of-globalisation.

[329] The Economist.

Licensing is another restrictive tool often used by governments for geopolitical reasons. When the conditions required in order to be offered a license are very strict, they can be used as a determinant of which companies can, for example, export goods.[330] As such, governments choose through licensing conditions which types of companies to support and which to discourage from performing activities within the domestic sphere. Licensing can be applied to any stage of the supply and value chains, as well as to investments.

5.2 Alliances

5.2.1 Resource Diplomacy

In a highly interdependent world such as today's, diplomatic means of cooperation dominate trade relations. Import-dependence on CRMs is possible due to the high degree of connectivity between domestic markets. Cooperation with supplying countries can increase market transparency and decrease uncertainty, leading to more stable trade relations.[331] Resource diplomacy is one of the most used strategies to secure supplies of raw materials. The strategy can be implemented through policy dialogues and alliances.[332]

Alliances are built with strategic partners – on one hand supplying countries and, on the other hand, countries which share similar import-dependence vulnerabilities. The EU's raw materials diplomacy is a noteworthy initiative in creating strategic relations with suppliers such as China and the African Union, and with other import-dependent countries such as the US and Japan.[333] The US Critical Materials Strategy outlined similar objectives of collaboration with the EU and Japan – in the form of a trilateral dialogue – based on their shared concerns of import-dependence.[334] An instrument that countries use to operationalize in resource diplomacy is development aid. Collaborative relations between donor and receiving countries often extend to agreements in trade, foreign investment or innovation.[335]

---

[330] Korinek and Kim, "Export Restrictions on Strategic Raw Materials and Their Impact on Trade and Global Supply," 109.

[331] U.S. Department of Energy, "Critical Materials Strategy," 108.

[332] Barteková and Kemp, "National Strategies for Securing a Stable Supply of Rare Earths in Different World Regions," 29.

[333] EU Commission, "Raw Materials Diplomacy," Text, Internal Market, Industry, Entrepreneurship and SMEs - European Commission, July 5, 2016, https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/international-aspects_en.

[334] U.S. Department of Energy, "Critical Materials Strategy," 109.

[335] Felicitas Nowak-Lehmann et al., "Aid and Trade – A Donor's Perspective," The Journal of Development Studies 45, no. 7 (August 1, 2009): 1184–1202, https://doi.org/10.1080/00220380902952407.

Box 4. Resource diplomacy policy interventions

Policy interventions for the Netherlands:

- Create new dossier combinations (e.g., with Agri-food) in order to increase interdependencies and create leverage in case China intends to restrict exports
- Focus on negotiations in the EU-China Comprehensive Agreement regarding the removal of joint venture requirements and equity caps in China, in order for EU companies to get better access to the Chinese market
- Invest in mines/sector that China is dependent on in order to create/increase trade dependency
- Connect diplomats and companies with knowledge institutions in order to educate and strengthen representations on materials dossiers
- Facilitate more collaboration through dialogues and partnerships on an international level in order to decrease likelihood of politically motivated restrictions
- Promote more collaboration through dialogues and partnerships on an international level in order to increase transparency
- Seek partnerships and agreements when excluded and combine dossiers to create interdependencies in order to maintain influence over relevant decisions
- Take legal and diplomatic action in order to protect intellectual property from theft
- Promote environmental and human rights norms and values in international institutions on raw materials

Additionally, international institutions are very important in resource diplomacy. The World Trade Organization (WTO) plays an important role in ensuring that global trade rules are not infringed upon.[336] The relevance of the WTO mechanism is supported by the repeated occasions where importing countries appealed against Chinese export restrictions on raw materials. In 2009 the European Communities, Mexico and the United States filed complaints to the WTO against 40 different Chinese export policies for raw materials that were illegal under international free trade rules.[337] Further, in 2012, the EU, Japan and the US complained against Chinese export quotas for REEs.[338] Export policies were found illegal in both cases, the verdict forcing China to withdraw them.[339] Imposing geopolitically motivated trade policies can affect the short-term security of supply of importing countries, but are unlikely to affect it on the long term if an international institution such as the WTO is involved. The WTO oversees such a large array of interdependent trade sectors, that refusing

---

[336] WTO, "Principles of the Trading System," WTO, 2020, https://www.wto.org/english/thewto_e/whatis_e/tif_e/fact2_e.htm.

[337] Stephanie Switzer, Leonardus Gerber, and Francesco Sindico, "Access to Minerals: WTO Export Restrictions and Climate Change Considerations," Laws 4 (September 22, 2015): 621, https://doi.org/10/gg9fkc.

[338] Switzer, Gerber, and Sindico, 623.

[339] Switzer, Gerber, and Sindico, 625.

to comply with rules in one sector could prove costly for other trade sectors as well. However, significant damage might still be caused, given that it took four years before the second WTO ruling was passed.[340]

5.2.2 Industrial Alliances

Alliances can also be formed on the industrial level, between companies and other stakeholders rather than purely between countries. A strategic alliance is defined as a "voluntary arrangement between two or more companies involving the exchange, sharing or co-development of resources or capabilities".[341] The ultimate purpose of parties involved in an alliance is to create value that they would not be able to independently.[342] This plays an important role in Western countries, where the sectors using critical raw materials are privatized and market actors become important players in ensuring secure supplies. Governments, although often not directly involved, can encourage and support such platforms of industrial collaboration.

Within the context of this report, two types of strategic industrial alliances are considered – horizontal and vertical, depending on the companies' positions in supply or value chain stages.[343] First, horizontal alliances can be created between companies with similar market positions within a value chain. Although these companies are generally competitors, they might be facing similar issues, for instance in the case of wind turbine manufacturers with an insecure supply of neodymium. Thus, pooling resources through an alliance would increase the likelihood of their mutual concerns being addressed.[344] Their bargaining power in negotiations with suppliers would furthermore be strengthened if their interests and strategies are coordinated.

Box 5. Industrial alliances policy interventions

Policy interventions for the Netherlands:

- Strengthen and expand European Raw Materials Alliance in order to increase cooperation between industrial actors
- Encourage participation of small-medium enterprises in national and international industry-wide alliances

The second type of strategic alliance is based on vertical cooperation within value chains. Companies collaborate with their upstream and downstream counterparts

---

[340] Kalantzakos, "The Race for Critical Minerals in an Era of Geopolitical Realignments," 4.

[341] Angelo Canzaniello, Evi Hartmann, and Matthias S. Fifka, "Intra-Industry Strategic Alliances for Managing Sustainability-Related Supplier Risks: Motivation and Outcome," International

[342] Canzaniello, Hartmann, and Fifka, 390.

[343] Canzaniello, Hartmann, and Fifka, 390.

[344] Canzaniello, Hartmann, and Fifka, 390.

in order to share resources and maximize profits.[345] In the critical materials sector, alliances can be made along strategic value chains in order to reduce dependency on external actors. This approach has been adopted within the EU, where transnational alliances can help reduce dependency on imports from non-EU members and become more resilient to disruptions in supply. The European Battery Alliance and the recently established Raw Materials Alliance (ERMA) are examples of vertical alliances in which companies across value chain stages cooperate in order to bring these industrial processes back to Europe.

5.3 Diversification of Suppliers

Diversification is one of the most widely used risk-mitigation strategies, with the goal of ensuring that the desired raw materials come from a variety of sources rather than a single one.[346] Thus, the influence of disruptions – either natural or geopolitical – on the general functioning of a supply chain becomes limited.[347] Diversification can be based on the material's location of origin, but also on ownership grounds.[348] This is of particular importance in the case of critical raw materials, as China controls many stages of the supply chains, not only domestically but abroad as well.[349] In other words, diversifying by investing in a mine abroad does not ensure independence from China due to e.g., high flows of Chinese foreign direct investment into supply chain facilities in Australia and Greenland.

Diversification as a strategy can be applied to all stages of a supply chain, from exploration and mining up to end-of-life. It can be done through investing in the exploration and exploitation of raw materials, or through purchasing concessions both domestically and abroad. Diversifying through investment in domestic mining and processing facilities for critical raw materials (CRM) was one of the main priorities of the United States' 2010 Critical Materials Strategy.[350]

Mitigating supply risks through investment in alternative facilities is a generally used strategy in supply chain management.[351] In the case of CRMs, opening new mines and facilities for the processing of minerals is a highly costly strategy both in terms of duration and financial requirements. Creating a more reliable market for

---

[345] Baojun Yu, Hangjun Xu, and Feng Dong, "Vertical vs. Horizontal: How Strategic Alliance Type Influence Firm Performance?," Sustainability 11, no. 23 (January 2019): 3, https://doi.org/10.3390/su11236594.

[346] Gaustad et al., "Circular Economy Strategies for Mitigating Critical Material Supply Issues," 31.

[347] Sprecher et al., "Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis," June 2, 2015, 6748.

[348] Gaustad et al., "Circular Economy Strategies for Mitigating Critical Material Supply Issues," 28.

[349] Sprecher et al., "Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis," June 2, 2015, 6743.

[350] U.S. Department of Energy, "Critical Materials Strategy," 6.

[351] Sprecher et al., "Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis," June 2, 2015, 6743.

materials involved in low-carbon technologies, such as CRMs, by reducing the risk for investments is one of the main policy recommendations of the World Bank's 2020 report[352] on the relationship between energy transition and demand of minerals.

It takes between six and ten years to shift from the exploration phase of an REE mine toward the mining process itself.[353] Additionally, costs are immense, and the time before a mine becomes profitable makes financial investments quite unpopular among market players. For example, investments in some of the most relevant REE mines outside of China, including the US Mountain Pass mine, owned by MP Materials, and Australian Mt Weld, owned by Lynus, consisted of more than 500 million US dollars each.[354]

Investment decisions in alternative mines are undermined by the high opacity of the REE market, characterized by a common lack of trust[355], as well as price volatility.[356] This problematic nature is influenced by uncertainty regarding current and predicted supply and demand, exploitation and production capabilities, the size of stockpiles, technological innovations as well as strategic considerations.[357] The opaque trade relations further complicate matters. Even though many raw materials such as copper are openly traded, REEs are traded bilaterally and thus information is only partially available.[358] Based on these uncertain features of the REE market, countries such as the US, Japan, Canada and Australia share serious concerns of market manipulation.[359]

Pricing mechanisms of REEs are controlled primarily by the quasi-monopolist power, China, who can offer low prices and therefore depress investments in alternative mines.[360] An illustration of how difficult it is to establish a new mining operation is the case of Australia, where between 2004 and 2014, only 10% of junior companies were able to institute a long-term operational mine.[361] Despite these issues, there was one case when investment in alternative facilities experienced a sharp and sudden increase. It occurred after the 2011 REE price peak, when many countries acknowledged the importance of diversification of their CRM supplier(s). This has been called the 'exploration boom', as more than 200 junior companies started

---

[352] Hund et al., "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition," 101.

[353] de Boer and Lammertsma, "Scarcity of Rare Earth Elements," 2049.

[354] de Boer and Lammertsma, 2049.

[355] Klossek, Kullik, and van den Boogaart, "A Systemic Approach to the Problems of the Rare Earth Market," 131.

[356] Karen Smith Stegen, "Heavy Rare Earths, Permanent Magnets, and Renewable Energies: An Imminent Crisis," Energy Policy 79 (2015): 6, https://doi.org/10.1016/j.enpol.2014.12.015.

[357] Klossek, Kullik, and van den Boogaart, "A Systemic Approach to the Problems of the Rare Earth Market," 134.

[358] Klossek, Kullik, and van den Boogaart, 135.

[359] US Department of Energy, "Critical Materials Rare Earths Supply Chain: A Situational White Paper," April 2020, 9.

[360] Mancheri et al., "Effect of Chinese Policies on Rare Earth Supply Chain Resilience," 108.

[361] Holger Paulick and Erika Machacek, "The Global Rare Earth Element Exploration Boom: An Analysis of Resources Outside of China and Discussion of Development Perspectives," Resources Policy 52 (2017): 136, https://doi.org/10.1016/j.resourpol.2017.02.002.

investing in REE exploration processes in 2011 alone.[362] However, the lengthy process of ensuring a mine is operational together with the immense costs led many initial investors to abandon their projects.[363] Low prices of Chinese raw materials before and after the surge – a double pricing structure – also made it difficult for alternative mines to function, as they became inefficient from a market perspective.[364] The high impact of Chinese policies over global prices is due to the monopolistic position that China plays in the market.

Lithium-ion battery production facilities are just as costly. More than $3 billion were raised by Northvolt, a Swedish company, for the construction of two factories in Sweden and Germany.[365] These factories aim at capturing 25% of the European market by 2030.[366] Moreover, Tesla is currently building its most advanced electric vehicle production facility – Gigafactory Berlin-Brandenburg – in Germany and has reported investments of up to $4.4 billion.[367] Another Tesla Gigafactory is under construction in Shanghai, China. Up to $1.6 billion was invested by Chinese-supported lenders.[368]

Box 6. Diversification of supplier's policy interventions

Policy interventions for the Netherlands:

- Adopt a long-term strategy in order to ensure alternative options exist in case of severe disruptions
- Decrease investment risk for companies by providing government guarantees in order to encourage diversification in supply chains for small, medium and large enterprises
- Decrease investment risk for companies by encouraging sustainable financing to redirect investments to responsible mining and accountable production

---

[362] Paulick and Machacek, 142.

[363] Klossek, Kullik, and van den Boogaart, "A Systemic Approach to the Problems of the Rare Earth Market," 132.

[364] Klossek, Kullik, and van den Boogaart, 133.

[365] "Northvolt Raises $1.6 Billion in Debt Financing through Consortium of Global Financial Institutions," Northvolt, July 29, 2020, https://northvolt.com/newsroom/Northvolt-July2020-financing.

[366] "Northvolt Raises $1.6 Billion in Debt Financing through Consortium of Global Financial Institutions."

[367] Tesla, "Gigafactory Berlin-Brandenburg," Tesla, 2020, https://www.tesla.com/en_eu/gigafactory-berlin; Rebecca Staudenmaier, "Tesla Factory Outside Berlin to Cost €4 Billion," DW, November 17, 2019, https://www.dw.com/en/tesla-factory-outside-berlin-to-cost-4-billion/a-51286353.

[368] Ryan McMorrow, "Tesla Lines up $1.6bn in Financing for Its Shanghai Gigafactory," December 27, 2019, https://www.ft.com/content/598b04cc-286d-11ea-9a4f-963f0ec7e134.

5.4 Standard setting

Standards can be thought of as conditions for a secure supply chain, as a strategic tool that could create a new market based on newly agreed upon practices. The market structure can be redesigned by establishing new norms and standards that companies are forced to comply with in order to retain their credibility[369] and their market share.[370]

Standards are generally created in order to solve or mitigate coordination issues between parties. This type of standardization is often done on the international level, in either public standard setting organizations such as the International Telecommunications Unit (ITU) or in international non-governmental bodies such as the International Standardization Organization (ISO). The former is distinguished through the participation of state representatives, normally mid-level public officials.[371] While state involvement does not translate to the development of binding rules in this case, the standards are often matched with policies to ensure compliance. [372]

The difference between these and international non-governmental standards organizations such as the ISO is that the latter tend to regulate private sector activity.[373] In such organizations, member states are primarily represented by private industry players rather than government officials. Internationally, this is how most standards are developed – approximately 80 % of all international product standards are introduced by ISO and the International Electrotechnical Commission.[374]

A third type of standards can be referred to as public market ones, typically introduced by regulators and thus enshrined in law.[375] They are meant to ensure minimum necessary requirements for activity, such as the EU competition policy. Studies have found that several factors, including the regulatory capacity of standard-setting entities and the economic weight of the markets they standardize, increase the chance that standards introduced at the local level will go on to be established as de-facto global standards.[376] Even though these standards are not internationally binding, they become mandatory for companies who want to remain active in a market.[377] Monopolistic companies – such as Chinese REE companies – are generally the ones with sufficient global influence to implement their domestic standards as de-facto international ones.

---

[369] T.A. Gardner et al., “Transparency and Sustainability in Global Commodity Supply Chains,” World Development 121 (September 2019): 173, https://doi.org/10/gfc4tp.

[370] Spencer Henson, “The Role of Public and Private Standards in Regulating International Food Markets,” Special Issue: Food Regulation And Trade: Institutional Framework, Concepts Of Analysis And Empirical Evidence, Journal of International Agricultural Trade and Development, 4, no. 1 (2008): 511.

[371] Tim Büthe and Walter Mattli, “International Standards and Standard Setting Bodies,” in The Oxford Handbook of Business and Government (Oxford: Oxford University Press, 2010), 449–53.

[372] Büthe and Mattli, 449–53.

[373] Büthe and Mattli, 455–60.

[374] Büthe and Mattli, 455–60.

[375] Büthe and Mattli, 453–55.

[376] Büthe and Mattli, 453–55.

[377] Henson, “The Role of Public and Private Standards in Regulating International Food Markets,” 65.

The last type of standard is purely private in nature. The private market model of standard setting refers to a process in which individual private-sector actors introduce standards (whether technological or otherwise) with the goal of capitalizing on their wider adoption.[378] Firms manufacturing products with specifications that are aligned with international standards can gain significant competitive advantage over other market players.[379] Often, companies attempt to steer international standard development in the direction of their own product designs.[380] The 'winner' can get market dominance and first-mover advantage by shaping standards to their advantage.[381]

The connection between intellectual property and standardization is another aspect relevant to the strategic role of standards. Companies compete for the patenting of strategic products that can be used in order to fulfil a standard – known as a standard-essential patent.[382] Many industries depend on standardized products which are protected through patents.[383] The most prominent examples are communication and high-tech sectors, such as 4G and Wi-Fi networks, that rely on hundreds of patented inventions in order to function effectively world-wide.[384] If a firm secures such strategic patents, it can reap significant financial benefits through royalty fees.[385] Moreover, being in charge of licensing a large number of companies becomes an important geopolitical advantage.[386]

These four categories of standards, though primarily technical in nature, have been increasingly used as strategic tools to further international influence. Given that they establish ways in which emerging technologies can be used, countries tend to compete for whose ideas are reflected in a new internationally strategic product, such as 5G, artificial intelligence or electric vehicles. Part of the power that standards have stems from their long-term applicability. Once they have been adopted and products are commercialized based on certain characteristics, it is virtually impossible to change them.

Additionally, standards tend to reflect normative ideas and values. For instance, the EU's GDPR regulations offer strict standards for, among others, the way data is

---

[378] Büthe and Mattli, "International Standards and Standard Setting Bodies," 460–63.

[379] The US-China Business Council, "China in International Standards Setting: USCBC Recommendations for Constructive Participation," February 2020, 6.

[380] John Seaman, "China and the New Geopolitics of Technical Standardization," Notes de l'Ifri (Ifri, 2020), 14.

[381] Seaman, 14.

[382] The US-China Business Council, "China in International Standards Setting: USCBC Recommendations for Constructive Participation," 6.

[383] EU Commission, "Patents and Standards," Text, Internal Market, Industry, Entrepreneurship and SMEs - European Commission, July 5, 2016, https://ec.europa.eu/growth/industry/policy/intellectual-property/patents/standards_en.

[384] EU Commission.

[385] The US-China Business Council, "China in International Standards Setting: USCBC Recommendations for Constructive Participation," 6.

[386] The US-China Business Council, 6.

collected by unauthorized parties.[387] This high degree of strictness is closely connected to the EU's promotion of respect for human rights and privacy. In other words, GDPR is simultaneously a technical standard for privacy and a way of furthering European norms and values. Yet technical standards are not the only way in which an entity can exert (indirect) normative influence – it can also be done directly by designing standards with the main purpose of formalizing norms.[388] Examples of the latter case are responsible mining initiatives that aim at preventing environmental damage or human rights violations such as the EU's Conflict Minerals Regulation.[389]

While transparency mechanisms are not involved in a direct causal relation with security of supply, they do play an important role in legitimizing sources of raw materials. Reputation costs can be significant for a company if, for instance, human rights violations are involved in the extraction of minerals. If a supplier does not obey transparency guidelines, its customers might want to choose an alternative supplier who does respect human rights and environmental standards, even though it means paying a premium for a similar product.[390] Consumers are able to directly influence the behavior of suppliers by means of performing a "politicized consumption".[391] In other words, consumers can hold firms accountable through their purchasing power and force them to comply with accountability standards along supply chains.[392]

Box 7. Standard setting policy interventions

Policy interventions for the Netherlands:

- Ensure that international technical standards are set based on European practices in order to combat market dominance of China
- Propose standards essential patents according to EU emerging technologies in order to achieve first-mover advantages
- Promote responsible labor and environmental standards to encourage mining activities outside of China
- Create awareness that standards have political effects in order to encourage standard setting in strategic sectors

---

[387] "What Is GDPR, the EU's New Data Protection Law?," GDPR.eu, November 7, 2018, https://gdpr.eu/what-is-gdpr/.

[388] Shi Chen, Qinqin Zhang, and Yong-Pin Zhou, "Impact of Supply Chain Transparency on Sustainability under NGO Scrutiny," Special Issue on Innovations and Sustainability 28, no. 12 (2018): 3003, https://doi.org/10.1111/poms.12973.

[389] "Regulation (EU) 2017/821 of the European Parliament and of the Council of 17 May 2017 Laying down Supply Chain Due Diligence Obligations for Union Importers of Tin, Tantalum and Tungsten, Their Ores, and Gold Originating from Conflict-Affected and High-Risk Areas," Pub. L. No. 32017R0821, 130 OJ L (2017), http://data.europa.eu/eli/reg/2017/821/oj/eng.

[390] Alexis Bateman and Leonardo Bonanni, "What Supply Chain Transparency Really Means," Harvard Business Review, August 20, 2019, https://hbr.org/2019/08/what-supply-chain-transparency-really-means.

[391] Jens Hainmueller, Michael J. Hiscox, and Sandra Sequeira, "Consumer Demand for Fair Trade: Evidence from a Multistore Field Experiment," Review of Economics and Statistics 97, no. 2 (May 2015): 242, https://doi.org/10/gg63w5.

[392] Hainmueller, Hiscox, and Sequeira, 242.

5.5 R&D

Research and Development (R&D) programs are commissioned in order to expand knowledge and encourage innovation. New technologies and techniques lead to increased productivity and decreased marginal costs within an industry.[393] In the case of critical raw materials, R&D initiatives are deployed not only privately, but also nationally to increase security of supply by discovering potential substitutes for critical materials, technologies that lengthen a material's lifespan – recycling – or that require less amounts of that same material – reducing. Developing a new technology in a strategically important sector such as CRMs is a highly desirable advantage.

