The Hague Centre
for Strategic Studies

Short Version

Reaching breaking point

The semiconductor and critical raw material ecosystem at a time of great power rivalry

Joris Teer, Mattia Bertolini

October 2022

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Authors:
Joris Teer, Mattia Bertolini

Contributors:
Jeff Amrish Ritoe, Saskia Heyster, Tim Sweijs, Rob de Wijk, Michel Rademaker, Martijn Vlaskamp, Irina Patrahau, Jack Thompson, Stella Kim, Raffaele Minicozzi, Adam Meszaros, Giovanni Cisco, and Michal Gorecki.

Visual design:
Jelle van der Weerd (www.odvl.nl)

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Executive summary

Both semiconductors and critical raw materials (CRM) have been described as *the oil of the 21st century*. Oil products have been central in mechanising the economy. Semiconductors play an indispensable role in powering the modern digital economy. Computers, smartphones, smart grids, automobiles and jetfighters all require chips. Notably, semiconductors play a key role in the energy transition, for instance, in new energy solutions such as solar and wind power. Without semiconductors no new semiconductors can be produced, as the design labs, foundries and equipment tools used to produce semiconductors require semiconductors as well. The semiconductor production process in turn relies on a wide variety of CRM. Prices of various CRM are on the rise, with some even becoming scarce. The move from oil and gas production to green energy, including solar panels and wind turbines, can be boiled down to "a shift from [reliance on] fossil fuels to metals".[1] Not only the energy transition, but also the digital transition, as well as defence-related manufacturing and other factors are pushing demand for CRM. The interlinking semiconductor and CRM ecosystem hence are the foundation of today's world economy .

The interlinking semiconductor and CRM ecosystem are the foundation of today's world economy.

As great power rivalry heats up, semiconductor and CRM value chains are in an early stage of being weaponised, similar to how the Organisation of Arab Petroleum Exporting Companies (OAPEC) used oil as a lever of power in 1973.[2] The semiconductor value chain is dominated by the technologically advanced democracies of the world, including Taiwan, South Korea, the US, Japan and European states. It is highly globalised, highly consolidated, depends on exceptionally high-levels of investment in R&D and has a high division of labour across continents.[3] Even though the majority of activities in the supply chain take part in Taiwan, South Korea, the United States and China, one company in the Netherlands functions as an irreplaceable node. The Netherlands-based lithography giant Advanced Semiconductor Materials Lithography (ASML) is the sole provider of extreme ultraviolet (EUV) lithography equipment, an essential tool used by semiconductor manufacturing companies, such as Taiwan Semiconductor Manufacturing Company (TSMC) and Samsung, to produce the world's most advanced chips.[4] NXP and ASM International, two additional innovative companies involved in the semiconductor value chain, are headquartered in the Netherlands too.

1 René Kleijn, "Leiden-Delft-Erasmus White Paper: Critical Materials, Green Energy and Geopolitics," Leiden-Delft-Erasmus Universities, June 21, 2022, 8.

2 Even though deposits for many CRM around the world are widespread, at the moment production, refining and conversion and processing of CRM for semiconductors is only done in a limited amount of states. Diversification of production cannot be easily done, especially for the mining phase, as the International Energy Agency (IEA) estimates the time from early exploration of a mine to full production to take anywhere between seven and 20 years (see Section 1). At the same time, US-led attempts to impose limits on exports of semiconductor technology to China as well as a comprehensive ban on exporting semiconductors to Russia contribute to the weaponisation of the semiconductor supply chain (see Section 3).

3 Antonio Varas et al., "Strengthening the Global Semiconductor Supply Chain in an Uncertain Era" (BCG, SIA, April 2021), https://www.semiconductors.org/strengthening-the-global-semiconductor-supply-chain-in-an-uncertain-era/.; Jan-Peter Kleinhans and Nurzat Baisakova, "The Global Semiconductor Value Chain: A Technology Primer for Policy Makers" (Stiftung Neue Verantwortung, October 2020), https://www.stiftung-nv.de/sites/default/files/the_global_semiconductor_value_chain.pdf; John Lee and Jan-Peter Kleinhans, "Mapping China's Semiconductor Ecosystem in Global Context" (Berlin: MERICS, June 2021), https://merics.org/sites/default/files/2021-06/China%E2%80%99s%20Semiconductor%20Ecosystem_0.pdf.

4 "ASML," ASML, 2022, https://www.asml.com/en.

Nowadays, supplies of the refined and processed CRM used to manufacture semiconductors are (indirectly) imported from the European Union's (EU) rivals, specifically China and Russia, and African countries with complicated political-economic or military contexts, such as the Democratic Republic of the Congo (DRC) and other states in Southern Africa. Today's cost efficient, global supply chains, increasingly come with security of supply risks, as trust between the large industrialised blocs of the world is rapidly eroding.

How sustainable will these dependencies prove to be in the next five and ten years? Throughout the previous decade, relations between the Netherlands, the EU and their partners in semiconductor production on the one hand, and Russia and China on the other, have deteriorated rapidly. Yet, as of September 2022, only relations with Russia have reached breaking point. A breaking point is reached when friction in an interstate relationship, often related to military-strategic tensions, becomes so overwhelming that states are no longer willing to supply all or some vital resources on which the economies of their rivals depend. European-Russian trade in vital resources survived the annexation of Crimea, the downing of MH17, and all other contentious events before February 2022. However, European-Russian relations reached breaking point following Russia's invasion of Ukraine and European retaliatory sanctions including a comprehensive ban on the export of semiconductors to Russia. Russia reduced the supply of natural gas to Europe to 25% of 2019 levels, freezing the export of neon gas altogether until the end of 2023 (see Case Study in Textbox 1). The continuation of palladium exports from Russia, a CRM used in the fabrication of semiconductors, throughout 2022 should not be taken for granted, as relations between Europe and Russia are still in decline.

European-Russia relations have reached breaking point.

Sino-European relations, unlike European-Russian relations, have not yet reached breaking point, but are similarly characterised by a downward trajectory over the course of the past decade. China's supply of silicon, gallium, germanium, cobalt and rare earth elements (REE) survived the EU designating Beijing as a *systemic rival*,[5] the Dutch House of Representatives becoming the first parliament in Europe to label China's mass-internment of Uyghurs a genocide,[6] EU sanctions against Chinese officials engaged in Xinjiang-related policy-making,[7] and the G7's condemnation of China's live-fire drills around Taiwan in August 2022.[8] So far, it has also survived the US spurring on allies in Europe and Asia to join its attempts to "freeze" China's technological development over the past years. Since 2019, the Dutch government has withheld a license for ASML to export its EUV system to China. Even though China has a history of weaponising access to its market and greatly limited its supply of REE to the world in 2010, it has not opted to weaponise the resource in the 2020s. Finally, the supply of cobalt survived an uptick in political instability in the DRC and other Southern African states as well as the dominance of Chinese (state-owned) companies in refining and control over mines in

5 "EU-China - A Strategic Outlook" (Brussels: European Commission, March 12, 2019).

6 "Motie van het lid Sjoerdsma c.s. over uitspreken dat in China genocide plaatsvindt op de Oeigoerse minderheid," Text, Tweede Kamer, February 25, 2021, https://www.tweedekamer.nl/kamerstukken/detail/2021Z03872/2021D08405.

7 "Chair's Statement of 23 March 2021 on EU Sanctions on Human Rights Violations; Counter-Sanctions by the PRC," European Parliament, March 23, 2021, https://www.europarl.europa.eu/delegations/en/chair-s-statement-of-23-march-2021-on-eu/product-details/20210324DPU29209.

8 U.S. Department of State, "G7 Foreign Ministers' Statement on Preserving Peace and Stability Across the Taiwan Strait," August 3, 2022, https://www.state.gov/g7-foreign-ministers-statement-on-preserving-peace-and-stability-across-the-taiwan-strait/#:~:text=We%20are%20concerned%20by%20recent,activity%20in%20the%20Taiwan%20Strait.

the DRC.[9] Even though the supply of CRM from or through China to Europe has survived until now, the downward trend in China's relations with technologically advanced democracies comes with realistic risks of reaching breaking point throughout this decade.

In the face of looming breaking points ensuring security of supply is becoming a central motivation for policies of states and companies. Especially contentious issues such as the status of Ukraine, Taiwan, the South China Sea and the East China Sea, can serve as flashpoints leading Russia or China to upend their supply of CRM to Europe. Whether political stability in Southern Africa and the DRC can be maintained remains an open question. At a time of great power rivalry, opposing camps in the semiconductor and CRM ecosystem try to win interdependence by building on their respective strengths and mitigate their vulnerabilities.

Europe in the semiconductor and CRM ecosystem

Indigenisation of the semiconductor and CRM value chain comes at a cost.

To ensure the unimpeded functioning of the European economy in an effective and efficient manner, the Netherlands and the EU need to strengthen their position in the fragile semiconductor and CRM ecosystem.[10] Much has been written on risks due to the interdependencies in the semiconductor supply chain, with industry players like ASML advocating industrial policies to strengthen Europe's place in the semiconductor ecosystem.[11] The European Chips Act, aiming to invest tens of billions of euros, intends to indigenise a greater share of the semiconductor supply chain.[12] The risks of the Netherlands and the EU's vast CRM dependence on third countries, especially its rivals, is widely acknowledged to be a threat and has been assessed in depth.[13] The European Commission President, in her 2022 state of the union address, announced the preparation of a European Critical Raw Material Act, to achieve greater control over CRM value chains.[14] The Dutch government will present a resource strategy by the end of 2022.

Indigenisation of the semiconductor and CRM value chain comes, however, at a cost. The Semiconductor Industry Association, the voice of the US semiconductor industry, has

9 Tsisilile A Igogo et al., "Supply Chain of Raw Materials Used in the Manufacturing of Light-Duty Vehicle Lithium-Ion Batteries" (CEMAC, August 30, 2019), https://doi.org/10.2172/1560124; Eric Lipton and Dionne Searcey, "Chinese Company Removed as Operator of Cobalt Mine in Congo," *The New York Times*, February 28, 2022, sec. World, https://www.nytimes.com/2022/02/28/world/congo-cobalt-mining-china.html; Dionne Searcey et al., "A Power Struggle Over Cobalt Rattles the Clean Energy Revolution," *The New York Times*, November 20, 2021, sec. World, https://www.nytimes.com/2021/11/20/world/china-congo-cobalt.html.

10 See Dutch Ministry of Justice and Security, "National Security Strategy" (Dutch Central Government, 2019), 12, https://english.nctv.nl/topics/national-security-strategy.

11 "ASML Position Paper on EU Chips Act" (ASML, February 2022), https://www.asml.com/-/media/asml/files/news/2022/asml-position-paper-on-eu-chips-act.pdf?rev=cc4554892d7a4304bee8b056b96e4dee.

12 European Commission, "A Chips Act for Europe" (Brussels: European Commission, February 8, 2022), https://digital-strategy.ec.europa.eu/en/library/european-chips-act-staff-working-document.

13 Irina Patrahau et al., "Securing Critical Materials for Critical Sectors" (The Hague Centre for Strategic Studies, 2020), https://hcss.nl/report/securing-critical-materials-for-critical-sectors-policy-options-for-the-netherlands-and-the-european-union/.; Magnus Gislev and Milan Grohol, "Report on Critical Raw Materials and the Circular Economy" (European Commission, 2018), https://op.europa.eu/en/publication-detail/-/publication/d1be1b43-e18f-11e8-b690-01aa75ed71a1. ; European Commission, "Communication from the Commission to the EU Parliament and the European Council: Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability" (European Commission, 2020), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0474.

14 European Commission, *State of the Union Speech by President von Der Leyen*, 2022, https://www.youtube.com/watch?v=K8LzZ2vgnwA.

highlighted the enormous added value of the global, sophisticated semiconductor supply chain, pointing out the way in which it supports "the industry's continuous technology innovation" and "how it ultimately benefits consumers and enables better technology and lower prices."[15] The pandemic-induced chip shortage inhibited the production of anything ranging from cars to essential medical devices, highlighting the costs of even just a temporary disruption to the ecosystem.[16] Similarly, re-shoring CRM production comes at a cost too, as for decades value chains were outsourced for reasons of cost efficiency and environmental pollution.[17] Strengthening Europe's place in the semiconductor and CRM fragile balance is a necessity, but disrupting the ecosystem entirely comes with great threats to economic security too.

This report covers new ground by specifically outlining pending disruptions in CRM value chains on which the EU relies for its access to semiconductors in the next five and ten years. The report also highlights key green technologies that rely on the same CRM value chains, as disruptions to these chains will also inhibit the energy transition. By doing so, an action plan is proposed for the Netherlands and the EU to deal with the risks and opportunities associated with the dependencies of the CRM needed for semiconductor production and green technologies. The action plan also outlines options to seize the opportunities related to the strengths of the Netherlands, the European Union and other technologically advanced democracies in the semiconductor value chain. A more extensive version of the action plan can be found in the long-version of this report.

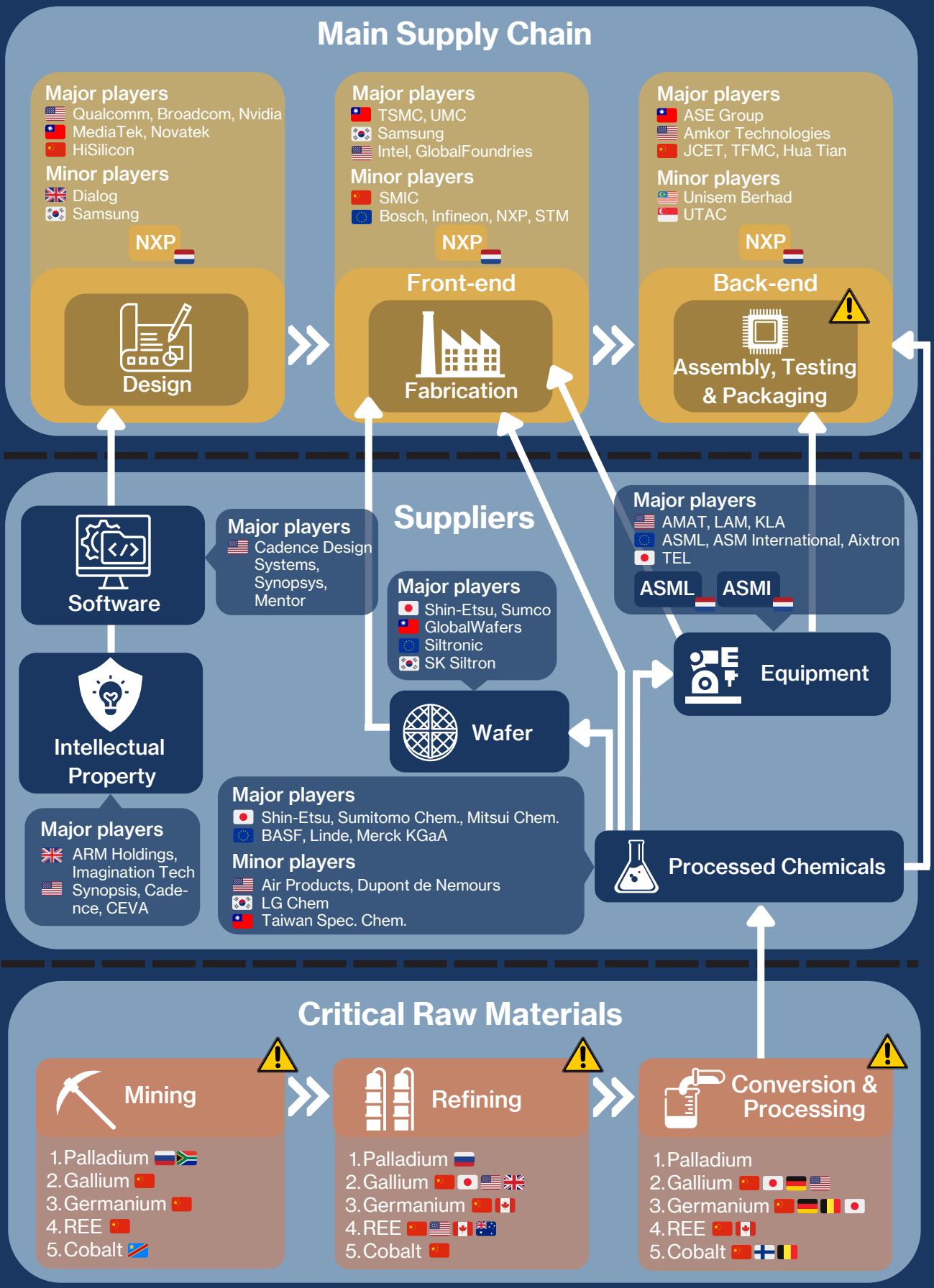
15 Antonio Varas et al., "Strengthening the Global Semiconductor Supply Chain in an Uncertain Era" (BCG, SIA, April 2021), https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf.

16 Frans van Houten, "Global Chip Shortages Put Life-Saving Medical Devices at Risk," World Economic Forum, 2022, https://www.weforum.org/agenda/2022/05/global-chip-shortages-put-life-saving-medical-devices-at-risk/.

17 During a visit to Inner-Mongolia in 1992, Deng Xiaoping outlined his "reform-and-open-up" policy further explicating the role he already envisioned in 1987 for Inner-Mongolia. He proclaimed "The Middle East has Oil. China has rare earth" (中东有石油；中国有稀土), China Broadcasting Network, "Deng Xiaoping pointed out during his southern tour: "The Middle East has oil, and China has rare earths"", CNR, August 16, 2007, http://nm.cnr.cn/nmzt/60dq/tjnmg/200704/t20070412_504442760.html; Dian L. Chu, "Seventeen Metals: 'The Middle East Has Oil, China Has Rare Earth,'" Business Insider, November 11, 2010, https://www.businessinsider.com/seventeen-metals-the-middle-east-has-oil-china-has-rare-earth-2011-1.

A fragile supply chain balance

The semiconductor and critical raw material ecosystem



1. A fragile balance: the semiconductor and critical raw material ecosystem

The semiconductor value chain and the critical raw material supply chain balance each other out: whereas the semiconductor value chain is dominated by technologically advanced democracies allied to the United States, the supply chains of crucial CRM for the production of semiconductors is based in the developing and autocratic world, including China and Russia.

The semiconductor supply chain is highly globalised, interdependent, and dependent on constant large-scale investment in R&D. Each step in the main supply chain is concentrated in different geographical regions of the world, has its own distinct market characteristics, and relies on its very own chain of suppliers. Whilst chip design is concentrated in the United States and Taiwan, high-end chip fabrication is located in Taiwan, South Korea, and the United States, and assembly, test, and packaging is mostly done in Taiwan, the United States and China.

Reliance on geopolitical rivals for essential resources poses a significant threat to European economy security.

The Netherlands plays a small yet indispensable role in the semiconductor supply chain, in which Dutch supplies of semiconductor manufacturing equipment forms a major choke-point in the entire value chain. Dutch industries are crucial both in specific markets, such as NXP in the automotive industry, as well as across the entire semiconductor industry, such as ASML and ASM International. The role of ASML in particular, as the key and even sole provider of crucial equipment necessary for advanced chip manufacturing provides the Netherlands and Europe with an irreplaceable node in the network to produce the oil of the 21st century. Europe's role in the rest of the semiconductor value chain, however, is modest.

CRM, such as palladium, cobalt, gallium, germanium, REE and silicon, constitute the foundation upon which the entire semiconductor supply chain rests, including essential supplies of anything ranging from equipment and wafers (see Table 1). Geological and economic limitations, the time needed to set up mining, refining and processing capacity, and its polluting and disruptive nature, complicate relocating the industry elsewhere.[18] Reliance on geopolitical rivals such as China and Russia in various steps of the CRM supply chain, poses a profound threat to the semiconductor industry as great power rivalry is heating up. At the same time, reliance on countries mired in political and social instability, such as the DRC, can also significantly disrupt the supply of CRM for the production of semiconductors.

18 "The Role of Critical Minerals in Clean Energy Transitions" (Paris: IEA, 2021), https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary; Rebekah Daunt, "Portugal's Government Approves Lithium Mining despite Growing Concerns," Euronews, May 2, 2022, https://www.euronews.com/2022/02/05/portugal-s-government-approves-lithium-mining-despite-protests-concerns; Darko Lagunas and Luuk van der Sterren, "De weg naar groene energie is een smerige zaak," Follow the Money - Platform voor onderzoeksjournalistiek, June 11, 2022, https://www.ftm.nl/artikelen/zeldzame-aard-metalen-energietransitie-china.

Table 1. Stranglehold: China and Russia's control over six key CRM for the fabrication of semiconductors and green applications

CRM	Function in fabrication semiconductors[19]	Function in green applications[20]	Production (mining) per country (total/ share of global production) in 2020[21]
Palladium	A component of a multilayer metallisation structure, improving adhesion	Semiconductors	In kilograms and share 1. Russia: 93,000; 43% 2. South Africa: 73,500; 34% 3. Canada: 20,000; 9% 4. US: 14,600; 7% 5. Zimbabwe: 12,900; 6%
Cobalt	To help copper make better circuits in the latest-generation of semiconductors	Electric Vehicle Batteries (EVB); Carbon Caputure and Storage (CCS); Semiconductors	In metric tons and share 1. DRC*: 98,000; 69% 2. Russia: 9,000; 6% 3. Australia: 5,630; 4% 4. Philippines: 4,500; 3% * Majority of mines owned by China, and refining operations in China
Gallium	A preferred material used in semiconductor manufacturing due to its high breakdown strength, fast switching speed, high thermal conductivity, and lower on-resistance	Solar-Photovoltaic (PV); EVs; Semiconductors	In kilograms and share 1. China: 317,000; 97% 2. Russia: 5,000; 2% 3. Japan: 3,000; 1% 4. South Korea: 2,000; 1%
Germanium	Alloyed with silicon in chip manufacturing for use in certain high-speed devices, including in the automotive industry	Solar PV; EVs; Semiconductors	In kilograms and share 1. China: 95,000; 68% 2. Russia: 5,000; 4% 3. Other countries incl. Belgium, Canada, Germany, Japan, Ukraine: 40,000; 29%
REE	A set of 17 closely-related metals that have applications in various subsets of semiconductor fabrication	Wind Turbines; EVs; Semiconductors	In metric tons and share 1. China: 140,000; 58% 2. US: 39,000; 16% 3. Burma: 31,000; 13% 4. Australia: 21,000; 9%
Silicon	Used to produce the wafers which are used to print patterns on and then sliced up to produce semiconductors.	Solar PV; Semiconductors	In thousand metric tons and share 1. China: 5,600; 69% 2. Russia: 576; 7% 3. Brazil: 404; 5% 4. Norway: 345; 4% 5. US: 277; 3%

19 S. Bobba et al., *Critical Raw Materials for Strategic Technologies and Sectors in the EU*; Patrahau et al., 'Securing Critical Materials'.

20 Patrahau et al., 'Securing Critical Materials for Critical Sectors', p. 27 and p. 111-112.

21 'Platinum-Group Metals'; 'Cobalt'; 'Gallium'; 'Germanium'; 'Rare Earth Elements'; USGS, 'Silicon'.

