The Hague Centre
for Strategic Studies

Executive Summary

Reaching breaking point

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

Joris Teer, Mattia Bertolini

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Executive summary

Both semiconductors and critical raw materials (CRM) have been described as *the oil of the 21st century*. 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 research and development (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 Ultra-Violet (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, https://www.leiden-delft-erasmus.nl/en/news/the-energy-transition-a-monumental-shift-in-resources-and-policies#:~:text=The%20energy%20transition%3A%20a%20monumental%20shift%20in%20resources%20and%20policies,-21%20Jun%202022&text=For%20dr%20Ren%C3%A9%20Kleijn%20time,than%202025%2C%E2%80%9D%20he%20says.

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 chapter 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 Chapter 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. 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-Russian 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 United States (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

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.

over mines in 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 behind 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 mitigating their vulnerabilities.

Europe in the semiconductor and CRM ecosystem

Opposing camps in the semiconductor and CRM ecosystem try to win interdependence.

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.

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

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.

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.

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 dominated by rival states, 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.

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

The Netherlands plays a small yet indispensable role in the semiconductor supply chain, in which Dutch supplies of semiconductor manufacturing equipment forms a major chokepoint 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.

A fragile supply chain balance

The semiconductor and critical raw material ecosystem

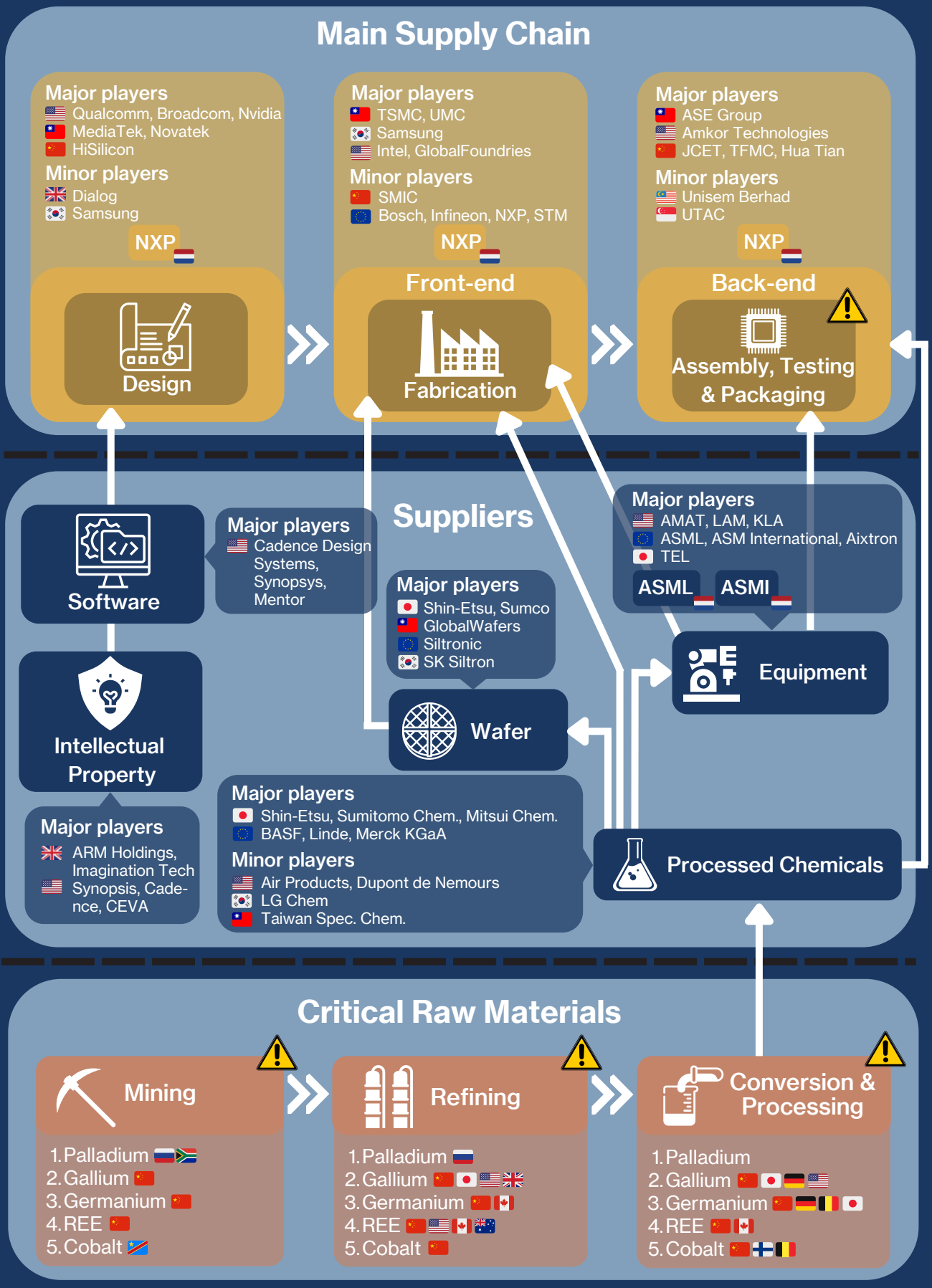

Table 1. Stranglehold: China and Russia's control over six key CRM for the fabrication of semiconductors and green applications

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 as Taiwan throughout this decade (see Table 2).

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 *ii. Case study Reaching breaking point: Weaponisation of European-Russian trade in vital commodities following Russia's invasion of Ukraine*). 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 2). 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.

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

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.[22]

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

The respondents found that there is a higher than 50% change that Taiwan will face a PLA maritime blockade or invasion before 2032.

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"[23] and three to have a "very high impact" (see Figure 2).[24] 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.

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.

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22 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/.

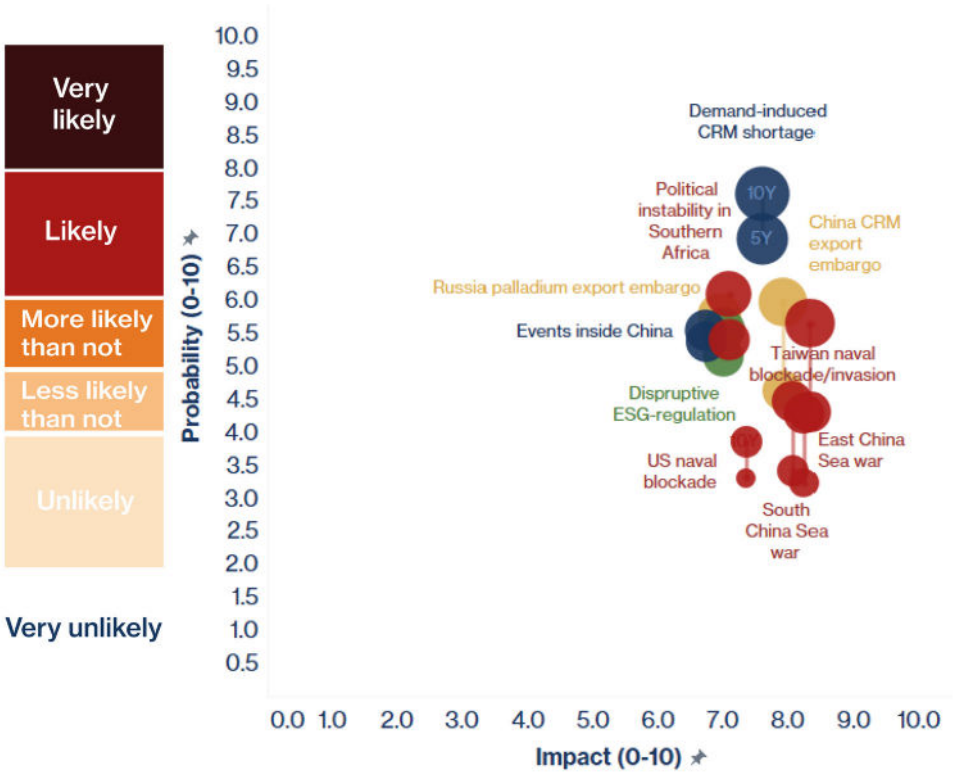
23 Threat 1, 2,3,4,6,9,10

24 Threat 5, 7, 8

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.[25] 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.