According to the International Energy Agency, low-carbon energy research accounted for 80% of national R&D energy spending in 2019.[394] There was a 7% increase in public spending on energy R&D in both the EU and US compared to 2018.[395] In the EU, the increase can be explained by the Horizon Europe research program and other R&D initiatives as integral parts of the Green Deal.[396] Moreover, China maintained in 2019 an upward trend of R&D energy spending in general and of low-carbon technologies in particular.[397] In terms of the private sector – an important addition to governmental spending – electro-mobility spending was the central focus of R&D energy spending.[398]

One way to measure the outcome of R&D programs is the number of patents owned within a country, by either the government or a domestically controlled company. Over the past decade, international patenting activity has been dominated by electric vehicle innovation, particularly in lithium-ion batteries.[399] Additionally, semiconductors are one of the technological fields in which most patents were filed between 2014 and 2018.[400]

---

[393] Sean Ross, "Why Should You Invest in Research and Development (R&D)?," Investopedia, July 22, 2019, https://www.investopedia.com/ask/answers/043015/what-are-benefits-research-and-development-company.asp.

[394] IEA, "R&D and Technology Innovation – World Energy Investment 2020," IEA, May 2020, https://www.iea.org/reports/world-energy-investment-2020/rd-and-technology-innovation.

[395] IEA.

[396] IEA.

[397] IEA.

[398] IEA.

[399] IEA and European Patent Office, "Innovation in Batteries and Electricity Storage - A Global Analysis Based on Patent Data," September 2020, 4.

[400] World Intellectual Property Organization, "Patent Cooperation Treaty Yearly Review" (Geneva, 2020), 12, https://www.wipo.int/edocs/pubdocs/en/wipo_pub_901_2020.pdf.

Box 8. R&D policy interventions

Policy interventions for the Netherlands:

- Invest in the development of greener production technology for mining in order to encourage mining outside of China
- Create a knowledge platform to analyze and predict future EU demand and map supply of secondary CRM from EU stocks and wastes
- Support development of modular/recyclable technology and develop efficient urban mining techniques in order to increase secondary supply of materials
- Support development of academic and professional expertise in mining and mineral exploration
- Make R&D in mining a national priority and develop national investment strategies together with the EU maintain autonomy over national resources
- Increase investment finding substitute technologies using non-critical materials
- Campaign to reduce the public resistance to mining in the EU through the promotion and development of sustainable (high-tech) mining practices
- In order to maintain influence over relevant international decisions:
  - Seek academic/research partnerships between EU and China
  - Train academics to sensitize their behavior regarding the critical dependencies with China
  - Decrease the reliance of academics on China for funding by making more R&D funding available
- Support R&D into Ecodesign principles to increase dematerialization, and reduce demand for critical materials

5.6 Circular Economy Strategies

5.6.1 Recycle (The Urban Mine)

Recycling is a core element of circular economy projections for the following decades. In the context of security of supply, recycling is seen as a method of meeting demand without the need to mine additional primary minerals, thus reducing dependence on foreign suppliers through diversification of sources.[401]

The design of the end-product is relevant for the success of the recycling process. An eco-design, or design for recycling, refers to using the least impactful procedures for

---

[401] Golev et al., “Rare Earths Supply Chains,” 55.

a product's life cycle when the product is designed and manufactured.[402] There are several ways to do so, including using less harmful materials, less integrated parts as well as more efficient production techniques.[403]

One issue commonly associated with the recycling of renewable technologies in order to secure supply is that newly commissioned wind turbines or batteries will only be available for recycling after years of functioning.[404] Furthermore, economic feasibility and energy intensiveness are impediments to recycling some materials. Primary materials are often cheaper than secondary ones, providing little grounds for recycling from an economic perspective.[405] Moreover, energy demand for certain recycling processes is so high that it creates additional environmental challenges.[406] Thus, from a circularity perspective, some recycling processes cause more damage to the environment than contribute to preserving it.

This is problematic particularly in the case of REE recycling methods. An innovative method of recycling REEs from end products that is effective from both financial and environmental perspectives has not yet been found.[407] Generally, only about 1% of REEs are successfully recycled from end-of-life products – the rest is transformed into waste.[408] Only low amounts of REEs are used in final products, making the separation of the latter in order to recycle REEs largely unprofitable.[409]

Outside of China, Rhodia Operations in France – owned by the La Solvay group – is the largest recycling facility of REEs. Another important actor in Europe is the Umicore recycling facility in Belgium, which focuses – among others – on secondary supply of cobalt and lithium.[410] Umicore collaborates with large vehicle manufacturers such as Tesla and Toyota.[411] By exploiting the already existing 'urban mine' in developed countries, dependence on the Democratic Republic of Congo's mines is reduced.[412]

---

[402] Elisabeth Maris et al., "Chapter 27 - From Recycling to Eco-Design," in Handbook of Recycling, ed. Ernst Worrell and Markus A. Reuter (Boston: Elsevier, 2014), 421–27, https://doi.org/10.1016/B978-0-12-396459-5.00027-1.

[403] Maris et al.

[404] Smith Stegen, "Heavy Rare Earths, Permanent Magnets, and Renewable Energies," 6.

[405] Hund et al., "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition," 80.

[406] Hund et al., 80.

[407] Smith Stegen, "Heavy Rare Earths, Permanent Magnets, and Renewable Energies," 6.

[408] Simon M. Jowitt et al., "Recycling of the Rare Earth Elements," Current Opinion in Green and Sustainable Chemistry 13 (October 2018): 1, https://doi.org/10/gf3wst.

[409] Golev et al., "Rare Earths Supply Chains," 55.

[410] Christian Hagelüken, "Critical Metals for Lithium-Ion Batteries - Umicore Strategies for Sustainable Sourcing of Cobalt" (RFG 2018 - Resources for Future Generations, Vancouver, 2018), 9, https://doi.org/10.13140/RG.2.2.17167.89764.

[411] Joey Gardiner, "The Rise of Electric Cars Could Leave Us with a Big Battery Waste Problem," The Guardian, August 10, 2017, sec. Guardian Sustainable Business, https://www.theguardian.com/sustainable-business/2017/aug/10/electric-cars-big-battery-waste-problem-lithium-recycling.

[412] Hagelüken, "Critical Metals for Lithium-Ion Batteries - Umicore Strategies for Sustainable Sourcing of Cobalt," 7.

5.6.2 Reuse/ Repurpose

Reuse is another commonly iterated strategy within circular economy scenarios. It refers to reusing a product on one hand, or a component such as a battery for an alternative use than it was initially intended on the other hand.[413] Like recycling, it provides an alternative to primary materials shortages.

In order to maximize reusing rates, the concept of 'design for reuse' has been developed in a similar way to 'design for recycle', which is useful for end-of-life products with reusable components. Ease of separation of components, standardization of functional units, material selection and waste minimization influence the efficiency of reusing processes.[414] Investing fewer financial resources and time into the disassembly of a product and the repurposing its components facilitates the reusing process.[415] As such, product manufacturing is an important determinant of component reuse or 'parts harvesting'.[416]

Reusing whole products is another initiative that can take place either through changing ownership or through changing users. The former refers to the relocation or reselling on the second-hand market, while the latter typically occurs when one owner allowing contractors to use the item.[417]

Lithium-ion batteries present a good opportunity for reusing. Typically, there are two types of reuse strategies for li-ion batteries used in electric vehicles. In the first case, the battery has reached 70-80% of its initial capacity by the end-of-life stage of an electric vehicle as a whole.[418] While it cannot be reused in another electric vehicle due to its decreased capacity, the battery can still be reused for stationary energy storage purposes, such as grid storage.[419] The second case regards batteries that can still operate at full capacity after the electric vehicle has reached its end-of-life stage.[420] This type of batteries can then be reused for another electric vehicle.[421]

The World Bank warns that reusing technologies should be carefully considered. With the pretext of reusing technologies, should they be transferred from developed to

---

[413] Hund et al., "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition," 83.

[414] Wendy Middleton and Lee Goldberg, "Design for Disassembly, Reuse and Recycling," in Green Electronics/Green Bottom Line : Environmentally Responsible Engineering (Boston: Newnes, 2000), 72, https://web-a-ebscohost-com.proxy.uba.uva.nl:2443/ehost/ebookviewer/ebook/ZTAwMHh3d19fMjA3NTIxX19BTg2?sid=42e65781-3c3d-43ae-94ba-9e92074c5593@sessionmgr4008&vid=0&format=EB&rid=1; Piero Morseletto, "Targets for a Circular Economy," Resources, Conservation and Recycling 153 (February 1, 2020): 7, https://doi.org/10/ghbzg6.

[415] Morseletto, "Targets for a Circular Economy," 8.

[416] Morseletto, 8.

[417] Morseletto, 7.

[418] Kirti Richa et al., "A Future Perspective on Lithium-Ion Battery Waste Flows from Electric Vehicles," Resources, Conservation and Recycling 83 (February 2014): 66, https://doi.org/10/f5twzm.

[419] Gaustad et al., "Circular Economy Strategies for Mitigating Critical Material Supply Issues," 28.

[420] Richa et al., "A Future Perspective on Lithium-Ion Battery Waste Flows from Electric Vehicles," 66.

[421] Richa et al., 66.

developing countries without a proper regulatory framework, the technology could be instead turned into waste.[422]

5.6.3 Reduce

This strategy refers to a general decrease in the amount of resources used, leading in turn to a decrease in inputs of energy, raw materials as well as waste. The strategies of reuse and reduce are closely interlinked, as reducing consumption of new products would lead to reusing older ones.[423] Reducing can be understood in two ways – as a decrease in the number of manufactured products; and as dematerialization, which is the decrease of the amount of material and waste generated per product.[424]

Dematerialization involves both product and process efficiency, or; using less and doing less to manufacture a product.[425] It is also referred to as the 'Factor X' approach, implying an increase in productivity and decrease in inputs by a certain X proportion.[426] Innovative technologies such as material substitution can lead to dematerialization.[427] Material substitution occurs when the requirements for manufacturing a product are fulfilled by another material without any change in product design.[428] Building samarium-cobalt magnets instead of neodymium ones is an illustrative example of material substitution.[429] Substitution is a security of supply strategy as it can decrease dependence of an industry on a particular raw material by finding alternatives.[430]

However, substitution has been criticized in the context of circular economy, as it could lead simply to the replacement of material rather than a reduction in the total amount of materials. Technology substitution refers to a transformation in product design whereby a certain critical material is not needed at all anymore.[431]

Possibilities for substitution are one of the factors used in assessing the criticality of a material. Significant R&D projects are being commissioned – particularly by import-

---

[422] Hund et al., "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition," 83.

[423] Morseletto, "Targets for a Circular Economy," 9.

[424] F. den Hond, "Industrial Ecology," in International Encyclopedia of the Social & Behavioral Sciences, ed. Neil J. Smelser and Paul B. Baltes (Oxford: Pergamon, 2001), 7320–26, https://doi.org/10.1016/B0-08-043076-7/04138-3.

[425] John Manoochehri, "Consumption Opportunities: Strategies for Change" (Geneva: United Nations Environment Program, 2001), 27.

[426] Manoochehri, 28.

[427] den Hond, "Industrial Ecology."

[428] Sprecher et al., "Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis," June 2, 2015, 6745.

[429] Sprecher et al., 6745.

[430] Claudiu C Pavel et al., "Substitution of Critical Raw Materials in Low-Carbon Technologies: Lighting, Wind Turbines and Electric Vehicles" (Luxembourg: European Commission, Oko-Institut e.V., 2016), 12.Tb, Y, In, Ga, Ge, Nd, Pr and Dy

[431] Sprecher et al., 6745.

dependent countries such as the EU – to find substitutes for critical materials and therefore reduce dependence.[432] [433]

Box 9. Circular economy policy interventions

Policy interventions for the Netherlands:

- Support circular procurement in government, industry and consumer purchasing
- Set requirements for minimum recycled material content by removing legislative hurdles, and reducing taxation on products with a high recycled metal %
- Encourage recycling activities of consumers through the creation of decentralized recycling centers, following best practices (e.g. Japan JBRC)
- Support recycling industry through EU funds, subsidization and/or tax benefits for organizations in order to ensure a steady supply of secondary raw materials and promote intra-EU cooperation
- Restrict export of metal scrap to non-EU countries in order to ensure a steady supply of secondary materials within the EU
- Reduce taxation on labor-intensive maintenance and repair of technologies to elongate their lifetime, and reduce dependence on new imported components
- Reduce taxation on labor in favor of taxation of minerals in order encourage use of secondary raw materials

---

[432] European Commission, "Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions. Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability" (Brussels: European Commission, September 3, 2020), 3, https://ec.europa.eu/docsroom/documents/42849.

[433] Sprecher et al., 6745.

5.7 Summary

Strategy		Description
Resource Nationalism	Vertical integration	Acquire a monopolistic position and create entry barriers for junior companies. States can nationalize companies or subsidize sectors to strengthen domestic companies' international competitive position.
	Stockpiling	Accumulate a strategic stock of a certain asset in order to become less vulnerable to short term disruptions in the market.
	Restrictions	Export quotas, export taxes, obligatory minimum export prices, licensing, taxation
Alliances	Resource Diplomacy	Build alliances with strategic partners – supplying countries as well as countries which share similar import-dependence vulnerabilities.
	Industrial Alliances	Establish horizontal and vertical strategic alliances between industry players in order to exchange and share resources and capabilities.
Diversification of Supply		Ensure that the desired materials and products come from a variety of sources. Both geographic diversification and in terms of ownership.
Standard Setting		Create differentiation between very similar products, allowing competition based on characteristics other than solely price. Could lead to first-mover advantage and market dominance.
R&D		Expand knowledge and encourage innovation in order to patent and control relevant future technologies.
Circular Economy Strategies		Recycle (the Urban Mine), reuse, reduce

Table 6. Strategies and their descriptions

6. Strategies applied by the Netherlands, the EU and China

6.1 The Netherlands

The Netherlands' strategy for bracing the country against the negative (economic) effects of a future explosive growth in global demand for critical raw materials places a heavy emphasis on circularity. The government does not implement policies consistent with resource nationalism, standard setting or diversification of supply. R&D policies are implemented in a way that, by and large, lend support to the overarching circularity goal. The government has worked towards circularity since 2016, when it introduced its Circular Economy Strategy – which aims to achieve full circularity and/ or sustainability by 2050.[434] The Government aims at achieving this goal by ensuring that legislative obstacles are removed and by developing legal frameworks that stimulate innovation.[435] This includes circular product designs, waste management policy as well as a 'sharing economy' for reusing and reducing products.[436] Smart incentives to stimulate the secondary material market, financial support and R&D are additional instruments used in order to achieve circularity.[437]

The Circular Economy Strategy outlines a five-pronged approach to achieving circularity by 2050. First and foremost, the government recognizes that some of the policies it is currently implementing do not incentivize small businesses or entrepreneurs to invest in or consider circular business models – something which it hopes to address by adjusting its policies. Second, the government wants to continue to incentivize businesses to embrace circular business models by designing conducive fiscal policies. Third, the government wants to supplement its fiscal policies with direct funding. Fourth, it wants to (continue to) invest in R&D within the field and, fifth, it wants to foster international cooperation. The degree to which it has succeeded in implementing these policies varies. The government consulted small business owners and entrepreneurs under its Ruimte in Regels program, which aimed to allow the

---

[434] Ministerie van Infrastructuur en Waterstaat, "Circular Dutch Economy by 2050" (Ministerie van Algemene Zaken, November 4, 2019), https://www.government.nl/topics/circulareconomy/circular-dutch-economy-by-2050.

[435] Ministerie van Infrastructuur en Waterstaat, "Nederland Circulair in 2050," 2016.

[436] Ministerie van Infrastructuur en Waterstaat.

[437] Ministerie van Infrastructuur en Waterstaat, "Circular Dutch Economy by 2050."

formulation of laws and policies that might facilitate further investments into more renewable business models on said actors' part.

As far as fiscal policy is concerned, the government has intervened in the country's internal market to increase demand for recyclable and bio-based materials, as well as to stimulate circular innovation and business models, through fiscal policies such as the *Milieu Investeringsaftrek* (MIA) and *Willekeurige Afschrijving Milieu-investeringen* (VAMIL), and has committed to exploring other policy options (including a Carbon tax and environmental protections) by 2020. As envisioned, these fiscal policies have been supplemented – both by the government and by major national financiers (major banks and foundations, etc.) by a.) the explicit allocation of funds towards circular initiatives, and b.) a rework (on the government side) of the tender system, which is now more likely to deduct points from requests which do not incorporate circularity in one way or another.

The government's efforts as far as R&D are concerned are implemented through institutions such as the NPRO and the NOW, which have respectively introduced the *KIEM-VANG* and the *Gesloten Kringlopen – Transitie naar de circulaire economie* programs. Fostering international cooperation has (by and large) proceeded most directly through the EU, where the Netherlands organized various multi-stakeholder panels on circularity and climate change during the period where it chaired the European Council (EC). The government has also supported Dutch companies seeking to sell renewable products abroad and has pushed circularity topics within the UN and the OECD.

While limited, the Dutch government has also alluded to its recognition of the need to engage in resource diplomacy. A 2011 paper outlined that the NL would, outside of the EU's extensive bilateral initiatives, look at conducting diplomacy to further strengthen its relationship with Germany. It also committed to "learning from" Chinese efforts at linking the provision of development aid to access to resources by more strategically exploring business opportunities with recipients of UN or EU-funded development aid.

6.2 The EU

CRM list 2020 & European Raw Materials Alliance (ERMA)

The European Union has recognized that member states might face supply security issues regarding certain critical raw materials ever since 2008, when the Raw Material Initiative was established.[438] The initiative was based upon three pillars – fair and

---

[438] European Commission, "Critical Raw Materials."

sustainable global supply of raw materials, sustainable supply within the EU, and circularity principles for secondary supply.[439] In order to achieve these goals, several relevant policy instruments were established. One of the most influential policy tool instituted by the Initiative is the List of CRMs, which has been published every three years since 2011. Moreover, the European Innovation Partnership (EIP) on raw materials was established as a stakeholder collaboration platform encouraging and promoting innovative solutions for ensuring sustainable and secure supply of CRMs.[440]

The latest list of CRMs was published in 2020 and introduced an Action Plan to ensure European security of supply by diversifying suppliers, investing in domestic sourcing and promoting circularity as a means to achieve secondary supplies.[441] The first step of the Action plan was the establishment of the European Raw Materials Alliance to promote cooperation and information sharing between relevant stakeholders. The Alliance is industry-led, involving actors from all relevant sectors of strategic technological value chains.[442] The two priority areas are REEs magnets and motors.

Further, the 2020 Action Plan focuses on researching and investing into European sourcing of CRMs. This does not only imply investment in mining and processing projects, but also in human capital associated with such processes. All of the future projects included in the Action Plan are brought together by sustainability standards. As such, programs such as Horizon Europe will be largely focused on sustainable sourcing as well as circular economy principles. Waste processing and substitution are given particular attention. The development of green European-based production technologies for secondary CRMs is key towards the achievement of the EU's CRM strategy. Promoting international partnerships is another goal of the EU.

Resource Diplomacy

The EU's 'Raw Materials Diplomacy' initiative is a strategic instrument for ensuring security of supply, through bilateral, regional or multilateral collaborative frameworks.[443] In this manner, the EU establishes strategic partnerships not only with supplying countries such as China, but also with other resource-dependent countries such as the US and Japan. Such national alliances are complementary to industry-based alliances in the field of CRMs.

The EU maintains constant dialogue with China regarding critical materials through two main mechanisms: the EU-China Working Group on Raw Materials, established

---

[439] European Commission.

[440] European Commission.

[441] European Commission, "COM(2020) 474 - Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability," 6.

[442] EIT RawMaterials, "About Us," ERMA, 2020, https://erma.eu/about-us/.

[443] EU Commission, "Raw Materials Diplomacy." EU Commission.

in partnership with the Chinese Ministry of Industry and Information Technology; and the Metals Working Group, together with the National Development and Reform Commission.[444]

The EU-China Trade and Economic High-Level Dialogue is the main channel through which the two entities collaborate on all issues. Although not focused on CRMs specifically, decisions made in this dialogue could influence CRM trade. Specifically, current negotiations for the EU-China Comprehensive Agreement include topics such as state-owned enterprises, subsidy transparency and levelling the playing field for EU companies in China.[445] If negotiations are successful, it would mean that EU companies could be able to invest in China without having to partner with Chinese domestic companies, and that subsidies of the Chinese government toward domestic companies will be in line with competition rules. Such decisions are indirectly relevant to CRMs, as they target several Chinese strategies identified in the next section (see 6.3 China).

Additionally, the EU collaborates with other resource-dependent countries. The trilateral partnership with the US and Japan was created in 2011 with the purpose of, among others, finding alternative suppliers of critical raw materials.[446] The time period for the creation of this partnership coincides with the rare earth price crisis of 2011, indicating that it was primarily created for geopolitical concerns.[447] Australia, Canada and South Africa are also often involved in these discussions.[448] Furthermore, the EU is collaborating closely with Japan in the science and innovation in sectors such as climate change and digital transition.[449]

While the EU collaborates with many countries, it also developed certain restrictive instruments. As a result of the EU being rated as one of the most open investment areas for foreign entities, the Commission created the first EU-wide FDI Screening Regulation in 2019.[450] This framework aims at preventing any FDI that might be threatening to EU security and social order.[451] It is not designed specifically for CRMs, but it could be applicable to Chinese investments if they are proved to undermine EU control over domestic resources and facilities.

---

[444] EU Commission, “Raw Materials Diplomacy.” EU Commission.

[445] European Commission, “EU-China: Commission and China,” Text, European Commission, September 10, 2020, https://ec.europa.eu/commission/presscorner/detail/en/IP_20_1600.

[446] EU Commission, “Raw Materials Diplomacy.” EU Commission.

[447] Kalantzakos, “The Race for Critical Minerals in an Era of Geopolitical Realignments,” 4.

[448] Barteková and Kemp, “National Strategies for Securing a Stable Supply of Rare Earths in Different World Regions,” 18.

[449] European Commission, “Japan | International Cooperation - Research and Innovation,” 2020, https://ec.europa.eu/research/iscp/index.cfm?amp;pg=japan.