2. Threats to the supply of CRM for semiconductors

The breakdown of European-Russian trade in vital resources following Russia's invasion of Ukraine shows that economic ties between rival states, even if mutually beneficial and on the surface solely commercial, cannot be guaranteed. Warning signs of a structural decline in Russia's relations with Europe, characterised by contentious events such as the annexation of Crimea and the downing of MH-17, preceded this breakdown. Today similar early indications of looming disruptions can be observed, showing that specific threats are likely to cause high impact disruptions in the supply of CRM to Europe or its semiconductor manufacturing partners such a Taiwan (see Table 2) throughout this decade.

Economic ties between rival states, even if mutually beneficial and on the surface solely commercial, cannot be guaranteed.

Ten pending threats, selected on the basis of a wide variety of data inputs, deserve special attention. Eight threats were identified by drawing lessons from how Russia's war in Ukraine led European-Russian relations to reach breaking point (see Case Study in Textbox 1). The supply of vital resources, primarily natural gas and neon but also temporarily palladium, to Europe was disrupted by an export embargo by Russia (a geopolitical threat), warfighting in Ukraine (a military threat) and European retaliatory sanctions (a legal threat). As a result, the looming risk of CRM embargoes by rival states, interstate and intrastate war-related disruptions in Asia and Africa, and European and American sanctions disrupting the supply of CRM should be assessed carefully (see Table 1). These eight threats were then verified on the basis of a literature review, prior research and expert interviews with both regional and thematic experts from academia, think tanks, government, and industry (see Appendix 1). Two additional threats, namely structural geoeconomic factors, were identified on the basis of a limited data analysis of CRM prices, demand projections and supply chain disruptions, primarily caused by China's COVID-19 lockdown policies.[22]

Finally, a ranking of these threats was brought about through a foresight survey filled out by 49 experts. The survey finds that the supply of semiconductors and end-products to the EU is likely to be strongly, negatively impacted by CRM supply disruptions, already in the next five but even more so in the next ten years. The most important threats to the supply of CRM for semiconductors in the next ten years are demand-induced CRM shortages due to the energy transition, a People's Liberation Army (PLA) invasion or maritime blockade of Taiwan and a CRM embargo by China. [23]

22 The additional two, geoeconomic threats were in part identified through the quantitative data analysis conducted in WP 5.1 in the Strategic Monitor.

23 Needless to say that since the Russia-Ukraine conflict is highly dynamic and shrouded in the fog of war, the findings below may not be exhaustive. These are based on open sources and expert interviews with among other experts a palladium trader. Brijesh Patel, "Palladium Tops $3,000/Oz as Supply Fears Grow, Gold Jumps over 1%," *Reuters*, March 4, 2022, sec. European Markets, https://www.reuters.com/markets/europe/gold-gains-after-russia-attacks-europes-largest-nuclear-plant-2022-03-04/; Peter Hobson, "Palladium Propelled to Record Highs by Russia Supply Concerns," *Reuters*, March 7, 2022, sec. Business, https://www.reuters.com/business/palladium-propelled-record-highs-by-russia-supply-concerns-2022-03-07/. Alexandra Alper, "Exclusive: Russia's Attack on Ukraine Halts Half of World's Neon Output for Chips," *Reuters*, March 11, 2022, sec. Technology, https://www.reuters.com/technology/exclusive-ukraine-halts-half-worlds-neon-output-chips-clouding-outlook-2022-03-11/.

Table 2. Pending threats to the critical raw material for semiconductor supply chain

	Theme	Region	Threat
1	Geopolitical	Eastern-Europe	Palladium export embargo by Russia
2	Geopolitical	East Asia	Gallium, Germanium, Cobalt, Rare Earth Element export embargo by China
3	Military	East Asia	People's Liberation Army naval blockade and/or invasion of Taiwan
4	Military	East Asia	Regional naval war in the East China Sea between China and Japan, South Korea and/or the US
5	Military	Southeast Asia	Regional naval war in the South China Sea between China and a Southeast Asian country and/or the US
6	Military	Southeast Asia and Persian Gulf	US blockade halting Chinese oil and gas imports (e.g., Malacca Strait or Strait of Hormuz)
7	Military	Southern Africa	Political instability or civil war in the DRC (or along transportation routes in Southern Africa)
8	Legal	Southern Africa and East Asia	Increasingly stringent EU and US ESG-regulation (e.g., disrupting imports from DRC-mined cobalt and China-mined Silicon)
9	Geo-economic	Global	Demand-induced resource shortage due to the energy transition and increase in semiconductor manufacturing
10	Geo-economic	East Asia	Events inside China such as pandemic-related lockdowns or work stoppages

Ranking risks: CRM-related threats to the supply of semiconductors survey outcome

The supply of semiconductors and end-products to the EU is likely to be strongly, negatively impacted by CRM supply disruptions.

The seriousness of the identified risks was gauged by experts, ranking the ten threats both in terms of probability of occurrence and level of impact (see Infographics Critical Raw Material Risks and Figure 1 and 2). Seven key findings can be derived from the survey:

1. **The supply of semiconductors and end-products to the EU is likely to be strongly, negatively impacted by CRM supply disruptions, already in the next five but even more so in the next ten years**. A demand-induced shortage due to the energy transition, a CRM export embargo by China, and a People's Liberation Army naval blockade/invasion of Taiwan are deemed the top risks in the next ten years. It is likely that one or more risks materialises before 2032 and possibly even before 2027, as five risks were awarded a higher than 50% probability to materialise in the next five years and seven in the next ten years. Out of all risks, seven are expected to have a "high impact"[24] and three to have a "very high impact" (see Figure 1).[25] If even just one of these risks materialises, the respondents expect that this will have either a "high impact" or "very high impact" on the supply of semiconductors and end-products to the EU and, hence, the bloc's overall economic security.

2. **A demand-induced CRM shortage due to the energy transition is the threat that is deemed most likely to materialise in both the next five and ten years.** A demand-induced shortage due to the energy transition is a structural, "high impact" challenge facing the CRM landscape. Five out of six CRM assessed in this report have important functions in both semiconductor production and the transition to green energy, meaning the energy transition will put pressure on their availability for semiconductor production.

24 Threat 1, 2,3,4,6,9,10

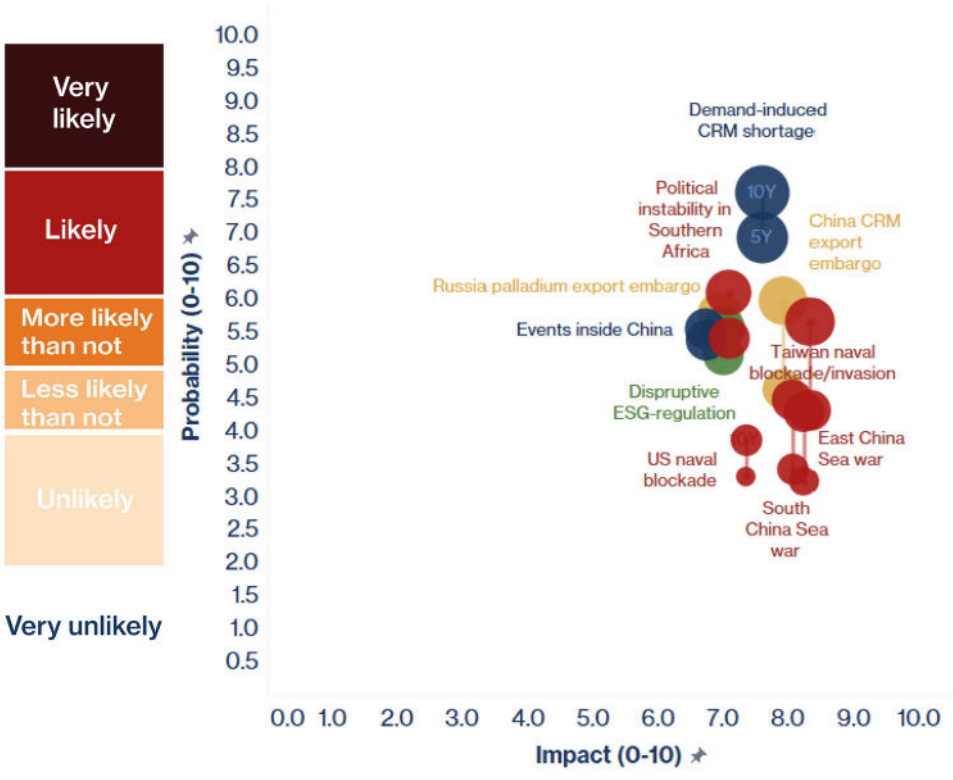
25 Threat 5, 7, 8

3. **The respondents fear that CRM embargoes enacted by China and Russia then aggravate these shortages (see Figure 2), similarly to the imposition of a natural gas and neon gas (partial-)embargo by Russia in 2022.** As prices rise due to increased demand, the "more likely than not" risk of a palladium export embargo by Russia in both the next five and ten years, and the "more likely than not/likely" risk of a CRM embargo by China in the next ten years, are expected to aggravate disruptions in the supply of semiconductors and end-products to the European Union.

4. **Military risks in the Indo-Pacific involving China and possibly the United States are considered the highest impact risks. They are, however, mostly still considered "unlikely" in the next five years and "less likely than not" in the next ten years – with the exception of a naval blockade/invasion of Taiwan.** Military risks involving China, such as 1. A naval blockade and/or invasion of Taiwan, 2. War in the East-China Sea, and 3. War in the South-China Sea are deemed the highest impact events by the overall respondents.[26] Whereas war in either the East-China Sea or South-China Sea is deemed to be "less likely than not" in both the next five and ten years, the odds of a naval blockade and/or invasion of Taiwan passes the respondents' threshold from "less likely than not" in the next five years to "more likely than not" in the next ten years – meaning a higher than 50% chance of occurrence. A PLA naval blockade or invasion of Taiwan is expected to have the greatest impact on the supply of semiconductors or end products to the European Union out of all the risks that were surveyed.

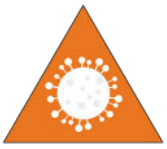
26 All expected to have a "very high impact".

Figure 1. Survey outcome: All CRM-related semiconductor risks are either "high" or "very high" impact



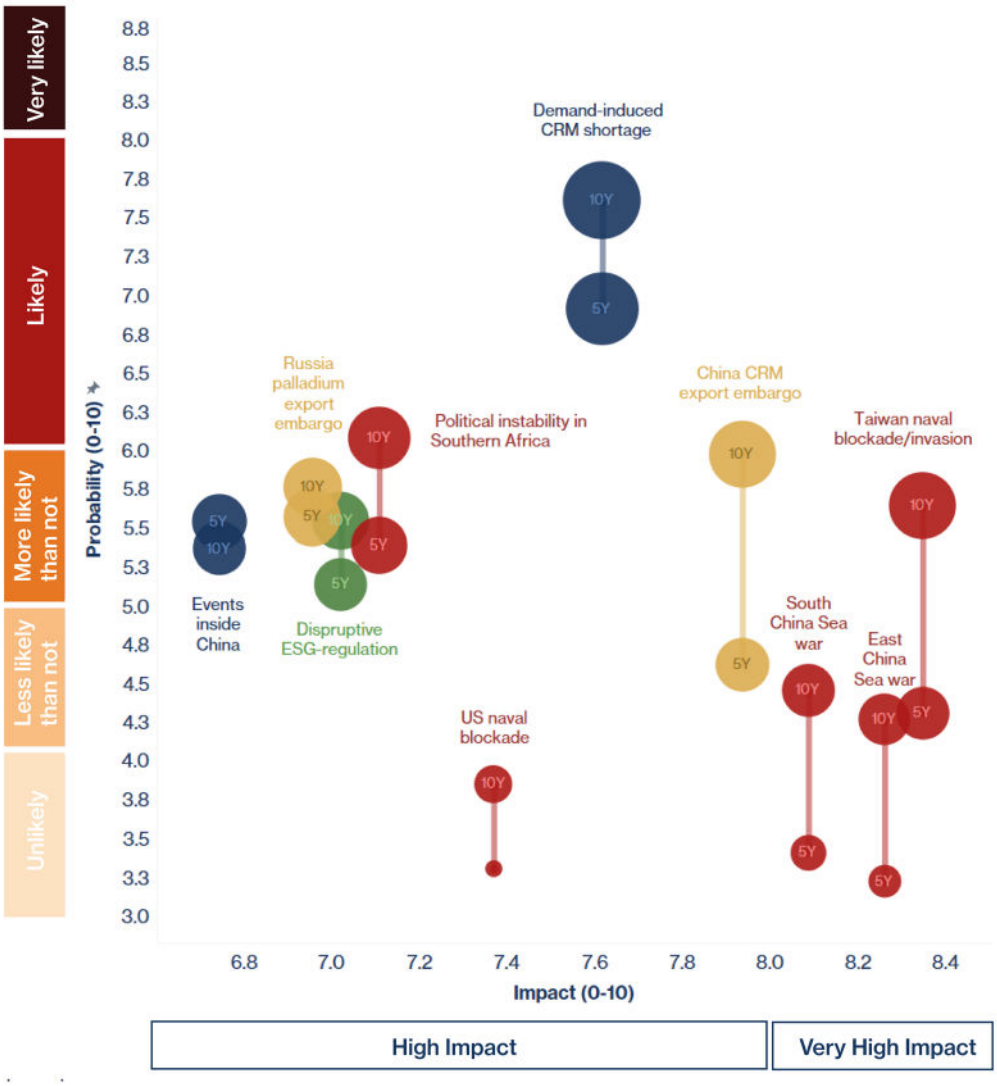
5. **Political unrest or even intrastate conflict in Southern African states are likely to disrupt the supply of cobalt (see Figure 2)**. Political unrest in Southern Africa, another military threat, is deemed "more likely than not" to disrupt the supply of CRM for semiconductors in the next five years, and "likely" to do so in the next ten years. This would have a "high impact" on the supply of semiconductors and end-products to the EU and hence the EU's economic security.

6. **ESG-related regulation and sanctions by the United States and the European Union were awarded a higher than 50% probability of causing a "high impact" disruption in the supply of CRM for semiconductor production.**



7. **Finally, events inside China such as pandemic related lockdowns are deemed "more likely than not" to disrupt the supply of CRM already in the next five years, and are expected to have a "high impact" on the supply of semiconductors and end-products to the European Union.**

Figure 2. Survey outcome: Seven out of ten threats are considered (at least) "more likely than not" to materialise over the next ten years



3. Winning interdependence: semiconductor and CRM rivalry in a de-globalising world

The current semiconductor and CRM equilibrium is not static: various Western governments, led by the US, have undertaken attempts to strengthen and leverage the West's collective dominance in the semiconductor value chain against Russia and China[27], whilst at the same time attempting to mitigate their CRM dependence.[28] However, current European efforts to mitigate CRM reliance are not on-track to bear fruit at a large-scale before the risks related to CRM dependence are expected to materialise.[29]

Bloc formation and intensifying technology competition risk upending the fragile CRM and semiconductor balance.

Bloc formation and intensifying technology competition risk upending the fragile CRM and semiconductor balance. Since 2019, the US has imposed restrictions on the export of vital American semiconductor manufacturing equipment to Chinese chip manufacturers, spurring on allies in Europe and Asia to do the same (see Infographic Sabotaging Xi).[30] Following Russia's 2022 invasion of Ukraine, the US and its allies, including Taiwan, South Korea and Japan, have banned the exports of semiconductors to Russia altogether.[31] This grants China and Russia, the rivals of Europe and its partners in semiconductor production (e.g., Taiwan), greater incentive to weaponise CRM dependence. The place of the Netherlands in this fragile balance is largely shaped by ASML, a key industry player bringing plentiful employment and economic benefits, as well as great power interest, to the Netherlands. However, ASML's EUV and Deep Ultra-Violet (DUV) lithography equipment has also put the Netherlands in an awkward position with both superpowers – the US and China – placing conflicting demands on the Netherlands, and China issuing a barely veiled threat of punishment.[32]

Policy-making efforts in the Netherlands and the European Union to reduce risks in the CRM supply chain are well underway, but translating plans into concrete action remains a problem. These plans include reshoring of mining, refining, and processing operations, CRM cooperation

27 See for example: Jenny Leonard, Ian King, and Debby Wu, "China's Chipmaking Power Grows Despite US Effort to Counter It," *Bloomberg*, June 13, 2022, https://www.bloomberg.com/news/articles/2022-06-13/china-s-growing-clout-in-global-chip-market-rings-alarm-bells-in-washington; John Lee and Jan-Peter Kleinhans, "Mapping China's Semiconductor Ecosystem in Global Context" (MERICS, June 2021); Ana Swanson, John Ismay, and Edward Wong, "U.S. Technology, a Longtime Tool for Russia, Becomes a Vulnerability," *The New York Times*, June 2, 2022, sec. Business, https://www.nytimes.com/2022/06/02/business/economy/russia-weapons-american-technology.html; Yang Jie and Jiyoung Sohn, "Chip Sanctions Challenge Russia's Tech Ambitions," *Wall Street Journal*, March 19, 2022, sec. Tech, https://www.wsj.com/articles/chip-sanctions-challenge-russias-tech-ambitions-11647682202; "America Has a Plan to Throttle Chinese Chipmakers," *The Economist*, April 25, 2022, https://www.economist.com/business/america-has-a-plan-to-throttle-chinese-chipmakers/21808959.

28 European Commission, "Commission Announces Actions on Critical Raw Materials," Text, European Commission, September 3, 2022, https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1542.; The White House, "Fact Sheet Securing a Made in America Supply Chain for Critical Minerals," The White House, February 22, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/22/fact-sheet-securing-a-made-in-america-supply-chain-for-critical-minerals/.

29 S. Bobba et al., *Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study*. (LU: European Commission, 2020), https://data.europa.eu/doi/10.2873/58081.

30 *The Economist*, "America Has a Plan to Throttle Chinese Chipmakers," *The Economist*, 2022, https://www.economist.com/business/america-has-a-plan-to-throttle-chinese-chipmakers/21808959.; Lee and Kleinhans, "Mapping China's Semiconductor Ecosystem in Global Context," June 2021.; Jenny Leonard, Ian King, and Debby Wu, "China's Chipmaking Power Grows Despite US Effort to Counter It."

31 "Remarks by President Biden on Russia's Unprovoked and Unjustified Attack on Ukraine," The White House, February 24, 2022, https://www.whitehouse.gov/briefing-room/speeches-remarks/2022/02/24/remarks-by-president-biden-on-russias-unprovoked-and-unjustified-attack-on-ukraine/.

32 Johan Leupen and Sandra Olsthoorn, "'We zouden niet willen dat Nederland zwicht onder de druk van de VS,'" FD.nl, January 15, 2020, https://fd.nl/economie-politiek/1330711/we-zouden-niet-willen-dat-nederland-zwicht-onder-de-politieke-druk-van-de-amerikanen.

with third-parties such as Japan, Canada, Australia, the US but also non-rival autocracies, recycling, reducing demand, deep-sea mining, and stockpiling.[33] These initiatives either come with challenges, such as *Not In My Backyard* (NIMBY) protests, environmental concerns, technological and economic limitations, limited alternative sourcing countries, or only provide short-term solutions.[34] If only current initiatives are executed, the EU's economic security is likely to be strongly, negatively affected by the disruptions in the supply of CRM that are likely to take place in the next ten years. Both the production of semiconductors and other means necessary to complete the transition to green energy will be affected, if these disruptions occur.

4. Policy implications, opportunities and recommendations

The Netherlands and EU would be advised to take a host of measures to strengthen resilience in the increasingly fragile and contested semiconductor and CRM ecosystem. The semiconductor and CRM ecosystem is, when simplified, best understood as a fragile geopolitical balance held up by American, European and Asian technologically advanced, semiconductor-fabricating, democracies and CRM-producing rival autocracies, namely Russia and China, and non-rival autocracies, such as the DRC (see 1. Fragile balance). This fragile balance may very well be upset in similar ways as Russia's invasion of Ukraine led to a chain reaction that disrupted the supply of essential commodities, namely natural gas, neon gas and temporarily palladium to Europe (see 2. Threats). Current European efforts to mitigate CRM reliance are not on-track to bear fruit at a large-scale before the risks related to CRM dependence are expected to materialise (see 3. Winning interdependence). An extended list of policy opportunities and recommendations is presented in the long version of this report.

To address these challenges policy-makers are advised to appreciate five high-level policy implication themes, which come with specific policy opportunities and recommendations.[35]

1. Prioritise security of supply in a world where hard competition between great powers structurally threatens European economic security, including disruptions in the near future supply of CRM.
2. Accept that the US-China tech rivalry is likely to put the supply of semiconductors, digital end-products, and products needed for the energy transition to the EU at risk.
3. Work with other technologically advanced democracies to mitigate semiconductor and CRM ecosystem risks vis-à-vis Russia and China.
4. Expand European leverage in the semiconductor and CRM ecosystem vis-à-vis other technologically advanced democracies such as the US, Taiwan, South Korea and Japan.

33 "Commission Announces Actions on Critical Raw Materials," Text, European Commission, September 3, 2020, https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1542; European Commission, "EU and Canada Set up a Strategic Partnership on Raw Materials," European Commission, June 21, 2021, https://ec.europa.eu/growth/news/eu-and-canada-set-strategic-partnership-raw-materials-2021-06-21_en.

34 Jeff Amrish Ritoe, "The New Great Game: Securing Critical Minerals Today for a Clean Energy System Tomorrow," HCSS Geo-Economics (Bangkok: The Hague Centre for Strategic Studies, July 2021), https://hcss.nl/wp-content/uploads/2021/08/The-New-Great-Game-August-2021.pdf; Lagunas and Sterren, "De weg naar groene energie is een smerige zaak"; Rebekah Daunt, "Portugal's Government Approves Lithium Mining despite Growing Concerns," May 2, 2022.

35 These policy implications, opportunities and recommendations were formulated on the basis of a global expert consultation with representatives from academia, think tanks, government and industry (see appendix 1) and a literature review.

5. Formulate a strategy to reduce dependence on China and Russia more broadly, as dependence for many other end-products for purposes such as the digital and energy transition remains.