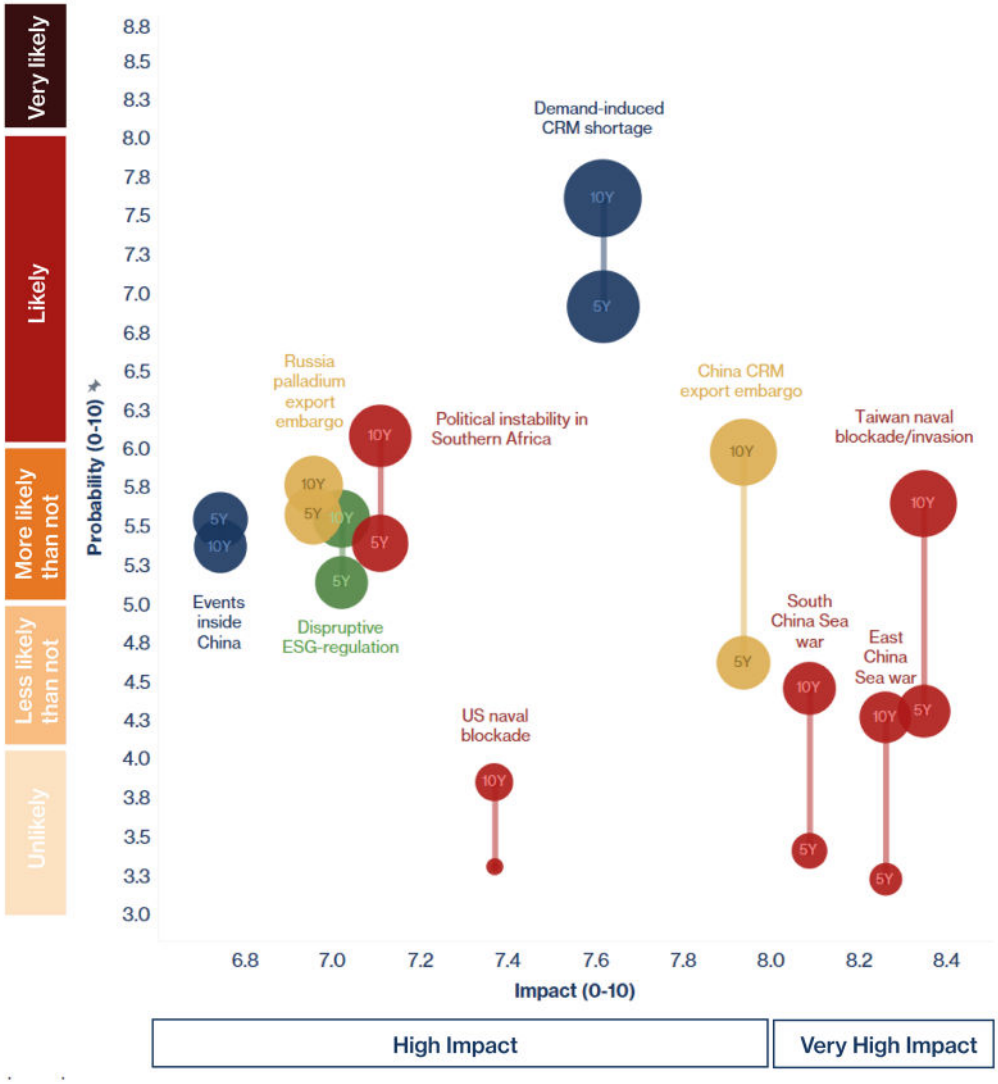
5. **Political unrest or even intrastate conflict in Southern African states are likely to disrupt the supply of cobalt (see Figure 2)**. Political unrest in Southern Africa, another military threat, is deemed "more likely than not" to disrupt the supply of CRM for semiconductors in the next five years, 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.

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



[25] All expected to have a "very high impact".

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



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.**

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[26], whilst at the same time attempting to mitigate their CRM dependence.[27] 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.[28]

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).[29] 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.[30] 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.[31]

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.

26 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.

27 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/.

28 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.

29 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."

30 "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/.

31 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.

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.[32] These initiatives either come with challenges, such as *Not In My Backyard-protests* (NIMBY), environmental concerns, technological and economic limitations, limited alternative sourcing countries, or only provide short-term solutions.[33] 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 advanced, semiconductor-fabricating, democracies and CRM-producing rival states, namely Russia and China, and non-rival states, meaning the DRC (see Chapter 1: A fragile supply chain 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 Chapter 2: Threats to the supply of CRM for semiconductors). 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 Chapter 3: Winning interdependence).

To address these challenges policy-makers are advised to appreciate five high-level policy implication themes, which come with specific policy opportunities and recommendations.[34]

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.

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32 "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.

33 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.

34 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.

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.[35]

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

[35] 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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