[450] European Commission, “EU Foreign Investment Screening Regulation Enters into Force,” Text, European Commission - European Commission, 2019, https://ec.europa.eu/commission/presscorner/detail/en/IP_19_2088.

[451] European Commission.

Standardization

The European standard setting process can be described as a hybrid between binding and non-binding rules. European Standards aim at streamlining trade and cooperation between EU member states, but their adoption depends on the national governments.[452] Binding EU standards are mandatory conditions that products must fulfil in order to be traded on the EU Single Market.[453] These standards are codified into EU legislation, which then needs to be implemented nationally. Non-binding EU standards are developed by European standardization organizations (most notably CEN-CENELEC) at the request of the EU Commission.[454] They are guidelines that can help countries achieve mandatory standards.

Broadly, future developments in important policy areas and technology are in Energy transition, Electrification, Transport and Cables and Digital Technologies. These are important sectors for the EU to concentrate its efforts in order to achieve its digital and climate goals for the following decades, as well as to maintain competitiveness. Especially the sectors in which standards have not been set represent priorities for the EU.

In the area of CRMs, the EU aims at promoting sustainable and responsible standards established through the Raw Materials Initiative. They would do so by compiling good practice reports and promoting the exchange of best practices among stakeholders.[455] Topics include land use planning, conditions for extraction and administrative regulations. Moreover, in 2018 the European Battery Alliance published a strategic action plan for the responsible sourcing of battery materials.[456]

A notable legislative tool is the Due Diligence framework for conflict minerals which will enter into force on January 1st, 2021. It includes tin, tantalum, tungsten and gold.[457] However, given that sourcing raw materials is part of national rather than supranational competencies[458], the EU's influence in the matter remains limited.

Moreover, the Re-Sourcing project of Horizon 2020 targets industrial actors, policymakers and civil society with the aim of ensuring minimum responsible sourcing requirements for mineral value chains. The stakeholder platform was established in

---

[452] European Committee for Standardization, "The 'New Approach,'" June 14, 2019, https://boss.cen.eu/reference%20material/guidancedoc/pages/newapproach.aspx.

[453] European Committee for Standardization.

[454] European Committee for Standardization.

[455] European Commission, "Raw Materials Diplomacy," Text, Internal Market, Industry, Entrepreneurship and SMEs - European Commission, July 5, 2016, https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/international-aspects_en.

[456] Joint Research Centre, "Responsible Sourcing of Materials for Batteries," 2020, https://rmis.jrc.ec.europa.eu/?page=responsible-sourcing-of-materials-for-batteries-f0f53b.

[457] EU Commission, "Due Diligence Ready!," Text, Internal Market, Industry, Entrepreneurship and SMEs - European Commission, November 5, 2019, https://ec.europa.eu/growth/sectors/raw-materials/due-diligence-ready_en.

[458] EU Commission. EU Commission. EU Commission. EU Commission.

2020 and collaborates for standard setting in value chains of strategic products for climate and digital ambitions.[459]

R&D

EU R&D activities for critical materials are divided into two broad categories: those commissioned through Horizon 2020; and those under the auspices of the European Institute of Innovation and Technology (EIT) Raw Materials. These categories are complementary and sometimes overlap in their research programs. Horizon 2020 is the EU's main Research and Innovation program. Main focus areas that are relevant to CRMs include energy transition, circular economy as well as the digitalization of European industry and services.[460] Additionally, the EIT Raw Materials plays an important role in R&D activities. EIT Raw Materials is a large stakeholder platform involving industry actors, research institutes and universities that aim at improving the domestic European raw materials sector and at securing resilient supply chains.[461] Among others, EIT Raw Materials supports the new European Raw Materials Alliance.

Circular Economy

Ever since 2015, the EU established circularity ambitions in the Commission Communication 'Closing the loop – An EU action plan for the Circular Economy'.[462] This strategic document encourages circularity actions in every step of product value chains.[463] As such, the EU supports R&D into the development of sustainable recycling techniques for CRMs in order to produce secondary sources and reduce import dependence. Moreover, the EU aims at establishing common technical standards for secondary raw materials in order to foster trade between European countries.[464] The EU is also active in waste management across member states. The Waste Framework Directive of 2008 established a common conceptual understanding of waste as well as requirements for waste management.[465]

---

[459] Joint Research Centre, "Re-Sourcing H2020 Project," 2020, https://rmis.jrc.ec.europa.eu/?page=re-sourcing-h2020-project-7f5bde.

[460] European Commission, "Focus Areas," Text, Horizon 2020, September 29, 2015, https://ec.europa.eu/programs/horizon2020/en/h2020-section/cross-cutting-activities-focus-areas.

[461] EIT RawMaterials, "About Us."

[462] European Union, "Closing the Loop - An EU Action Plan for the Circular Economy," Pub. L. No. COM/2015/0614, 52015DC0614, accessed October 26, 2020, https://eurlex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0614.

[463] European Union.

[464] Joint Research Centre, "Circular Economy & Secondary Raw Materials," 2020, https://rmis.jrc.ec.europa.eu/?page=policies-and-definitions-2d5b5e.

[465] European Commission, "EU Waste Legislation," 2020, https://ec.europa.eu/environment/waste/legislation/a.htm.

6.3 China

China's resource and production nationalism strategies are in line with the Chinese government's current national strategies. Specifically, ambitions laid out in China's 2025 and 2049 national strategies indicate that the country intends to become a leading actor in many high-tech sectors, including energy saving technologies and high precision machinery.[466] As mentioned in the previous sections, China's control over global supplies of raw materials needed for such technologies guarantees significant advantages in achieving future goals.

In order to illustrate the exceptional status that China has acquired over time in the critical raw materials' sector, several strategies are analyzed from the Chinese perspective. To begin with, policies before the 1990s are briefly considered, followed by a more elaborate discussion of resource nationalistic strategies. The latter include vertical integration of state-owned enterprises; stockpiling; as well as restrictions. Moreover, Chinese diversification policies are discussed in terms of FDI, as well as standardization and R&D – in line with the definitions provided earlier in the report. Control over trade channels plays an important strategic role for China, which is why this aspect is also analyzed. Lastly, circularity strategies are mentioned.

6.3.1 Initial policies – Investing in facilities and R&D

Established in 1963, the Baotou Research Institute of Rare Earths has been the largest rare earth research institute in the world.[467] The following decades saw little progress, until China achieved technological leadership in the extraction of REE in the 1990s, overtaking the United States.[468] Critical raw materials, and specifically rare earth elements (REE), have been considered strategic goods by the Chinese government since the 1990s.[469] China has achieved dominance over supply chains of critical raw materials by implementing resource nationalistic policies ever since 1990.[470] At the beginning of the 1990s, the Chinese REE upstream and midstream sectors already represented half of the global production.[471]

---

[466] N Preziosi et al., "China: Challenges and Prospects from an Industrial and Innovation Powerhouse." (Luxembourg: Publications Office of the European Union, 2019), 13, https://data.europa.eu/doi/10.2760/445820.

[467] Carlos Aguiar De Medeiros et al., "Transforming Natural Resources into Industrial Advantage: The Case of China's Rare Earths Industry," Brazilian Journal of Political Economy 37, no. 3 (July 2017): 516, https://doi.org/10.1590/0101-31572017v37n03a03.

[468] Medeiros et al., 516.

[469] Shen, Moomy, and Eggert, "China's Public Policies toward Rare Earths, 1975–2018," 131.

[470] Klossek, Kullik, and van den Boogaart, "A Systemic Approach to the Problems of the Rare Earth Market," 134.

[471] Shen, Moomy, and Eggert, "China's Public Policies toward Rare Earths, 1975–2018," 127.

6.3.2 Resource Nationalism

Vertical integration and subsidization

One of the main resource nationalistic policies is the Chinese government's support of vertical integration between upstream and downstream companies, particularly in the rare earth industry, in order to maximize domestic competitive advantage and social welfare.[472] This contradicts the profit-maximization market approach that is generally implemented by private companies abroad.[473] At the moment, there are six dominant enterprises that control virtually the entire upstream and midstream sectors of REEs in China. Three of them – China Minmetals Corporation, Aluminum Corporation of China Limited, and China Northern Rare Earth Group High-tech Limited – are directly controlled by the Chinese government, while the other three – Xiamen Tungsten Corporation, China Southern Rare Earth Group and Guangdong Rare Industry Group – have local Chinese governmental units as main stakeholders.[474] The entire Chinese REE industry is dominated by the six integrated enterprises. Once they integrated, these companies were assigned 90% of total national production quotas, thus controlling 22 of 23 mines and 54 of 59 smelting facilities by June 2016.[475]

Another policy supporting the competitive advantage of Chinese domestic companies is the pricing structure within the REE industry.[476] The six dominant enterprises are heavily subsidized by both national and local governmental units.[477] The significant subsidies combined with minimal labor costs and weak law enforcement mechanisms within mines and production facilities, allow Chinese companies to offer prices lower than anywhere else in the world.[478] Given that privately-owned companies ultimately need to become profitable by recovering their high initial investments, the prices they establish are often uncompetitive.

China has also employed vertical integration strategies for lithium supply chain companies. Jiangxi Ganfeng Lithium is a vertically integrated Chinese state-owned company and the largest producer of lithium in China.[479] Heavy subsidization toward manufacturers of electric vehicles (EV) – for which lithium batteries are essential components – occurred until 2019, when the US-China trade war decreased the demand for Chinese EVs.[480] This forced the Chinese government to halt most

---

[472] Aiping Han, Jianping Ge, and Yalin Lei, "Vertical vs. Horizontal Integration: Game Analysis for the Rare Earth Industrial Integration in China," Resources Policy 50 (December 1, 2016): 158, https://doi.org/10.1016/j.resourpol.2016.09.006.

[473] Han, Ge, and Lei, 158.

[474] Shen, Moomy, and Eggert, "China's Public Policies toward Rare Earths, 1975–2018," 139.

[475] Mancheri et al., "Effect of Chinese Policies on Rare Earth Supply Chain Resilience," 108.

[476] Klossek, Kullik, and van den Boogaart, "A Systemic Approach to the Problems of the Rare Earth Market," 132.

[477] Klossek, Kullik, and van den Boogaart, 132.

[478] Klossek, Kullik, and van den Boogaart, 132.

[479] Kalantzakos, "The Race for Critical Minerals in an Era of Geopolitical Realignments," 7.

[480] Kalantzakos, 8.

subsidization programs in the EV industry.[481] The period in which subsidies were offered was nonetheless significant for the development of the industry.[482]

Stockpiling

Stockpiling in China can be regarded as part of the country's monopolist strategy. In 2011, the Chinese government commissioned a public-private strategic stockpile of REEs[483], and in 2016 a commercial one.[484] Considering the influence that national stockpiles can have on the global market, Chinese stockpiles are believed to have the ultimate goal of maintaining dominance over global market volumes and pricing.[485]

Restrictions

Over time, China has been implementing different export restrictions for critical minerals. The most salient have been those applied to REEs, but others such as the 2008 export tax on germanium and export quota for indium and silicon are additional notable instances.[486]

In the REE sector, resource nationalistic policies started with restrictions on foreign investment in the 1990s. Foreign investment was allowed only under very specific circumstances by the Chinese government agencies and licenses were only issued for governmental exploration projects.[487] Between 2000 and 2009, export and production quotas as well as export taxes were widely imposed by the Chinese government.[488] This was – at least partly – an attempt to develop the Chinese domestic downstream sector by offering local companies significantly lower prices for raw materials than to their foreign competitors.[489] In 2002, foreign companies were further restricted as the Chinese government prohibited them from smelting and separation processes too. Instead, only domestic companies or consortia between foreign and domestic companies could be licensed.[490] Increasingly stricter export quotas were established, which, together with production quotas, contributed to a decrease in REE exports from 68,547 tons (t) in 1999 to 43,918 t in 2009.[491] In 2009, export quotas of REEs forced foreign consumers of REE to pay 31% more than Chinese consumers for the same products.[492]

---

[481] Kalantzakos, 8.

[482] Kalantzakos, 8.

[483] Jost Wübbeke, "Rare Earth Elements in China: Policies and Narratives of Reinventing an Industry," Resources Policy 38, no. 3 (September 1, 2013): 387, https://doi.org/10.1016/j.resourpol.2013.05.005.

[484] Mancheri et al., "Effect of Chinese Policies on Rare Earth Supply Chain Resilience," 109.

[485] Klossek, Kullik, and van den Boogaart, "A Systemic Approach to the Problems of the Rare Earth Market," 135.

[486] Korinek and Kim, "Export Restrictions on Strategic Raw Materials and Their Impact on Trade and Global Supply," 127.

[487] Shen, Moomy, and Eggert, "China's Public Policies toward Rare Earths, 1975–2018," 131.

[488] Shen, Moomy, and Eggert, 131.

[489] Shen, Moomy, and Eggert, 131.

[490] Lucia Baldi, Massimo Peri, and Daniela Vandone, "Clean Energy Industries and Rare Earth Materials: Economic and Financial Issues," Energy Policy 66 (March 1, 2014): 54, https://doi.org/10.1016/j.enpol.2013.10.067.

[491] Shen, Moomy, and Eggert, "China's Public Policies toward Rare Earths, 1975–2018," 133.

[492] Horizon Scanning Program, "Resource Nationalism," 6.

Increasingly stricter export restrictions led to a surge in global REE prices between 2010-2011.[493] A conflict emerged between exporting China on one hand and import-dependent US, Japan and the EU on the other hand.[494] The three countries reported Chinese practices to the World Trade Organization (WTO) as illegal under the GATT.[495] China's claim under Article XX that restrictions were aimed at preserving domestic resources was not accepted as a reasonable and sufficient explanation.[496] In 2014, the WTO declared China's policies incompatible with free trade rules and therefore the Chinese government removed restrictions by 2015.[497]

Although export quotas were hardly passed after 2015, China did continue resource nationalistic policies in the form of, among others, vertical integration. While vertical integration was justified as a way of stopping illegal production as well as of protecting the environment, it had a similar effect to licensing mechanisms.[498] As mentioned in the previous section, vertically integrated domestic companies cover 90% of production quotas. Moreover, since 2018, no new licenses for exploration or mining of REEs have been passed.[500] Through this measure, the government aims to maintain control over domestic production capacity.[501] Thus, vertical integration ensured that domestic companies control the entire industry and that foreign companies' activity is virtually terminated.

6.3.3 Diversification of Supply - Chinese FDI

Not only does China have about 37% of the world's reserves of REE, but they have also been actively acquiring concessions abroad.[502] Chinese state-owned institutions attempted at purchasing Mountain Pass, the largest REE mine in the United States, as well as a significant share of Lynas Corporation, an Australian REE mining company.[503] However, these investments were not successful due to American and Australian concerns about Chinese influence.[504]

China's Shenghe Resources Holding Co Ltd did manage to acquire 9.9% of MP Materials, the consortium owning the Mountain Pass mine.[505] Other notable

---

[493] Golev et al., "Rare Earths Supply Chains," 52.
[494] Golev et al., 52.008
[495] Shen, Moomy, and Eggert, "China's Public Policies toward Rare Earths, 1975–2018," 137.
[496] Shen, Moomy, and Eggert, 137.
[497] Shen, Moomy, and Eggert, 137.
[498] Mancheri et al., "Effect of Chinese Policies on Rare Earth Supply Chain Resilience," 108.
[499] Mancheri et al., 108.
[500] Ministry of Natural Resources, "China Mineral Resources 2019" (Beijing, 2019), 39, https://www.gov.cn/xinwen/2018-10/22/5333589/files/01d0517b9d6c430bbb927ea5e48641b4.pdf.
[501] Ministry of Natural Resources, 39.
[502] Cindy Hurst, "China's Rare Earth Elements Industry: What Can the West Learn?" (Institute for the Analysis of Global Security, March 1, 2010), 13.
[503] Hurst, 14.
[504] Hurst, 14.
[505] Ernest Scheyder, "U.S. Rare Earths Miner MP Materials to Go Public in $1.47 Billion Deal," Reuters, July 15, 2020, https://www.reuters.com/article/us-mp-materials-ipoidUSKCN24G1WT.

acquisitions include the US company Magnequench in 1995, a neodymium magnet producer, whose operations and expertise were subsequently transferred to China.[506] Additionally, China purchased a 25% share of another Australian developer, Arafura Resources Ltd.[507], a 12.5% of the Kvanjefjeld REE mining project in Greenland in 2018[508], as well as a part of a separation plant project in Vietnam in 2017.[509]

Chinese companies have been proactive in purchasing shares of companies involved in the downstream supply chain of lithium in South America and Australia. Tianqi Lithium, a vertically integrated Chinese company, is the second largest shareholder in a Chilean company involved in lithium extraction, Sociedad Quimica y Minera.[510] Tianqi Lithium also purchased 51% shares in the largest lithium mine in the world, Greenbushes in Western Australia.[511]

Notably, Chinese companies have also been investing in the high-tech sector of the Netherlands. In 2015, Jianguang Asset Management – or JAC Capital – owned by China Jianyin Investment Ltd, a Chinese state-owned company, purchased a part of NXP – the Semiconductors division of Royal Phillips.[512] Specifically, JAC Capital bought the Radio Frequency Power department, which is the producer of chips for cell phone towers.[513] Further, in 2017, the Standard Products department of NXP was purchased by a Chinese consortium.[514] The investments made in the Netherlands are in line with the 'Made in China 2025' strategic goals, particularly that of capturing more segments of global value chains.[515]

6.3.4 Standards Setting

Standardization is increasingly being used as a geopolitically strategic instrument.[516] Recently, based on *China Standards 2035* as well as on the *Chinese dream*, China identified standardization as an essential tool in advancing their interests.[517] As one of the Chinese government's main ambitions is to become a superpower in the technological sector, setting the standards for basic features of emerging technologies grants them great influence over the market.[518] Conversely, becoming a leading power

---

[506] Klossek, Kullik, and van den Boogaart, "A Systemic Approach to the Problems of the Rare Earth Market," 133.

[507] Hurst, "China's Rare Earth Elements Industry," 14.

[508] Ties Dams, Louise van Schaik, and Adaja Stoetman, "Presence before Power: China's Arctic Strategy in Iceland and Greenland" (Clingendael, June 2020), 33, https://www.clingendael.org/pub/2020/presence-before-power/4-greenland-what-is-china-doing-there-and-why/.

[509] Jesper Zeuthen, "Part of the Master Plan? Chinese Investment in Rare Earth Mining in Greenland," 2017, 10.

[510] Kalantzakos, 7.

[511] Kalantzakos, 7.

[512] van der Putten, 2.

[513] van der Putten, 2.

[514] van der Putten, 2.

[515] van der Putten, 2.

[516] Björn Fägersten and Tim Rühlig, "China's Standard Power and Its Geopolitical Implications for Europe —" (Swedish Institute of International Affairs, 2019), 4.

[517] Fägersten and Rühlig, 3.

[518] ägersten and Rühlig, 3.

in the innovative sector and developing cutting-edge technologies offers China an advantageous position in standard setting.[519]

In terms of hard law standardization instruments, the Chinese government has been restricting the activity of companies through legally binding standards. The main motivation until now has been environmental degradation, which is caused by two phenomena. On one hand, intensive exploration and extraction of raw materials since the 1990s led to concerning issues of environmental degradation. On the other hand, illegal mining causes environmental concerns given that such producers do not comply with any regulatory frameworks. In order to combat these issues, the Chinese government has been taking drastic measures in the shape of, among others, mandatory standardization. Such regulations to encourage sustainable practices include the Rare Earth Industrial Standards from 2016, Emission Standards of Pollutants from Rare Earth Industry from 2011, and the Norm of Energy Consumption per Unit Products of RE Metallurgical Enterprise.[520] In 2011, it was expected that 80% of companies would fail to respect the freshly passed environmental standards regarding REE waste.[521]

Although these legally binding standards were aimed at improving product quality and tackling environmental issues, it has been argued that they were also geopolitically motivated.[522] Setting strict standards inhibits the activity of foreign companies who are not able to adjust. Instead, the same strict standards would be favorable to Chinese state-owned enterprises with the means to restructure their activity accordingly with the help of high subsidies from the Chinese government.[523] In this sense, such hard law mechanisms can be seen as a resource nationalistic policy.[524]

The Standardization Law of China that entered into force in 2018 provides a new legal basis for standardization mechanisms, which are undergoing domestic reform.[525] The purpose of the reform is to encourage technological innovation by transferring some power in standardization from the centralized Chinese Communist Party to private market actors.[526] In this way, the party would retain its influence while also ensuring that national ambitions regarding innovative technologies are achieved.[527]

The standardization process in China is highly complex, involving many institutions that set standards in a hierarchical way. As such, lower-class standards must be in compliance with higher-class standards. Standards are divided into five hierarchical

---

[519] Seaman, “China and the New Geopolitics of Technical Standardization,” 10.
[520] Shen, Moomy, and Eggert, “China’s Public Policies toward Rare Earths, 1975–2018,” 142.
[521] Wübbeke, “Rare Earth Elements in China,” 389.
[522] Seaman, “China and the New Geopolitics of Technical Standardization,” 11.
[523] Klossek, Kullik, and van den Boogaart, “A Systemic Approach to the Problems of the Rare Earth Market,” 132.
[524] Fägersten and Rühlig, “China’s Standard Power and Its Geopolitical Implications for Europe —,” 5.
[525] Seaman, “China and the New Geopolitics of Technical Standardization,” 16.
[526] Fägersten and Rühlig, “China’s Standard Power and Its Geopolitical Implications for Europe —,” 5.
[527] Seaman, “China and the New Geopolitics of Technical Standardization,” 16.

categories, depending on the decision-making level on which they are developed: national, sector (industrial), local, association, and enterprise. Except for the national standards, which can be either mandatory or voluntary, the rest of the categories can only include voluntary standards. While the national government encourages the adoption of voluntary standards by the lower decision-making bodies, they must nonetheless comply with the mandatory ones.