Table 3. Overview of high-level policy implications, policy opportunities and policy recommendations (full list in section 4)

Security implication	Policy recommendation
1. Prioritise security of supply in a world in which hard competition between great powers structurally threatens European economic security, including disruptions in the near future supply of CRM.	1.1 Prepare for persistent pressure on Dutch and broader European prosperity, which will go hand-in-hand with shortages, delays in delivery of products, and constant inflationary pressure due to geopolitical fracturing.
	1.2 The 2022 Dutch Ministry for Foreign Trade and Development Cooperation (BHOS) natural resource strategy is advised to take a "worst-case-scenario" approach to preventing, mitigating, and preparing for the consequences of severe CRM supply disruptions.
	1.3 The government should engage in stress testing to identify the effects of likely and impactful CRM supply disruptions.
	1.4 Institute a top-down approach to reducing strategic dependencies, for instance through the establishment of a National Security Council and an Energy Council, an advisory body for energy affordability, robustness of the energy system and security of supply.
2. Accept that the US-China tech rivalry is likely to put the supply of semiconductors, digital end-products and products needed for the energy transition to the EU at risk.	2.1 Address the adverse (un)intended consequences of the US-China tech rivalry. European policy-makers are advised to anticipate that Europe's enormous strategic dependence on Washington will increasingly impel the EU to participate in the US-China tech rivalry on the side of the US.
	2.2 The Dutch government and its semiconductor companies are advised to explore new approaches to get more in return for participating in the US-led tech-showdown with China.
3. Work with other technologically advanced democracies and non-rival CRM-producing autocracies to mitigate semiconductor and CRM ecosystem risks vis-à-vis Russia and China.	3.1. Make use of the opportunities provided by the dominance of technologically advanced democracies in the semiconductor value chain, for instance in order to deter destabilising acts by rivals.
	3.2. Start policy-initiatives to mitigate CRM-related dependencies and risks now to achieve results in the medium-term.
4. Expand European leverage in the semiconductor and CRM ecosystem vis-à-vis other democracies such as the US, Taiwan, South Korea and Japan.	4.1 Invest in CRM mitigation efforts first and foremost in Canada and Australia, but also the US, as soon as possible, as these states are making the most serious gains to address the CRM issue.
	4.2 Increase the European part of the technologically advanced democracy-dominated semiconductor ecosystem
5. Formulate and execute a broader strategy to reduce dependence on China and Russia.	5.1 The Netherlands and the EU should look for synergies between semiconductor production and large-scale efforts to mitigate dependence that are starting to achieve successes already.
	5.2 The Dutch government's National Security Council, announced in the Coalition Agreement of Rutte IV in January 2022, should be established as soon as possible.
	5.3 Invest in strengths, in line with the advice given by ASML CEO Peter Wennink on how to compete with China: "This is what you do: relentless investment in innovation".[36]
	5.4 Avoid fatalism. If appropriate measures are taken and costs are accepted, taking back control over larger parts of the supply chain is a political decision that the Netherlands and the EU can take.

36 NPO, 'Het geheim van ASML gemist? Start met kijken op NPO Start', www.npostart.nl, accessed 28 September 2022, https://www.npostart.nl/vpro-tegenlicht/12-09-2022/VPWON_1335235.

Lexicon

ASML = Advanced Semiconductor Materials Lithography

ATP = Assembly, testing, processing

BHOS = Ministry for Foreign Trade and Development Cooperation of the Kingdom of the Netherlands

CRM = Critical raw materials

DRC = Democratic Republic of the Congo

DUV = Deep ultraviolet

ESG = Environmental, Social and Governance

EU = European Union

EUV = Extreme ultraviolet

EU-US TTC = EU–US Trade & Technology Council

EVB = Electric vehicle batteries

IEA = International Energy Agency

IP = Intellectual Property

IPCEI = Important Project of Common European Interest

JOGMEC = Japan Oil, Gas and Metals National Corporation

LNG = Liquified Natural Gas

NATO = North Atlantic Treaty Organisation

NIMBY = Not In My Backyard

OAPEC = Organisation of Arab Petroleum Exporting Countries

PLA = People's Liberation Army

PV = Photovoltaic

R&D = Research and development

REE = Rare earth elements

SMIC = Semiconductor Manufacturing International Cooperation

US = United States

Introduction

"God decided where the oil reserves are. We can decide where the fabs [for semiconductor manufacturing] are."

Pat Gelsinger, CEO of Intel, 2021[37]

"The Middle East has its oil. China has rare earth."

Deng Xiaoping, China's Paramount Leader, Southern Tour 1992[38]

The interlinking semiconductor and CRM ecosystem are the foundation of today's world economy.

Both semiconductors and critical raw materials (CRM) have been described as *the oil of the 21st century*. Oil products have been central in mechanising the economy. Semiconductors play an indispensable role in powering the modern digital economy. Computers, smartphones, smart grids, automobiles and jetfighters all require chips. Notably, semiconductors play a key role in the energy transition, for instance, in new energy solutions such as solar and wind power. Without semiconductors no new semiconductors can be produced, as the design labs, foundries, and equipment used to produce semiconductors require semiconductors as well. The semiconductor production process in turn relies on a wide variety of CRM. Prices of various CRM are on the rise, with some even becoming scarce. The move from oil and gas production to green energy, including solar panels and wind turbines, can be boiled down to "a shift from [reliance on] fossil fuels to metals".[39] Not only the energy transition, but also the digital transition, as well as defence-related manufacturing and other factors are pushing demand for CRM. The interlinking semiconductor and CRM ecosystem hence are the foundation of today's world economy.

37 Ina Fried, 'Intel Pressures the U.S. Government to Help Subsidize Chip Manufacturing', Axios, 18 October 2021, https://www.axios.com/intel-semiconductor-chips-national-security-4ffc8949-4bc7-4460-932c-2c95bebf1daa.html. Ina Fried, 'Intel Pressures the U.S. Government to Help Subsidize Chip Manufacturing', Axios, 18 October 2021, https://www.axios.com/intel-semiconductor-chips-national-security-4ffc8949-4bc7-4460-932c-2c95bebf1daa.html.

38 During a visit to Inner-Mongolia in 1992, Deng Xiaoping outlined his "reform-and-open-up" policy further explicating the role he already envisioned in 1987 for Inner-Mongolia. He proclaimed "The Middle East has Oil. China has rare earth" (中东有石油；中国有稀土), China Broadcasting Network, "Deng Xiaoping pointed out during his southern tour: "The Middle East has oil, and China has rare earths"", CNR, August 16, 2007,http://nm.cnr.cn/nmzt/60dq/tjnmg/200704/t20070412_504442760.html; Dian L. Chu, "Seventeen Metals: 'The Middle East Has Oil, China Has Rare Earth,'" Business Insider, November 11, 2010, https://www.businessinsider.com/seventeen-metals-the-middle-east-has-oil-china-has-rare-earth-2011-1. China has rare earth" (中东有石油；中国有稀土), China Broadcasting Network, "Deng Xiaoping pointed out during his southern tour: "The Middle East has oil, and China has rare earths"", CNR, August 16, 2007, http://nm.cnr.cn/nmzt/60dq/tjnmg/200704/t20070412_504442760.html; Dian L. Chu, "Seventeen Metals: 'The Middle East Has Oil, China Has Rare Earth,'" Business Insider, November 11, 2010, https://www.businessinsider.com/seventeen-metals-the-middle-east-has-oil-china-has-rare-earth-2011-1.

39 Kleijn, 'Critical Materials, Green Energy and Geopolitics: A Complex Mix (White Paper)', 8.

As great power rivalry heats up, semiconductor and CRM value chains on which semiconductor production relies are in an early stage of being weaponised, similar to how the Organisation of Arab Petroleum Exporting Companies (OAPEC) used oil as a lever of power in 1973.[40] The semiconductor value chain is dominated by the technologically advanced democracies of the world, including Taiwan, South Korea, the US, Japan and European states. Even though the majority of activities in the supply chain take part in Taiwan, South Korea, the United States and China, one company in the Netherlands functions as an irreplaceable node. The Netherlands-based lithography giant Advanced Semiconductor Materials Lithography (ASML) is the sole provider of extreme ultraviolet (EUV) lithography equipment, an essential tool used by semiconductor manufacturing companies, such as Taiwan Semiconductor Manufacturing Company (TSMC) and Samsung, to produce the world's most advanced chips.[41] Nowadays, supplies of the refined and processed CRM used to manufacture semiconductors are (indirectly) imported from the European Union's (EU) rivals, specifically China and Russia, as well as African countries with complicated political-economic or military contexts, such as the Democratic Republic of the Congo (DRC) and other states in Southern Africa. Today's cost efficient, global supply chains, increasingly come with security of supply risks, as trust between the large industrialised blocs of the world is rapidly eroding.

Sino-European relations are characterised by a downward trajectory over the course of the past decade.

How sustainable will these dependencies prove to be in the next five and ten years? Throughout the previous decade, relations between the Netherlands, the EU and their partners in semiconductor production on the one hand, and Russia and China on the other, have deteriorated rapidly. Yet, as of September 2022, only relations with Russia have reached breaking point. A breaking point is reached when friction in an interstate relationship, often related to military-strategic tensions, becomes so overwhelming that states are no longer willing to supply some or all vital resources on which the economies of their rivals depend. European-Russian trade in vital resources survived the annexation of Crimea, the downing of MH17, and all other contentious events before February 2022. However, European-Russian relations reached breaking point following Russia's invasion of Ukraine and European retaliatory sanctions including a comprehensive ban on the export of semiconductors to Russia. Russia reduced the supply of natural gas to Europe to 25% of 2019 levels, freezing the export of neon gas altogether until the end of 2023 (see Textbox 1). The continuation of palladium exports from Russia, a CRM used in the fabrication of semiconductors, throughout 2022 should not be taken for granted, as relations between Europe and Russia are still in decline.

Sino-European relations, unlike European-Russian relations, have not yet reached breaking point, but are similarly characterised by a downward trajectory over the course of the past decade. China's supply of silicon, gallium, germanium, cobalt and rare earth elements (REE) survived the EU designating Beijing as a *systemic rival*,[42] the Dutch House of Representatives becoming the first parliament in Europe to label China's mass-internment of Uyghurs a

40 Even though deposits for many CRM around the world are widespread, at the moment production, refining and conversion and processing of various CRM for semiconductors and the transition to green energy, for instance cobalt, is only done in a limited amount of states. Diversification of production cannot be easily done, especially for the mining phase, as the International Energy Agency (IEA) estimates the time from early exploration of a mine to full production to take anywhere between seven and 20 years (see Section 1). At the same time, US-led attempts to impose limits on exports of semiconductor technology to China as well as a comprehensive ban on exporting semiconductors to Russia contribute to the weaponisation of the semiconductor supply chain (see Section 3).

41 ASML, 'ASML | The World's Supplier to the Semiconductor Industry', 2022.

42 'EU-China - A Strategic Outlook'.

genocide,[43] EU sanctions against Chinese officials engaged in Xinjiang-related policy-making,[44] and the G7's condemnation of China's live-fire drills around Taiwan in August 2022.[45] So far, it has also survived the US spurring on allies in Europe and Asia to join its attempts to "freeze" China's technological development over the past years. Since 2019, the Dutch government has withheld a license for ASML to export its EUV system to China. Even though China has a history of weaponising access to its market and greatly limited its supply of REE to the world in 2010, it has not opted to weaponise the resource in the 2020s. Finally, the supply of cobalt survived an uptick in political instability in the DRC and other Southern African states as well as the dominance of Chinese (state-owned) companies in refining and control over mines in the DRC.[46] Even though the supply of CRM from or through China to Europe has survived until now, the downward trend in China's relations with technologically advanced democracies comes with realistic risks of reaching breaking point throughout this decade.

In the face of looming breaking points, ensuring security of supply is becoming a central policy motivation for states and companies. Especially contentious issues, such as the status of Ukraine, Taiwan, the South China Sea and the East China Sea, can serve as flashpoints leading Russia or China to upend their supply of CRM to Europe. Whether political stability in Southern Africa and the DRC can be maintained remains an open question. At a time of great power rivalry, opposing camps in the semiconductor and CRM ecosystem try to win interdependence by building on their respective strengths and mitigate their vulnerabilities.

Indigenisation of the semiconductor and CRM value chain comes at a cost.

Europe in the semiconductor and CRM ecosystem

To ensure the unimpeded functioning of the European economy in an effective and efficient manner, the Netherlands and the EU need to strengthen their position in the fragile semiconductor and CRM ecosystem.[47] Much has been written on risks due to the interdependencies in the semiconductor supply chain, with industry players like ASML advocating industrial policies to strengthen Europe's place in the semiconductor ecosystem.[48] The European Chips Act, aiming to invest tens of billions of euros, intends to indigenise a greater share of the semiconductor supply chain.[49] The risks of the Netherlands and the EU's vast CRM dependence on third countries, especially its rivals, is widely acknowledged to be a threat and has

43 'Motie van het lid Sjoerdsma c.s. over uitspreken dat in China genocide plaatsvindt op de Oeigoerse minderheid'.

44 'Chair's Statement of 23 March 2021 on EU Sanctions on Human Rights Violations; Counter-Sanctions by the PRC'.

45 U.S. Department of State, "G7 Foreign Ministers' Statement on Preserving Peace and Stability Across the Taiwan Strait," August 3, 2022, https://www.state.gov/g7-foreign-ministers-statement-on-preserving-peace-and-stability-across-the-taiwan-strait/#:~:text=We%20are%20concerned%20by%20recent,activity%20in%20the%20Taiwan%20Strait.

46 Igogo et al., 'Supply Chain of Raw Materials Used in the Manufacturing of Light-Duty Vehicle Lithium-Ion Batteries'; Lipton and Searcey, 'Chinese Company Removed as Operator of Cobalt Mine in Congo'; Searcey et al., 'A Power Struggle Over Cobalt Rattles the Clean Energy Revolution'.

47 "The unimpeded functioning of the Dutch economy in an effective and efficient manner." - The government of the Netherlands' definition of Economic Security "National Security Strategy" (Dutch Central Government, 2019), p.12.

48 "ASML Position Paper on EU Chips Act" (ASML, February 2022), https://www.asml.com/-/media/asml/files/news/2022/asml-position-paper-on-eu-chips-act.pdf?rev=cc4554892d7a4304bee8b056b96e4dee.

49 European Commission, 'Digital Sovereignty'.

been assessed in depth.[50] The President of the European Commission, in her 2022 State of the Union Address, announced the preparation of a European Critical Raw Material Act, to achieve greater control over CRM value chains.[51] The Dutch government, in turn, will present a resource strategy by the end of 2022.

Indigenisation of the semiconductor and CRM value chain comes, however, at a cost. The Semiconductor Industry Association, the voice of the US semiconductor industry, has highlighted the enormous added value of the global, sophisticated semiconductor supply chain, pointing out the way in which it supports "the industry's continuous technology innovation" and "how it ultimately benefits consumers and enables better technology and lower prices."[52] The pandemic-induced chip shortage inhibited the production of anything ranging from cars to essential medical devices, highlighting the costs of even just a temporary disruption to the ecosystem.[53] Similarly, reshoring CRM production comes at a cost too, as for decades value chains were outsourced for reasons of cost efficiency and environmental pollution.[54] Strengthening Europe's place in the semiconductor and CRM fragile balance is a necessity, but disrupting the ecosystem entirely comes with great threats to economic security too.

This report covers new ground by specifically outlining pending disruptions in CRM value chains on which the EU relies for its access to semiconductors in the next five and ten years. The report also highlights key green technologies that rely on the same CRM value chains, as disruptions to these chains will also inhibit the energy transition. By doing so, an action plan is proposed for the Netherlands and the EU to deal with the risks and opportunities associated with the dependencies on the CRM needed for semiconductor production and green technologies. The action plan also outlines options to seize the opportunities related to the strengths of the Netherlands, the European Union and other technologically advanced democracies in the semiconductor value chain. A more extensive version of the action plan can be found in the long-version of this report.

- Section 1 shows that the semiconductor and CRM value chains together make up a single highly complex ecosystem, characterised by interdependencies between technologically advanced democracies on the one hand and both rival and non-rival autocracies on the other. The section relies on a literature review, desk research, prior research, stakeholder interviews, and expert interviews with both regional and thematic experts from academia, think tanks, government, and the CRM and semiconductor industry.[55]

50 Patrahau et al., 'Securing Critical Materials'; Gislev and Grohol, 'Report on Critical Raw Materials and the Circular Economy'; European Commission, 'Communication from the Commission to the EU Parliament and the European Council: Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability'.; "Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability" (European Commission, 2020), https://ec.europa.eu/docsroom/documents/42849.

51 European Commission, *State of the Union Speech by President von Der Leyen*.

52 Antonio Varas et al., "Strengthening the Global Semiconductor Supply Chain in an Uncertain Era" (BCG, SIA, April 2021), https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf.

53 van Houten, 'Global Chip Shortages'.

54 During a visit to Inner-Mongolia in 1992, Deng Xiaoping outlined his "reform-and-open-up" policy further explicating the role he already envisioned in 1987 for Inner-Mongolia. He proclaimed "The Middle East has Oil. China has rare earth" (中东有石油；中国有稀土), China Broadcasting Network, "Deng Xiaoping pointed out during his southern tour: "The Middle East has oil, and China has rare earths"", CNR, August 16, 2007, http://nm.cnr.cn/nmzt/60dq/tjnmg/200704/t20070412_504442760.html; Chu, 'Seventeen Metals'.

55 For prior research by HCSS respectively on vital resources, threats to supply chains in the Indo-Pacific and China's rise, please find the extensive work done by our Energy & Natural Resources initiative, the Europe in the Indo-Pacific Hub (EIPH) and our China Desk.

- Section 2 maps and ranks ten threats that may well disrupt the supply of CRM to Europe or its partners in semiconductor manufacturing (e.g., Taiwan) in both the next five and ten years. Eight threats are identified on the basis of a case study into how Russia's war in Ukraine led to a breaking point, meaning the near total collapse of European-Russian trade in natural and neon gas. Two additional structural threats are identified and all threats are verified on the basis of a literature review, prior research, expert interviews with both regional and thematic experts from academia, think tanks, government, and industry and a limited data analysis of CRM prices and demand projections. Ranking of the threats (*probability * impact*) was done on the basis of a foresight survey in which 49 experts participated (see Appendix 2).

- Section 3 maps the measures that technologically advanced democracies and autocracies already took in order to "win" interdependence in a de-globalising world, specifically focusing on semiconductor and CRM rivalry. Special attention is paid to how US-led attempts to sabotage China's development of a domestic semiconductor industry and the imposition of a comprehensive semiconductor export ban on Russia provide additional incentives for Moscow and Beijing to weaponise CRM exports in the near future. This section relies on a literature review, desk research, expert interviews and stakeholder interviews.

- Section 4 proposes an action plan that the Netherlands and the EU can adopt, in conjunction with other partners, to mitigate geopolitical risks and capitalise on opportunities in the semiconductor and CRM ecosystem.[56] The Netherlands and the EU should focus on implementing policies immediately to achieve two main goals. First, to maintain and expand the dominance of technologically advanced democracies in the semiconductor industry in the short-term (i.e., next five years). By doing so, technologically advanced democracies can maintain sufficient leverage vis-à-vis Moscow and Beijing not to weaponise CRM. Second, the Netherlands and the EU should seek to achieve mitigation of the vulnerabilities in the CRM value chain in the medium-term (i.e., next ten years), for instance by bringing back or expanding mining, refining and processing in Europe, the US, Canada, Australia or other partner countries.

The formulation of the policy implications, opportunities, and recommendations relies on the findings of the previous sections, additional desk research, and a global expert consultation consisting of two parts. First, 22 individual interviews were conducted with representatives from academia, think tanks, government and both the CRM and semiconductor industry from the US, Canada, Australia, Japan, and European states (see Appendix 1). Second, a stakeholder consultation session was conducted with representatives of the Ministry of Foreign Affairs and the Ministry of Defence of the Netherlands in July 2022.

56 The action plan builds on current policy efforts that have already been implemented. It analyses the challenges these efforts ran into and proposes solutions to overcome these challenges.

1. Fragile balance: the semiconductor and critical raw material ecosystem

The semiconductor value chain and the CRM supply chain balance each other out: whereas the semiconductor value chain is dominated by technologically advanced democracies allied to the United States, supply chains of CRM currently used for the production of semiconductors are dominated by rival autocracies, namely China and Russia, and non-rival autocracies, such as the DRC (see Infographic Fragile Balance for an overview of the semiconductor and CRM ecosystem).

1.1 Semiconductor production: A highly globalised supply chain

The Netherlands plays a small yet indispensable role in the semiconductor supply chain.

The semiconductor supply chain is global, characterised by a high division of labour and dependent on constant large-scale investments in research and development (R&D). Each step in the main supply chain is concentrated in different geographical regions of the world, has its own distinct market characteristics, and relies on its very own chain of suppliers. Whilst chip design is concentrated in the United States, high-end chip fabrication is predominantly located in Taiwan, as well as South Korea and the United States,[57] while assembly, testing, and packaging (ATP) is mostly done in Taiwan, the United States, and China.[58] The majority of activities in the main semiconductor supply chain, hence, take place in technologically advanced democracies (see Infographic Fragile Balance).

The Netherlands plays a small yet indispensable role in the semiconductor supply chain. Dutch companies are important players in the semiconductor fabrication process, as ASML and ASM International produce important semiconductor manufacturing equipment, as well as in specific markets, such as NXP in the automotive industry.[59] The role of ASML in particular, as the key and even sole provider of crucial equipment necessary for advanced chip manufacturing, provides the Netherlands and Europe with an irreplaceable node in the network to produce the oil of the 21st century (see Table 4 and Infographic Fragile Balance). Europe's role in the rest of the semiconductor value chain, however, is modest.

57 Matt Hamblen, 'Foundries See Wafer, Chip Demand on Rise', Fierce Electronics, 24 August 2020, https://www.fierceelectronics.com/electronics/foundries-see-wafer-chip-demand-rise; Ian King, Adrian Leung, and Demetrios Pogkas, 'Why Making More Chips Is So Hard', *Bloomberg*, 6 May 2021, https://www.bloomberg.com/graphics/2021-chip-production-why-hard-to-make-semiconductors/; Jan-Peter Kleinhans and Nurzat Baisakova, 'The Global Semiconductor Value Chain: A Technology Primer for Policy Makers', October 2020.

58 Utmel Electronic, 'Top 10 OSAT (Outsourced Semiconductor Assembly and Test) Companies'.

59 NXP, 'NXP', NXP, accessed 3 October 2022, https://www.nxp.com/; ASML, 'ASML', ASML, 2022, https://www.asml.com/en; ASML, 'Annual Report 2021' (ASML, 2022), https://www.asml.com/en/investors/annual-report/2021; CNBC, *Why The World Relies On ASML For Machines That Print Chips*, 2022, https://www.youtube.com/watch?v=iSVHp6CAyQ8.

Table 4. Dominance of ASML in the lithography market

	DUV Lithography	EUV Lithography	EUV 0.55 NA, High-NA (under development)
ASML market share	80+%[60]	100%[61]	100%[62]

1.2 Critical raw materials for semiconductor production

Reliance on geopolitical rivals such as China and Russia for essential resources poses a profound threat to European economic security.

The EU's rivals, Russia and China, and non-rival autocracies, such as the DRC, dominate the value chains of many CRM that are currently used to produce semiconductors. CRM, such as palladium, cobalt, gallium, germanium, REE and silicon, constitute the foundation upon which the entire semiconductor supply chain rests, including essential supplies of anything ranging from equipment and wafers. Each of these CRM has very specific and specialised functions in current semiconductor manufacturing practices (see Table 5). Green technology applications rely on many of the same CRM either directly, as solar panels are made of polysilicon, or indirectly, as gallium is used to produce the semiconductors used in solar panels.[63] Geological and economic limitations, the time needed to set up mining, refining and processing capacity, and its polluting and disruptive nature, complicate relocating the industry elsewhere.[64] China and Russia, hence, hold levers of power to disrupt the semiconductor and various other industries (see Infographic West's Achilles Heel).

Reliance on geopolitical rivals such as China and Russia for essential resources poses a profound threat to European economic security, as is evidenced by Russia's (partial-)natural gas embargo and neon gas embargo against the EU. Especially China, but also Russia still hold dominant roles in various steps of the CRM for semiconductor supply chain. At the same time, reliance on countries mired in political and social instability, such as the DRC, can also significantly disrupt the supply of CRM for the production of semiconductors. By assessing the chain reactions as a result of which European-Russian relations reached breaking point following the invasion of Ukraine, threats can be identified that - throughout the next decade - may well disrupt the CRM value chains on which Europe relies.

60 Robert Castellano, 'ASML: Not Just A Monopoly In EUV Lithography (NASDAQ:ASML)', Seeking Alpha, 15 June 2020, https://seekingalpha.com/article/4354007-asml-not-just-monopoly-in-euv-lithography, https://seekingalpha.com/article/4354007-asml-not-just-monopoly-in-euv-lithography; René Raaijmakers, '"We Underestimated the Demand for DUV"', Bits & Chips, 4 February 2021, https://bits-chips.nl/artikel/we-underestimated-the-demand-for-duv/.

61 ASML, 'ASML | The World's Supplier to the Semiconductor Industry', 2022, https://www.asml.com/en.

62 ASML is currently the only company developing this new technology, which is based on EUV lithography, see ASML, 'ASML'.

63 Patrahau et al., 'Securing Critical Materials'.

64 'The Role of Critical Minerals in Clean Energy Transitions' (Paris: IEA, 2021), https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary; Rebekah Daunt, 'Portugal's Government Approves Lithium Mining despite Growing Concerns'; Lagunas and Sterren, 'De weg naar groene energie is een smerige zaak'.

Table 5. Stranglehold: China and Russia's control over six key CRM for the fabrication of semiconductors and green applications

CRM	Function in fabrication semiconductors[65]	Function in green applications[66]	Production (mining) per country (total/ share of global production) in 2020[67]
Palladium	A component of a multilayer metallisation structure, improving adhesion	Semiconductors	In kilograms and share 1. Russia: 93,000; 43% 2. South Africa: 73,500; 34% 3. Canada: 20,000; 9% 4. US: 14,600; 7% 5. Zimbabwe: 12,900; 6%
Cobalt	To help copper make better circuits in the latest-generation of semiconductors	Electric Vehicle Batteries (EVB); Carbon Caputure and Storage (CCS); Semiconductors	In metric tons and share 1. DRC*: 98,000; 69% 2. Russia: 9,000; 6% 3. Australia: 5,630; 4% 4. Philippines: 4,500; 3% * Majority of mines owned by China, and refining operations in China
Gallium	A preferred material used in semiconductor manufacturing due to its high breakdown strength, fast switching speed, high thermal conductivity, and lower on-resistance	Solar-Photovoltaic (PV); EVs; Semiconductors	In kilograms and share 1. China: 317,000; 97% 2. Russia: 5,000; 2% 3. Japan: 3,000; 1% 4. South Korea: 2,000; 1%
Germanium	Alloyed with silicon in chip manufacturing for use in certain high-speed devices, including in the automotive industry	Solar PV; EVs; Semiconductors	In kilograms and share 1. China: 95,000; 68% 2. Russia: 5,000; 4% 3. Other countries incl. Belgium, Canada, Germany, Japan, Ukraine: 40,000; 29%
REE	A set of 17 closely-related metals that have applications in various subsets of semiconductor fabrication	Wind Turbines; EVs; Semiconductors	In metric tons and share 1. China: 140,000; 58% 2. US: 39,000; 16% 3. Burma: 31,000; 13% 4. Australia: 21,000; 9%
Silicon	Used to produce the wafers which are used to print patterns on and then sliced up to produce semiconductors.	Solar PV; Semiconductors	In thousand metric tons and share 1. China: 5,600; 69% 2. Russia: 576; 7% 3. Brazil: 404; 5% 4. Norway: 345; 4% 5. US: 277; 3%

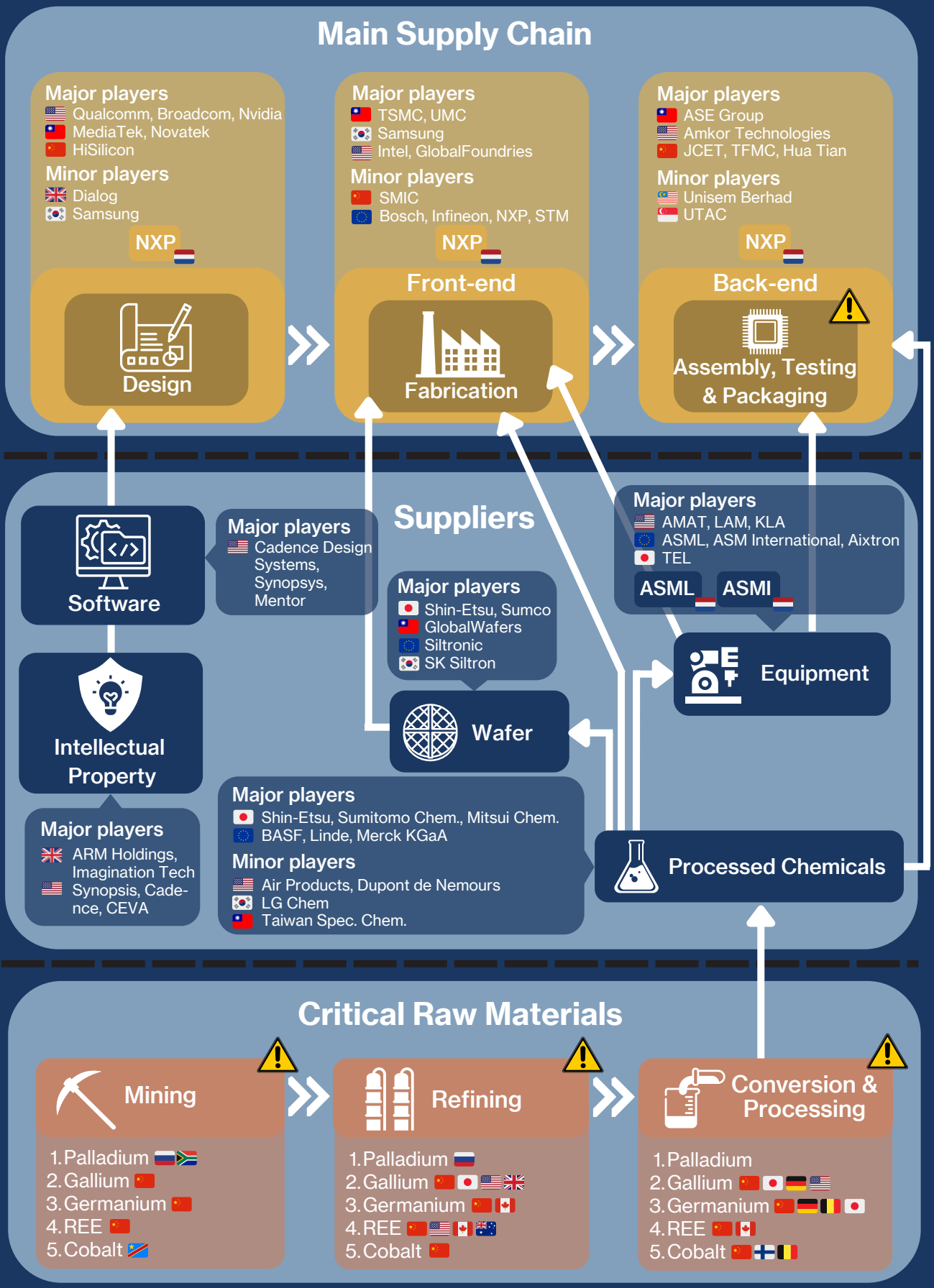
65 S. Bobba et al., *Critical Raw Materials for Strategic Technologies and Sectors in the EU*; Patrahau et al., 'Securing Critical Materials'.

66 Patrahau et al., 'Securing Critical Materials for Critical Sectors', p. 27 and p. 111-112.

67 'Platinum-Group Metals'; 'Cobalt'; 'Gallium'; 'Germanium'; 'Rare Earth Elements'; USGS, 'Silicon'.

A fragile supply chain balance

The semiconductor and critical raw material ecosystem



The West's critical raw material Achilles heel

A supply chain dominated by China, Russia and the DRC

Critical Raw Materials

Mining

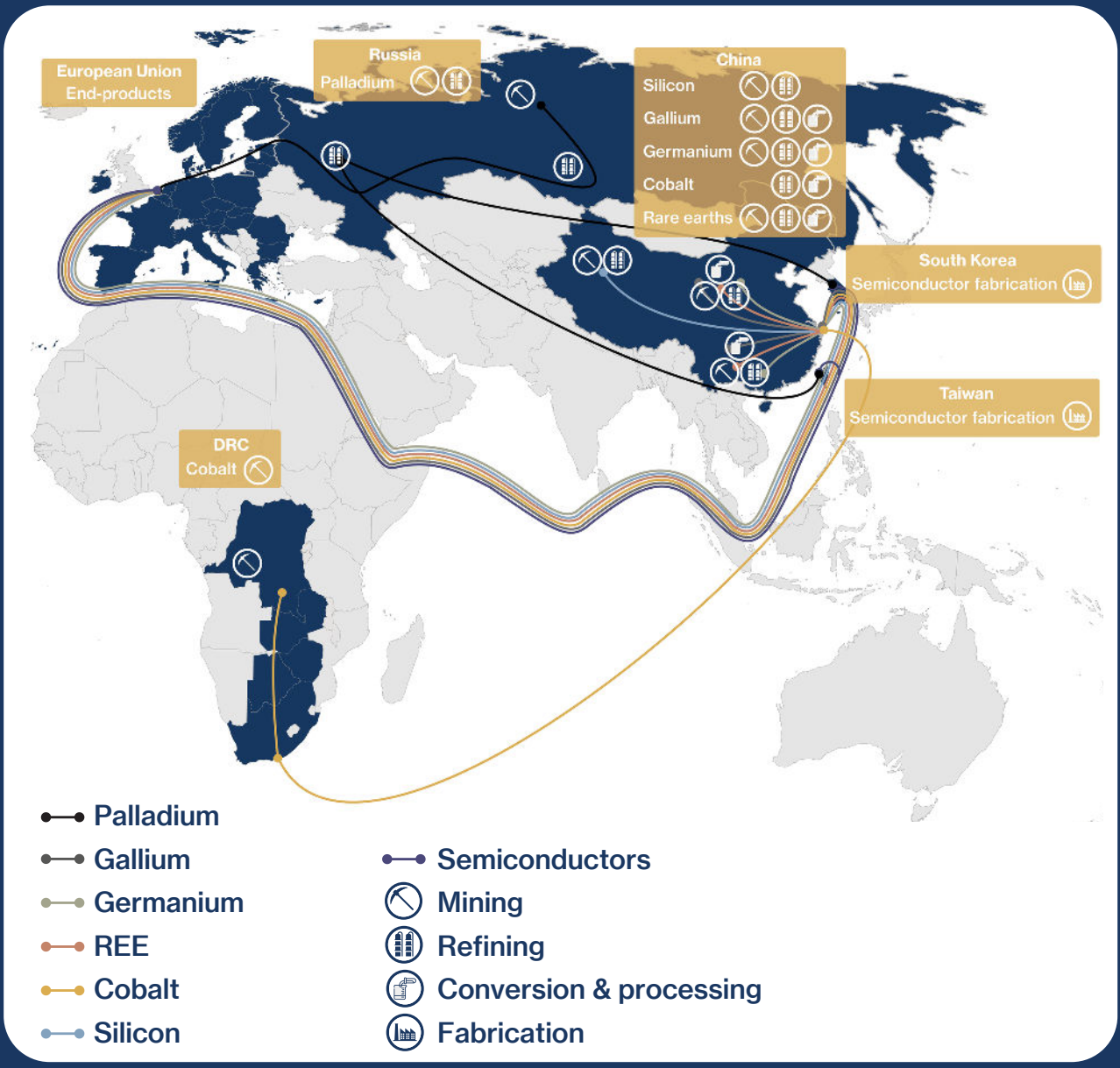
1. Palladium
2. Gallium
3. Germanium
4. REE
5. Cobalt

Refining

1. Palladium
2. Gallium
3. Germanium
4. REE
5. Cobalt

Conversion & Processing

1. Palladium
2. Gallium
3. Germanium
4. REE
5. Cobalt



2. Threats to the supply of CRM for semiconductors

"Undoubtedly, the U.S. side wants to use the products made by China's exported rare earths to counter and suppress China's development. The Chinese people will never accept this! [...] The US is doomed to be met with a slap in the face after it wakes up and stops dreaming."

Wu Yuehu, Commentator for China state newspaper the People's Daily, on 31 May 2019.[68]

"The unimpeded functioning of the Dutch economy in an effective and efficient manner."

The government of the Netherlands' definition of Economic Security.[69]

Economic ties between rival states, even if mutually beneficial and on the surface solely commercial, cannot be guaranteed.

The breakdown of European-Russian trade in vital resources following Russia's invasion of Ukraine shows that economic ties between rival states, even if mutually beneficial and on the surface solely commercial, cannot be guaranteed. Warning signs of a structural decline in Russia's relations with Europe, characterised by contentious events such as the annexation of Crimea and the downing of MH-17, preceded this breakdown. Today similar early indications of looming disruptions can be observed, showing that specific threats are likely to cause high impact disruptions in the supply of CRM to Europe or its semiconductor manufacturing partners such a Taiwan throughout this decade (see Table 6).

Ten pending threats, selected on the basis of a wide variety of data inputs, deserve special attention. Eight threats were identified by drawing lessons from how Russia's war in Ukraine led European-Russian relations to reach breaking point (see Case Study in Textbox 1). The supply of vital resources, primarily natural gas and neon but also temporarily palladium, to Europe was disrupted by an export embargo by Russia (a geopolitical threat), warfighting in Ukraine (a military threat) and European retaliatory sanctions (a legal threat). As a result, the looming risk of CRM embargoes by rival states, interstate and intrastate war-related disruptions in Asia and Africa, and European and American sanctions disrupting the supply

68 Wu Yuehe, "United States, Don't Underestimate China's Ability to Strike Back," *The People's Daily Online*, May 31, 2019, http://en.people.cn/n3/2019/0531/c202936-9583292.html.

69 Dutch Ministry of Justice and Security, "National Security Strategy," 12.

of CRM should be assessed carefully (see Table 6). These eight threats were then verified on the basis of a literature review, prior research and expert interviews with both regional and thematic experts from academia, think tanks, government, and industry (see Appendix 1). Two additional threats, namely structural geoeconomic factors, were identified on the basis of a limited data analysis of CRM prices, demand projections and supply chain disruptions, primarily caused by China's COVID-19 lockdown policies.[70]

Table 6. Pending threats to the critical raw material for semiconductor supply chain

	Theme	Region	Threat
1	Geopolitical	Eastern-Europe	Palladium export embargo by Russia
2	Geopolitical	East Asia	Gallium, Germanium, Cobalt, Rare Earth Element export embargo by China
3	Military	East Asia	People's Liberation Army naval blockade and/or invasion of Taiwan
4	Military	East Asia	Regional naval war in the East China Sea between China and Japan, South Korea and/or the US
5	Military	Southeast Asia	Regional naval war in the South China Sea between China and a Southeast Asian country and/or the US
6	Military	Southeast Asia and Persian Gulf	US blockade halting Chinese oil and gas imports (e.g., Malacca Strait or Strait of Hormuz)
7	Military	Southern Africa	Political instability or civil war in the DRC (or along transportation routes in Southern Africa)
8	Legal	Southern Africa and East Asia	Increasingly stringent EU and US ESG-regulation (e.g., disrupting imports from DRC-mined cobalt and China-mined Silicon)
9	Geo-economic	Global	Demand-induced resource shortage due to the energy transition and increase in semiconductor manufacturing
10	Geo-economic	East Asia	Events inside China such as pandemic-related lockdowns or work stoppages

Finally, a ranking of these threats was brought about through a foresight survey filled out by 49 experts. The survey finds that the supply of semiconductors and end-products to the EU is likely to be strongly, negatively impacted by CRM supply disruptions, already in the next five but even more so in the next ten years. The most important threats to the supply of CRM for semiconductors in the next ten years are demand-induced CRM shortages due to the energy transition, a People's Liberation Army (PLA) invasion or maritime blockade of Taiwan and a CRM embargo by China.[71]

70 The additional two, geoeconomic threats were in part identified through the quantitative data analysis conducted in WP 5.1 in the Strategic Monitor.

71 Needless to say that since the Russia-Ukraine conflict is highly dynamic and shrouded in the fog of war, the findings below may not be exhaustive. These are based on open sources and expert interviews with among other experts a palladium trader. Patel, 'Palladium Tops $3,000/Oz as Supply Fears Grow, Gold Jumps over 1%'; Hobson, 'Palladium Propelled to Record Highs by Russia Supply Concerns'. Alper, 'Exclusive'.

Case study Reaching breaking point[1] – Weaponisation of European-Russian trade in vital commodities following Russia's invasion of Ukraine

The war in Ukraine and Europe's sanctions against Russia after 15 years of deteriorating relations finally led European-Russian relations to reach *breaking point*, meaning the moment when military-strategic challenges in the relationship became so overwhelming that

1. Russia became unwilling to deliver the essential commodities on which European economies depend (i.e., natural gas and neon embargo),
2. Military action by Russia in Ukraine became so consequential that the supply of an essential commodity to Europe has been disrupted (i.e., neon gas) and,
3. European sanctions against Russia (temporarily) inhibited the trade of a critical CRM for the production of semiconductors (i.e., palladium).

Russia-EU relations reached "breaking point" following the 2022 Russian invasion of Ukraine: natural gas and neon supplies are now being fully weaponised by Russia against the European Union, but the supply of palladium has largely and curiously remained untouched. Measures by the Russian government, such as [1.] export squeezes/embargoes, have severely disrupted the supply of neon gas and natural gas to the European Union, but did not affect palladium exports. [2.] War-fighting in Ukraine has severely disrupted the supply of neon gas to the EU as half of the world's semiconductor-grade neon is produced in the country, including at the besieged Azovstal steel plant in Mariupol. The European sanction packages have evaded sanctioning essential commodities from Russia, including palladium, neon extract, and natural gas. However, [3.] European and partner sanctions, specifically the closure of European airspace for Russia, have temporarily disrupted palladium imports, as direct flights from Moscow to European capitals are now rerouted via Doha and Istanbul.

It remains to be seen whether Russia will put an outright ban on the export of all essential materials, including palladium, needed to keep the production of semiconductors running. The War in Ukraine has however led to steep price rises for palladium and the supply of neon gas, needed by both producers of lithography equipment and semiconductor manufacturers. The continuation of security and human rights disputes between NATO and Russia and further escalation in the War in Ukraine may lead to an additional breaking point, ending the supply of palladium from Russia to the EU.

Table 7. Reaching breaking-point? Disruptions in the supply of essential energy supplies and natural resources from Ukraine and Russia since 24 February 2022

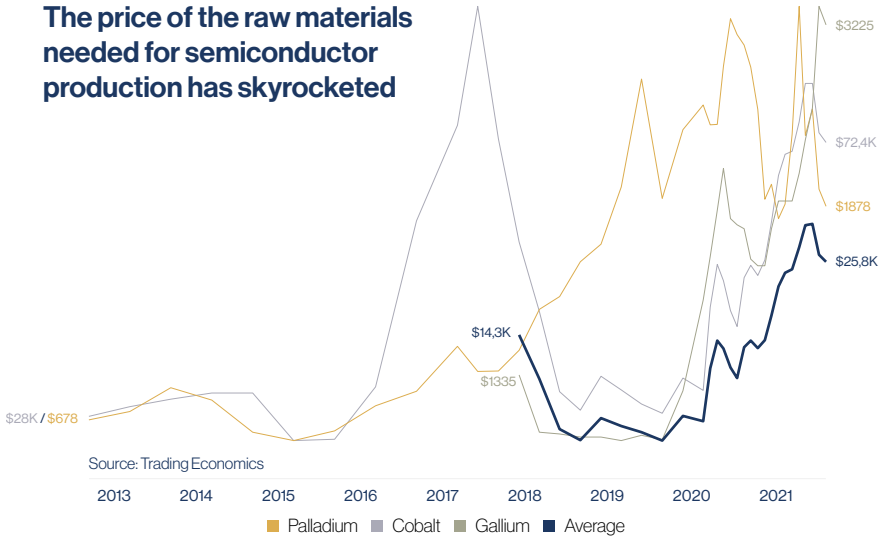
	Palladium	Neon Gas	Natural Gas
Russian export squeeze or embargo	No disruption	High disruption	High disruption
War-fighting in Ukraine	No disruption	High disruption	Medium disruption
EU and partner sanctions	Low disruption	No disruption	Low disruption

[1] Needless to say that since the Russia-Ukraine conflict is highly dynamic and shrouded in the fog of war, the findings below may not be exhaustive. These are based on open sources and an expert interview with a palladium trader and will be undoubtedly be added onto as time progresses. Alexandra Alper, "Exclusive: Russia's Attack on Ukraine Halts Half of World's Neon Output for Chips," Reuters, March 11, 2022, sec. Technology, https://www.reuters.com/technology/exclusive-ukraine-halts-half-worlds-neon-output-chips-clouding-outlook-2022-03-11/. Izabella Kaminska, "Noble Gases Are Suffering From Putin's War in Ukraine," Bloomberg, May 19, 2022, https://www.bloomberg.com/opinion/articles/2022-05-19/ukraine-war-mariupol-noble-gases-neon-helium-are-suffering-from-putin-s-war. Mary Villareal, "Russia Responds to Another Round of EU Sanctions by Restricting Exports of Noble Gases like Neon, Which Is Essential for Making Computer Chips," Supply Chain Warning, June 7, 2022, https://www.supplychainwarning.com/2022-06-07-russia-responds-eu-sanctions-limits-neon-exports.html. Tsvetelia Tsolova and Anna Koper, "Europe Decries 'blackmail' as Russia Cuts Gas to Poland, Bulgaria," Reuters, April 27, 2022, sec. Energy, https://www.reuters.com/business/energy/gazprom-says-it-halts-gas-supplies-poland-bulgaria-payments-row-2022-04-27/; BBC News, "Russia Halts Gas Supplies to Finland," BBC News, May 21, 2022, sec. Europe, https://www.bbc.com/news/world-europe-61524933; America Hernandez, "Russia Halts Gas Supply to the Netherlands," Politico, May 31, 2022, https://www.politico.eu/article/russia-halts-gas-supply-to-the-netherlands/; Jan M. Olsen, "Russia Cuts off Natural Gas Supply to Denmark, Company Says | AP News," AP News, June 1, 2022, https://apnews.com/article/russia-ukraine-putin-government-and-politics-netherlands-10923b26194d11c555f6176799465dd2. Interview Markus Meurer. "Russia's Palladium Exports Face Disruption From Flight Bans."