China Standard 2035 – National Standardization Development Strategy Research is a governmental project with the purpose of determining effective ways of introducing national standards.[528] The scope of the research is very extensive, involving not only governmental agencies, but also private and state-owned companies, universities, research institutes, local actors. One of the goals of China Standard 2035 is to influence international standard setting platforms, such as the International Organization of Standardization (ISO).[529] Moreover, the Chinese government aims to increasing the number of international standards it proposes, as well as gain more influence over how newly developed technologies work.[530] The focus of China 2035 is new technologies, such as artificial intelligence, telecommunication networks – including 5G – as well as internet of things and big data.[531]

Another relevant Chinese policy instrument is the *Main Points of National Standardization Work 2020*[532]. This document provides instructions about the inclusion of standardization in China's 14th Five Year Plan, in the form of a National Standardization Strategy Outline. This Strategy will be based on the results of the research phase of China Standards 2035, which is currently taking place. Like in the Standards 2035 strategy, the Main Points document also mentions the participation in international standardization processes as one of the main priorities. However, apart from international standards, the *Main Points* also emphasizes multilateral, bilateral and regional cooperation. There are explicit mentions of BRICS, the EU, the African Union, ASEAN, the Belt and Road Initiative, and Asia in general. Additionally, Saudi Arabia stands out as one of the main individually named countries.

While critical raw materials are not mentioned explicitly in *Main Points 2020*, there is a desire to standardize carbon fiber (carbon), rare earths and graphene – critical materials over which China has significant dominance. In terms of other strategic

---

[528] State Administration for Market Regulation, "'China Standard 2035' Project Closing Meeting and 'National Standardization Development Strategy Research' Project Kick-off Meeting Held in Beijing," January 15, 2020, http://www.samr.gov.cn/xw/zj/202001/t20200115_310519.html.

[529] Sima Hong, "Sima Hong, Member of the National Committee of the Chinese People's Political Consultative Conference: Proposal on Docking the International High-Standard Market Rule System to Further Improve the Internationalization Level of Chinese Standards," Sohu, May 21, 2020, https://m.sohu.com/a/396716867_120056211.

[530] Hong.

[531] The State Council of the People's Republic of China, "Main Points of National Standardization Work in 2020," 2020, http://www.gov.cn/zhengce/zhengceku/2020-03/24/content_5494968.htm.

[532] 年全国标准化工作要点

sectors, high-tech products are discussed as well. Among others, the Main Points document mentions blockchain, internet of things, new cloud computing, big data, AI, new smart cities and geographic information. These are also the main priorities of the China Standards 2035 document.

6.3.5 Research and Development

Research and development have played an important role in China acquiring their dominant role over many critical raw materials, especially REEs.[533] The Baotou Research Institute of Rare Earths has been the world's largest research center on REEs ever since its establishment in 1963.[534] The amount invested in R&D by the Chinese government has steadily increased over the years. The National High Technology Research and Development Program – known as Program 863 – was instituted in 1986 and was aimed at securing and strengthening China's global position in high-tech sectors by increasing innovation capacities.[535] This large-scale national program led to concerns among US officials that China's position in defense and strategic sectors could be secured through their use of REEs.[536]

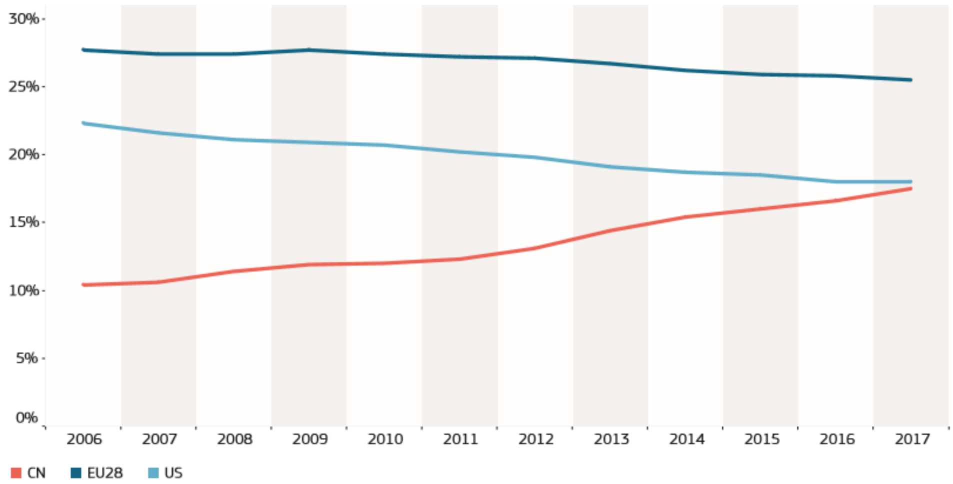


Figure 6. Top 10% highly cited publications of China, the EU and US. Source: Preziosi et al., 2019, p. 61.

One of China's most notable R&D programs is the 15 year Medium-to-Long-Term plan (MLP) in Development and Science Technology. The last one, 2006-2020, placed significant emphasis on research and innovation, with the goal of becoming technological leaders in new scientific areas. In 2006, China had a 10% share of the top 10% highly cited publications in science and technology, compared to approximately

---

[533] Barteková and Kemp, "National Strategies for Securing a Stable Supply of Rare Earths in Different World Regions," 156.

[534] Medeiros et al., "Transforming Natural Resources into Industrial Advantage," July 2017, 516.

[535] Barteková and Kemp, "National Strategies for Securing a Stable Supply of Rare Earths in Different World Regions," 156.

[536] Medeiros et al., "Transforming Natural Resources into Industrial Advantage," July 2017, 517.

22% for the US and the 28% for the EU, the latter having been dominant in R&D programs until then.[537] This can be observed in Figure 6. Moreover, China's R&D expenditure was less than half of that of the EU in 2010.[538] By 2015/2016, the situation changed drastically. As seen in Figure 7, not only did China overtake the EU in the level of R&D expenditure, but it also levelled with the US on the most cited publications. In 2017, they both had a share of about 19% of the total 10% most cited publications. The EU secured a relatively stable share of 26%.[539]

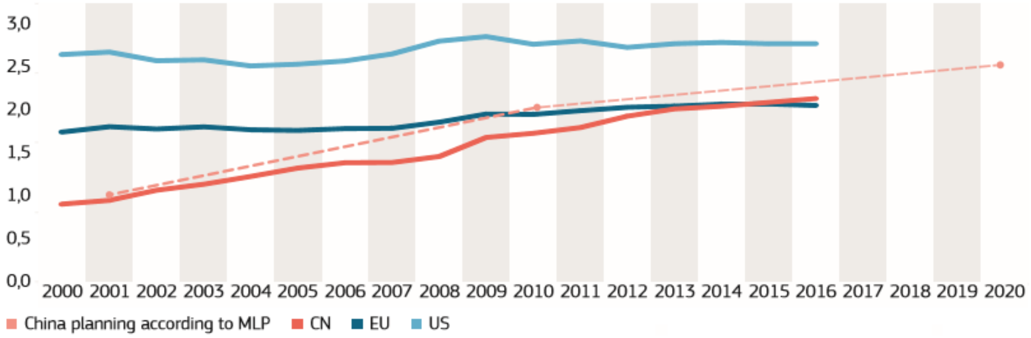


Figure 7. Gross Expenditure in R&D by China, the EU and US. China's objective according to the MLP is also illustrated.[540]

6.3.6 Trade Channels

Over time, China has been attempting to acquire control over significant mineral trading platforms worldwide. In 2012, Hong Kong Exchange & Clearing (HKEX) purchased London Metal Exchange (LME), the most relevant trading platform for metals, accounting for 80% of world trade.[541] HKEx paid a price that was 180 times higher than the platform's annual revenues and had China Development Bank as its biggest sponsor.[542] When the transfer of ownership took place, the HKEx justified the high price in that it would lead to a stronger connection between western countries and China, the largest industrial consumer of metals.[543] The chief executive of HKEx, Charles Li, has maintained strong ties with Chinese party officials, but a more concrete connection between the LME and China is yet to be publicly announced.[544]

The London Metal Exchange is the biggest commodity exchange platforms in the world for non-ferrous metals including, among others, aluminum, copper, lead and

---

[537] Preziosi et al., "China," 61.
[538] Preziosi et al., 60.
[539] Preziosi et al., 61.
[540] Preziosi et al., 59.
[541] The Hague Centre for Strategic Studies, "A Strategic Coup? A Brilliant Acquisition of the World Metal Market," The Hague Centre for Strategic Studies, October 5, 2012, https://hcss.nl/news/a_strategic_coup_a_brilliant_acquisition_of_the_world_metal_market_1.
[542] The Hague Centre for Strategic Studies.
[543] Henry Sanderson and Neil Hume, "HKEX yet to Realise Its Grand Ambitions for London Metal Exchange," Financial Times, September 11, 2019, https://www.ft.com/content/73ecd7b4-d494-11e9-a0bd-ab8ec6435630.
[544] Sanderson and Hume.

tin.[545] Precious metals – gold and silver – and minor metals – cobalt – are also included in contract specifications.[546] The LME functions primarily on the basis of derivatives, by allowing its members to trade futures and options contracts.[547] These two are complemented by other financial products such as Traded Average Price Options and Monthly Average Futures.[548]

In order to facilitate the physical exchange of goods additional to the purely financial one, the LME created a network of warehouses around the world where stocks of metals are kept.[549] Even though reports are published by LME on a daily basis regarding the available stocks of these warehouses, transparency concerns have been raised over time.[550] The concerns stem from the way in which off warrant stocks are measured.[551] While metals on warrant are those registered on the LME as available to be traded, off warrant stocks are generally about to be physically delivered to buyers.[552] An increase in 'cancelled warrants', i.e. amounts of metals that are no longer registered with the LME because they have been traded, can signal an increase in the demand of the metal.[553] Given that the LME is the main price setting authority for certain metals, fluctuations in demand can have global implications.[554] Transparency problems arise given that stock owners are able to cancel warrants for reasons other than their transfer on the physical market.[555] As such, secret stockpiles can be kept in the same LME warehouses and, due to their off-warrant characteristics, the sizes of metal stocks are not known to the public.[556] The lack of stock transparency of the LME has come to be known as "shadow warehousing"[557], which is one of the reasons why the institution has tried to reform its system. In July 2020, the LME published its first report on the status of off warrant stocks, aiming to increase transparency of global metal supply.[558]

---

545 LME, "London Metal Exchange: About," The London Metal Exchange - an HKEX Company, 2020, https://www.lme.com/About.
546 LME, "Guide to the London Metal Exchange" (London Metal Exchange, 2020), 12.
547 LME, 11.
548 LME, 11.
549 LME, 2.
550 Andy Home, "Low Stocks, Low Transparency; LME Warehousing Back in Focus," Reuters, April 12, 2019, https://www.reuters.com/article/uk-lme-warehouse-ahome-idUKKCN1RO0XB.
551 Izabella Kaminska, "Re-Evaluating Cancelled Warrants," Financial Times, June 17, 2011, http://ftalphaville.ft.com/2011/06/17/597436/re-evaluating-cancelled-warrants/.
552 Jaehwan Park, "The Role of Canceled Warrants in the LME Market," International Journal of Financial Studies 7, no. 1 (March 2019): 2, https://doi.org/10.3390/ijfs7010010.
553 Park, 2.
554 "London Metal Exchange: Home," The London Metal Exchange - an HKEX Company, 2020, https://www.lme.com/.
555 Kaminska, "Re-Evaluating Cancelled Warrants."
556 Home, "Column."
557 LME, "Discussion Paper on LME Warehouse Reform" (London Metal Exchange, March 2019), 9.
558 LME, "Warehouse Reform 2019," London Metal Exchange - an HKEX Company, 2020, https://www.lme.com/Trading/Warehousing/2019-warehouse-reform.

6.3.7 Resource Diplomacy

The Belt and Road Initiative is the most elaborate strategy of foreign investment of the Chinese government.[559] Its aims are to establish interdependencies with 85 countries not only through enhanced trade, but also increased cultural connection and travel.[560] The BRI consists of significant investment in infrastructure including railways, highways, airports, pipelines and open trade networks.[561] Combined, the countries along the BRI routes possess more than half of the global REE resources.[562] In other words, the BRI does not only provide China with important logistical facilities, but it also gives it access to additional foreign reserves. Along the lines of increased cooperation with BRI countries, enhanced cooperation regarding resources in particular is being promoted as well.[563]

Geopolitically, the BRI is seen as a way of expanding Chinese global influence. Not only does the BRI provide China with access to a variety of logistical and transport facilities along multiple continents, but it also creates obligations for the countries involved.[564] Countries along the BRI will receive significant loans from China in order to develop their infrastructure and participate in the BRI, therefore entering a long-term dependency relation with China.[565] Between 2002 and 2019, there were 116 ports either constructed or owned by Chinese enterprises abroad.[566]

Apart from the BRI, which is China's most important approach for promoting resource diplomacy, the country is involved in other policy dialogues and international institutions as well. Exchange platforms – China Mining and the China-ASEAN Mining Forum – were mentioned in China's 2019 Mineral Resources report as priorities for multilateral cooperation regarding minerals.[567] Bilateral dialogues with the US, Germany, Canada, Australia, Italy and Korea are also being highlighted.[568]

---

[559] George Barakos and Helmut Mischo, "The Potentials of Scientific and Industrial Collaborations in the Field of REE through China's Belt and Road Initiative," International Journal of Georesources and Environment 4, no. 3 (July 20, 2018): 86, https://doi.org/10.15273/ijge.2018.03.015.

[560] Thanasis Karlis and Dionysios Polemis, "The Belt and Road Initiative. A Geopolitical Analysis," April 2019, 1, https://doi.org/10.13140/RG.2.2.12968.21764.

[561] Kalantzakos, "The Race for Critical Minerals in an Era of Geopolitical Realignments," 11.

[562] Barakos and Mischo, "The Potentials of Scientific and Industrial Collaborations in the Field of REE through China's Belt and Road Initiative," 89.

[563] Ministry of Natural Resources, "China Mineral Resources 2019," 65.

[564] Karlis and Polemis, "The Belt and Road Initiative. A Geopolitical Analysis," 1.

[565] Karlis and Polemis, 1.

[566] Zhigao Liu, Seth Schindler, and Weidong Liu, "Demystifying Chinese Overseas Investment in Infrastructure: Port Development, the Belt and Road Initiative and Regional Development," Journal of Transport Geography 87 (July 1, 2020): 3, https://doi.org/10.1016/j.jtrangeo.2020.102812.

[567] Ministry of Natural Resources, "China Mineral Resources 2019," 63.

[568] Ministry of Natural Resources, 64.

6.3.8 Circular Economy strategies

China's circular economy policies and ambitions encompass the 3R framework – recycle, reduce and reuse.[569] Circularity is a national strategy in China, its aims including an increase in production efficiency, prevention of waste disposal, sustainable consumption and life cycle approaches.[570] Policies often focus on demonstration projects, in which leading practitioners exhibit best practices for different circularity strategies.[571] Circularity policies have been steadily increasing in importance in China, ever since the Circular Economy Promotion Law was passed in 2008.[572] The Eleventh (2006-2010) and Thirteenth (2016-2020) Five-Year Plans include chapters specifically addressing the importance of circularity for the Chinese economy.[573] Furthermore, the Made in China 2025 strategy outlines the development of a green economy as one of the main priorities.[574]

Chinese circular economy strategies focus on three different levels of activity. The micro level refers to industrial enterprises who need to respect requirements of reuse, reduce and recycling of waste.[575] On the meso level, industries ought to cooperate closely in order to, among others, facilitate energy and by-product exchanges or share infrastructural capacity.[576] Lastly, the macro level concerns governmental decision-making on both municipal and ministerial levels that can ensure broad environmental policies.[577]

In 2010, the Chinese National Development and Reform Commission together with the Ministry of Finance introduced a joint policy initiative with the purpose of encouraging urban mining on a national scale.[578] The program is built upon eight categories of products that generate the most waste – such as vehicles, cables, household appliances and electronic products.[579] Out of the 50 urban mining facilities included in the program, 28 of them were commissioned until 2018.[580]

---

[569] Marco Pesce et al., "Circular Economy in China: Translating Principles into Practice," Sustainability 12, no. 3 (January 22, 2020): 2, https://doi.org/10/ghbzgz.

[570] Pesce et al., 2.

[571] Junming Zhu et al., "Efforts for a Circular Economy in China: A Comprehensive Review of Policies," Journal of Industrial Ecology 23, no. 1 (2019): 116, https://doi.org/10/gf4q4m.

[572] Pesce et al., "Circular Economy in China: Translating Principles into Practice," 2.

[573] Pesce et al., 2.

[574] Preziosi et al., "China," 14.

[575] Raquel Balanay and Anthony Halog, "Charting Policy Directions for Mining's Sustainability with Circular Economy," Recycling 1, no. 2 (September 2016): 222, https://doi.org/10/ghbzgx.

[576] Balanay and Halog, 222.

[577] Balanay and Halog, 222.

[578] Yanyan Xue, "Sustainable Urban Minig: The Case of China" (PhD, Enschede, The Netherlands, University of Twente, 2018), 43, https://doi.org/10.3990/1.9789036546294.

[579] Xue, 43.

[580] Xue, 43.

6.4 Conclusion

As illustrated in this chapter, China has been pursuing a long-term strategy largely due to the deep involvement of the government in industrial extraction and production of raw materials.[581] Ever since 1990, the country has been investing considerable amounts in many segments of strategic supply chains, making it dominant over not only upstream processes, but also downstream.[582] This is the case for advanced digital technologies as well as for energy transition technologies.

In Western countries, however, the industry has been dominated by market players rather than governments. Western high-tech companies are focused on product development and short-term investment decisions, lacking the necessary concerted approach to make significant changes to the market.[583] Moreover, in the energy sector, liberalization was encouraged through the Energy Packages – legislative frameworks with the aim of fragmenting European energy markets, transforming vertically integrated monopolies into competitive market actors.[584] One of the main ramifications of the EU energy market liberalization was to shift – to a large degree – the responsibility of securing supply from governmental to market actors.[585]

In practice, this means that firms will be the ones primarily in charge of securing product supply and value chains. As firms are profit-based actors, information regarding their relationships with suppliers is often kept confidential in order to preserve competitiveness.[586] Decentralization and market-based decision making led to a lack of government involvement in strategies to secure supply, and therefore to gradual knowledge erosion within the public sector. Moreover, the high degree of dependence on global supply chains has led to a dissolution of EU domestic infrastructure and expertise in industrial fields associated with mining and processing of raw materials. In other words, not only is a national integrated policy for securing supply lacking, but also the necessary technical knowledge to completely grasp the challenges that the EU is facing. In order to design long-term effective policies, situational awareness within the Dutch public sector surrounding the problem of critical materials and strategic supply and value chains must first be developed. Situational awareness can be fostered through research. This acquired knowledge allows for a holistic understanding of the problem, leading to the development of efficient strategies.

---

[581] Klossek, Kullik, and van den Boogaart, "A Systemic Approach to the Problems of the Rare Earth Market," 136.
[582] Klossek, Kullik, and van den Boogaart, 136.
[583] Klossek, Kullik, and van den Boogaart, 136.
[584] EU Commission, "Third Energy Package," Text, Energy - European Commission, May 21, 2019, https://ec.europa.eu/energy/topics/markets-and-consumers/market-legislation/third-energy-package_en.
[585] Christian Egenhofer et al., "Market-Based Options for Security of Energy Supply," SSRN Electronic Journal, 2004, i, https://doi.org/10/fxpsnv.
[586] Nuss et al., "Mapping Supply Chain Risk by Network Analysis of Product Platforms," 15.

As such, the leading role of governments in reducing dependence on imports of raw materials should not be neglected. The role of the government is strongly intertwined with activities undertaken by private actors to secure their supply chains. Policymaking must therefore remain compatible with and complementary to market activity.[587] Governments share the responsibility with market actors, their role revolving around the translation of strategic, economic and social objective into policy that ought to be followed by market actors.[588] Governments do not only establish strategic goals in the national interest, but also develop effective policy instruments for market actors to achieve the strategic goals.[589]

---

[587] Egenhofer et al., "Market-Based Options for Security of Energy Supply," 1.

[588] Egenhofer et al., i.

[589] Egenhofer et al., i.

7. Interventions to mitigate bottlenecks

The analysis of critical sectors in chapter 4 together with the empirical applications of strategies in chapter 6 led to the identification of potential bottlenecks for securing supply of CRMs in the Netherlands and the EU. These bottlenecks are matched with interventions aimed at mitigating risks. For a complete overview of bottlenecks and specific interventions, see Appendix 5. In order to determine the feasibility of implementing these interventions in the Netherlands, the proposed interventions are compared with the most recent document put forward by the Dutch government on the critical raw materials issue.[590] In this way, the most politically feasible instruments are selected.

7.1 General interventions

> *What can the Netherlands do, in collaboration with the European Union, to reduce the dependencies regarding critical raw materials?*

China holds a near-monopolistic position when it comes to the mining, refining and manufacturing of multiple critical materials, creating a strong NL/EU dependence on imports. It is challenging for the Netherlands to start new mining explorations due to high financial investment, need for long-term planning, and associated risks. Furthermore, for international mines (e.g. Australia, Russia), it is difficult to meet environmental standards such as appropriately disposing of radioactive waste, which prevents large-scale refining of rare earth metals outside China (amongst other reasons). Strategies such as investing in **R&D, establishing alliances, stockpiling, resource nationalism or support for circular economy** are relevant interventions. Investment in R&D to develop greener technology would open doors for refining materials outside China; establishing a European Consortium of metal users' industries would enhance buying power against monopolists; stockpiling components or metals would decrease investment risks of companies; restricting investments to responsible mining and accountable production would decrease investment risks of companies; and reducing taxation on labor in favor of taxation of minerals would support circular economy aims.

---

[590] Ministerie van Economische Zaken en Klimaat, "Veerkracht Op Het Gebied van Kritieke Grondstoffen: De Weg Naar Een Grotere Voorzieningszekerheid En Duurzaamheid Uitstippelen."

China's own increasing domestic consumption needed to achieve its development goals decreases the international supply of CRMs. Stockpiles in other countries influence import prices and availability of supply for the EU. In order to mitigate the consequent supply risks to the Netherlands, a combination of **resource diplomacy, diversification of suppliers, R&D and support for circular economy strategies** should be applied. Creating new dossier combinations (with e.g. Agri-food) would increase interdependencies and create leverage in case China intends to restrict exports; adopting a long-term strategy of diversification would ensure alternative supply options exist in case of severe disruptions; creating a knowledge platform to track and predict future EU demand and map supply of secondary CRM from EU stocks and wastes; and reduction of tax on labor intensive work to support maintenance and repair of technologies to elongate their lifetime would reduce import dependence by circulating technologies within the EU for longer.