Structural geoeconomic pressure on the supply of CRM

In addition to the eight geopolitical, military, and legal threats that can be identified on the basis of the case study, two additional structural, geoeconomic threats can have a profound impact on the supply of CRM for semiconductors to Europe and partners. First, a looming demand-induced CRM shortage due to skyrocketing-demand (for many CRM due to the energy transition) is likely to put pressure on the supply of those CRM that also have green applications, such as cobalt, REE, and silicon.[72] Global demand for cobalt, REE, and silicon is expected to grow annually by respectively 4-to-6%, 5% and 2.2-to-2.6% until 2050 to keep up with the energy transition.[73] For example, cobalt is not only a key material necessary for semiconductor production but is also used in various other technological applications of the energy transition, most notably EVB. To reach the 2030 required cobalt supply for governments to deliver on their climate pledges on electric vehicles, another 17 cobalt mines should be opened worldwide by 2030.[74] Increased demand for these different technologies is already leading to price rises and will in the future lead to further strain on supplies of cobalt (see Figure 3). Second, events inside China such as pandemic related lockdowns have proven to be highly disruptive for trade between China and the rest of the world, leading containerised freight prices to skyrocket (see Figure 4). Since China is not likely to move away from Xi Jinping's "Dynamic Zero-COVID" policy anytime soon, "Events inside China" is another important risk that may upend the supply of CRM for semiconductor production in Europe, Taiwan, the US, and South Korea in the next five and ten years.

Figure 3. Sky rocketing prices as demand for CRM is growing[75]



72 The move from oil and gas production to green energy, including solar panels and wind turbines, can be boiled down to "a shift from [reliance on] fossil fuels to metals". Kleijn, 'Critical Materials, Green Energy and Geopolitics: A Complex Mix (White Paper)'.

73 KU Leuven, 'Pathways to Solving Europe's Raw Materials Challenge', April 2022, 25, https://www.eurometaux.eu/metals-clean-energy/?5.

74 IEA, 'Global Supply Chains of EV Batteries – Analysis' (IEA, 2022), 48, https://www.iea.org/reports/global-supply-chains-of-ev-batteries. This calculation is based on the IEA's "Announced Pledges Scenario (APS)". https://www.iea.org/reports/world-energy-model/announced-pledges-scenario-aps

75 Trading Economics, 'Gallium', Trading Economics, 2022, https://tradingeconomics.com/commodity/gallium; Trading Economics, 'Palladium', Trading Economics, 2022, https://tradingeconomics.com/commodity/palladium; Trading Economics, 'Cobalt', Trading Economics, 2022, https://tradingeconomics.com/commodity/cobalt; Ranjeetha Pakiam and Eddie van der Walt, 'How Palladium Became a Really, Really Precious Metal', *Bloomberg*, 23 April 2021, https://www.bloomberg.com/news/articles/2021-04-23/how-palladium-became-a-really-really-precious-metal-quicktake.

Figure 4. The cost of shipping: Containerised freight[76]

The per-container cost of freight out of Shanghai has skyrocketed, indicating significant pressures on the integrity of global supply chains

2.1 Ranking risks: CRM-related threats to the supply of semiconductors survey outcome

The supply of semiconductors and end-products to the EU is likely to be strongly, negatively impacted by CRM supply disruptions.

The seriousness of the identified risks was gauged by experts, ranking the ten threats both in terms of probability of occurrence and level of impact (see Infographics Critical Raw Material Risks and Figure 5 and 6). Seven key findings can be derived from the survey:

1. **The supply of semiconductors and end-products to the EU is likely to be strongly, negatively impacted by CRM supply disruptions, already in the next five but even more so in the next ten years**. A demand-induced shortage due to the energy transition, a CRM export embargo by China, and a People's Liberation Army naval blockade/invasion of Taiwan are deemed the top risks in the next ten years. It is likely that one or more risks materialises before 2032 and possibly even before 2027, as five risks were awarded a higher than 50% probability to materialise in the next five years and seven in the next ten years. Out of all risks, seven are expected to have a "high impact"[77] and three to have a "very high impact" (see Figure 5).[78] If even just one of these risks materialises, the respondents expect that this will have either a "high impact" or "very high impact" on the supply of semiconductors and end-products to the EU and, hence, the bloc's overall economic security.

76 Martin Placek, 'Shanghai Containerized Freight Rate Index from January 2019 to June 2022', Statista, 22 August 2022, https://www.statista.com/statistics/1309698/monthly-china-shanghai-container-freight-rate-index/.

77 Threat 1, 2,3,4,6,9,10

78 Threat 5, 7, 8

2. **A demand-induced CRM shortage due to the energy transition is the threat that is deemed most likely to materialise in both the next five and ten years.** A demand-induced shortage due to the energy transition is a structural, "high impact" challenge facing the CRM landscape. Five out of six CRM assessed in this report have important functions in both semiconductor production and the transition to green energy, meaning the energy transition will put pressure on their availability for semiconductor production.

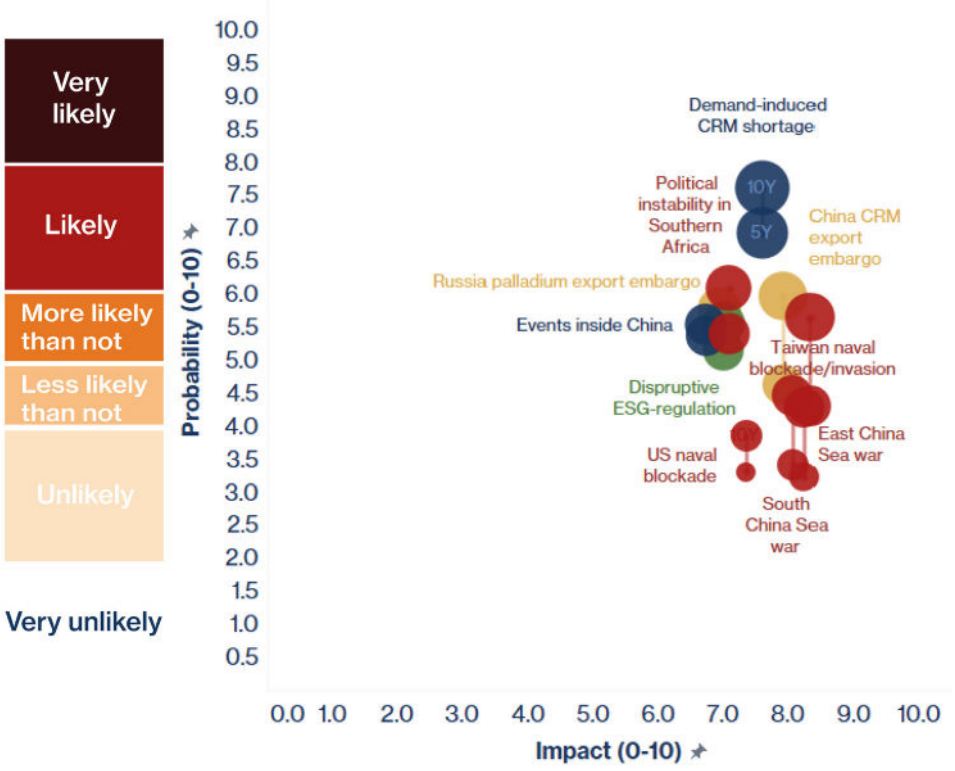
3. **The respondents fear that CRM embargoes enacted by China and Russia then aggravate these shortages (see Figure 6), similarly to the imposition of a natural gas and neon gas (partial-)embargo by Russia in 2022.** As prices rise due to increased demand, the "more likely than not" risk of a palladium export embargo by Russia in both the next five and ten years, and the "more likely than not/likely" risk of a CRM embargo by China in the next ten years, are expected to aggravate disruptions in the supply of semiconductors and end-products to the European Union. The respondents with economic security expertise ranked a CRM embargo by China as the highest impact threat out of all the risks appreciated, whereas China, Japan, East Asia, and international security experts maintained that a Chinese CRM embargo is only a "high impact risk".

4. **Military risks in the Indo-Pacific involving China and possibly the United States are considered the highest impact risks. They are, however, mostly still considered "unlikely" in the next five years and "less likely than not" in the next ten years – with the exception of a naval blockade/invasion of Taiwan.** Military risks involving China, such as 1. A naval blockade and/or invasion of Taiwan, 2. War in the East-China Sea, and 3. War in the South-China Sea are deemed the highest impact events by the overall respondents.[79] Whereas war in either the East-China Sea or South-China Sea is deemed to be "less likely than not" in both the next five and ten years, the odds of a naval blockade and/or invasion of Taiwan passes the respondents' threshold from "less likely than not" in the next five years to "more likely than not" in the next ten years – meaning a higher than 50% chance of occurrence. A PLA naval blockade or invasion of Taiwan is expected to have the greatest impact on the supply of semiconductors or end products to the European Union out of all the risks that were surveyed. However, the judgment of respondents with East Asia expertise differs from the overall group as they maintain that the risk of an invasion of Taiwan is "unlikely" before 2027 and still "less likely than not" before 2032. An American maritime blockade of the Strait of Hormuz or the Strait of Malacca to choke China's supply of petrochemical products is, unlike a Taiwan scenario, considered an "unlikely" event by the overall respondents, both before 2027 and 2032.

5. **Political unrest or even intrastate conflict in Southern African states are likely to disrupt the supply of cobalt (see Figure 6).** Political unrest in Southern Africa, another military threat, is deemed "more likely than not" to disrupt the supply of CRM for semiconductors in the next five years, and "likely" to do so in the next ten years. This would have a "high impact" on the supply of semiconductors and end-products to the EU and hence the EU's economic security.

79 All expected to have a "very high impact".

Figure 5. Survey outcome: All CRM-related semiconductor risks are either "high" or "very high" impact

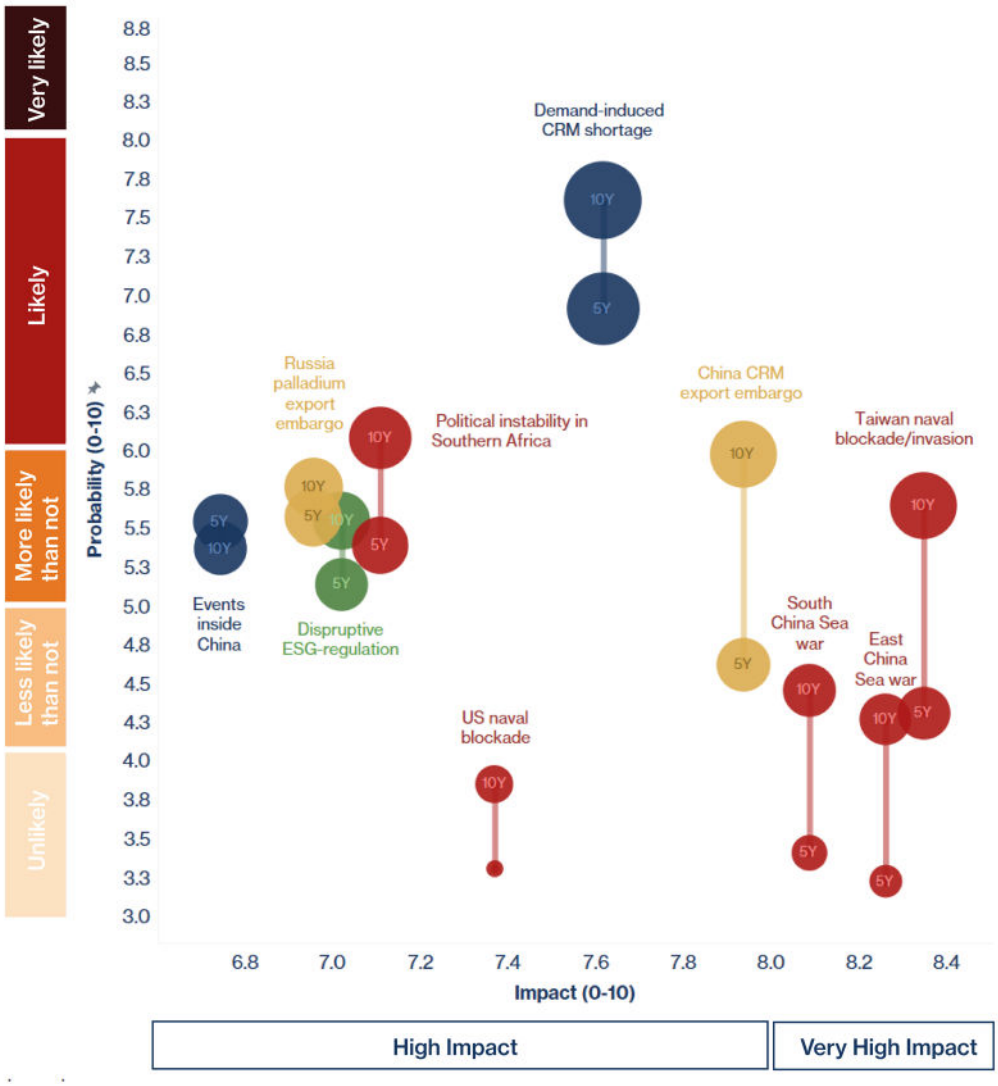


6. **ESG-related regulation and sanctions by the United States and the European Union were awarded a higher than 50% probability of causing a "high impact" disruption in the supply of CRM for semiconductor production.** Economic security experts found that ESG-related regulation was "less likely than not" to affect the supply of CRM to Europe in both the next five and ten years. International security and China, Japan, and East Asia experts, however, found the risk to be "more likely than not" to materialise in the next five and ten years.[80]

7. **Finally, events inside China such as pandemic related lockdowns are deemed "more likely than not" to disrupt the supply of CRM already in the next five years, and are expected to have a "high impact" on the supply of semiconductors and end-products to the European Union.** Economic security experts on average ranked the probability and impact of events inside China disrupting the supply of CRM both before 2027 and 2032 higher than international security experts and East Asia experts.

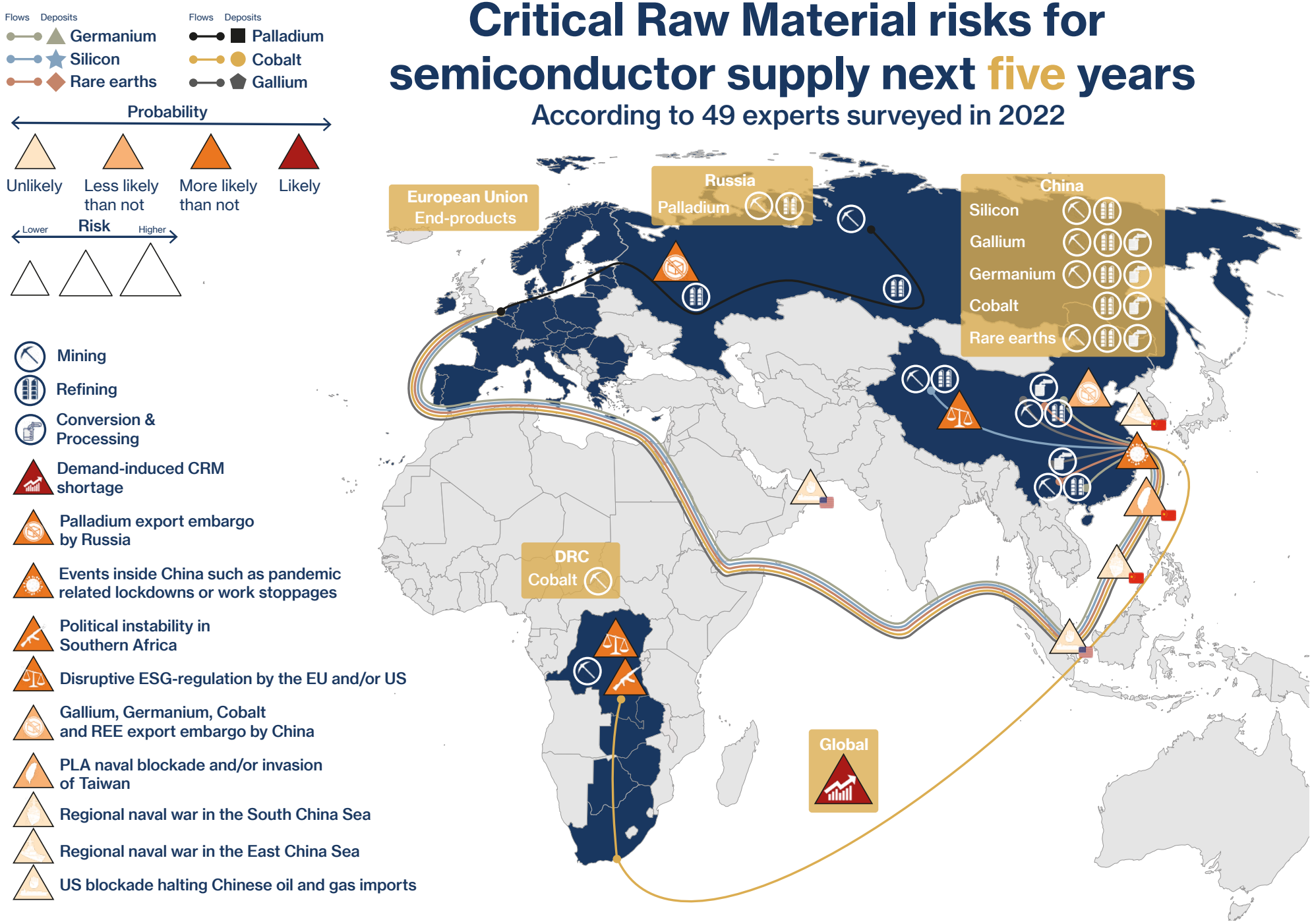
80 The Netherlands and the EU are working on increasingly stringent Environmental, Social and Governance (ESG) guidelines, rules and regulations. Child labour has been a problem in DRC cobalt mines. Around 40 to 50% of the world's silicon metal, a material used for the production of semiconductors, is mined in Xinjiang. On June 21, 2022, the Uygur Forced Labor Prevention Act entered into force in the US with more human rights related regulation in the making.

Figure 6. Survey outcome: Seven out of ten threats are considered (at least) "more likely than not" to materialise over the next ten years



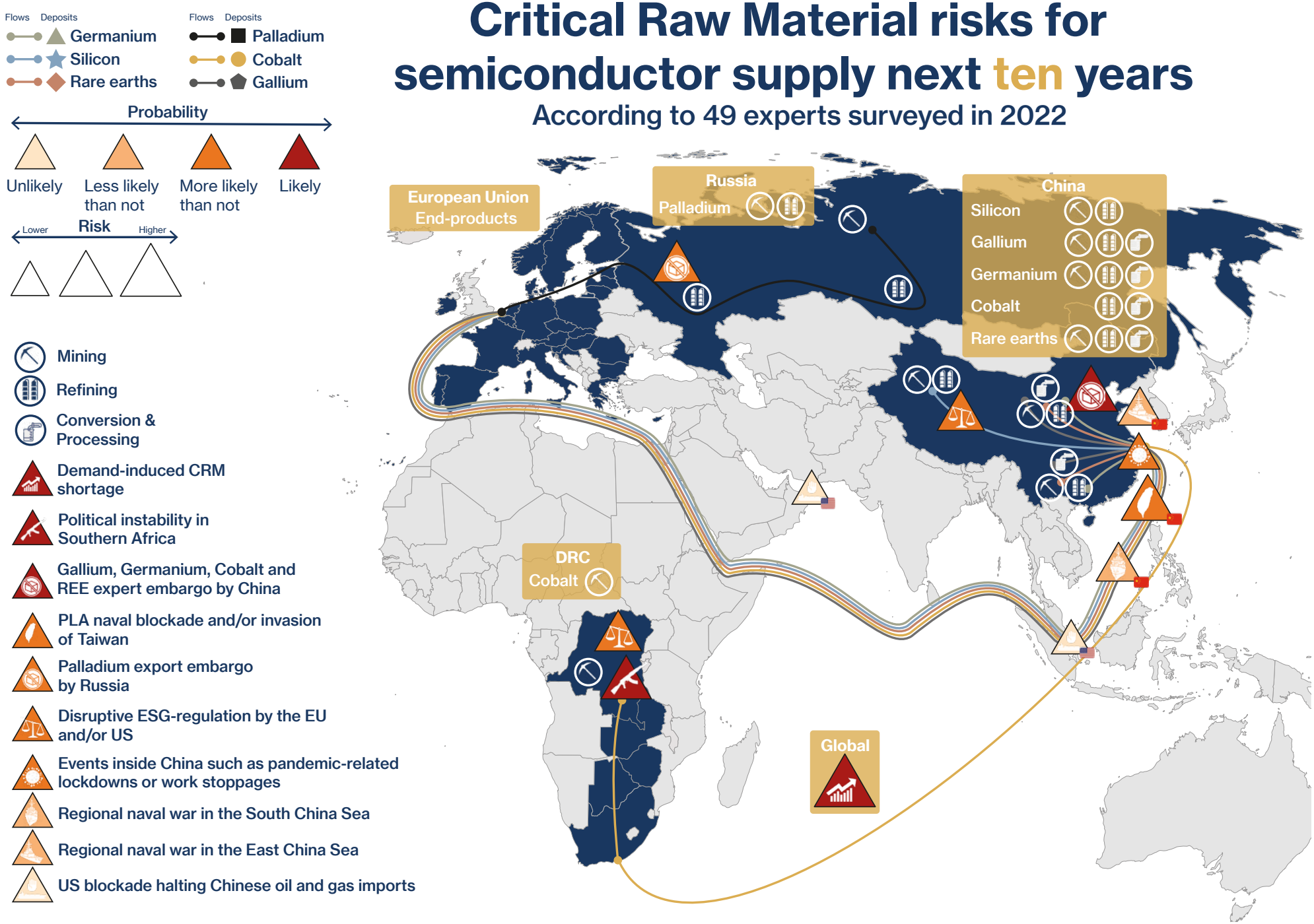
Critical Raw Material risks for semiconductor supply next five years

According to 49 experts surveyed in 2022



Critical Raw Material risks for semiconductor supply next ten years

According to 49 experts surveyed in 2022



Survey methodology

The ranking of the risks (i.e., *probability * impact*) was brought about through a foresight survey filled out by a group of 49 experts from different fields of expertise and work, of whom 29 are named (see Appendix 2). Respondents ranked the identified ten risks in terms of probability of occurrence in both the next five and ten years. Respondents were also asked to assess the impact that these scenarios would have on the supply of semiconductors and end-products to Europe (see section Survey Outcome).

Respondents filled out 30 questions ranking the probability in five years, the probability in ten years, and the impact for each of the ten threats (see Figure 5 and 6). 'Probability' is defined as the chance of an event occurring. 'Impact' is defined as the impact an event would have on the supply of CRM to the EU or its partners in semiconductor manufacturing (e.g., Taiwan), and therefore also the supply of semiconductors to the EU.

For each question, respondents scored probability or impact on a scale from zero to ten. Zero indicated "extremely unlikely" or "extremely low impact", while ten indicated "extremely likely" or "extremely high impact". The numerical probability responses were categorised in six categories, namely very unlikely (0.0-2.0), unlikely (2.01-4.0), less likely than not (4.01-5.0), more likely than not (5.01-6.0), likely (6.01-8.0), and very likely (8.01-10.0). The numerical impact responses were similarly categorised in five categories, namely very low impact (0.0-2.0), low impact (2.01-4.0), medium impact (4.01-6.0), high impact (6.01-8.0), and very high impact (8.01-10.0).

Ranges	Probability	Impact
0,0 - 2,00	Very unlikely	Very low impact
2,01 - 4,00	Unlikely	Low impact
4,01 - 5,00	Less likely than not	Medium impact
5,01 - 6,00	More likely than not	Medium impact
6,01 - 8,00	Likely	High impact
8,01 - 10.0	Very Likely	Very high impact

Responses were excluded when a respondent mentioned not to have the expertise needed to answer a specific question. The survey was conducted from the last week of May until the end of June 2022.

3. Winning interdependence: semiconductor and CRM rivalry in a de-globalising world

"We have made it very clear to the Dutch: We believe that this kind of sensitive technology does not belong in 'certain places'"

US Ambassador Pete Hoekstra 17 January 2020; on the export of ASML's EUV lithography system to China[81]

"This is yet another example of the US practice of "coercive diplomacy" by abusing state power and wielding technological hegemony. It is also classic *technological terrorism*."

PRC Foreign Ministry Spokesperson Zhao Lijian June/July 2022, in response to reported US government pressure on the Netherlands and Japan to block exports of ASML and Nikon Deep Ultraviolet Lithography (DUV) equipment to China.[82]

The current semiconductor and CRM equilibrium is not static: various Western governments, led by the US, have undertaken attempts to strengthen and leverage the West's collective dominance in the semiconductor value chain against Russia and China[83], whilst at the same

81 Sandra Olsthoorn and Johan Leupen, "'ASML-Technologie Hoort Niet Thuis Op Bepaalde Plaatsen,'" FD.nl, January 17, 2020, https://fd.nl/economie-politiek/1331153/asml-technologie-hoort-niet-thuis-op-bepaal-de-plaatsen-org2caw9zGbx.

82 Ministry of Foreign Affairs of the People's Republic of China, "Foreign Ministry Spokesperson Zhao Lijian's Regular Press Conference on July 6, 2022," Ministry of Foreign Affairs of the People's Republic of China, July 6, 2022, https://www.fmprc.gov.cn/mfa_eng/xwfw_665399/s2510_665401/2511_665403/202207/t20220706_10716417.html.

83 See for example: Jenny Leonard, Ian King, and Debby Wu, 'China's Chipmaking Power Grows Despite US Effort to Counter It'; Lee and Kleinhans, 'Mapping China's Semiconductor Ecosystem in Global Context'; Swanson, Ismay, and Wong, 'U.S. Technology, a Longtime Tool for Russia, Becomes a Vulnerability'; Yang Jie and Jiyoung Sohn, 'Chip Sanctions Challenge Russia's Tech Ambitions'; 'America Has a Plan to Throttle Chinese Chipmakers'.

time attempting to mitigate their CRM dependence.[84] However, current European efforts to mitigate CRM reliance are not on-track to bear fruit at a large-scale before the risks related to CRM dependence are expected to materialise.[85]

Bloc formation and intensifying technology competition risk upending the fragile CRM and semiconductor balance. Since 2019, the US has imposed restrictions on the export of vital American semiconductor manufacturing equipment to Chinese chip manufacturers, spurring on allies in Europe and Asia to do the same (see Infographic Sabotaging Xi).[86] Following Russia's 2022 invasion of Ukraine, the US and its allies, including Taiwan, South Korea and Japan, have banned the exports of semiconductors to Russia altogether.[87] This grants China and Russia, the rivals of Europe and its partners in semiconductor production (e.g., Taiwan), greater incentive to weaponise CRM dependence. The place of the Netherlands in this fragile balance is largely shaped by ASML, a key industry player bringing plentiful employment and economic benefits, as well as great power interest, to the Netherlands. However, ASML's EUV and DUV lithography equipment has also put the Netherlands in an awkward position with both superpowers – the US and China – placing conflicting demands on the Netherlands, and China issuing a barely veiled threat of punishment.[88]

Bloc formation and intensifying technology competition risk upending the fragile CRM and semiconductor balance.

Policy-making efforts in the Netherlands and the European Union to reduce risks in the CRM supply chain are well underway, but translating plans into concrete action remains a problem. These plans include reshoring of mining, refining, and processing operations, CRM cooperation with third-parties such as Japan, Canada, Australia, the US but also non-rival autocracies, recycling, reducing demand, deep-sea mining, and stockpiling.[89] These initiatives either come with challenges, such as *Not In My Backyard*-protests), environmental concerns, technological and economic limitations, limited alternative sourcing countries, or only provide short-term solutions.[90] If only current initiatives are executed, the EU's economic security is likely to be strongly, negatively affected by the disruptions in the supply of CRM that are likely to take place in the next ten years. Both the production of semiconductors and other means necessary to complete the transition to green energy will be affected, if these disruptions occur.[91]

84 'Commission Announces Actions on Critical Raw Materials'; 'FACT SHEET'.

85 S. Bobba et al., *Critical Raw Materials for Strategic Technologies and Sectors in the EU*.

86 *The Economist*, 'America Has a Plan to Throttle Chinese Chipmakers'. Lee and Kleinhans, 'Mapping China's Semiconductor Ecosystem in Global Context'; Jenny Leonard, Ian King, and Debby Wu, 'China's Chipmaking Power Grows Despite US Effort to Counter It'.

87 'Remarks by President Biden on Russia's Unprovoked and Unjustified Attack on Ukraine'.

88 Johan Leupen and Sandra Olsthoorn, '"We zouden niet willen dat Nederland zwicht onder de druk van de VS"'.

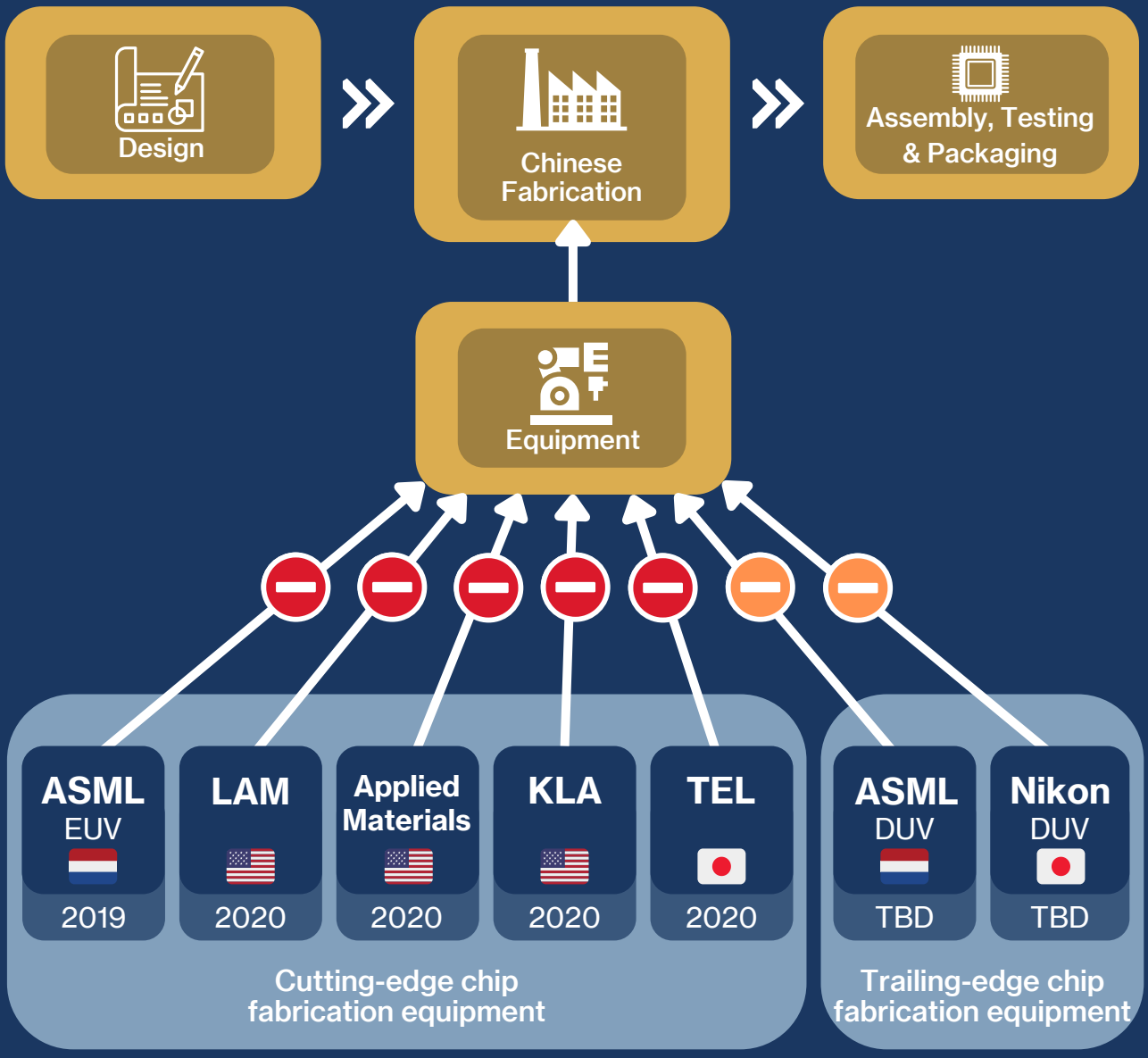
89 'Commission Announces Actions on Critical Raw Materials'; European Commission, 'EU and Canada Set up a Strategic Partnership on Raw Materials'.

90 Ritoe, 'The New Great Game'; Lagunas and Sterren, 'De weg naar groene energie is een smerige zaak'; Rebekah Daunt, 'Portugal's Government Approves Lithium Mining despite Growing Concerns'.

91 For a full appreciation of risks, please find the long-version of the report here.

Sabotaging Xi's indigenization efforts

The United States imposes more and more restrictions on the export of vital American semiconductor manufacturing equipment to Chinese chip manufacturers, spurring on allies in Europe and Asia to do the same.



Legend

	Export blocked	**ASML**	Advanced Semiconductors Materials Lithography
	Ongoing US diplomatic campaign to block export	**LAM**	Lam Research Corporation
EUV	Extreme ultraviolet lithography system	**KLA**	KLA Corporation
DUV	Deep ultraviolet litography system	**TEL**	Tokyo Electron Limited
Applied Materials	Applied Materials, Inc.	**Nikon**	Nikon Corporation

4. Policy implications, opportunities and recommendations

The Netherlands and EU would be advised to take a host of measures to strengthen resilience in the increasingly fragile and contested semiconductor and CRM ecosystem. The semiconductor and CRM ecosystem is, when simplified, best understood as a fragile geopolitical balance held up by American, European and Asian technologically advanced, semiconductor-fabricating, democracies and CRM-producing rival autocracies, namely Russia and China, and non-rival autocracies, such as the DRC (see 1. Fragile balance). This fragile balance may very well be upset in similar ways as Russia's invasion of Ukraine led to a chain reaction that disrupted the supply of essential commodities, namely natural gas, neon gas and temporarily palladium to Europe (see 2. Threats). Current European efforts to mitigate CRM reliance are not on-track to bear fruit at a large-scale before the risks related to CRM dependence are expected to materialise (see 3. Winning interdependence). An extended list of policy opportunities and recommendations is presented in the long version of this report.

To address these challenges policy-makers are advised to appreciate five high-level policy implication themes, which come with specific policy opportunities and recommendations.[92]

1. Prioritise security of supply in a world where hard competition between great powers structurally threatens European economic security, including disruptions in the near future supply of CRM.

2. Accept that the US-China tech rivalry is likely to put the supply of semiconductors, digital end-products, and products needed for the energy transition to the EU at risk.

3. Work with other technologically advanced democracies to mitigate semiconductor and CRM ecosystem risks vis-à-vis Russia and China.

4. Expand European leverage in the semiconductor and CRM ecosystem vis-à-vis other technologically advanced democracies such as the US, Taiwan, South Korea and Japan.

5. Formulate a strategy to reduce dependence on China and Russia more broadly, as dependence for many other end-products for purposes such as the digital and energy transition remains.

92 These policy implications, opportunities and recommendations were formulated on the basis of a global expert consultation with representatives from academia, think tanks, government and industry (see appendix 1) and a literature review.

1. Prioritise security of supply

Prioritise security of supply in a world in which hard competition between great powers structurally threatens European economic security, including disruptions in the near future supply of CRM. Policymakers should prepare the Netherlands for a world in which "high impact" disruptions to the supply of CRM for semiconductors occur, as the case of Russia's natural and neon gas embargoes against Europe and the outcomes of the expert survey show (see section 2). While European dependence on Russian gas was only addressed after relations reached 'breaking-point', European dependencies in the supply of CRM for semiconductors should be addressed now to guard for probable future disruptions.

Policymakers should prepare the Netherlands for a world in which "high impact" disruptions to the supply of CRM for semiconductors occur.

1.1 Prepare for persistent pressure on Dutch and broader European prosperity. This will go hand-in-hand with shortages, delays in delivery of products and constant inflationary pressure due to geopolitical fracturing. Politicians should communicate clearly to the population that regular geopolitical, economic, and likely also military crises will put the prosperity of the electorate under pressure.

1.2 The 2022 Dutch Ministry for Foreign Trade and Development Cooperation (BHOS) natural resource strategy should take a "worst-case-scenario" approach. The BHOS should take a "worst-case-scenario" approach to preventing, mitigating, and preparing for the consequences of severe CRM supply disruptions. Encourage and support companies in the semiconductor value chain to map their supply chains, up to and including the mining and refining of CRM used.

1.3 The government should engage in stress testing to identify the effects of likely and impactful CRM supply disruptions. Economic security experts from academia, think tanks and the private sector, especially those focusing on CRM and semiconductors, can best be included in this exercise. Private sector companies, like ASML, NXP and ASM International, should be included in these exercises to exchange best practices and triangulate approaches. This exercise may be repeated together with EU, the North Atlantic Treaty Organisation (NATO) and other partners.

1.4 Institute a top-down approach to reducing strategic dependencies. This can be achieved through the establishment of a National Security Council, as promised in the 2021 Coalition Agreement, and an Energy Council, an advisory body for energy affordability, robustness of the energy system and security of supply. Both bodies should test if policies in the realm of the energy transition are sufficiently robust to survive high-impact geopolitical events.[93]

93 Lucia van Geuns, Strategic Advisor Energy at the Hague Centre for Strategic Studies, advocates this position, including in her presentation in the Dutch House of Representatives in September 2022.

2. Accept that the US-China tech rivalry will put supply lines to the EU at risk

Accept that the US-China tech rivalry is likely to put the supply of semiconductors, digital end-products, and products needed for the energy transition to the EU at risk. The US-China tech rivalry is likely to intensify, more often pushing the EU and other American allies to act with Washington against Beijing. US attempts to sabotage China's semiconductor indigenisation efforts risk unsettling the semiconductor value chain for two reasons: 1) it risks reducing the total global output of semiconductors (i.e., supply chain resilience) by causing intended and unintended consequences in a highly complicated ecosystem during a transition period; and 2) it risks unsettling the fragile semiconductor supply balance across rival blocs, as it incentivises China (or Russia) to weaponise parts of the semiconductor value chain under its control, namely the CRM supply chain. The Netherlands and the EU's space to carve out an independent position in the intensifying US-China tech and trade competition remains limited, as ASML and other companies in the semiconductor value chain are reliant on production facilities in the US, as well as dependent on access to the US market and trade in dollars. Tellingly, Trump's reimposition of sanctions on Iran in 2018 led all major European oil giants to leave the country within months. In the *all-or-nothing* realm of territorial security, Europe still relies on the conventional deterrence of 100.000 troops that the US provides in Central Europe's NATO member-states and the American nuclear umbrella under which Europe still shelters.[94]

The US-China tech rivalry is likely to intensify, pushing the EU and other American allies to act with Washington against Beijing.

2.1 Address the adverse (un)intended consequences of the US-China tech rivalry. European policy-makers should anticipate that Europe's enormous strategic dependence on Washington will increasingly impel the EU to participate in the US-China tech rivalry on the side of the US.

2.2 The Dutch government and its semiconductor companies are advised to explore new approaches to get more in return for participating in the US-led tech-showdown with China.[95] Government ministries are advised to explore if ASML's outstanding order list, consisting of orders by top semiconductor manufacturing companies like TSMC, Samsung, Intel and Semiconductor Manufacturing International Cooperation (SMIC) for 100s of lithography systems, can be employed in closer coordination with the government to achieve Dutch national and European policy goals. The Dutch government is advised to explore if leverage would increase if export licensing are on other regulatory levels for instance the European level instead of the national level.

94 Russia's war in Ukraine has made Europe's reliance on the US even more acute for two reasons. The invasion revealed the lengths Russia is willing to go to enforce what it sees as its historical prerogatives and European states. In addition, European states are very unlikely to have any realistic alternative for the US security guarantee to Europe for at least another 10-to-15 years.

95 "To my knowledge, neither the Dutch state nor ASML received anything in return for withholding the EUV export license to China." Expert interview with Henne Schuwer, Former Dutch Ambassador to the US.

3. Work with others to mitigate risks

Work with other technologically advanced democracies and non-rival CRM-producing autocracies to mitigate semiconductor and CRM ecosystem risks vis-à-vis Russia and China. Greater security of supply and the mitigation of threats to the CRM for semiconductor ecosystem can only be achieved together with allies and partners. In the short term, the Netherlands, the EU and like-minded technologically advanced democracies must keep intact the fragile semiconductor and CRM ecosystem by capitalising on semiconductor strengths (0-5 years). In the medium-to-long term, the technological skill necessary to create a semiconductor supply chain without China and Russia and mitigation of CRM vulnerabilities may be achievable if the EU works with the US, Canada, Australia, Japan, South Korea, India and countries in the Global South (0-10 years).[96]

Greater security of supply and the mitigation of threats to the CRM for semiconductor ecosystem can only be achieved together with allies and partners.

3.1 Make use of the opportunities provided by the dominance of technologically advanced democracies in the semiconductor value chain.

In the short term, mitigating dependence on Russia, China, and the DRC for the CRM for semiconductor supply chain at just one of its key stages (i.e., mining, refining or conversion and processing) is unrealistic, in spite of CRM deposits in Europe, Canada, Australia, the US, parts of the Global South not controlled by Chinese mining companies, and the deep-sea. Dominance in the semiconductor value chain comes with opportunities to dissuade China and Russia to weaponise the CRM supply chain. Key points of strength, such as Taiwan's TSMC and the Netherlands' ASML, should therefore be protected and expanded upon. The Brain-port region has many practical needs the government can help satisfy, such as 70.000 vacancies in engineering-related fields. ASML, in need of "mechanics and top-level STEM talent" is expected to double its personnel file in the upcoming years.[97] Meanwhile, efforts should be made to make hostile acts, such as China enacting a CRM boycott against the EU or its partners in semiconductor production (e.g., Taiwan) or the PLA taking military action against Taiwan, as unappealing as possible.

3.1.1 Invest in capacity, both human resources and technologies, to continuously screen Chinese advances in the semiconductor value chain. China's level of success in indigenising this technology enabling sector will partially determine the strategic space it has to act disruptively (e.g., enact a CRM export embargo or take military action against Taiwan).[98] Invest in economic security knowledge, both inside and outside the Dutch government, with a focus on China. Establish partnerships throughout Asia with knowledge institutes specialising in technology and China-analysis, for instance in South Korea, Japan and Taiwan.

96 However, also these geopolitical mitigation efforts take place against a non-geopolitical structural factor that continually threatens security of supply, namely growing demand for CRM as a result of the energy transition.

97 NRC, 'In twee weken kunnen de chips op zijn, waarschuwt Eurocommissaris Breton', *NRC*, accessed 28 September 2022, https://www.nrc.nl/nieuws/2022/09/06/eurocommissaris-breton-vreest-blokkade-taiwanese-chips-en-dan-hebben-we-in-twee-weken-tijd-geen-chips-meer-2-a4140942.

98 The importance of tracking China's semiconductor indigenisation efforts can hardly be overstated. The former Prime-Minister of Australia, Kevin Rudd, argues that "whether China can succeed in closing the semiconductor manufacturing gap between itself and the US and its allies, given that silicon chips underpin the future drivers of the global digital economy and military technology, including the unfolding artificial intelligence revolution" is one of five factors determining much of "the great strategic race between Washington and Beijing over the course of the next decade". Kevin Rudd, *The Avoidable War: The Dangers of a Catastrophic Conflict between the US and XI Jinping's China* (New York: PublicAffairs, 2022), 354.

3.1.2 Advanced democracies should invest in better protection of intellectual property (IP) to protect the technological edge that advanced democracies hold in semiconductor production. The Dutch government, making use of its great cyber security ecosystem consisting of both the intelligence services and world-leading private companies such as Fox-IT, may help strengthen the defensive cyber capabilities of key Dutch, South-Korean, Taiwanese and American companies like ASML, Samsung, TSMC and Intel. The Dutch government is advised to expand its knowledge security agenda, as concerning examples of unwanted knowledge transfer, also in the military realm, have occurred over recent years.[99] The government is advised in its establishment of a "toetsingskader" for universities and a "investeringstoets", to 1. introduce an obligation to notify the government about business and university collaborations with China in high-risk fields, 2. define "high-risk fields" based on the military-technological gaps geopolitical rivals struggle with and the technologies they want to use to master the warfare of the future, 3. mandate a specialised government body to - if necessary - block corporate takeovers as well as commercial and university collaborations.[100]

3.1.3 Strengthen the technological edge of advanced democracies. Maintain an active conversation with leading semiconductor firms, both European and non-European, on their needs and drivers behind decisions on starting new fabs or expanding existing ones in specific localities.

a. Make more Dutch and European funds available along the semiconductor supply chain that come closer to the sums provided by the US, Japan or South Korea.
b. Use funds from InvestNL, NXTGEN High Tech and FMO to help contribute to this aim. Encourage these funds to ensure that geopolitical risk is sufficiently accounted for in their investment strategies.
c. Provide tax incentives for semiconductor design, manufacturing, and ATP companies to open offices in Europe.
d. Speed-up permitting for the enlargement or the development of new fabs in the Netherlands and other European states. Support the completion and enactment of the European Chip Act, whilst looking actively to how central, eastern-, and southern-European member-states can benefit from reshoring CRM value chains.
e. Accept that bringing semiconductor production to Europe, which will necessarily require lots of electricity, is a vital step to eventually ensure the security of supply necessary for digitalisation and greening the economy.[101] For instance, the production of New Energy Vehicles (NEV) relies on chips produced by semiconductor companies active in the automotive industry such as NXP.
f. Accept that semiconductor manufacturers rely on digital infrastructure, such as data centres, that require a lot of energy. Accept that this is a vital step to ensure the security of supply necessary for digitalisation and greening the economy.
g. Expand funding broadly for pre-competitive research along the semiconductor and CRM value chain. Expand government subsidies to enable university and other research teams to commercialise their products.
h. Expand funding for companies who do research on how to make semiconductors more energy-efficient.