The Chinese government favors domestic firms to secure its own metal sector. In the upstream sector in China, licensing mechanisms exclude companies from the Netherlands/EU from investing in alternative mines and facilities, as well as other existing operations. Export tax alleviation for Chinese domestic upstream producers encourages technology development in China rather than raw material exports, creating an uneven playing field for EU producers. This allows China to maintain full autonomy over domestic resources. In order to mitigate the consequent supply risks, a multi-strategy approach will be necessary: **vertical integration within the EU, resource diplomacy, campaigning, standard-setting and support for circular economy**. Subsidizing small and medium enterprises along the existing value-chain would provide a competitive advantage to NL/EU companies; while tax alleviation for EU raw material imports would encourage intra-EU production of strategic technologies and create a level playing field with Chinese producers. Negotiations in the EU-China Comprehensive Agreement regarding the removal of joint venture requirements and equity caps in China would give EU companies better access to the Chinese market. Campaigning to increase awareness about problematic labor and environmental practices in China might encourage companies to support producers outside of China; and restricting export of metal scrap to non-EU countries would ensure a steady supply of secondary materials within the EU. Finally, R&D is an important strategy; investing in mining exploration and exploitation within the EU, investing in the development of sustainable (high-tech) mining in order to reduce the public resistance to mining in the EU, and investing in finding substitute technologies using non-critical materials.

In addition to protecting its own industry, China secures and expands its future supply of technology through several measures: it uses FDI and mergers & acquisitions as tools to increase control over the NL/EU internal market and establish dominance in supply and value chains. Furthermore, it invests in foreign mines and infrastructure to increase its supply chain resilience and consequently hinders diversification attempts of the NL/EU. Over time, China has been increasing its visibility and involvement in international institutions, as well as trading platforms such as the London Metal Exchange. In response, the NL/EU could place **licensing restrictions, increase standard setting efforts, increase diplomatic ties regarding resources within the EU and support circular economy practices**. Investing in mergers and acquisitions to nationalize organizations would ensure a degree of control remains in NL/EU; preventing Chinese investments in potential Western mining capacity would increase autonomy over domestic resources; developing international agreements on human rights and responsible sourcing would set de facto international standards; connecting diplomats and companies with knowledge institutions would educate and strengthen representation on materials dossiers; and supporting circular procurement and setting standards for minimum recycled material content would remove legislative hurdles for circular practices.

The EU is further influenced by dynamic global trends. Export restrictions in the form of taxes, quotas and minimum export prices influence global price and availability of supply. Standard setting privileges some countries to achieve market dominance through first-mover advantage. Foreign R&D programs and patents increase domestic dependence on foreign technology. Opaque trade relations, political instability and demand uncertainty depress investments in new facilities. In response, **resource diplomacy, standard setting and diversification of suppliers** increase security of supply. Facilitating more collaboration through dialogues and partnerships between governments as well as industries (e.g. European Raw Materials alliance, and with countries such as Australia) would decrease likelihood of politically motivated restrictions; setting standards according to EU norms and principles would create a first-mover advantage and reduce the market dominance of China for emerging technologies; taking legal and diplomatic actions against IP theft would maintain domestic competitiveness; and adopting a long-term strategy of diversification would ensure alternative options exist in case of severe disruptions.

To conclude, multi-level strategic interventions are necessary to increase the Dutch and EU security of supply for critical raw materials and for the components and technologies that utilize them. The Dutch cabinet does not see strategic autonomy as a goal in itself, rather aiming at increased resilience within the EU to meet societal goals. In terms of jurisdiction, subsidiarity, urgency and finances, the following actions are positively evaluated to be implemented on a national scale: industrial alliances to develop sustainable financing for mining and refining sector; R&D for innovative waste processing, advanced materials and substitution in support of the circular economy; capacity-building of technical expertise in policymakers; strategic investments in resource-abundant countries to diversify supply.[591] Interventions that should be taken on broader, EU level are: expanding and strengthening the European Raw Materials alliance; supporting R&D in waste processing, recycling and material substitution; mapping supply of secondary CRM from EU stocks and wastes; investing in mining expertise within the EU; setting standards for sustainable finance and responsible mining practices; developing strategic international partnerships and alliances; and levelling the (tax) playing field between EU and Chinese technology manufacturers.

7.2 Technology-specific interventions

7.2.1 Energy

Disruptions in supply and price volatility of rare earth elements may affect future deployment of wind power generation. **Supporting R&D, setting standards and circular economy strategies** are important in creating a secure supply of rare earth elements and permanent magnets in the Netherlands and EU. Researching the potential for REE mining and refining in Europe (e.g. in Sweden, Finland, Germany, Spain, Norway and Greenland) would diversify supply of metals. Initiating secure contracts with producing countries would improve the EU sector's competitiveness in the long-term. Establishing adequate collection and recycling capacity to deal with increasing flows of permanent magnets from industrial machinery would increase the circulation of rare earths within the EU. The introduction of a labelling system that indicates types of permanent magnets would regulate and facilitate a European recycling process.

Investing in R&D on substitution would open avenues on multiple scales: metal substitution within magnets (e.g. Pr for Nd, Ce and Co for Nd and Fe, Te for Dy), alternative magnets (e.g. AlNiCo, ferrite, SmCo) and alternative generators (e.g. non-permanent magnet generators).[592] Furthermore, efficient rare earth-free turbines are currently the norm and can be further innovated. There are, of course, trade-offs: direct-drive wind turbines that use neodymium-dysprosium based permanent magnets are more expensive to produce, but cheaper in their exploitation phase. Turbines without permanent magnets require less critical metals but are generally understood to have higher maintenance costs because they have more moving parts. They have a shorter energy payback time.[593] Furthermore, it is important to note that substitution does not remove material demand, it simply shifts the burden onto other materials.

---

[591] Ministerie van Economische Zaken en Klimaat.

[592] Pavel et al., "Substitution Strategies for Reducing the Use of Rare Earths in Wind Turbines."

[593] van Exeter et al., "METAL DEMAND FOR RENEWABLE ELECTRICITY GENERATION IN THE NETHERLANDS."

In photovoltaic systems, metals are generally not recovered due to a lack of financial incentive (low secondary material value) and due to technical challenges (difficulty in disassembling without damaging components). Supporting R&D and circular economy strategies is important to create a secure supply of photovoltaic systems in the Netherlands and EU. Including a recycling strategy in the manufacturing process for PV modules would ensure secondary material flows for PV manufacturers, investing in the improvement of recycling technology would improve purity of recovered materials and decrease energy consumption of recycling, and including a circular economy strategy in the tendering process of large-scale PV powerplants would encourage the industry to reduce demand for imported materials.

7.2.2 Electric vehicles

> *With regard to the energy transition in the Netherlands: To what extent are policy options available for batteries required for the electrification of transport?*

The EU Industry has some involvement in every segment of the battery value chain, but it is far from being self-sufficient. In the raw and processed materials, cell component and cell manufacturing value chain segments, Europe holds a minor share of the market, whereas in the pack and vehicle manufacturing and recycling segments, Europe is among the market leaders.[594] In addition to making significant investments into mining of critical minerals all around the world, China is also the dominant player in materials refining. This has given it the advantage over Japan and Korea. Other countries seeking to be dominant players in the overall value chain may need to support upstream metals mining and refining development, while also formulating policies that will safeguard the environment. Access to raw materials, human capital and infrastructure will be vital in attracting investment into the value chain.[595] Efforts towards more integrated and resilient supply chains are needed.[596]

The EU has already taken some measures to secure supply of materials: trade agreements and R&D partnerships in various steps of the value chains (e.g. mining of REEs, diversification of suppliers, substitution of materials), investments in domestic production of key components for e-mobility (e.g. European Battery Alliance), improvement of end-of-life strategies, definition of standards for components/products design, the extension the lifetime of key components (such as traction motors).[597]

Looking to the future, important strategies will be **encouraging diversification of suppliers, increased R&D and standard setting**. Considering the long lead times,

---

[594] Lebedeva, DI PERSIO, and BRETT, "Lithium Ion Battery Value Chain and Related Opportunities for Europe."
[595] "China Dominates the Lithium-Ion Battery Supply Chain, but Europe Is on the Rise."
[596] Baars et al., "Circular Economy Strategies for Electric Vehicle Batteries Reduce Reliance on Raw Materials."
[597] Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study."

promoting new business models and innovation that enhance reuse of EV batteries would offer rapid replacement options and integration with energy storage systems using remaining capacity in end-of-live EV batteries.[598] Continuous research into material substitution (e.g. Li-Air batteries) in collaboration with material scientists and industry, as well as learning from best practices abroad, would lead to decreasing material demand. Setting standards that favor markets for secondary battery resources would strengthen industrial capacities for battery and cathode production and recycling in the EU. Research into the environmental and economic implications of different new battery recycling processes and the advantages compared with primary raw material extractions is required.[599] Policies such as extended producer responsibility are feasible and are triggers for change that will encourage recycling and enhance collection rates of EV batteries.[600]

7.2.3 Digital technologies

> *Regarding high-tech products that fulfil an essential societal role: To what extent are there policy options available for the microchips related industries?*

The EU is largely dependent on other countries (mainly South- East Asia) for digital technology components and assemblies (i.e. hard drives, smartphones). Furthermore, some of the highest Chinese direct investment transactions in the Netherlands have occurred in the high-tech sector. The EU has called for greater ‘digital sovereignty’, which can be achieved using strategies such as: **restricting access to domestic markets, stronger resource diplomacy and R&D**. R&D, in particular, has proven to be an advantage for the Netherlands. China has found it hard to make progress in cutting-edge manufacturing, which is the most demanding part of chipmaking. Chinese start-ups must compete with technological leads and engineers with decades of hard-won know-how. In the Netherlands, the Dutch firm ASML has finally commercialized ‘extreme ultra-violet lithography’, a manufacturing process needed for the most advanced chips. Here, building alliances in sectors where China is vulnerable (e.g. semiconductors) would create leverage for the EU in case China intends to restrict exports. In addition, supporting further R&D for circular economy practices, such as domestic recycling of gallium, would increase secondary supply of materials.

---

[598] Baars et al., “Circular Economy Strategies for Electric Vehicle Batteries Reduce Reliance on Raw Materials.”
[599] Baars et al.
[600] Baars et al.

8. Conclusions and recommendations

8.1 Conclusions

The EU's climate neutrality and digital sovereignty goals rely heavily on imports of critical raw materials, semi-finished and end-products. This report identified high European import dependency on China for technologies and components in the energy sector – including wind turbines, solar power, energy grid infrastructure and CCS; in the electrification of transport; and in digital technologies.

China's control of important CRM supply chain stages has been developed over decades of planning and investing in mines, logistics, trading platforms as well as in manufacturing sectors. China is employing a wide range of strategies not only to develop segments of domestic supply chains, but also to secure access to strategic resources abroad. The close cooperation between state and industry allowed China to pursue a long-term integrated strategy with the goal of furthering national interest. This placed China in a highly advantageous international position, leading to a steady increase in the EU's dependence on Chinese imports.

The EU has identified this dependency issue since the creation of the first CRM list in 2011. Ever since then, EU action has primarily revolved around the formulation of CRM lists and the creation of alliances to secure supply. Yet this approach has not been effective in decreasing import dependence, leading to a strong reformulation of EU CRM policy in 2020. The current strategy focuses heavily on European self-sufficiency and autonomy in the procurement of critical materials and strategic technologies. European R&D projects are extensive and relevant to future supply of CRMs, yet some overlap has been noticed between the topics addressed by different entities.

The Netherlands participates in EU activities aimed at securing the supply of CRMs, especially in research and development. On national level, the attention of policy makers has primarily focused on the development of circular economy policies. An interesting observation is that substitution, despite being a strategy to reduce use of specific metals, has not been included in the circular economy policy cluster by the Netherlands.

While CE can be an important strategy for securing supply of secondary materials, an overarching strategy lacks regarding the security of supply of primary critical raw materials and products. Market actors are responsible for ensuring resilient supply chains for themselves, while the role of the government has been marginalized. A lack of long-term strategic direction and a phenomenon of knowledge erosion have resulted from reduced government involvement.

Policy makers have become unfamiliarized with issues of security of supply and, at the same time, the role of technical expertise has been increasingly neglected in policymaking. Situational awareness and context must be created so that policy interventions to secure supply become meaningful. Foresight capabilities on the governmental level should be strengthened in order to facilitate the development of long-term strategies. Technological foresight into future technology and material requirements is pivotal in realizing durable strategies.

The phenomenon of knowledge erosion did not occur solely on the governmental level, but also on the industrial and academic levels. Due to heavy reliance on global value chains for imports of materials, intermediate and end products, the EU and the Netherlands currently lack the industrial knowledge and facilities to become self-sufficient. There is a lack of academic and professional focus on developing industrial expertise for mining, refining and other supply chain stages.

For the time being, the **most suitable national policy instruments** that could be of use in reducing a broad spectrum of dependencies from China are: industrial alliances to collaborate on long term industrial objectives and to develop sustainable financing for the mining and refining sector; R&D for innovative waste processing, advanced materials and substitution in support of the circular economy; capacity-building for technical skills in policymakers; strategic investments in neighboring countries as well as developing countries to diversify supply.[601] **Interventions that should be supported on broader, EU level are:** expanding and strengthening the European Raw Materials alliance; supporting R&D in waste processing, recycling and material substitution; mapping supply of secondary CRMs from the EU urban mine in the form of stock and wastes; investing in mining expertise within the EU; setting standards for sustainable finance and responsible mining practices; developing strategic international partnerships and alliances; and levelling the (tax) playing field between EU and Chinese technology manufacturers.

Aside from these general interventions, **sector-specific interventions** are important. In the energy sector: supporting R&D, setting standards and circular economy strategies

---

[601] Ministerie van Economische Zaken en Klimaat, “Veerkracht Op Het Gebied van Kritieke Grondstoffen: De Weg Naar Een Grotere Voorzieningszekerheid En Duurzaamheid Uitstippelen.”

will be important to creating a strong market for secondary raw materials in NL/EU, thereby reducing dependency on imports. In the transport sector, important strategies will be: encouraging diversification of suppliers, increased R&D and standard setting. Continuous research into material substitution (e.g. Li-Air batteries) in collaboration between material scientists and industry, as well as learning from best practices abroad, could lead to decreasing material demand. Finally, the EU has called for greater 'digital sovereignty', which can be achieved with strategies such as: restricting access to domestic markets, stronger resource diplomacy and R&D. R&D, in particular, has proven to be an advantage for the Netherlands - China has found it hard to make progress in cutting-edge manufacturing, which is the most demanding part of chipmaking.

8.2 Recommendations

Reducing the Netherlands' import dependence of CRMs and products requires a concerted approach on the industrial, national and international levels. A collaborative effort between private and public, national and international players is the most effective way of applying the proposed policy interventions.

The priority for the Netherlands in securing the supply of CRMs and related technologies is the development of a long-term national strategy that reflects the needs of industrial actors. The government should take on a leading role in developing the national strategic direction for securing critical materials and technologies. Close cooperation with industry players can allow the government to determine vulnerabilities in supply chains, further incorporating that information into a national strategy. Public-private partnerships within the Netherlands would facilitate the development of a long-term coherent strategic vision for securing supply.

Capacity building within relevant ministries in the Netherlands should be conducive to more effective and meaningful policymaking. Technical expertise among policy makers should be expanded and technological foresight should become a key instrument in designing strategies to secure supply of CRMs. Multilateral programming and policy coherence should be prioritized so that both public and private entities can work toward the same mutually beneficial objectives. An example of such action would be the integration of substitution (i.e. to reduce dependence on certain metals) with the other circular economy strategies on the national level.

Additionally, the government of the Netherlands should be a proponent and supporter of alliances in which market players and research institutes collaborate in problem-solving. In this way, the government would be investing in bringing mining, industry and manufacturing back to the Netherlands and to the EU. Simultaneously, significant investment in human capital should be made. The current gap in expertise regarding mining, refining and other processes within CRM supply chains should be filled by encouraging universities to take a more active role in teaching and researching new advanced industrial practices.

Cooperation on the EU level is also pivotal in reducing dependence on non-EU players such as China. Within the EU, research and policies should not overlap but complement each other. The Netherlands should align with EU objectives as well as advocate an increased focus on EU level for domestically important CRMs rather than all CRMs. Seeking alliances with likeminded countries such as Germany, Australia or the US can also strengthen the Netherlands' position.

Appendices

Appendix 1. Critical materials and their uses

Critical material		Symbol	Technology	Use
Light Rare Earth Elements	Cerium	Ce	Electric vehicles	In catalytic converters
	Lanthanum	La	Electric vehicles	In optics
	Neodymium	Nd	Wind turbines	In the permanent magnets of wind turbine generator, as well as in magnets for attaching internal fixtures within the turbine tower.
			Electric vehicles	In electric motor
			Digital technologies	In NdFeB permanent magnets used in hard drives
	Praseodymium	Pr	Wind turbines	Used together with Nd in the permanent magnets of wind turbine generator.
			Electric vehicles	In electric motor
	Samarium	Sm	Electric vehicles	In magnetic materials
Heavy Rare Earth Elements	Dysprosium	Dy	Wind turbines	In the permanent magnets of wind turbine generator, as well as in magnets for attaching internal fixtures within the turbine tower.
			Electric vehicles	In electric motor
			Digital technologies	In NdFeB permanent magnets
	Terbium	Tb	Wind turbines	In the permanent magnet of the turbine generator where it replaces dysprosium
			Electric vehicles	In NdFeB permanent magnets as substitute for Dy
Cobalt		Co	Carbon Capture and Storage (CCS)	A more affordable catalyst to replace platinum in PEM fuel cells.
			Electric vehicles	In cathode materials in LCO, NCA and NMC batteries.
			Digital technologies	In HDDs, semi-conductors and integrated circuits
Gallium		Ga	Solar PV technologies	A dopant in semiconductors or in CIGS technology.
			Electric vehicles	In semiconductors
			Digital technologies	In semiconductors for Integrated Circuits
Germanium		Ge	Solar PV technologies	A semiconductor material for multi-junction solar cells.
			Electric vehicles	In semiconductors
			Digital technologies	In glass for fiber-optic Ge cables, infrared optics (night-vision), in semiconductors

Critical material	Symbol	Technology	Use
Graphite		Digital technologies	Used for production of graphene, electrically and thermally conductive material destined for many applications
Indium	In	Solar PV technologies	Used as a ITO conductive layer or in CIGS technology.
		Electric vehicles	In-built screens
		Digital technologies	In screens as indium-tin- oxide
Lithium	Li	Electric vehicles	Used as Li-Co oxide (cathode) and as salt (electrolyte) in Li-ion battery.
		Digital technologies	In primary batteries
Niobium	Nb	Carbon Capture and Storage (CCS)	In CCS pipelines.
Palladium	Pd	Digital technologies	In printed circuit boards and in multi-layered ceramic capacitators (in mobile phones)
		Electric vehicles	In semiconductors
Silicon	Si	Solar PV technologies	Semiconductor material in crystalline or amorphous solar cells.
		Digital technologies	Electronics grade silicon in Si semiconductors, SSDs and microelectronics
Tantalum	Ta	Digital technologies	In special capacitators. Thin layers of tantalum are also used in integrated circuits
Titanium	Ti	Geo-thermal energy	Used to make corrosion-resistant alloys of steel for pipes
Tungsten	W	Digital technologies	Heat resistant in ICs, dielectric materials and transistors. In light bulbs and vacuum tube filaments
Vanadium	V	Carbon Capture and Storage (CCS)	In CCS pipelines.

Source: aggregated data from Carrera et al.[602], World Bank Group[603], Bobba et al.[604], Hund et al.[605], Moss et al.[606], and Ku.[607]

Table 7. Critical raw materials considered in this report and their uses

---

[602] Carrara et al., “Raw Materials Demand for Wind and Solar PV Technologies in the Transition towards a Decarbonised Energy System.”

[603] World Bank Group, The Growing Role of Minerals and Metals for a Low Carbon Future.

[604] Bobba et al., “Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study.”

[605] Hund et al., “Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition.”

[606] R. L Moss et al., Critical Metals in Strategic Energy Technologies: Assessing Rare Metals as Supply-Chain Bottlenecks in Low-Carbon Energy Technologies. (Luxembourg: Publications Office, 2011), http://dx.publications.europa.eu/10.2790/35716.

[607] Ku, “Anticipating Critical Materials Implications from the Internet of Things (IOT).”

Appendix 2. Overview HS Codes for CRMs

The CRMs are matched with Harmonized System (HS) codes from the UN Comtrade and CBS databases. The Harmonized System is a universal classification of goods and services that can be used to track trade flows across borders. Should any further research into the CRMs that are relevant to the Netherlands be needed, the HS codes below can be used.

Critical material		HS Codes for CRMs[608]
Light Rare Earth Elements	Cerium	**2805 -** *Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium, whether or not intermixed or interalloyed; mercury.*
	Lanthanum	
	Neodymium	
	Praseodymium	
	Samarium	
Heavy Rare Earth Elements	Dysprosium	
	Terbium	
Cobalt		**2605 -** *Cobalt ores and concentrates*
Gallium		**8112** - *Beryllium chromium, germanium, vanadium, gallium, hafnium, indium, niobium, rhenium, thallium; and articles of these metals, including waste and scrap*
Germanium		**8112**
Graphite		**2504 –** *Graphite; natural*
Indium		**8112**
Lithium		**283691** – *Carbonates; lithium*
Niobium		**2615** - *Niobium, tantalum, vanadium, or zirconium ores and concentrates*
Palladium		**711021** - *Metals; palladium, unwrought or in powder form*
Silicon		**280461** – *Silicon; containing by weight not less than 99.99% silicon*
Tantalum		**2615**
Titanium		**2614** – *Titanium ores and concentrates*
Tungsten		**2611** – *Tungsten ores and concentrates*
Vanadium		**2615**

Source: UN Comtrade Database[609]

Table 8. Overview HS codes for CRMs considered in this report

---

[608] HS Codes are extracted from the UN Comtrade database. This database is compatible with the Netherlands' CBS coding system.

[609] UN, "UN Comtrade | International Trade Statistics Database," accessed October 28, 2020, https://comtrade.un.org/.