99 Annebelle de Bruijn et al., 'Drones and Concrete to Withstand Bullets: Collaboration with "Ordinary" Chinese Universities Also Poses Risks', Follow the Money - Platform for investigative journalism, 26 May 2022, https://www.ftm.eu/articles/collaborating-with-ordinary-chinese-universities-also-poses-risks.; Joris Teer et al., 'China's Military Rise and the Implications for European Security' (The Hague Centre for Strategic Studies, 2021), https://hcss.nl/report/chinas-military-rise/.

100 Joris Teer, 'China's Military Rise and European Technology: The Policy Debate in the Netherlands' (The Hague Centre for Strategic Studies, 2022), 7–8, https://hcss.nl/report/chinas-military-rise-and-european-technology/.

101 Betty Hou and Stephen Stapczynski, 'Chipmaking's Next Big Thing Guzzles as Much Power as Entire Countries', *Bloomberg.*Com, 25 August 2022, https://www.bloomberg.com/news/articles/2022-08-25/energy-efficient-computer-chips-need-lots-of-power-to-make.

3.1.4 Anticipate that both in the semiconductor and CRM industries engineering talent and other skilled workers are a bottleneck resource, by:

a. Providing tax incentives for semiconductor talent to study, work, and live in the Netherlands, for instance by at least maintaining (and not shortening) the 30% tax benefit rule.[102]
b. Pursue visa liberalisation for countries that train engineers on a large scale, such as India.
c. Promote STEM fields among high school students, including by offering financial incentives.[103] Similarly, try to grow the pool of mechanics by promoting relevant education in trade schools.
d. Invest in large-scale housing in the Netherlands, first and foremost in Eindhoven, the brain port of the Netherlands.
e. Expand student exchanges with technologically advanced democracies active in the semiconductor value chain.
f. Pursue the expansion of traineeship schemes at companies throughout the semiconductor value chain.

3.1.5 Expand cooperation with Indo-Pacific states on CRM and semiconductors. Explore the viability and desirability of starting an EU-South Korea Trade and Technology Council focusing on strengthening the semiconductor ecosystems. Do the same for a EU-Japan Trade and Technology Council, focusing on Japan's great success in decreasing its reliance on Chinese CRM and wafer production. Join the QUAD-working group on semiconductors.

3.1.6 Continue to sell semiconductor end-products on the Chinese market, as long as this does not aid the development of China's PLA. Sales of end-products on China's market, in total 25% of global semiconductor consumption, can help maintain the enormous R&D costs of the industry.

3.1.7 Leverage newfound post-Ukraine unity among technologically advanced democracies to disincentivise China from enacting a CRM export embargo or putting a naval blockade around/invading Taiwan. Technologically advanced democracies should communicate to China what the consequences would be if Beijing takes action to disrupt the supply of CRM to Europe and its partners in semiconductor production before such an event occurs. EU, G7, South Korean, Taiwanese and Australian punishment of Russia was hinted on by the European Council already in December 2021 in broad terms, as the Council warned of "massive consequences" and "severe cost" that would be imposed and "coordinated with partners" to deter Russia from "any further military aggression" Ukraine.[104] The cohesion coming out of that crisis should be maintained and used to deter Beijing at moments of high tension, by informing it of the collective economic consequences technologically advanced democracies would inflict on China. In addition, technologically advanced democracies are advised to communicate to China that Taiwan's semiconductor industry will be inoperable, if China decides to invade. Behind closed-doors, the Dutch government, its EU partners, the US and its partners in Asia could assess together what economic tools they are willing to leverage against China in the event of an attack on Taiwan. This should include the viability

102 Ministerie van Algemene Zaken, 'Expat Tax Break to Be Shortened - Income Tax - Government.Nl', onderwerp (Ministerie van Algemene Zaken, 6 July 2018), https://www.government.nl/topics/income-tax/shortening-30-percent-ruling.

103 Beatrijs Ritsema, 'Goed plan: gratis exact studeren', *HP/De Tijd* (blog), 2 June 2012, https://www.hpdetijd.nl/2012-06-02/goed-plan-gratis-exact-studeren/.

104 European Council, 'European Council Meeting (16 December 2021) - Conclusions' (European Council, 16 December 2021)., Conclusion 2.3

and desirability of a NATO for Trade-like arrangement with technologically advanced democracies in Europe, the Americas, Asia and Oceania. In addition, they should put together a comprehensive overview of pressure points technologically advanced democracies have vis-a-vis China and evaluate to what extent each party is willing to use these pressure points to deter China.

3.2. Mitigate CRM-related dependencies and risks in the medium-term.

Accept that ensuring security of supply of vital resources such as CRM in the medium-term requires a foreign policy based on "mutual interests" towards non-rival, CRM-producing autocratic states. The overarching theme is the following:

Accept that ensuring security of supply of vital resources such as CRM in the medium-term requires a foreign policy based on "mutual interests".

3.2.1 Note that current security of supply efforts, especially in the realm of CRM, by technologically advanced democracies, especially the EU and to a lesser extent the US, are not going fast enough to mitigate these risks. Canada, Australia and Japan are notable exceptions.

3.2.2 Mind the gap: Policies implemented, for instance building refining and processing capacity in Europe, can take up-to a decade to bear fruit. Mining-related policies will likely take even longer.

3.2.3 Embed security of supply goals better in the national government's set-up by establishing an Energy Council, an advisory body for energy affordability, robustness of the energy system and security of supply, and broadening the mandate of the Minister of Energy and Climate to become the Minister of Energy, Security of Supply and Climate.

3.2.4 All other things being equal, it is better to rely on non-rival autocracies than on rival autocracies for the supply of vital resources such as CRM, Liquified Natural Gas (LNG) and oil. Expanding security of supply through dealings with states such as the DRC, Qatar or Saudi Arabia requires a formulation of resource policy in terms of "mutual-interests".[105]

3.2.5 The EU should accept that there will be environmental and climate costs, which have been exported overseas in the past, when reshoring mining, refining, and conversion and processing operations.

3.2.6 Accept that mitigating dependence on CRM from China, Russia, and the DRC cannot be done without the private sector, nor without governments coordinating industrial policy.

3.2.7 Mobilise the CRM-reliant private sector, including green transition, semiconductor, defence and car companies, to mitigate CRM dependence conjointly. These capital-intensive industries require many of the same CRM to produce their products.

3.2.8 The semiconductor industry should prioritise stockpiling and recycling in the short-term. The semiconductor industry, using lower volumes of CRM, is in a better position to prioritise stockpiling and recycling in the short-term to fulfil its needs. The defense industry, in turn, should use stockpiling for semiconductors and products reliant on CRM to produce the tools necessary to preserve European security.

105 Adviesraad Internationale Vraagstukken, 'Urgentie van een nieuwe Nederlandse Afrika-strategie', publicatie (Adviesraad Internationale Vraagstukken, 14 July 2022), 8, https://www.adviesraadinternationalevraagstukken.nl/documenten/publicaties/2022/07/14/urgentie-van-een-nieuwe-afrika-strategie.

The more detailed policy recommendations (see overview in Table 8 below) build on current policy initiatives and address existing challenges they encountered.[106]

Table 8. Policy recommendations to overcome the challenges to expanding CRM security of supply

Current Initiative	Challenges	Policy Recommendation
Reshoring of mining operations to Europe:	(1) NIMBY movements (e.g., from indigenous communities) (2) Environmental concerns (3) Lack of refining and processing operations (4) Lack of capital (5) Lack of skilled workers (6) Dependence on foreign (e.g., Chinese) equipment and expertise	(1) Create a political support base in wider society to address NIMBY and environmental concerns by communicating the need to reshore mining operations to Europe for decarbonisation and digitalisation efforts to be successful. Learn lessons from gas production in Groningen and compensate affected communities generously and early. Communicate the need for R&D efforts to make mining more sustainable and attract talent from around the world, with financial incentives and increased investment in education, to expand mining. (2) Build capabilities along the entire CRM supply chain, including mining, refining, and conversion and processing (not just mining operations) (3) Assess the equipment and expertise needed to reshore/onshore CRM mining operations in Europe. Seek alternatives to reliance on systemic rivals (e.g., China) (4) Engage in public-private partnerships, focusing on affluent companies in the semiconductor (e.g., ASML and NXP), EV-supply chains (e.g., Volkswagen), financial institutions (e.g., ABN AMRO) and the defence industry (e.g., Thales) to reshore refining, processing and where possible mining operations to Europe. Include key policy-industrialists councils in this, such as the Brussels-based Egmont Beraad and VNO-NCW. Organise a roundtable with all the aforementioned parties, including CRM mining, refining, and processing companies. (5) Advocate the inclusion of mining, refining and processing of those CRM required for the green transition and those needed for semiconductor production on the "green list" of the European sustainable finance taxonomy, provided that mining companies work on making the industry more sustainable and implement policies to "do no significant harm". (6) 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.
Reshoring of refining and processing operations to Europe	(1) NIMBY movements (2) Environmental concerns (3) Dependence on foreign (e.g., Chinese) equipment and expertise (4) Dependence on mines nearby refining and processing operations (5) Lack of skilled workers	(1) Create a political support base in wider society to address NIMBY and environmental concerns by communicating the need to reshore, refining, and conversion and processing (C&P) operations to Europe for de-carbonisation and digitalisation efforts to be successful. Learn lessons from gas production in Groningen and compensate affected communities generously and early. Communicate the need for R&D efforts to make refining and C&P more sustainable and attract talent from around the world, with financial incentives and increased investment in education, to expand mining. (2) Assess the equipment and expertise needed to reshore/onshore CRM operations in Europe. Seek alternatives to reliance on systemic rivals (e.g., China); and send trade mission especially to South-Korea, Japan, Canada and Australia for these purposes. Assess the desirability to set up a EU-Japan Trade and Technology council with specific appreciation for CRM-dependence reduction efforts (include the Japan External Trade Organisation and the Japanese Ministry of Economy, Trade and Industry). (3) Make the Port of Rotterdam the CRM refining and processing hub of Europe, by leveraging the Port's technological expertise build up due to its centrality in the EU economy, as well as its function as a fossil-fuel hub. • Expanding refining capacity can improve access to cobalt sulphate, as cobalt is predominantly refined in China but mined in the DRC. Creating a reliable new customer for DRC-cobalt, beyond Glencore and Chinese customers, may give European parties greater security of supply as well as a leverage to make demands on DRC-governance and human rights policies. Currently, Europe also relies on DRC-cobalt in the end-products it buys from states such as China.

106 An overview of all European semiconductor and CRM initiatives is included in section 3.

Table 8. Policy recommendations to overcome the challenges to expanding CRM security of supply (continued)

Current Initiative	Challenges	Policy Recommendation
Diversifying supply chain to partner states	(1) Limited sourcing countries	(1) Expand strategic partnerships for raw materials with other states to diversify the supply chain (e.g., Australia, Canada, Japan) (2) Promote closer cooperation between the public and private sector to identify and invest in foreign mining, refining and C&P operations with a coordinating role for governments. (3) Similar to Japan Oil, Gas and Metals National Corporation (JOGMEC), create a state-led company that coordinates and invests in overseas projects in partner states
Diversifying supply chain to third party states (mostly in the Global South other than China)	(1) Limited sourcing countries (2) Uncertain political allegiances (3) Regulatory uncertainty and political instability	(1) Expand strategic partnerships for raw materials with other states to diversify the supply chain (e.g., Turkey, DRC). The CRM work group as part of the CETA agreement is a good example. (2) Acknowledge that China's disinterest in including human rights and good governance clauses gives it short-term advantages in obtaining access to CRM in dictatorships (e.g., China Moly's dominance in the DRC). Appreciate global competition with China when devising ESG-related regulation and offer alternatives (such as investment opportunities in parts of the supply chain that add greater value, such as semiconductor production and battery-making) to companies and governments in the Global South to compete with China. ESG-related guidelines, especially those obliging companies to take responsibility for their entire supply-chain, now risk pushing out European companies. This runs counter to the goal of creating greater security of supply vis-à-vis China and Russia. (3) Engage in close cooperation between the public and private sector to identify and invest in foreign mining operations. (4) To mimic Japan's great success in limiting CRM-dependence on China, create a state-led company, like JOGMEC, that coordinates and invests in overseas CRM projects in third countries. Tools like InvestNL, NXTGEN High Tech and FMO may also prove suitable to expand access to CRM in third-party states.
Deep sea mining	(1) In early technological stages (exploration, not yet exploitation) (2) Limiting permitting environment as part of UNCLOS (3) Deposits in international waters, to which other countries (e.g., China) can also lay claim. (4) Environmental pollution	(1) Sponsor environmental impact studies of deep-sea mining. (2) Insist that permit-procedure for Deep Sea Mining licenses is speeded-up at the relevant sub-body within International Seabed Authority (ISA), under the UNCLOS. (3) Invest early in companies with deep-sea mining expertise. (4) Sponsor companies as the Netherlands government in order to already lay claim to particular deposits now under discussion at the ISA at UNCLOS. (5) Do not install a one-sided EU moratorium on Deep-Sea Mining. This risks strengthening China's position in the CRM value chain. Should environmental risks around deep-sea mining turn out to be too extreme over time, advocate global measures to minimise externalities.
Recycling	(1) Scientific limitations (2) Limited economic viability	(1) Initiate campaigns to make both consumers and producers aware of the importance of CRM recycling. (2) Financially incentivise CRM recycling operations through subsidies, etc. to increase economic viability. (3) Invest in R&D of CRM recycling. In particular, those on which the EU depends most on foreign sourcing. As gasoline and then hybrid cars in the EU are phased out from 2030 onwards, recycling can expand access for semiconductor producers to palladium as EV cars do not require this precious metal.
Reducing demand	(1) Growing demand due to energy transition (2) Limited alternatives to certain CRM	(1) In the energy transition, take into account the CRM needed for each course of action. (2) Invest in R&D to find viable alternatives to certain especially problematic CRM for products. (3) Fund research on making more efficient use of CRM in energy and digital applications.
Stockpiling	(1) Only a short-term solution for limited supply of CRM (2) Risks driving-up price (cost of silos and shortage)	(1) Create a network of secure storage locations. Especially the semiconductor industry can benefit from more CRM storage, as they make use of relatively small quantities of CRM. Expand private partnerships to combine private and public storage locations (see Strategic Petroleum Reserves USA). In addition, stockpile to guarantee defense production for reasons of national security.

4. Expand European leverage in the semiconductor and CRM ecosystem vis-à-vis other democracies

Dependence on fellow technologically advanced democracies, including the US, Taiwan, South Korea and Japan, in the CRM and semiconductor ecosystem comes with risks too. De-democratisation in the US, best exemplified by the January 6th riots in 2021 and the looming return of a Trump-like America First figure to the Presidency, risk renewed EU-US friction.[107] Taiwan faces a realistic risk of PLA military action against it. Military tensions between the US and Asian allies and China threaten freedom of navigation in the South and East China Sea, making access to Japan and South Korea no longer a given in a worst case scenario. The EU should achieve an indispensable position in the semiconductor and the CRM value chain within the camp of technologically advanced democracies.

Dependence on fellow technologically advanced democracies, including the US, Taiwan, South Korea and Japan, in the CRM and semiconductor ecosystem comes with risks too.

4.1 Invest in CRM mitigation efforts in first and foremost Canada and Australia, but also the US, as soon as possible. These states are making the most serious gains to address the CRM issue.

4.2 Increase the European part of the technologically advanced democracy-dominated semiconductor ecosystem. This can be achieved through further expansion of dominance in strong sectors (automotive), in lithography equipment, and by investing in vertically integrated chip manufacturing with industries that Europe is strong in. Continue to make a push for TSMC to set up a fab in Europe, as TSMC currently already does in the US and Japan.

5. Formulate and execute a broader strategy to reduce dependence on China and Russia

Mitigating dependence in the CRM for semiconductor ecosystem on China and Russia is not a silver bullet, as dependence for many end-products for purposes such as the digital and energy transition remains. In fact, cobalt mined in the DRC, refined in China, and fabricated into a semiconductor in Taiwan, is then exported to China for Foxconn to manufacture iPhones. In short, even if full mitigation of CRM-related risks could be achieved in several decades, this still leaves the world reliant on China for the production of over half a million iPhones per day and over a hundred different product categories.[108] A broader industrial policy to protect the EU against geopolitical fracture is necessary to safeguard economic security.

5.1 The Netherlands and the EU should look for synergies between semiconductor production and large-scale efforts to mitigate dependence. Many initiatives are already starting to achieve successes. These include the construction of giga factories for battery

107 These unilateral acts include imposing steel tariffs against the EU and the secondary sanctions on Iran blocking almost all European-Iranian trade following the US-withdrawal from the Iran-nuclear deal.

108 David Barboza, 'How China Built "IPhone City" With Billions in Perks for Apple's Partner', *The New York Times*, 29 December 2016, sec. Technology, https://www.nytimes.com/2016/12/29/technology/apple-iphone-china-foxconn.html.

production around Europe and the possibilities of growing demand for solar panels on the European market to attract mining, refining, and processing CRM capacity to Europe.[109] Both battery production for EVs and high demand for solar panels create strong demand for mining, refining and conversion, and processing of CRM, which are also needed for semiconductor production.

5.2 The Dutch government's National Security Council, announced in the Coalition Agreement of Rutte IV in January 2022, should be established as soon as possible. This body can make security of supply a top priority and oversee as well as coordinate the strategic dimension of all these dependencies.

5.3 Invest in strengths, in line with the advice given by ASML CEO Peter Wennink on how to compete with China: "This is what you do: relentless investment in innovation".[110]

5.4 Avoid fatalism. The world's reliance on China only came about in the last 40 years following Deng Xiaoping's political decision to reform and open-up the country. Industries largely moved to China in an era driven by cost-efficiency. If appropriate measures are taken and costs are accepted, taking back control over larger parts of the supply chain is a political decision that the Netherlands and the EU can take.

109 40% of China's supply of silicon for production comes from Xinjiang and is hence at risk of making use of large-scale forced labour.

110 NPO, 'Het geheim van ASML gemist?'

Table 9. Overview of high-level policy implications, policy opportunities and policy recommendations

Security implication	Policy recommendation
1. Prioritise security of supply in a world in which hard competition between great powers structurally threatens European economic security, including disruptions in the near future supply of CRM.	1.1 Prepare for persistent pressure on Dutch and broader European prosperity, which will go hand-in-hand with shortages, delays in delivery of products, and constant inflationary pressure due to geopolitical fracturing.
	1.2 The 2022 Dutch Ministry for Foreign Trade and Development Cooperation (BHOS) natural resource strategy is advised to take a "worst-case-scenario" approach to preventing, mitigating, and preparing for the consequences of severe CRM supply disruptions.
	1.3 The government should engage in stress testing to identify the effects of likely and impactful CRM supply disruptions.
	1.4 Institute a top-down approach to reducing strategic dependencies, for instance through the establishment of a National Security Council and an Energy Council, an advisory body for energy affordability, robustness of the energy system and security of supply.
2. Accept that the US-China tech rivalry is likely to put the supply of semiconductors, digital end-products and products needed for the energy transition to the EU at risk.	2.1 Address the adverse (un)intended consequences of the US-China tech rivalry. European policy-makers are advised to anticipate that Europe's enormous strategic dependence on Washington will increasingly impel the EU to participate in the US-China tech rivalry on the side of the US.
	2.2 The Dutch government and its semiconductor companies are advised to explore new approaches to get more in return for participating in the US-led tech-showdown with China.
3. Work with other technologically advanced democracies and non-rival CRM-producing autocracies to mitigate semiconductor and CRM ecosystem risks vis-à-vis Russia and China.	3.1. Make use of the opportunities provided by the dominance of technologically advanced democracies in the semiconductor value chain, for instance in order to deter destabilising acts by rivals.
	3.2. Start policy-initiatives to mitigate CRM-related dependencies and risks now to achieve results in the medium-term.
4. Expand European leverage in the semiconductor and CRM ecosystem vis-à-vis other democracies such as the US, Taiwan, South Korea and Japan.	4.1 Invest in CRM mitigation efforts first and foremost in Canada and Australia, but also the US, as soon as possible, as these states are making the most serious gains to address the CRM issue.
	4.2 Increase the European part of the technologically advanced democracy-dominated semiconductor ecosystem
5. Formulate and execute a broader strategy to reduce dependence on China and Russia.	5.1 The Netherlands and the EU should look for synergies between semiconductor production and large-scale efforts to mitigate dependence that are starting to achieve successes already.
	5.2 The Dutch government's National Security Council, announced in the Coalition Agreement of Rutte IV in January 2022, should be established as soon as possible.
	5.3 Invest in strengths, in line with the advice given by ASML CEO Peter Wennink on how to compete with China: "This is what you do: relentless investment in innovation".[111]
	5.4 Avoid fatalism. If appropriate measures are taken and costs are accepted, taking back control over larger parts of the supply chain is a political decision that the Netherlands and the EU can take.

111 NPO, 'Het geheim van ASML gemist? Start met kijken op NPO Start', www.npostart.nl, accessed 28 September 2022, https://www.npostart.nl/vpro-tegenlicht/12-09-2022/VPWON_1335235.

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Annex

Appendix 1: Expert Interview List

Note: This list is not exhaustive. Only the expert and stakeholder interviewees that stated they were willing to be mentioned in the report are listed. It does contain the majority of people interviewed (17 out of 22).

1. David Bekkers, Senior Innovation, Technology & Science Officer at the Dutch Consulate in Shanghai
2. Sebastiaan Bennink, Export Control Lawyer at BenninkAmar Advocaten
3. Rutger Bosland, Project Manager Deep Sea Mining at Allseas
4. Rogier Creemers, Assistant professor in the Law and Governance of China at Leiden University
5. Tom Diederen, Dutch representative at the International Seabed Authority and Legal Counsel at the Ministry of Foreign Affairs (Minbuza)
6. Peter Flory, Senior Fellow and Director, at SAFE's American Semiconductor Center
7. Fergus Hunter, Analyst at the Australian Strategic Policy Institute (ASPI)'s Cyber Policy Centre
8. Muriel van der Klei, Senior Policy Advisor at the Division "Topsectoren en industriebeleid" (i.e., High-value sectors and industrial policy) at the Ministry of Economic Affairs and Climate (MinEZK)
9. Linda Lengowski, Vice-President Strategy, Geopolitics and ESG at NXP Semiconductors
10. Jonathan Miller, Director of the Indo-Pacific Program at the MacDonald Laurier Institute
11. Stephen Nagy, Senior Associate Professor at the International Christian University in Japan
12. Michel Rademaker, Deputy Director of HCSS and Subject Matter Expert on Critical Raw Materials
13. Jeff Amrish Ritoe, HCSS Subject Matter Expert on Energy & Raw Materials
14. Henne Schuwer, Former Dutch Ambassador to the United States
15. Philip Shetler-Jones, James Cook Associate Fellow in Indo-Pacific Geopolitics at the Council on Geostrategy and Japan Expert
16. Martijn Vlaskamp, Juan de la Cierva Incorporación Research Fellow at Barcelona Institute of International Studies and natural resource expert expert
17. Abigail Wolf, Director of the Ambassador Alfred Hoffman, Jr. Center for Critical Minerals Strategy at SAFE

Appendix 2: Expert Survey Respondents

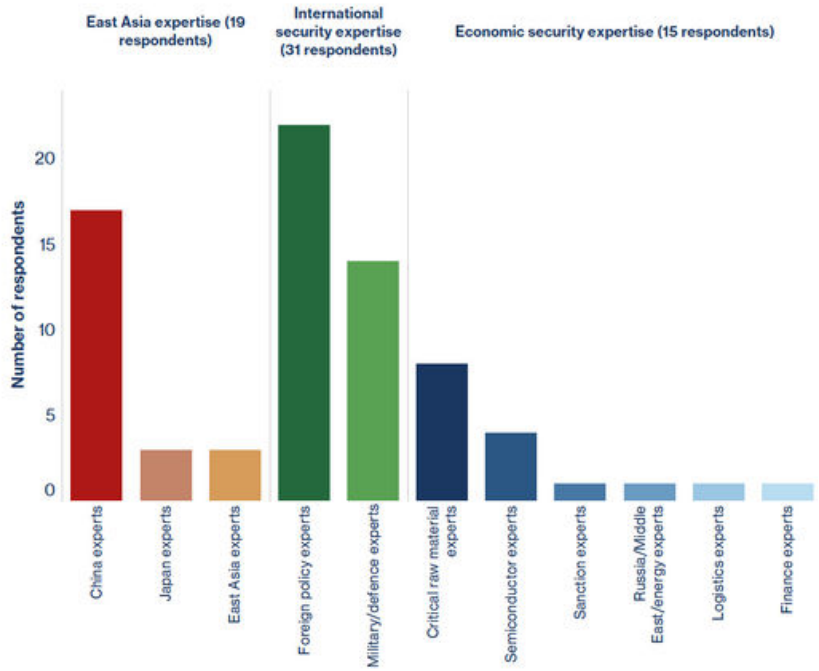
Note: This list is not exhaustive. Only the participants that stated they were willing to be mentioned in the report are listed. It does contain the majority of respondents (29 out of 49).

1. Ties Dams, Research Fellow at the Clingendael Institute
2. Tom Middendorp, Former General of the Royal Netherlands Army
3. Fons Stoelinga, Former Dutch Ambassador to India
4. Ed Kronenburg, Former Dutch Ambassador to China
5. Jagannath Panda, Director Indo-Pacific ISDP in Sweden
6. Henne Schuwer, Former Dutch Ambassador to the US
7. Michel Rademaker, Deputy Director at HCSS
8. Jonathan Berkshire Miller, Senior Fellow on the Indo-Pacific at the Macdonald Laurier Institute
9. Stephen Nagy, Senior Associate Professor at the International Christian University in Japan
10. Philip Geurts, Oil analyst at BloombergNEF
11. Frank Bekkers, Program Director at HCSS
12. Tim Sweijs, Director of Research at HCSS
13. Irina Patrahau, Strategic Analyst at HCSS
14. Maurice Fremont, Former Business Europe Political Secretary at the European Parliament
15. Zsuzsa Anna Ferenczy, Assistant Professor at National Dong Hwa University
16. Valérie Hoeks, Managing Partner at China Inroads
17. Martijn Vlaskamp, Juan de la Cierva Incorporación Research Fellow at Barcelona Institute of International Studies
18. Giliam Bresser, Military Advisor at the Dutch Ministry of Foreign Affairs
19. Jeroen de Jonge, Business Director Naval and Maritime at TNO
20. Wendela Haringhuizen, Strategic Advisor Security Policy at the Dutch Ministry of Foreign Affairs
21. Josanne van Gorkum, Strategic Policy Advisor at the Dutch Ministry of Defense
22. Julian Kamasa, Senior Researcher at the Center for Security Studies
23. Tobias Gehrke, CRM Expert Research Fellow at the Egmont Institute
24. Jan van der Putten, Former China Correspondent at Volkskrant and Current China Editor at De Groene Amsterdammer
25. Benjamin Sprecher, CRM Expert and Guest Researcher at Leiden University
26. Jeff Amrish Ritoe, HCSS Subject Matter Expert on Energy and Raw Materials
27. Henk Schölte Nordholt, Professor at Leiden University
28. Paul Verhagen, HCSS Subject Matter Expert
29. Friso Stevens, HCSS China and East Asia Affairs Specialist

The Critical Raw Material risks for semiconductor supply foresight survey

The 49 respondents

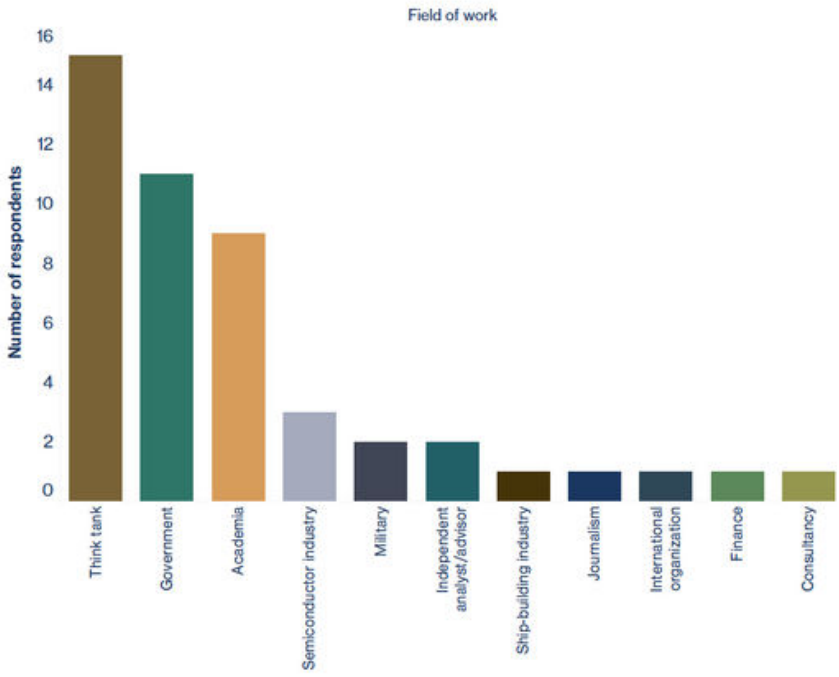
Respondents' field of expertise



The foresight survey was filled out by 49 experts, who were asked to choose the area(s) of knowledge that best describe(s) their expertise, their sector of current/former employment and whether their names could be mentioned in the report (without connecting their identities to their answers). The group of respondents is diverse, as it contains respondents with expertise on China, Japan, Russia, military/defense, critical raw materials, semiconductors and other topics. The respondents come from a variety of sectors of employment such as the thinktank world, government, academia, industry and the military.

The respondents have different levels of seniority: some are early/mid-career specialists whilst others are (retired) senior diplomats (e.g., former Dutch ambassadors to China, India and the United States), thinktank directors and military commanders (e.g., a former Netherlands Chief of Defence). The full list of the experts who indicated they could be mentioned as respondents (29 out of 49) can be found in the annex. The respondents are mostly Dutch nationals, but some experts from other European states, the Americas and the Indo-Pacific region also participated.

Respondents' field of work



Appendix 3: Survey Outcome – Raw Data

Overall Outcome

- Geopolitical risks
- Geoeconomic risks
- Military risks
- Legal risks

Question	Impact	Years	Probability	Total
Palladium export embargo by Russia	6,957	5	5,574	38,779
Gallium, Germanium, Cobalt REE export embargo by China	7,936	5	4,625	36,705
Demand-induced resource shortage	7,617	5	6,918	52,697
Events inside China	6,745	5	5,542	37,377
PLA naval blockade/invasion of Taiwan	8,348	5	4,313	36
Political instability in DRC	7,109	5	5,396	38,357
War in East China Sea	8,261	5	3,229	26,676
War in South China Sea	8,087	5	3,417	27,630
US blockade halting Chinese oil and gas imports	7,370	5	3,313	24,412
Stringent ESG-regulation	7,021	5	5,143	36,109
Palladium export embargo by Russia	6,957	10	5,766	40,111
Gallium, Germanium, Cobalt REE export embargo by China	7,936	10	5,979	47,452
Demand-induced resource shortage	7,617	10	7,612	57,983
Events inside China	6,745	10	5,375	36,253
PLA naval blockade/invasion of Taiwan	8,348	10	5,646	47,130
Political instability in DRC	7,109	10	6,083	43,245
War in East China Sea	8,261	10	4,271	35,281
War in South China Sea	8,087	10	4,458	36,054
US blockade halting Chinese oil and gas imports	7,370	10	3,854	28,404
Stringent ESG-regulation	7,021	10	5,551	38,975

China, Japan, East-Asia Experts

Geopolitical risks

Geoeconomic risks

Military risks

Legal risks

Question	Impact	Years	Probability	Total
Palladium export embargo by Russia	6,611	5	4,778	31,586
Gallium, Germanium, Cobalt REE export embargo by China	7,684	5	4,474	34,377
Demand-induced resource shortage	7,158	5	6,737	48,222
Events inside China	6,263	5	5,316	33,294
PLA naval blockade/invasion of Taiwan	8,684	5	3,842	33,366
Political instability in DRC	6,944	5	5,111	35,494
War in East China Sea	8,579	5	4,125	35,388
War in South China Sea	8,474	5	3,263	27,651
US blockade halting Chinese oil and gas imports	6,842	5	3,579	24,488
Stringent ESG-regulation	6,684	5	5,105	34,125
Palladium export embargo by Russia	6,611	10	5,389	35,627
Gallium, Germanium, Cobalt REE export embargo by China	7,684	10	5,684	43,679
Demand-induced resource shortage	7,158	10	7,316	52,366
Events inside China	6,263	10	5,211	32,634
PLA naval blockade/invasion of Taiwan	8,684	10	4,789	41,593
Political instability in DRC	6,944	10	5,778	40,123
War in East China Sea	8,579	10	3,947	33,864
War in South China Sea	8,474	10	4,158	35,233
US blockade halting Chinese oil and gas imports	6,842	10	3,632	24,848
Stringent ESG-regulation	6,684	10	5,684	37,994

International Security Experts

Geopolitical risks

Geoeconomic risks

Military risks

Legal risks

Question	Impact	Years	Probability	Total
Palladium export embargo by Russia	7,207	5	5,633	40,599
Gallium, Germanium, Cobalt REE export embargo by China	7,931	5	4,667	37,011
Demand-induced resource shortage	7,759	5	7,065	54,811
Events inside China	6,966	5	5,600	39,007
PLA naval blockade/invasion of Taiwan	8,464	5	4,333	36,679
Political instability in DRC	7,379	5	5,452	40,229
War in East China Sea	8,250	5	2,933	24,200
War in South China Sea	8,286	5	3,200	26,514
US blockade halting Chinese oil and gas imports	7,321	5	2,967	21,720
Stringent ESG-regulation	6,793	5	5,258	35,719
Palladium export embargo by Russia	7,207	10	5,967	43,001
Gallium, Germanium, Cobalt REE export embargo by China	7,931	10	6,000	47,586
Demand-induced resource shortage	7,759	10	7,710	59,816
Events inside China	6,966	10	5,467	38,078
PLA naval blockade/invasion of Taiwan	8,464	10	5,667	47,964
Political instability in DRC	7,379	10	6,355	46,894
War in East China Sea	8,250	10	3,867	31,900
War in South China Sea	8,286	10	4,357	36,102
US blockade halting Chinese oil and gas imports	7,321	10	3,857	28,240
Stringent ESG-regulation	6,793	10	4,867	33,060

Economic Security Experts

Geopolitical risks

Geoeconomic risks

Military risks

Legal risks

Question	Impact	Years	Probability	Total
Palladium export embargo by Russia	6,929	5	5,154	35,709
Gallium, Germanium, Cobalt REE export embargo by China	8,533	5	4,643	39,619
Demand-induced resource shortage	7,400	5	6,733	49,827
Events inside China	7,133	5	6,000	42,800
PLA naval blockade/invasion of Taiwan	8,214	5	3,786	31,097
Political instability in DRC	7,286	5	5,214	37,990
War in East China Sea	8,143	5	3,357	27,337
War in South China Sea	7,714	5	3,357	25,898
US blockade halting Chinese oil and gas imports	7,000	5	3,857	27,000
Stringent ESG-regulation	7,600	5	4,400	33,440
Palladium export embargo by Russia	6,929	10	4,615	31,978
Gallium, Germanium, Cobalt REE export embargo by China	8,533	10	6,214	53,029
Demand-induced resource shortage	7,400	10	7,600	56,240
Events inside China	7,133	10	5,500	39,233
PLA naval blockade/invasion of Taiwan	8,214	10	5,143	42,245
Political instability in DRC	7,286	10	6,214	45,276
War in East China Sea	8,143	10	4,286	34,898
War in South China Sea	7,714	10	4,357	33,612
US blockade halting Chinese oil and gas imports	7,000	10	3,857	27,000
Stringent ESG-regulation	7,600	10	4,867	36,987

Raw Data

	Geopolitical risks						Geoeconomic risks						Legal risks		
Respondent #	Probability 5: Palladium export embargo by Russia	Probability 10: Palladium export embargo by Russia	Impact: Palladium export embargo by Russia	Probability 5: Gallium, Germanium, Cobalt REE export embargo by China	Probability 10: Gallium, Germanium, Cobalt REE export embargo by China	Impact: Gallium, Germanium, Cobalt REE export embargo by China	Probability 5: Demand-induced resource shortage	Probability 10: Demand-induced resource shortage	Impact: Demand-induced resource shortage	Probability 5: Events inside China	Probability 10: Events inside China	Impact: Events inside China	Probability 5: Stringent ESG-regulation	Probability 10: Stringent ESG-regulation	Impact: Stringent ESG-regulation
1	5	5	3	3	3	7	8	8	3	3	3	3	3	3	3
2	4	5	5	1	2	7	6	8	7	5	3	5	3	4	3
3	2	3	6	2	4	8	7	7	6	8	5	7	6	6	7
4	7	7	7	7	7	7	7	7	7	5	7	7	6	6	8
5	7	7	9	6	7	9	7	9	9	5	6	8	7	8	8
6	2	2	3	3	4	7	8	8	8	3	2	2	2	2	7
7	3	4		2	3		6	6		2	2		2	2	
8	8	8		5	5		9	9		5	5		7	7	
9	3	3	5	6	9	8	3	8	9	9	9	9	5	5	9
10	8	9	8	5	6	8	6	7	8	5	7	8	7	8	6
11	2	2	7	2	3	8	8	9	9	10	10	4	3	5	6
12	8	7	8	6	7	9	9	8	6	8	7	8	6	6	6
13	8	4	7	3	5	8	8	9	7	5	5	8	0	0	7
14	7	8	10	5	7	9	8	8	10	4	7	7	6	5	8
15	2	3	4	3	7	10	6	6	4	2	3	7	2	5	7
16	5	5	7	3	4	8	6	7	8	7	6	8	7	6	6
17	4	3	8	5	7	8	5	8	8	4	3	8	3	3	6
18	3	5	8	4	5	8	6	7	7	4	3	3	7	8	8
19	6	6	7	6	6	7	6	6	7	7	7	6	4	2	8
20	7	7	6	3	4	7	9	10	9	3	3	5	4	5	7
21	4	8	7	3	6	9	10	10	10	7	2	8	10	7	9
22	3	2	2	2	3	4	4	5	4	0	0	0	2	2	3
23	6	7	8	5	8	8	8	7	7	6	6	6	8	8	6
24	5	7	8	6	8	9	7	8	9	7	7	8	4	5	9

	Geopolitical risks						Geoeconomic risks						Legal risks		
Respondent #	Probability 5: Palladium export embargo by Russia	Probability 10: Palladium export embargo by Russia	Impact: Palladium export embargo by Russia	Probability 5: Gallium, Germanium, Cobalt REE export embargo by China	Probability 10: Gallium, Germanium, Cobalt REE export embargo by China	Impact: Gallium, Germanium, Cobalt REE export embargo by China	Probability 5: Demand-induced resource shortage	Probability 10: Demand-induced resource shortage	Impact: Demand-induced resource shortage	Probability 5: Events inside China	Probability 10: Events inside China	Impact: Events inside China	Probability 5: Stringent ESG-regulation	Probability 10: Stringent ESG-regulation	Impact: Stringent ESG-regulation
25	8	8	8	6	7	7	7	7	7	8	8	8	8	7	7
26	7	9	4	4	5	8	8	7	9	4	3	7	7	7	8
27	8	9	9	8	8	8	8	8	9	9	9	8	8	8	8
28	8	5	9	8	9	9	9	10	10	8	3	9	7	8	9
29	4	3	5	5	4	5	7	7	7	4	4	6	6	5	8
30	4	2	4	2	4	7	7	9	8	5	8	8	2	4	7
31	8	8	9	5	8	8	5	8	8	7	5	8	8	9	8
32	5	5	7	6	7	8	7	8	9	6	7	6	6	6	6
33	7	7	9	6	7	9	6	7	8	8	6	9	8	9	8
34	9	7	9	7	8	9	7	8	9	3	1	7	5	6	8
35	8	8	7	5	5	7	6	8	6	5	5	5	6	6	4
36	7	8	6	7	7	7	8	8	7	7	7	5	5	7	8
37	6	7	8	6	7	8	8	9	9	7	8	8	6	7	8
38	5	7	9	3	7	9	3	7	7	2	5	7	8	9	9
39			9			10	8	8	8			8	5	8	7
40	3	2	6	2	6	8	6	6	8	2	2	8	1	1	8
41	8	8	8	4	9	10	7	8	8	8	8	6	4	4	9
42				7	8	9	7	8	9	7	8	9	6	7	9
43	7	7	6	2	2	7	8	7	8	3	3	8	3	3	7
44	6	6	7	4	6	7	6	7	6	5	6	7	4	5	6
45	5	5	5	6	7	7	5	5	5	6	6	6	8	9	5
46	1	7	9	6	8	7	7	7	8	4	4	4	1	1	2
47	8	7	5	7	8	8	7	6	6	7	7	7	3	5	5
48	5	5	9	7	7	9	8	8	9	8	8	9	4	4	9
49	6	4	10	3	3	9	7	7	8	9	9	9	9	9	10

	Military risks														
Respondent #	Probability 5: PLA naval blockade/ invasion of Taiwan	Probability 10: PLA naval blockade/ invasion of Taiwan	Impact: PLA naval blockade/ invasion of Taiwan	Probability 5: Political instability in DRC	Probability 10: Political instability in DRC	Impact: Political instability in DRC	Probability 5: War in East China Sea	Probability 10: War in East China Sea	Impact: War in East China Sea	Probability 5: War in South China Sea	Probability 10: War in South China Sea	Impact: War in South China Sea	Probability 5: US blockade halting Chinese oil and gas imports	Probability 10: US blockade halting Chinese oil and gas imports	Impact: US blockade halting Chinese oil and gas imports
1	4	5	3	3	3	3	3	6	3	4	5	3	3	3	3
2	2	4	10	3	4	5	1	2	10	2	3	9	1	2	9
3	3	5	8	8	9	7	2	2	5	3	3	6	3	3	8
4	7	6	7	5	8	9	5	6	9	5	6	9	5	5	8
5	5	8	8	7	8	8	5	8	8	5	8	8	5	6	7
6	2	3	7	5	5	6	1	1	9	1	1	7	0	0	9
7	1	3		1	2		1	1		0	1		1	1	
8	3	6		7	7		3	4		2	2		2	2	
9	3	3	7	4	7	9	3	3	7	3	3	7	3	3	8
10	5	8	8	8	8	6	4	5	8	6	8	8	2	3	8
11	1	1	9	2	4	9	0	1	10	0	0	10	1	1	5
12	6	6	9	6	7	8	6	6	8	6	6	8	5	6	8
13	2	6	7	1	4	8	3	5	8	2	6	8	3	3	5
14	2	3	10	4	4	8	1	2	10	1	2	10	2	4	8
15	1	3	10	4	8	6	1	1	10	1	1	10	2	3	2
16	4	5	9	7	7	6	4	5	8	5	6	8	3	4	8
17	1	2	8	6	7	9	1	2	8	1	2	7	1	1	2
18	4	6	8	5	5	5	4	5	6	3	5	7	4	5	6
19	4	4	8	5	5	5	4	4	8	4	4	6	4	4	8
20	3	4	8	7	8	7	2	3	8	2	2	8	2	3	7
21	6	9	10	8	7	10	2	7	10	1	3	7	5	7	10
22	5	7	8	3	3	3	5	6	9	5	6	8	2	2	2
23	3	6	10	6	7	6	1	3	9	2	4	8	1	1	7
24	6	8	9	3	4	7	1	2	9	2	3	10	2	4	8

	Military risks														
Respondent #	Probability 5: PLA naval blockade/ invasion of Taiwan	Probability 10: PLA naval blockade/ invasion of Taiwan	Impact: PLA naval blockade/ invasion of Taiwan	Probability 5: Political instability in DRC	Probability 10: Political instability in DRC	Impact: Political instability in DRC	Probability 5: War in East China Sea	Probability 10: War in East China Sea	Impact: War in East China Sea	Probability 5: War in South China Sea	Probability 10: War in South China Sea	Impact: War in South China Sea	Probability 5: US blockade halting Chinese oil and gas imports	Probability 10: US blockade halting Chinese oil and gas imports	Impact: US blockade halting Chinese oil and gas imports
25	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
26	6	7	9	5	5	7	3	4	8	3	4	8	3	4	8
27	8	8	9	7	7	8	6	6	8	8	8	8	8	8	8
28	9	6	9	6	8	8	7	8	9	7	9	9	3	5	9
29	4	4	7	6	6	6	2	2	8	3	3	8	2	2	6
30	8	9	8	7	8	9	2	4	9	2	3	9	2	3	7
31	5	8	8	5	7	8	3	5	8	3	5	8	3	7	8
32	6	8	5	5	5	8	2	2	7	4	6	7	2	2	7
33	9	10	10	4	4	9	6	7	8	4	5	8	7	8	9
34	7	8	9	5	6	9	6	7	9	5	6	7	6	7	9
35	5	7	9	4	4	5	2	4	9	2	3	9	1	2	10
36	5	8	8	6	8	7	4	6	6	5	7	8	7	5	7
37	4	5	8	6	5	7	8	6	8	6	7	9	6	5	8
38	8	9	9	5	5	5	5	8	9	6	9	9	3	7	9
39				7	8	8									
40	1	5	8	6	7	8	1	2	8	1	2	8	1	1	8
41	3	7	10	8	8	6	2	6	10	2	6	10	2	6	9
42	6	7	10				6	7	10	6	7	10	6	6	8
43	2	2	8	8	8	9	0	0	9	0	0	9	2	2	8
44	3	4	7	6	7	6	4	5	7	3	4	6	3	5	6
45	2	3	10	5	5	5	2	3	8	2	3	8	1	2	8
46	0	0	9	3	3	8	0	0	8	0	0	9	1	1	9
47	7	8	7	6	6	6	4	6	7	7	7	6	6	6	6
48	6	8	8	8	8	9	8	8	9	8	8	9	6	6	9
49	2	1	10	5	5	8	1	1	10	3	4	10	8	1	9

The Hague Centre
for Strategic Studies

HCSS
Lange Voorhout 1
2514 EA Hague

Follow us on social media:
@hcssnl

The Hague Centre for Strategic Studies
Email: info@hcss.nl
Website: www.hcss.nl