Appendix 3. Overview HS Codes for relevant technologies

Technology	Relevant HS Code	Description
Solar PV	854140	Electrical apparatus; photosensitive, including photovoltaic cells assembled or not in modules or made up into panels, light-emitting diodes (LED)
Wind Energy	850231	Electric generating sets; wind-powered, (excluding those with spark-ignition or compression-ignition internal combustion piston engines)
Permanent Magnets	8505	Electro-magnets; permanent magnets, intended permanent magnets; electro-magnetic, permanent magnet chucks, clamps, similar; electromagnetic couplings, clutches, brakes; electro-magnetic lifting heads
Batteries	850650	Cells and batteries; primary lithium
	850760	Electric accumulators; lithium-ion, including separators, whether or not rectangular (including square)
Semiconductors	8542	Electronic integrated circuits and microassemblies

Note: These are the existing codes relevant to the technologies included in this report.

Source: UN Comtrade Database.[610]

Table 9. HS codes for relevant technologies

---

[610] UN.

Appendix 4. Resilient supply chains for CRMs

Resilience refers to “the capacity to supply enough of a given material to satisfy the demands of society, and to provide suitable alternatives if insufficient supply is available”.[611] In order to ensure resilience, a supply chain should be characterized by resistance, rapidity and flexibility.[612] A supply chain should be resistant to different disruptions without it becoming completely unfunctional, as well as rapid to recover after it has been disturbed.[613] Lastly, a supply chain should be flexible to change between various subsystems when one of them is disturbed.[614]

Resilience ensures that supply is secure enough to overcome disruptions. Generally, security of supply considerations are divided into short and long term. On the short-term, the focus is placed on current relations between importing and exporting countries, and on how the former react to sudden disruptions in supply.[615] Such a dynamic relationship between suppliers and consumers is connected to the capacity of governments or firms to address rapidly arising challenges.

Contrastingly, long-term security of supply refers to strategic considerations of ensuring that future projected demand will be met.[616] Given that long-term relations in global politics are dominated by uncertainty, import-dependent countries take into account a variety of factors that could influence their future needs, such as environmental concerns, pricing mechanisms, infrastructural capacities, and geopolitical trends.[617] Long-term security of supply refers to a static relationship between suppliers and consumers, as strategic action is generally taken with the purpose of influencing future relationships. The main priority of import-dependent countries is to find ways of aligning long term investments in energy infrastructure with projected future needs of raw materials so that their vulnerability to disruptions in supply is minimized.[618]

---

[611] Sprecher et al., “Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis,” June 2, 2015, 6741.

[612] Sprecher et al., 6742.

[613] Sprecher et al., 6742.

[614] Sprecher et al., 6742.

[615] Ignacio J Pérez-Arriaga, “Security of Electricity Supply in Europe in a Short, Medium and Long-Term Perspective” 2, no. 2 (2007): 7.

[616] Pérez-Arriaga, 7.

[617] Pérez-Arriaga, 7.

[618] IEA, “Energy Security,” IEA, December 2, 2019, https://www.iea.org/areas-of-work/ensuring-energy-security.

Appendix 5. Interventions per bottleneck

1. **Bottleneck:** Export restrictions (taxes, quotas, minimum export prices) influence global price and availability of supply, leading to increased import prices for NL/EU.

   Interventions:

   Restrictions:

   - Take legal action with support of WTO against export restrictions in order to establish a level playing field.

   Resource diplomacy:

   - Facilitate more collaboration through dialogues and partnerships in order to decrease likelihood of politically motivated restrictions.

   Diversification of suppliers:

   - Adopt a long-term strategy of diversification in order to ensure alternative options exist in case of severe disruptions.

   Standard setting:

   - Promote responsible labor and environmental standards to encourage mining activities outside of China.

2. **Bottleneck:** China uses FDI into NL/EU in order to increase control over the NL/EU internal market and establish dominance in supply and value chains. If sectors of European supply chains are controlled by China, it is difficult and even impossible for NL to become independent from imports.

   Interventions:

   Stockpiling:

   - Invest in mining exploration and exploitation in EU countries in order to gain autonomy over raw materials and prevent EU resources from being controlled by foreign powers.

   Restrictions:

   - Institute licensing requirements in order to maintain control over domestic markets
     - Only allow maximum % of investment;
     - Require domestic presence in the company after investment;
     - Discourage possibilities for acquisitions and mergers led by foreign companies in order to protect and restore intellectual property.

Circular economy:

- Support recycling industry through EU funds, subsidization and/or tax benefits for organizations in order to ensure a steady supply of secondary raw materials and promote intra-EU cooperation.
- Restrict export of metal scrap to non-EU countries in order to ensure a steady supply of secondary materials within the EU.

3. **Bottleneck:** China uses mergers and acquisitions in order to increase control over NL/EU internal market and establish dominance in foreign supply and value chains.

   Interventions:

   Vertical integration:

   - Invest in mergers and acquisitions to nationalise organizations in order to ensure a degree of control remains in NL/EU.

   Restrictions:

   - Institute licensing requirements in order to maintain control over domestic markets
     - Only allow maximum % of investment;
     - Require domestic presence in the company after investment;
     - Discourage possibilities for acquisitions and mergers led by foreign companies in order to protect and restore intellectual property.

4. **Bottleneck:** Domestic support by the Chinese government provides competitive advantage to domestic firms by offering low global prices. This inhibits Dutch investment in alternative mines and facilities, as well as other existing operations, because prices offered by NL/EU are not competitive compared to Chinese ones.

   Interventions:

   Vertical integration:

   - Subsidize domestic companies and invest in company shares in order to provide a competitive advantage to NL/EU companies.
   - Provide VAT tax returns for NL/EU companies that import raw materials rather than finished products in order to create a level playing field between NL/EU and Chinese manufacturers and encourage domestic production.

   Restrictions:

   - Take legal action with support of WTO against unbalanced subsidization by monopolists in order to establish a level playing field.

Standard setting:

- Promote responsible labor and environmental standards to encourage mining activities outside of China.

R&D:

- Campaign to reduce the public resistance to mining in the EU through the promotion and development of sustainable (high-tech) mining practices.
- Make R&D in mining a national priority and develop national investments strategies together with the EU maintain autonomy over national resources.
- Support development of academic and professional expertise in mining and mineral exploration.
- Invest in the development of greener production technology for mining in order to encourage mining outside of China.

Circular economy:

- Encourage recycling activities of consumers through the creation of decentralized recycling centers, following best practices (e.g. Japan JBRC).
- Support recycling industry through EU funds, subsidization and/or tax benefits for organizations in order to ensure a steady supply of secondary raw materials and promote intra-EU cooperation.

5. **Bottleneck:** Licensing mechanisms exclude NL/EU companies for operating in the upstream sector in China, who maintains full autonomy over domestic resources. NL/EU are thus unable to influence any supply chain sector in China and leverage it to their advantage to secure imports.

   Interventions:

   Resource diplomacy:

   - Focus on negotiations in the EU-China Comprehensive Agreement regarding the removal of joint venture requirements and equity caps in China, in order for EU companies to get better access to the Chinese market.

   Circular economy:

   - Restrict export of metal scrap to non-EU Countries in order to ensure a steady supply of secondary materials within the EU.

6. **Bottleneck**: Standard setting to achieve market dominance through first-mover advantage: Chinese influence in the standardization of global strategic sectors means that NL/EU companies remain marginalized and cannot achieve market dominance.

   Interventions:

   Standard setting:

   - Ensure that international standards are set based on European practices in order to combat market and political influence of China.
   - Propose standard essential patents according to EU emerging technologies in order to achieve first-mover advantages.
   - Create awareness that standards have political effects in order to encourage standard setting in strategic sectors.

   Circular economy:

   - Set requirements for minimum recycled material content by removing legislative hurdles, and reducing taxation on products with a high recycled metal %.
   - Support recycling industry through EU funds, subsidization and/or tax benefits for organizations in order to ensure a steady supply of secondary raw materials and promote intra-EU cooperation.

7. **Bottleneck:** Non-transparent price-setting practices create opaque trade relations and uncertainty, depressing investments in new facilities. NL/EU companies cannot become competitive as attempts are too financially risky.

   Interventions:

   Restrictions:

   - Impose legal obligations for reporting on EU/NL level in order to increase transparency.

   Resource diplomacy:

   - Promote more collaboration through dialogues and partnerships in order to increase transparency.

   R&D:

   - Create a knowledge platform to analyze and predict future EU demand and map supply of secondary CRM from EU stocks and wastes.

   Circular economy:

   - Set requirements for minimum recycled material content by removing legislative hurdles, and reducing taxation on products with a high recycled metal %.

8. **Bottleneck**: Increased domestic consumption to achieve development goals in exporting countries can negatively influence the amount of supply available for exports. If China redirects its resources domestically in order to achieve climate and strategic ambitions, the supply of materials will be used internally, and little will remain available for NL/EU to import.

   Interventions:

   Resource diplomacy:

   - Create new dossier combinations (Agri-food) in order to increase interdependencies and create leverage in case China intends to restrict exports.

   Diversification of suppliers:

   - Adopt a long-term strategy of diversification in order to ensure alternative options exist in case of severe disruptions.

   Circular economy:

   - Reduce taxation on labor-intensive maintenance and repair of technologies to elongate their lifetime, and reduce dependence on new imported components.

9. **Bottleneck:** Increasing visibility and involvement in international institutions can reshape norms and influence agenda-setting. China's contestation of Western liberal values might lead to a shift in the understanding of human rights and environmental protection. This nullifies NL/EU efforts of normative global influence.

   Interventions:

   Resource diplomacy:

   - Connect diplomats and companies with knowledge institutions in order to educate and strengthen representations on materials dossiers.
   - Promote environmental and human rights norms and values in international institutions on raw materials.

   Standard setting:

   - Promote responsible labor and environmental standards to encourage mining activities outside of China.
   - Ensure that international standards are set based on European practices in order to combat market and political influence of China.
   - Create awareness that standards have political effects in order to encourage standard setting in strategic sectors.

10. **Bottleneck:** Strategic partnerships/alliances with other countries/organizations excluding NL/EU, negatively impacts the capacity of NL/EU to create interdependencies by leaving them out of decision-making and collaborative fora.

    Interventions:

    Resource diplomacy:

    - Seek partnerships and agreements when excluded and combine dossiers to create interdependencies in order to maintain influence over relevant international decisions.

    R&D: In order to maintain influence over relevant international decisions:

    - Seek academic/research partnerships between EU and China.
    - Train academics to sensitize their behavior regarding the critical dependencies with China.
    - Decrease the reliance of academics on China for funding by making more R&D funding available.

11. **Bottleneck:** Foreign R&D programs and patents increase dependence of NL/EU on foreign technology.

    Interventions:

    Resource diplomacy:

    - Take legal and diplomatic action in order to protect intellectual property from theft.

    R&D:

    - Decrease the reliance of academics on China for funding by making more R&D funding available.

12. **Bottleneck:** Stockpiles influence import price and availability of supply. If stockpiles are made by another country, supply of that material for NL/EU suddenly decreases. Prices increase, making it expensive and difficult to satisfy internal NL/EU demand.

    Intervention:

    R&D:

    - Create a knowledge platform to analyze and predict future EU demand and map supply of secondary CRM from EU stocks and wastes.

13. **Bottleneck:** Investment in foreign mines and infrastructure by China increases their own resilience and hinders diversification attempts of the NL/EU.

    Interventions:

    Vertical integration:

    - Create laws that prevent Chinese investments in Western mining capacity in order to maintain autonomy over domestic resources.

    Stockpiling:

    - Create national/EU bonds for mining investments in EU countries in order to encourage domestic investments.

    Resource diplomacy:

    - Invest in mines/sectors that China is dependent on in order to create/increase trade dependency.

    Diversification of suppliers:

    - Decrease investment risk for companies by providing government guarantees in order to encourage diversification in supply chains for small, medium and large enterprises.

    R&D:

    - Invest in the development of greener production technology for mining in order to encourage mining outside of China.
    - Create a knowledge platform to analyze and predict future EU demand and map supply of secondary CRM from EU stocks and wastes.
    - Make R&D in mining a national priority and develop national investments strategies together with the EU maintain autonomy over national resources.

14. **Bottleneck:** Mining/refining/manufacturing Chinese domestic resources places the country in a monopolistic position, increasing NL dependence on imports.

    Interventions:

    Resource diplomacy:

    - Focus on negotiations in the EU-China Comprehensive Agreement regarding the removal of joint venture requirements and equity caps in China, in order for EU companies to get better access to the Chinese market.
    - Invest in mines/sectors that China is dependent on in order to create/increase trade dependency.

R&D:

- Support development of modular/recyclable technology and develop efficient urban mining techniques in order to increase secondary supply of materials.

Circular economy:

- Encourage recycling activities of consumers through the creation of decentralized recycling centers, following best practices (e.g. Japan JBRC).
- Set requirements for minimum recycled material content by removing legislative hurdles, and reducing taxation on products with a high recycled metal %.
- Support recycling industry through EU funds, subsidization and/or tax benefits for organizations in order to ensure a steady supply of secondary raw materials and promote intra-EU cooperation.

15. **Bottleneck:** Challenges in appropriately disposing of radioactive waste in line with environmental standards prevent large-scale refining of rare earth metals outside China (amongst other reasons).

    Interventions:

    R&D:

    - Invest in the development of greener production technology for mining in order to encourage mining outside of China.

16. **Bottleneck:** Chinese control over the London Metal Exchange and other trading platforms.

    Interventions:

    Restrictions:

    - Establish a European minerals and metals exchange excluding monopolists in order to create a trading facility an investment platform for metals and minerals.

    Resource diplomacy:

    - Promote more collaboration through dialogues and partnerships on an international level in order to increase transparency.

17. **Bottleneck**: High financial investments and duration increase the risk of starting an exploration project.

    Interventions:

    Industrial alliances:

    - Strengthen and expand European Raw Materials Alliance in order to increase cooperation between industrial actors and decrease investment risks.

- Encourage participation of small-medium enterprises in national and international industry-wide alliances.

Stockpiling:

- Create an EU investment fund for responsible EU mining exploration and exploitation in order to decrease investment risks of companies.

Restrictions in order to decrease investment risks of companies:

- Create enhanced legal restrictions such as the Dodd Frank act and equivalent EU legislation.
- Require Chinese investors to be listed on Western Exchanges when investing in the CRM value chains.

Diversification of suppliers:

- Provide governmental guarantees in order to decrease investment risks for companies.

Circular economy:

- Reduce taxation on labor in favor of taxation of minerals in order to reduce dependencies on metal imports.

18. **Bottleneck**: Disruptions in supply and price volatility of rare earth affect the cost of permanent magnets, and therefore the future deployment of wind power generation.

    Interventions:

    R&D:

    - Invest in research of the potential for REE mining and refining in Europe (e.g. in Sweden, Finland, Germany, Spain, Norway and Greenland) in order to diversify supply of metal.
    - Research substitution on multiple scales: metal substitution within magnets (e.g. Pr for Nd, Ce and Co for Nd and Fe, Te for Dy), alternative magnets (e.g. AlNiCo, ferrite, SmCo) and alternative generators (e.g. non-permanent magnet generators).

    Circular economy:

    - Innovate collection and recycling capacity to deal with increasing flows of permanent magnets from industrial machinery in order to increase the circulation of rare earths within the EU.

    Standard setting:

    - Introduce a labelling system that indicates types of permanent magnets in products in order to regulate and facilitate the European recycling process.

19. **Bottleneck**: In photovoltaic systems, metals are generally not recovered due to a lack of financial incentive (low secondary material value) and due to technical challenges (difficulty in disassembling without damaging components).

    Interventions:

    R&D:

    - Include a recycling strategy in the manufacturing process for PV modules in order to ensure secondary material flows for PV manufacturers.
    - Invest in the improvement of recycling technology in order to improve purity of recovered materials and decrease energy consumption of recycling.

    Circular economy:

    - Include a circular economy strategy in the tendering process of large-scale PV powerplants in order to encourage the industry to reduce demand for imported materials.

20. **Bottleneck:** The EU Industry has some involvement in all segments of the electric vehicle battery value chain, but it is far from being self-sufficient.

    Interventions:

    R&D:

    - Continuous research into material substitution (e.g. Li-Air batteries) in collaboration between material scientists and industry, as well as learning from best practices abroad, in order to decreasing imported material demand.
    - Research into the environmental and economic implications of different new battery recycling processes and the advantages compared with primary raw material extractions.

    Standard setting:

    - Set standards that favor markets for secondary battery resources in order to strengthen industrial capacities for battery and cathode production and recycling in the EU.

    Circular economy:

    - Promote new business models and innovation that enhance reuse of EV batteries in order to offer rapid replacement options and integration with energy storage systems using remaining capacity in end-of-live EV batteries.
    - Extended producer responsibility in order to encourage recycling and enhance collection rates of EV batteries.

21. **Bottleneck:** The EU is largely dependent on other countries (mainly South-East Asia) for digital technology components and assemblies (i.e. hard drives, smartphones). Furthermore, some of the highest Chinese direct investment transactions in the Netherlands have occurred in the high-tech sector.

    Interventions:

    Restrictions:

    - Restrict access to domestic markets in order to reduce risk of countries using FDI and mergers & acquisitions to control domestic intellectual property.

    Resource diplomacy/industrial alliances:

    - Build alliances in sectors where China is vulnerable (e.g. semiconductors) in order to create leverage for the EU in case China intends to restrict exports.

    R&D:

    - Support R&D in cutting-edge manufacturing in order to maintain technology lead.

Bibliography

Adamas Intelligence. “FORESIGHT: Wind Industry Prepares for Bottlenecks and Price Hikes.” Adamas Intelligence. Accessed November 12, 2020. https://www.adamasintel.com/foresight-wind-industry-bottlenecks-price-hikes/.

Alonso, Elisa, Jeremy Gregory, Frank Field, and Randolph Kirchain. “Material Availability and the Supply Chain: Risks, Effects, and Responses.” Environmental Science & Technology 41, no. 19 (October 1, 2007): 6649–56. https://doi.org/10/fh7k45.

Windpower Engineering & Development. “Analyzing the Global Market for Wind-Turbine Towers,” 2016. https://www.windpowerengineering.com/analyzing-the-global-market-for-wind-turbine-towers/.

Arcesati, Rebecca. “Competing with China in the Digital Age.” In Towards a “Principles First Approach” in Europe’s China Policy, 47–56. MERICS, 2020. https://merics.org/sites/default/files/2020-09/200910_MPOC_EU-China_final_0.pdf.

Baars, Joris, Teresa Domenech, Raimund Bleischwitz, Hans Eric Melin, and Oliver Heidrich. “Circular Economy Strategies for Electric Vehicle Batteries Reduce Reliance on Raw Materials.” Nature Sustainability, September 7, 2020, 1–9. https://doi.org/10/ghgss4.

Balanay, Raquel, and Anthony Halog. “Charting Policy Directions for Mining’s Sustainability with Circular Economy.” Recycling 1, no. 2 (September 2016): 219–31. https://doi.org/10/ghbzgx.

Baldi, Lucia, Massimo Peri, and Daniela Vandone. “Clean Energy Industries and Rare Earth Materials: Economic and Financial Issues.” Energy Policy 66 (March 1, 2014): 53–61. https://doi.org/10.1016/j.enpol.2013.10.067.

Ballinger, Benjamin, Diego Schmeda-Lopez, Benjamin Kefford, Brett Parkinson, Martin Stringer, Chris Greig, and Simon Smart. “The Vulnerability of Electric-Vehicle and Wind-Turbine Supply Chains to the Supply of Rare-Earth Elements in a 2-Degree Scenario.” Sustainable Production and Consumption 22 (April 1, 2020): 68–76. https://doi.org/10/gg9chm.

Barakos, George, and Helmut Mischo. “The Potentials of Scientific and Industrial Collaborations in the Field of REE through China’s Belt and Road Initiative.” International Journal of Georesources and Environment 4, no. 3 (July 20, 2018). https://doi.org/10.15273/ijge.2018.03.015.

Barteková, Eva, and René Kemp. “National Strategies for Securing a Stable Supply of Rare Earths in Different World Regions.” Resources Policy 49 (September 2016): 153–64. https://doi.org/10.1016/j.resourpol.2016.05.003.

Bateman, Alexis, and Leonardo Bonanni. “What Supply Chain Transparency Really Means.” Harvard Business Review, August 20, 2019. https://hbr.org/2019/08/what-supply-chain-transparency-really-means.

Bayer, Lili. “Meet von Der Leyen’s ‘Geopolitical Commission.’” POLITICO, December 4, 2019. https://www.politico.eu/article/meet-ursula-von-der-leyen-geopolitical-commission/.

Bobba, S, Samuel Carrara, J Huisman, F Mathieux, and C Pavel. “Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study.” JRC, European Commission, 2020.

Boer, M. A. de, and K. Lammertsma. “Scarcity of Rare Earth Elements.” ChemSusChem 6, no. 11 (2013): 2045–2055. https://doi.org/10.1002/cssc.201200794.

Boo, Bee Chun. “China Aims for Win-Win Partnership with African Mining Sector.” Baker McKenzie, January 24, 2020. https://www.bakermckenzie.com/en/insight/publications/2020/01/china-partnership-with-african-mining-sector.

Bosch, Sybren, Pieter van Exeter, Benjamin Sprecher, Henrik De Vries, and Noortje Bonenkamp. “Metal Demand for Electric Vehicles.” Metabolic, 2019. https://www.metabolic.nl/publications/metal-demand-for-electric-vehicles/.

Brink, Susan van den, René Kleijn, Arnold Tukker, and Jaco Huisman. “Approaches to Responsible Sourcing in Mineral Supply Chains.” Resources, Conservation and Recycling 145 (June 1, 2019): 389–98. https://doi.org/10/gf3t43.

Büthe, Tim, and Walter Mattli. “International Standards and Standard Setting Bodies.” In The Oxford Handbook of Business and Government. Oxford: Oxford University Press, 2010.

Canzaniello, Angelo, Evi Hartmann, and Matthias S. Fifka. “Intra-Industry Strategic Alliances for Managing Sustainability-Related Supplier Risks: Motivation and Outcome.” International Journal of Physical Distribution & Logistics Management 47, no. 5 (January 1, 2017): 387–409. https://doi.org/10.1108/IJPDLM-01-2016-0034.

Carrara, Samuel, ALVES DIAS, Patricia, PLAZZOTTA, Beatrice, and PAVEL, Claudiu. “Raw Materials Demand for Wind and Solar PV Technologies in the Transition towards a Decarbonised Energy System,” 2020. https://ec.europa.eu/jrc/en/publication/raw-materials-demand-wind-and-solar-pv-technologies-transition-towards-decarbonised-energy-system.

Castilloux, Ryan. “Rare Earth Elements: Market Issues and Outlook.” Adamas Intelligence, 2019.

Chappelow, Jim. “Natural Monopoly.” Investopedia, August 29, 2019. https://www.investopedia.com/terms/n/natural_monopoly.asp.

Chen, Shi, Qinqin Zhang, and Yong-Pin Zhou. “Impact of Supply Chain Transparency on Sustainability under NGO Scrutiny.” Special Issue on Innovations and Sustainability 28, no. 12 (2018): 3002–22. https://doi.org/10.1111/poms.12973.

BloombergNEF. “China Dominates the Lithium-Ion Battery Supply Chain, but Europe Is on the Rise,” September 16, 2020. https://about.bnef.com/blog/china-dominates-the-lithium-ion-battery-supply-chain-but-europe-is-on-the-rise/.

Counterpoint Research. “China’s Smartphone Production Falls Under 70% for the First Time in 2019,” March 23, 2020. https://www.counterpointresearch.com/chinas-smartphone-production-falls-70-first-time-2019/.

Coffin, David, and Jeff Horowitz. “The Supply Chain for Electric Vehicle Batteries,” 2018, 21.

Commonwealth of Australia. “Australia’s Critical Minerals Strategy.” Australian Government, 2019.

Dalla Longa, Francesco, Larissa P. Nogueira, Jon Limberger, Jan-Diederik van Wees, and Bob van der Zwaan. “Scenarios for Geothermal Energy Deployment in Europe.” Energy 206 (September 1, 2020): 118060. https://doi.org/10.1016/j.energy.2020.118060.

Dams, Ties, Louise van Schaik, and Adaja Stoetman. “Presence before Power: China’s Arctic Strategy in Iceland and Greenland.” Clingendael, June 2020. https://www.clingendael.org/pub/2020/presence-before-power/4-greenland-what-is-china-doing-there-and-why/.

Dasgupta, Probal. “Xi May Have Lost the Plot on China’s Dream of Great Rejuvenation - The Economic Times.” The Economic Times, June 29, 2020. https://economictimes.indiatimes.com/news/international/world-news/view-xi-may-have-lost-the-plot-on-chinas-dream-of-great-rejuvenation/articleshow/76679355.cms?from=mdr.

Leading The Charge. “Do We Have Enough Rare Earth Metals for EVs?” Accessed October 12, 2020. https://www.leadingthecharge.org.nz/do_we_have_enough_rare_earth_metals_for_evs.

Dominish, Elsa, Sven Teske, and Nick Florin. “Responsible Minerals Sourcing for Renewable Energy.” Report prepared for Earthworks by the Institute for Sustainable Futures, University of Technology Sydney. Earthworks, 2019. https://www.uts.edu.au/sites/default/files/2019-04/ISFEarthworks_Responsible%20minerals%20sourcing%20for%20renewable%20energy_Report.pdf.

Egenhofer, Christian, Kyriakos Gialoglou, Giacomo Luciani, Maroeska Boots, Martin Scheepers, Valeria Costantini, Francesco Gracceva, Anil Markandya, and Giorgio Vicini. “Market-Based Options for Security of Energy Supply.” SSRN Electronic Journal, 2004. https://doi.org/10/fxpsnv.

EIT RawMaterials. “About Us.” ERMA, 2020. https://erma.eu/about-us/.

“Electric Vehicle Life Cycle Analysis and Raw Material Availability | Transport & Environment.” Accessed September 30, 2020. https://www.transportenvironment.org/publications/electric-vehicle-life-cycle-analysis-and-raw-material-availability.

“Electric Vehicle Motor Market | Industry Size, Share Analysis Report 2019-2023.” Accessed October 12, 2020. https://www.marketresearchfuture.com/reports/electric-vehicle-motor-market-5385.

Elshkaki, Ayman, and T. E. Graedel. “Dynamic Analysis of the Global Metals Flows and Stocks in Electricity Generation Technologies.” Journal of Cleaner Production 59 (November 15, 2013): 260–73. https://doi.org/10/f5f8zh.

Ericsson, Magnus, Olof Lof, and Anton Lof. “Chinese Control over African and Global Mining—Past, Present and Future.” Mineral Economics 33 (2020): 153–81. https://doi.org/10/ghkmjp.

EU Commission. “Critical Raw Materials.” Text. Internal Market, Industry, Entrepreneurship and SMEs - European Commission, July 5, 2016. https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en.

———. “Due Diligence Ready!” Text. Internal Market, Industry, Entrepreneurship and SMEs - European Commission, November 5, 2019. https://ec.europa.eu/growth/sectors/raw-materials/due-diligence-ready_en.

———. “Patents and Standards.” Text. Internal Market, Industry, Entrepreneurship and SMEs - European Commission, July 5, 2016. https://ec.europa.eu/growth/industry/policy/intellectual-property/patents/standards_en.

———. “Raw Materials Diplomacy.” Text. Internal Market, Industry, Entrepreneurship and SMEs - European Commission, July 5, 2016. https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/international-aspects_en.

———. “Third Energy Package.” Text. Energy - European Commission, May 21, 2019. https://ec.europa.eu/energy/topics/markets-and-consumers/market-legislation/third-energy-package_en.

European Commission. “2030 Climate & Energy Framework.” Text. Climate Action - European Commission, November 23, 2016. https://ec.europa.eu/clima/policies/strategies/2030_en.

———. “China Is on Track to Achieve Its Objective of Global Industrial and Technological Leadership in Key Sectors by 2049.” Text. EU Science Hub - European Commission, July 15, 2019. https://ec.europa.eu/jrc/en/facts4eufuture/china-report-challenges-and-prospects/industrie-innovation-leadership-2049.

———. “COM(2020) 474 - Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability.” Brussels, March 9, 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0474.

———. “Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions. Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability.” Brussels: European Commission, September 3, 2020. https://ec.europa.eu/docsroom/documents/42849.

———. “Critical Raw Materials.” Text. Internal Market, Industry, Entrepreneurship and SMEs - European Commission, 2020. https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en.

———. “EU Climate Target Plan 2030: Key Contributors and Policy Tools.” Text. European Union, September 17, 2020. https://ec.europa.eu/commission/presscorner/detail/en/fs_20_1610.

———. “EU Foreign Investment Screening Regulation Enters into Force.” Text. European Commission - European Commission, 2019. https://ec.europa.eu/commission/presscorner/detail/en/IP_19_2088.

———. "EU Position in World Trade," February 18, 2019. https://ec.europa.eu/trade/policy/eu-position-in-world-trade/.

———. "EU Waste Legislation," 2020. https://ec.europa.eu/environment/waste/legislation/a.htm.

———. "EU-China: Commission and China." Text. European Commission, September 10, 2020. https://ec.europa.eu/commission/presscorner/detail/en/IP_20_1600.

———. "European Industrial Strategy." Text. European Commission, 2020. https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en.

———. "Focus Areas." Text. Horizon 2020, September 29, 2015. https://ec.europa.eu/programmes/horizon2020/en/h2020-section/cross-cutting-activities-focus-areas.

———. "Japan | International Cooperation - Research and Innovation," 2020. https://ec.europa.eu/research/iscp/index.cfm?amp;pg=japan.

———. "Raw Materials Diplomacy." Text. Internal Market, Industry, Entrepreneurship and SMEs - European Commission, July 5, 2016. https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/international-aspects_en.

European Committee for Standardization. "The 'New Approach,'" June 14, 2019. https://boss.cen.eu/reference%20material/guidancedoc/pages/newapproach.aspx.

European Political Strategy Center. "Rethinking Strategic Autonomy in the Digital Age." Website. Publications Office of the European Union, November 21, 2019. http://op.europa.eu/en/publication-detail/-/publication/889dd7b7-0cde-11ea-8c1f-01aa75ed71a1/language-en/format-PDF.

European Union. A New Industrial Strategy for Europe, 52020DC0102 § (2020). https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1593086905382&uri=CELEX%3A52020DC0102.

———. Closing the loop - An EU action plan for the Circular Economy, Pub. L. No. COM/2015/0614, 52015DC0614. Accessed October 26, 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0614.

Exeter, Pieter van, Sybren Bosch, Branco Schipper, Benjamin Sprecher, and René Kleijn. "METAL DEMAND FOR RENEWABLE ELECTRICITY GENERATION IN THE NETHERLANDS." Metabolic, 2018.

Fägersten, Björn, and Tim Rühlig. "China's Standard Power and Its Geopolitical Implications for Europe —." Swedish Institute of International Affairs, 2019.

Fan, Hong-Rui, Kui-Feng Yang, Fang-Fang Hu, Shang Liu, and Kai-Yi Wang. "The Giant Bayan Obo REE-Nb-Fe Deposit, China: Controversy and Ore Genesis." Geoscience Frontiers, Special Issue: Giant Mineral Deposits, 7, no. 3 (May 1, 2016): 335–44. https://doi.org/10/ghbzg8.

Fraunhofer Institute for Solar Energy Systems, Fraunhofer Ise, Werner Warmuth, and PSE Projects GmbH. "Photovoltaics Report," 2020, 48.

Garcia Herrero, Alicia, and Jianwei Wu. "How Big Is China's Digital Economy?" Working Paper. Bruegel, May 17, 2018. https://www.bruegel.org/wp-content/uploads/2018/05/WP04_Digital-economy_Bruegel.pdf.

Gardiner, Joey. "The Rise of Electric Cars Could Leave Us with a Big Battery Waste Problem." The Guardian, August 10, 2017, sec. Guardian Sustainable Business. https://www.theguardian.com/sustainable-business/2017/aug/10/electric-cars-big-battery-waste-problem-lithium-recycling.

Gardner, T.A., M. Benzie, J. Börner, E. Dawkins, S. Fick, R. Garrett, J. Godar, et al. "Transparency and Sustainability in Global Commodity Supply Chains." World Development 121 (September 2019): 163–77. https://doi.org/10/gfc4tp.

Garrett, Peter, 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.

Gaustad, Gabrielle, Mark Krystofik, Michele Bustamante, and Kedar Badami. “Circular Economy Strategies for Mitigating Critical Material Supply Issues.” Resources, Conservation and Recycling, Sustainable Resource Management and the Circular Economy, 135 (August 1, 2018): 24–33. https://doi.org/10.1016/j.resconrec.2017.08.002.

GCSSI. “Global Status of CCS 2019,” 2019. https://www.globalccsinstitute.com/resources/global-status-report/.

“GE RENEWABLE ENERGY LOCATIONS | GE Renewable Energy.” Accessed September 2, 2020. https://www.ge.com/renewableenergy/about-us/locations.

“Global Crude Steel Output Increases by 3.4% in 2019,” 2020. http://www.worldsteel.org/media-center/press-releases/2020/Global-crude-steel-output-increases-by-3.4--in-2019.html.

Technavio. “Global Wind Turbine Nacelle Market 2017-2021.” Accessed September 2, 2020. https://www.technavio.com/report/global-wind-turbine-nacelle-market.

Golev, Artem, Margaretha Scott, Peter D. Erskine, Saleem H. Ali, and Grant R. Ballantyne. “Rare Earths Supply Chains: Current Status, Constraints and Opportunities.” Resources Policy 41 (September 1, 2014): 52–59. https://doi.org/10.1016/j.resourpol.2014.03.004.

Green, Martin A. “Ag Requirements for Silicon Wafer-Based Solar Cells.” Progress in Photovoltaics: Research and Applications 19, no. 8 (2011): 911–16. https://doi.org/10/dcf7zm.

GreenMatch. “How Are Solar Panels Made?,” 2019. https://www.greenmatch.co.uk/blog/2014/12/how-are-solar-panels-made.

Guan, Wei, and Jakob Rehme. “Vertical Integration in Supply Chains: Driving Forces and Consequences for a Manufacturer’s Downstream Integration.” Supply Chain Management: An International Journal 17, no. 2 (March 9, 2012): 187–201. https://doi.org/10/f2zr4z.

Hagelüken, Christian. “Critical Metals for Lithium-Ion Batteries - Umicore Strategies for Sustainable Sourcing of Cobalt.” Vancouver, 2018. https://doi.org/10.13140/RG.2.2.17167.89764.

Hainmueller, Jens, Michael J. Hiscox, and Sandra Sequeira. “Consumer Demand for Fair Trade: Evidence from a Multistore Field Experiment.” Review of Economics and Statistics 97, no. 2 (May 2015): 242–56. https://doi.org/10/gg63w5.

Haldar, Swapan Kumar. “Chapter 4 - Exploration Geology.” In Mineral Exploration (Second Edition), edited by Swapan Kumar Haldar, 2nd ed., 69–84. Elsevier, 2018. https://doi.org/10.1016/B978-0-12-814022-2.00004-6.

Han, Aiping, Jianping Ge, and Yalin Lei. “Vertical vs. Horizontal Integration: Game Analysis for the Rare Earth Industrial Integration in China.” Resources Policy 50 (December 1, 2016): 149–59. https://doi.org/10.1016/j.resourpol.2016.09.006.

Haslam, Paul A, and Pablo Heidrich. “From Neoliberalism to Resource Nationalism. States, Firms and Development.” In Political Economy of Natural Resources and Development. From Neoliberalism to Resource Nationalism, 1–32. Routledge Studies in Development Economics. Routledge, 2016. https://www.researchgate.net/publication/340680811_Political_Economy_of_Natural_Resources_and_Development_From_neoliberalism_to_resource_nationalism.

Helbig, Christoph, Lars Wietschel, Andrea Thorenz, and Axel Tuma. “How to Evaluate Raw Material Vulnerability - An Overview.” Resources Policy 48 (June 2016): 13–24. https://doi.org/10.1016/j.resourpol.2016.02.003.

Henson, Spencer. “The Role of Public and Private Standards in Regulating International Food Markets.” Special Issue: Food Regulation And Trade: Institutional Framework, Concepts Of Analysis And Empirical Evidence, Journal of International Agricultural Trade and Development, 4, no. 1 (2008): 63–81.

Home, Andy. “Low Stocks, Low Transparency; LME Warehousing Back in Focus.” Reuters. April 12, 2019. https://www.reuters.com/article/uk-lme-warehouse-ahome-idUKKCN1RO0XB.

Hond, F. den. “Industrial Ecology.” In International Encyclopedia of the Social & Behavioral Sciences, edited by Neil J. Smelser and Paul B. Baltes, 7320–26. Oxford: Pergamon, 2001. https://doi.org/10.1016/B0-08-043076-7/04138-3.

Hong, Sima. “Sima Hong, Member of the National Committee of the Chinese People’s Political Consultative Conference: Proposal on Docking the International High-Standard Market Rule System to Further Improve the Internationalization Level of Chinese Standards.” Sohu, May 21, 2020. https://m.sohu.com/a/396716867_120056211.

Horizon Scanning Program. “Resource Nationalism.” HM Government, December 2014. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/389085/Horizon_Scanning_-_Resource_Nationalism_report.pdf.

Horst –Verschelling, Judith van der. “A Circular Economy in 2050: A Look at the Stocks and Flows of Electricity Cables in the Netherlands.” Master thesis. Delft: TU Delft & Leiden Unversity, 2020. http://resolver.tudelft.nl/uuid:00611754-0599-4b9c-9218-1bd8fd9c2111.

“How China’s Electric Vehicle (EV) Policies Have Shaped the EV Market – Sustainalytics,” July 31, 2020. https://www.sustainalytics.com/esg-blog/how-chinas-electric-vehicle-policies-have-shaped-the-ev-market/.

Hund, Kirsten, Daniele La Porta, Thao P Fabregas, Tim Laing, and John Drexhage. “Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition.” World Bank Group, 2020.

Hurst, Cindy. “China’s Rare Earth Elements Industry: What Can the West Learn?” Institute for the Analysis of Global Security, March 1, 2010.

IEA. “Energy Security.” IEA, December 2, 2019. https://www.iea.org/areas-of-work/ensuring-energy-security.

———. “Global EV Outlook 2020,” 2020.

———. “R&D and Technology Innovation – World Energy Investment 2020.” IEA, May 2020. https://www.iea.org/reports/world-energy-investment-2020/rd-and-technology-innovation.

IEA, and European Patent Office. “Innovation in Batteries and Electricity Storage - A Global Analysis Based on Patent Data,” September 2020.

“Innovative Wind Turbine Blade Manufacturing | GE Renewable Energy.” Accessed September 8, 2020. https://www.ge.com/renewableenergy/stories/lm-castellon-wind-turbine-blade-manufacturing.

IRENA. “Future of Solar Photovoltaic: Deployment, Investment, Technology, Grid Integration and Socio-Economic Aspects.” Abu Dhabi: International Renewable Energy Agency, 2019.

IRENA, and IEA-PVPS. “End-of-Life Management: Solar Photovoltaic Panels.” International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems, 2016.

Jean, Joel, Patrick R. Brown, Robert L. Jaffe, Tonio Buonassisi, and Vladimir Bulović. “Pathways for Solar Photovoltaics.” Energy & Environmental Science 8, no. 4 (2015): 1200–1219. https://doi.org/10/gg2wtk.

Jensen, Jonas Pagh. “Evaluating the Environmental Impacts of Recycling Wind Turbines.” Wind Energy 22, no. 2 (2019): 316–26. https://doi.org/10/ggtbt2.

Jing, Ye, and Hans Dietrich Haasis. “Impacts of the BRI on International Logistics Network.” In Dynamics in Logistics, 250–54, 2018. https://doi.org/10.1007/978-3-319-74225-0_34.

Joint Research Center. “Circular Economy & Secondary Raw Materials,” 2020. https://rmis.jrc.ec.europa.eu/?page=policies-and-definitions-2d5b5e.

———. “Re-Sourcing H2020 Project,” 2020. https://rmis.jrc.ec.europa.eu/?page=re-sourcing-h2020-project-7f5bde.

———. “Responsible Sourcing of Materials for Batteries,” 2020. https://rmis.jrc.ec.europa.eu/?page=responsible-sourcing-of-materials-for-batteries-f0f53b.

Jowitt, Simon M., Timothy T. Werner, Zhehan Weng, and Gavin M. Mudd. “Recycling of the Rare Earth Elements.” Current Opinion in Green and Sustainable Chemistry 13 (October 2018): 1–7. https://doi.org/10/gf3wst.

Kalantzakos, Sophia. “The Race for Critical Minerals in an Era of Geopolitical Realignments.” The International Spectator 55, no. 3 (July 2, 2020): 1–16. https://doi.org/10/gg9fkb.

Kaminska, Izabella. “Re-Evaluating Cancelled Warrants.” Financial Times, June 17, 2011. http://ftalphaville.ft.com/2011/06/17/597436/re-evaluating-cancelled-warrants/.

Karlis, Thanasis, and Dionysios Polemis. “The Belt and Road Initiative. A Geopolitical Analysis,” April 2019. https://doi.org/10.13140/RG.2.2.12968.21764.

Kleijn, René, Ester van der Voet, Gert Jan Kramer, Lauran van Oers, and Coen van der Giesen. “Metal Requirements of Low-Carbon Power Generation.” Energy 36, no. 9 (September 1, 2011): 5640–48. https://doi.org/10/d2nhpp.

Klinger, Julie Michelle. “Rare Earth Elements: Development, Sustainability and Policy Issues.” The Extractive Industries and Society 5, no. 1 (January 1, 2018): 1–7. https://doi.org/10.1016/j.exis.2017.12.016.

Klossek, Polina, Jakob Kullik, and Karl Gerald van den Boogaart. “A Systemic Approach to the Problems of the Rare Earth Market.” Resources Policy 50 (December 1, 2016): 131–40. https://doi.org/10.1016/j.resourpol.2016.09.005.

Koch, Natalie, and Tom Perreault. “Resource Nationalism.” Progress in Human Geography 43, no. 4 (August 2019): 611–31. https://doi.org/10/gfc952.

Korinek, Jane, and Jeonghoi Kim. “Export Restrictions on Strategic Raw Materials and Their Impact on Trade and Global Supply.” In The Economic Impact of Export Restrictions on Raw Materials, 103–30. OECD Trade Policy Studies. OECD Publishing, 2010. https://read.oecd-ilibrary.org/trade/the-economic-impact-of-export-restrictions-on-raw-materials_9789264096448-en.

Ku, Anthony Y. “Anticipating Critical Materials Implications from the Internet of Things (IOT): Potential Stress on Future Supply Chains from Emerging Data Storage Technologies.” Sustainable Materials and Technologies 15 (April 1, 2018): 27–32. https://doi.org/10/ghgss5.

Lebedeva, Natalia, Franco DI PERSIO, and Lois BRETT. “Lithium Ion Battery Value Chain and Related Opportunities for Europe.” Text, December 19, 2016. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/lithium-ion-battery-value-chain-and-related-opportunities-europe.

Li, Jiashuo, Kun Peng, Peng Wang, Ning Zhang, Kuishuang Feng, Dabo Guan, Jing Meng, Wendong Wei, and Qing Yang. “Critical Rare-Earth Elements Mismatch Global Wind-Power Ambitions.” One Earth 3, no. 1 (July 24, 2020): 116–25. https://doi.org/10/ghbzg3.

Lighthizer, Robert. “How to Set World Trade Straight.” Wall Street Journal, August 20, 2020. https://www.wsj.com/articles/how-to-set-world-trade-straight-11597966341.

Liu, Zhigao, Seth Schindler, and Weidong Liu. “Demystifying Chinese Overseas Investment in Infrastructure: Port Development, the Belt and Road Initiative and Regional Development.” Journal of Transport Geography 87 (July 1, 2020): 102812. https://doi.org/10.1016/j.jtrangeo.2020.102812.

LME. “Discussion Paper on LME Warehouse Reform.” London Metal Exchange, March 2019.

———. “Guide to the London Metal Exchange.” London Metal Exchange, 2020.

———. “London Metal Exchange: About.” The London Metal Exchange - an HKEX Company, 2020. https://www.lme.com/About.

———. “Warehouse Reform 2019.” London Metal Exchange - an HKEX Company, 2020. https://www.lme.com/Trading/Warehousing/2019-warehouse-reform.

The London Metal Exchange - an HKEX Company. “London Metal Exchange: Home,” 2020. https://www.lme.com/.

Machacek, Erika, and Niels Fold. “Alternative Value Chains for Rare Earths: The Anglo-Deposit Developers.” Resources Policy 42 (December 1, 2014): 53–64. https://doi.org/10.1016/j.resourpol.2014.09.003.

Madiega, Tambiama. “Digital Sovereignty for Europe.” EPRS Ideas Paper. European Parliament, 2020.

Magnana, Davide, SHORTALL Ruth, TELSNIG Thomas, UIHLEIN Andreas, VAZQUEZ HERNANDEZ Cristina, and team. “Supply Chain of Renewable Energy Technologies in Europe: An Analysis for Wind, Geothermal and Ocean Energy.” Text, November 27, 2017. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/supply-chain-renewable-energy-technologies-europe-analysis-wind-geothermal-and-ocean-energy.

Mancheri, Nabeel. “World Trade in Rare Earths, Chinese Export Restrictions, and Implications.” Resources Policy 46 (December 1, 2015): 262–71. https://doi.org/10.1016/j.resourpol.2015.10.009.

Mancheri, Nabeel A., Benjamin Sprecher, Gwendolyn Bailey, Jianping Ge, and Arnold Tukker. “Effect of Chinese Policies on Rare Earth Supply Chain Resilience.” Resources, Conservation and Recycling 142 (March 1, 2019): 101–12. https://doi.org/10.1016/j.resconrec.2018.11.017.

Manoochehri, John. “Consumption Opportunities: Strategies for Change.” Geneva: United Nations Environment Program, 2001.

Maris, Elisabeth, Daniel Froelich, Améziane Aoussat, and Emmanuel Naffrechoux. “Chapter 27 - From Recycling to Eco-Design.” In Handbook of Recycling, edited by Ernst Worrell and Markus A. Reuter, 421–27. Boston: Elsevier, 2014. https://doi.org/10.1016/B978-0-12-396459-5.00027-1.

McMorrow, Ryan. “Tesla Lines up $1.6bn in Financing for Its Shanghai Gigafactory,” December 27, 2019. https://www.ft.com/content/598b04cc-286d-11ea-9a4f-963f0ec7e134.

Medeiros, Carlos Aguiar De, Nicholas M. Trebat, Carlos Aguiar De Medeiros, and Nicholas M. Trebat. “Transforming Natural Resources into Industrial Advantage: The Case of China’s Rare Earths Industry.” Brazilian Journal of Political Economy 37, no. 3 (July 2017): 504–26. https://doi.org/10/ggbhwn.

———. “Transforming Natural Resources into Industrial Advantage: The Case of China’s Rare Earths Industry.” Brazilian Journal of Political Economy 37, no. 3 (July 2017): 504–26. https://doi.org/10.1590/0101-31572017v37n03a03.

Middleton, Wendy, and Lee Goldberg. “Design for Disassembly, Reuse and Recycling.” In Green Electronics/Green Bottom Line : Environmentally Responsible Engineering, 69–82. Boston: Newnes, 2000. https://web-a-ebscohost-com.proxy.uba.uva.nl:2443/ehost/ebookviewer/ebook/ZTAwMHh3d19fMjA3NTI1xX19BTg2?sid=42e65781-3c3d-43ae-94ba-9e92074c5593@sessionmgr4008&vid=0&format=EB&rid=1.

Ministerie van Economische Zaken. “Encouraging Innovation - Enterprise and Innovation.” Onderwerp. Ministerie van Algemene Zaken, December 21, 2011. https://www.government.nl/topics/enterprise-and-innovation/encouraging-innovation.

Ministerie van Economische Zaken en Klimaat. “*Klimaatakkoord*.” Publicatie. Ministerie van Economische Zaken en Klimaat, June 28, 2019. https://www.*klimaatakkoord*.nl/documenten/publicaties/2019/06/28/*klimaatakkoord*.

———. “Veerkracht Op Het Gebied van Kritieke Grondstoffen: De Weg Naar Een Grotere Voorzieningszekerheid En Duurzaamheid Uitstippelen,” n.d.

Ministerie van Infrastructuur en Waterstaat. “Circular Dutch Economy by 2050.” Ministerie van Algemene Zaken, November 4, 2019. https://www.government.nl/topics/circular-economy/circular-dutch-economy-by-2050.

———. “Nederland Circulair in 2050,” 2016.

Ministry of Natural Resources. “China Mineral Resources 2019.” Beijing, 2019. https://www.gov.cn/xinwen/2018-10/22/5333589/files/01d0517b9d6c430bbb927ea5e48641b4.pdf.

Mishnaevsky, Leon, Kim Branner, Helga Nørgaard Petersen, Justine Beauson, Malcolm McGugan, and Bent F. Sørensen. “Materials for Wind Turbine Blades: An Overview.” Materials 10, no. 11 (November 9, 2017). https://doi.org/10/gf8hb4.

“More than Minerals.” The Economist, March 23, 2013. https://www.economist.com/middle-east-and-africa/2013/03/23/more-than-minerals.

Morseletto, Piero. “Targets for a Circular Economy.” Resources, Conservation and Recycling 153 (February 1, 2020): 104553. https://doi.org/10/ghbzg6.

Moss, R. L, E Tzimas, H Kara, P Willis, J Kooroshy, European Commission, Joint Research Center, Institute for Energy and Transport, Oakdene Hollins Ltd, and Hague Center for Strategic Studies. Critical Metals in Strategic Energy Technologies: Assessing Rare Metals as Supply-Chain Bottlenecks in Low-Carbon Energy Technologies. Luxembourg: Publications Office, 2011. http://dx.publications.europa.eu/10.2790/35716.

Moss, Ray, and Evangelos Tzima. “Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector,” 2013. https://setis.ec.europa.eu/sites/default/files/reports/JRC-report-Critical-Metals-Energy-Sector.pdf.

Myers, Steven Lee. “China’s Pledge to Be Carbon Neutral by 2060: What It Means.” The New York Times, September 23, 2020, sec. World. https://www.nytimes.com/2020/09/23/world/asia/china-climate-change.html.

Nikogosian, Vigen, and Tobias Veith. “Vertical Integration, Separation and Non-Price Discrimination: An Empirical Analysis of German Electricity Markets for Residential Customers.” SSRN Electronic Journal, 2011. https://doi.org/10/gg9fm6.

Northvolt. “Northvolt Raises $1.6 Billion in Debt Financing through Consortium of Global Financial Institutions,” July 29, 2020. https://northvolt.com/newsroom/Northvolt-July2020-financing.

Notter, Dominic A., Marcel Gauch, Rolf Widmer, Patrick Wäger, Anna Stamp, Rainer Zah, and Hans-Jörg Althaus. “Contribution of Li-Ion Batteries to the Environmental Impact of Electric Vehicles.” Environmental Science & Technology 44, no. 17 (September 1, 2010): 6550–56. https://doi.org/10/c58rcv.

Nowak-Lehmann, Felicitas, Inmaculada Martínez-Zarzoso, Stephan Klasen, and Dierk Herzer. “Aid and Trade – A Donor’s Perspective.” The Journal of Development Studies 45, no. 7 (August 1, 2009): 1184–1202. https://doi.org/10.1080/00220380902952407.

Nuss, Philip, T. E. Graedel, Elisa Alonso, and Adam Carroll. “Mapping Supply Chain Risk by Network Analysis of Product Platforms.” Sustainable Materials and Technologies 10 (December 1, 2016): 14–22. https://doi.org/10/ghbzg4.

ODI. “Global China 2049 Initiative.” ODI. Accessed November 11, 2020. https://www.odi.org/projects/china-2049-initiative.

OECD. OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas: Third Edition. 3rd ed. Paris: OECD Publishing, 2016. https://doi.org/10.1787/9789264252479-en.

Olivetti, Elsa A., Gerbrand Ceder, Gabrielle Gaustad, and Xinkai Fu. “Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals.” Joule 1, no. 2 (October 11, 2017): 229–43. https://doi.org/10/gg9q58.

Oorschot, Janneke van, Jochem van der Zaag, Ester van der Voet, Vincent van Straalen, and Roel Delahaye. “Voorraden in de Maatschappij: De Grondstoffenbasis Voor Een Circulaire Economiemet Case Studies Op Gebied van Het Elektriciteitssysteem, Elektronica En Voertuigen.” CBS, 2020. https://www.universiteitleiden.nl/binaries/content/assets/science/cml/final-rapportage-voorraden-in-de-maatschappij_edit_23.01.2020.pdf.

Park, Jaehwan. “The Role of Canceled Warrants in the LME Market.” International Journal of Financial Studies 7, no. 1 (March 2019): 10. https://doi.org/10.3390/ijfs7010010.

Paulick, Holger, and Erika Machacek. “The Global Rare Earth Element Exploration Boom: An Analysis of Resources Outside of China and Discussion of Development Perspectives.” Resources Policy 52 (2017): 134–153. https://doi.org/10.1016/j.resourpol.2017.02.002.

Pavel, Claudiu C., Roberto Lacal-Arántegui, Alain Marmier, Doris Schüler, Evangelos Tzimas, Matthias Buchert, Wolfgang Jenseit, and Darina Blagoeva. “Substitution Strategies for Reducing the Use of Rare Earths in Wind Turbines.” Resources Policy 52 (June 1, 2017): 349–57. https://doi.org/10/gbprkx.

Pavel, Claudiu C, Alain Marmier, Patricia Alves, Darina Blagoeva, Evangelos Tzimas, Doris Schüler, Tobias Schleicher, Stefanie Degreif, and Matthias Buchert. “Substitution of Critical Raw Materials in Low-Carbon Technologies: Lighting, Wind Turbines and Electric Vehicles.” Luxembourg: European Commission, Oko-Institut e.V., 2016.

Pérez-Arriaga, Ignacio J. “Security of Electricity Supply in Europe in a Short, Medium and Long-Term Perspective” 2, no. 2 (2007): 28.

“Permanent Magnets Market Size & Share | Industry Report, 2027.” Accessed September 2, 2020. https://www.grandviewresearch.com/industry-analysis/permanent-magnets-industry.

Pesce, Marco, Ilaria Tamai, Deyan Guo, Andrea Critto, Daniele Brombal, Xiaohui Wang, Hongguang Cheng, and Antonio Macromini. “Circular Economy in China: Translating Principles into Practice.” Sustainability 12, no. 3 (January 22, 2020). https://doi.org/10/ghbzgz.

Pike, Lili. “Xi Jinping Wants China to Be Carbon Neutral by 2060. These Researchers Have a Plan for That.” Vox, October 15, 2020. https://www.vox.com/2020/10/15/21516537/climate-change-china-xi-jinping-coal-carbon-neutral.

Preziosi, N, P Fako, H Hristov, K Jonkers, X Geonaga, P Alves Dias, S Amoroso, et al. “China: Challenges and Prospects from an Industrial and Innovation Powerhouse.” Luxembourg: Publications Office of the European Union, 2019. https://data.europa.eu/doi/10.2760/445820.

European Commission. “Priorities.” Text. Accessed November 11, 2020. https://ec.europa.eu/info/strategy/priorities-2019-2024_en.

Statista. “Production of Electric Vehicles: Selected Countries.” Accessed October 12, 2020. https://www.statista.com/statistics/270537/forecast-for-electric-car-production-in-selected-countries/.

Provoost, Melanie, Laurien Albeda, and Bas Godschalk. “Geothermal Energy Use, Country Update for The Netherlands,” n.d., 8.

Pryke, Sam. “Explaining Resource Nationalism.” Global Policy 8, no. 4 (2017): 474–82. https://doi.org/10/ghbzg5.

Putten, Frans-Paul van der. “Chinese Direct Investment in the Netherlands: Patterns, Reception and Political Significance.” Clingendael, 2017. https://www.clingendael.org/sites/default/files/2017-12/PB_Chinese_Investment_Netherlands.pdf.

———. “Chinese Direct Investment in the Netherlands: Patterns, Reception and Political Significance.” Clingendael, 2017. https://www.clingendael.org/sites/default/files/2017-12/PB_Chinese_Investment_Netherlands.pdf.

Regulation (EU) 2017/821 of the European Parliament and of the Council of 17 May 2017 laying down supply chain due diligence obligations for Union importers of tin, tantalum and tungsten, their ores, and gold originating from conflict-affected and high-risk areas, Pub. L. No. 32017R0821, 130 OJ L (2017). http://data.europa.eu/eli/reg/2017/821/oj/eng.

ReportLinker. “Wind Turbine Tower Market - Growth, Trends, and Forecast (2019 - 2024).” GlobeNewswire News Room, February 26, 2020. http://www.globenewswire.com/news-release/2020/02/26/1991466/0/en/Wind-Turbine-Tower-Market-Growth-Trends-and-Forecast-2019-2024.html.

Richa, Kirti, Callie W. Babbitt, Gabrielle Gaustad, and Xue Wang. “A Future Perspective on Lithium-Ion Battery Waste Flows from Electric Vehicles.” Resources, Conservation and Recycling 83 (February 2014): 63–76. https://doi.org/10/f5twzm.

Ross, Sean. “Why Should You Invest in Research and Development (R&D)?” Investopedia, July 22, 2019. https://www.investopedia.com/ask/answers/043015/what-are-benefits-research-and-development-company.asp.

Sanderson, Henry, and Neil Hume. “HKEX yet to Realise Its Grand Ambitions for London Metal Exchange.” Financial Times, September 11, 2019. https://www.ft.com/content/73ecd7b4-d494-11e9-a0bd-ab8ec6435630.

Sandor, Debra, Donald Chung, David Keyser, Margaret Mann, and Jill Engel-Cox. “BENCHMARKS OF GLOBAL CLEAN ENERGY MANUFACTURING.” NREL, 2017.

Scheyder, Ernest. “U.S. Rare Earths Miner MP Materials to Go Public in $1.47 Billion Deal.” Reuters, July 15, 2020. https://www.reuters.com/article/us-mp-materials-ipo-idUSKCN24G1WT.

Seaman, John. “China and the New Geopolitics of Technical Standardization.” Notes de l’Ifri. Ifri, 2020.

Shen, Yuzhou, Ruthann Moomy, and Roderick G. Eggert. “China’s Public Policies toward Rare Earths, 1975–2018.” Mineral Economics 33, no. 1–2 (July 2020): 127–51. https://doi.org/10.1007/s13563-019-00214-2.

SIA. “BEYOND BORDERS: THE GLOBAL SEMICONDUCTOR VALUE CHAIN,” 2016. https://www.semiconductors.org/wp-content/uploads/2018/06/SIA-Beyond-Borders-Report-FINAL-June-7.pdf.

Smith Stegen, Karen. “Heavy Rare Earths, Permanent Magnets, and Renewable Energies: An Imminent Crisis.” Energy Policy 79 (2015): 1–8. https://doi.org/10.1016/j.enpol.2014.12.015.

Sprecher, Benjamin, Ichiro Daigo, Shinsuke Murakami, Rene Kleijn, Matthijs Vos, and Gert Jan Kramer. “Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis.” Environmental Science & Technology 49, no. 11 (June 2, 2015): 6740–50. https://doi.org/10.1021/acs.est.5b00206.

———. “Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis.” Environmental Science & Technology 49, no. 11 (June 2, 2015): 6740–50. https://doi.org/10/f7f8bf.

State Administration for Market Regulation. “‘China Standard 2035’ Project Closing Meeting and ‘National Standardization Development Strategy Research’ Project Kick-off Meeting Held in Beijing,” January 15, 2020. http://www.samr.gov.cn/xw/zj/202001/t20200115_310519.html.

“Statistieken - Windstats.Nl.” Accessed October 5, 2020. https://windstats.nl/statistieken/#data_results.

Staudenmaier, Rebecca. “Tesla Factory Outside Berlin to Cost €4 Billion.” DW, November 17, 2019. https://www.dw.com/en/tesla-factory-outside-berlin-to-cost-4-billion/a-51286353.

Stavridou, N., E. Koltsakis, and C. C. Baniotopoulos. “A Comparative Life-Cycle Analysis of Tall Onshore Steel Wind-Turbine Towers.” Clean Energy 4, no. 1 (April 4, 2020): 48–57. https://doi.org/10/ggtbvs.

Stone & Associates. “Overview of the Solar Energy Industry and Supply Chain,” 2011. https://www.bgafoundation.org/wp-content/uploads/2016/08/Solar-Overview-for-BGA-Final-Jan-2011.pdf.

Sun, Xin, Han Hao, Philipp Hartmann, Zongwei Liu, and Fuquan Zhao. “Supply Risks of Lithium-Ion Battery Materials: An Entire Supply Chain Estimation.” Materials Today Energy 14 (December 1, 2019): 100347. https://doi.org/10/ghgss7.

Switzer, Stephanie, Leonardus Gerber, and Francesco Sindico. “Access to Minerals: WTO Export Restrictions and Climate Change Considerations.” Laws 4 (September 22, 2015): 617–37. https://doi.org/10/gg9fkc.

Tesla. “Gigafactory Berlin-Brandenburg.” Tesla, 2020. https://www.tesla.com/en_eu/gigafactory-berlin.

The Economist. “The Chips Are down - The Semiconductor Industry and the Power of Globalisation.” The Economist, December 2018. https://www.economist.com/briefing/2018/12/01/the-semiconductor-industry-and-the-power-of-globalisation.

European Union. “The EU in Brief.” Text, June 16, 2016. https://europa.eu/european-union/about-eu/eu-in-brief_en.

The General Agreement on Tariffs and Trade, § Article XX (1947). https://www.wto.org/english/docs_e/legal_e/gatt47_01_e.htm.

The Hague Center for Strategic Studies. "A Strategic Coup? A Brilliant Acquisition of the World Metal Market." The Hague Center for Strategic Studies, October 5, 2012. https://hcss.nl/news/a_strategic_coup_a_brilliant_acquisition_of_the_world_metal_market_1.

The State Council of the People's Republic of China. "Main Points of National Standardization Work in 2020," 2020. http://www.gov.cn/zhengce/zhengceku/2020-03/24/content_5494968.htm.

The US-China Business Council. "China in International Standards Setting: USCBC Recommendations for Constructive Participation," February 2020, 12.

UN. "UN Comtrade | International Trade Statistics Database." Accessed October 28, 2020. https://comtrade.un.org/.

US Department of Energy. "Critical Materials Rare Earths Supply Chain: A Situational White Paper," April 2020.

U.S. Department of Energy. "Critical Materials Strategy," 2010. https://www.energy.gov/sites/prod/files/edg/news/documents/criticalmaterialsstrategy.pdf.

Vonsée, Bram, Wina Crijns-Graus, and Wen Liu. "Energy Technology Dependence - A Value Chain Analysis of Geothermal Power in the EU." Energy 178 (July 1, 2019): 419–35. https://doi.org/10/ghgss8.

Weiss, Bettina. "International Technology Roadmap for Photovoltaic (ITRPV): 2013 Results." ITRPV, 2014. https://resources.solarbusinesshub.com/images/reports/37.pdf.

GDPR.eu. "What Is GDPR, the EU's New Data Protection Law?," November 7, 2018. https://gdpr.eu/what-is-gdpr/.

Widmer, James D., Richard Martin, and Mohammed Kimiabeigi. "Electric Vehicle Traction Motors without Rare Earth Magnets." Sustainable Materials and Technologies 3 (April 1, 2015): 7–13. https://doi.org/10/ghgss6.

Wilson, Jeffrey D. "Resource Nationalism or Resource Liberalism? Explaining Australia's Approach to Chinese Investment in Its Minerals Sector." Australian Journal of International Affairs 65, no. 3 (June 2011): 283–304. https://doi.org/10/bxw4jk.

"Wind Turbine Rotor Blade Market | Growth, Trends, and Forecasts (2020 - 2025)." Accessed September 2, 2020. https://www.mordorintelligence.com/industry-reports/wind-turbine-rotor-blades-market.

World Bank Group. The Growing Role of Minerals and Metals for a Low Carbon Future. World Bank, 2017. https://doi.org/10.1596/28312.

World Intellectual Property Organization. "Patent Cooperation Treaty Yearly Review." Geneva, 2020. https://www.wipo.int/edocs/pubdocs/en/wipo_pub_901_2020.pdf.

WTO. "Principles of the Trading System." WTO, 2020. https://www.wto.org/english/thewto_e/whatis_e/tif_e/fact2_e.htm.

Wübbeke, Jost. "Rare Earth Elements in China: Policies and Narratives of Reinventing an Industry." Resources Policy 38, no. 3 (September 1, 2013): 384–94. https://doi.org/10.1016/j.resourpol.2013.05.005.

Xue, Yanyan. "Sustainable Urban Minig: The Case of China." PhD, University of Twente, 2018. https://doi.org/10.3990/1.9789036546294.

Yang, X. Jin, Hanjun Hu, Tianwei Tan, and Jinying Li. "China's Renewable Energy Goals by 2050." Environmental Development 20 (November 1, 2016): 83–90. https://doi.org/10/ghkmjk.

Yang, Yongxiang, Allan Walton, Richard Sheridan, Konrad Güth, Roland Gauß, Oliver Gutfleisch, Matthias Buchert, et al. "REE Recovery from End-of-Life NdFeB Permanent Magnet Scrap: A Critical Review." Journal of Sustainable Metallurgy 3, no. 1 (March 1, 2017): 122–49. https://doi.org/10/gbvt2r.

Young, Steven B. “Responsible Sourcing of Metals: Certification Approaches for Conflict Minerals and Conflict-Free Metals.” The International Journal of Life Cycle Assessment 23, no. 7 (July 1, 2018): 1429–47. https://doi.org/10/gdtf7f.

Yu, Baojun, Hangjun Xu, and Feng Dong. “Vertical vs. Horizontal: How Strategic Alliance Type Influence Firm Performance?” Sustainability 11, no. 23 (January 2019). https://doi.org/10.3390/su11236594.

Zeuthen, Jesper. “Part of the Master Plan? Chinese Investment in Rare Earth Mining in Greenland,” 2017, 14.

Zhu, Junming, Chengming Fan, Haijia Shi, and Lei Shi. “Efforts for a Circular Economy in China: A Comprehensive Review of Policies.” Journal of Industrial Ecology 23, no. 1 (2019): 110–18. https://doi.org/10/gf4q4m.

The Hague Centre for Strategic Studies

info@hcss.nl

hcss.nl

Address:
Lange Voorhout 1
2514EA
The Hague
The Netherlands