The Hague Centre for Strategic Studies

Worlds of Access or Absence

Supply Security and Maritime Security in an Era of Intense Geopolitical Competition

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Executive summary

Policymakers and business leaders should pay attention to the multiple ways in which access to key economic inputs can be disrupted, whether through control over supplies or threats to transport, specifically maritime transport routes. Even in optimistic high access scenarios where there is increased supply and more suppliers, much of the world's trade will still take place over a limited set of maritime transport routes and through very few maritime chokepoints. European and Asian powers, as each other's key trade partners, should therefore invest in diversification of supply and suppliers, and cooperate on maritime security provision.

The current situation is the consequence of the advent of hyper-globalization after 1989 and the lowering of trade barriers, which made specialisation increasingly possible. Supply chains consequently more and more complex. Effective maritime transport allowed a further emphasis on efficiency between disparate markets and just-in-time deliveries. Yet, the increasing complexity of supply chains also enhanced their vulnerabilities, by increasing the number of points where their flows can be interrupted. This applies to materials, energy, and technology components, as well as the physical routes that these goods cross.

Key states in Europe and Asia – especially small and middle powers – are particularly affected by this dual challenge to access.

Today, the supply of crucial resources depends heavily on international shipping, particularly through several chokepoints stretching from the Western Pacific to the Suez Canal. In the past, US unipolarity and power were particularly useful for protecting the maritime commons and ensuring that these chokepoints remained unobstructed. However, this period of dominance is over, if not globally, at least regionally in the Indo-Pacific. China's rise poses not only a technological-economic challenge, it is also a military threat to maritime and air access due to the country's investments in various weapons capabilities on land, in the air, and at sea.

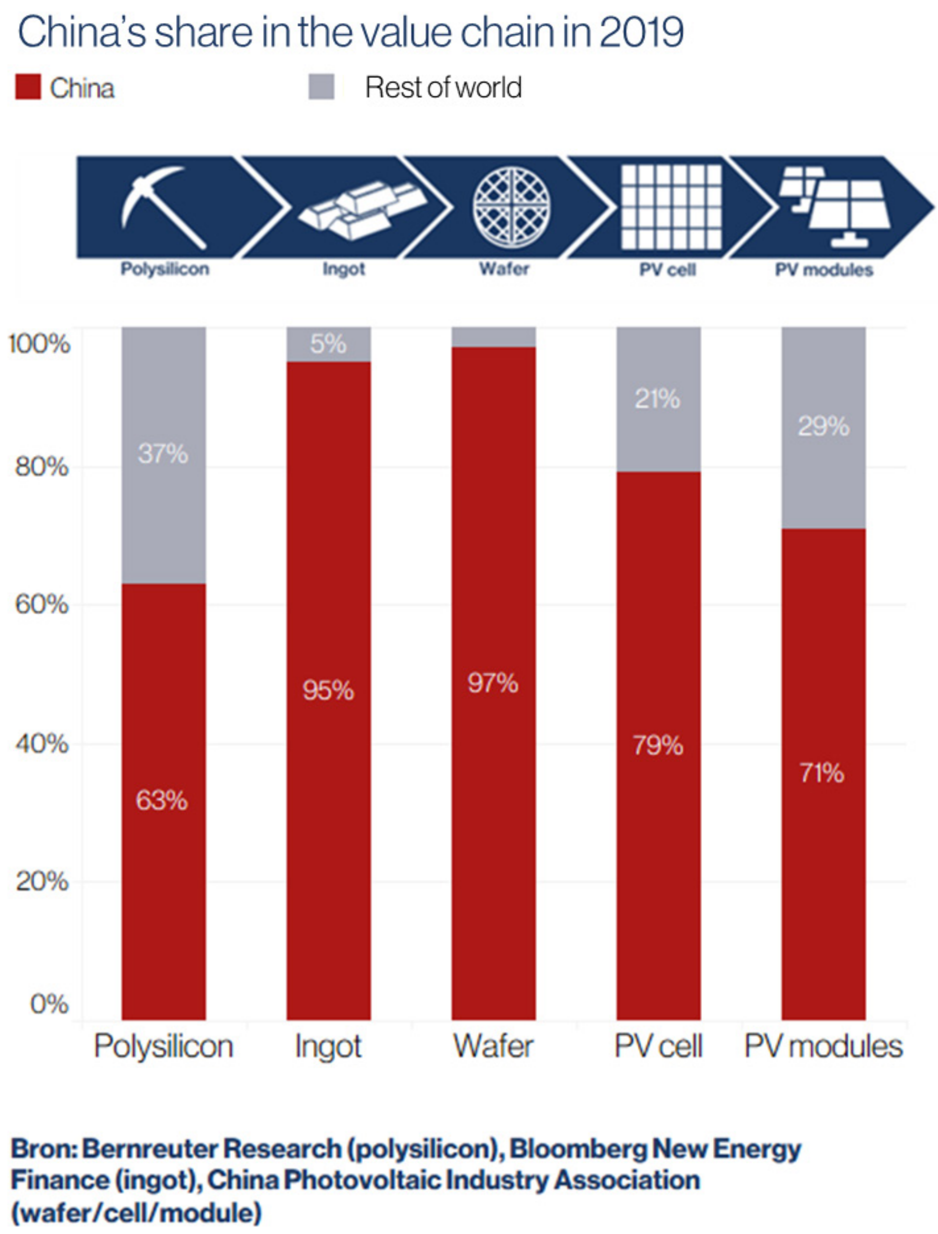
Key states in Europe and Asia – especially small and middle powers – are particularly affected by this dual challenge to access. They owe their prosperity both to their advanced technology sectors and trade more broadly, and they are dependent on and thus very vulnerable to access to the global maritime commons and markets. This includes states and actors like Japan, South Korea, Taiwan, Germany, France, the UK, the Netherlands, and others. However, these nations are also crucial in reverse; not only do their economies contribute to the global economy disproportionately, their technologies are also key to competitive military applications that directly shape the global balance of power. This presents them with a conundrum: they are both vulnerable and can be exploited for the vulnerabilities others have towards them.

This report assesses the supply of key economic resources along global supply chains from the Indo-Pacific, the stability of access to them in the future, as well as potential vulnerabilities. Access is thereby conceived of as depending on the interaction between the overall supply of a critical economic input and the number of suppliers, combined with the maritime (and air) transport means available. Great powers with revisionist intentions threatening or owning one or more technological or physical chokepoints are only a risk if few or no alternatives are available. Costs may still go up, but the credibility of the threat to deny access is less pressing. In our view, if multiple access points exist, the threat emanating from any great power decreases.

While acknowledging that the analysis is not exhaustive, this report focuses on a cross-section of key economic inputs including high-end technologies, raw materials, and energy, specifically: (I) oil and liquified natural gas; (II) cobalt and silicon; and (III) semiconductors. All of these resources are set to remain essential in the upcoming decades and even increase in demand. Several of them are currently highly dominated by a limited number of suppliers. For example. As Figure 1 shows, China dominates the entire global solar panel supply chain, starting from silicon.

These five key economic inputs also depend on a limited number of transport routes, or sea lines of communication, between East Asia, the Middle East and North Africa (MENA), Europe, and North America. The trade of crude oil and LNG inevitably passes by the Asia Pacific, Middle East and Europe. Middle Eastern countries such as Saudi Arabia, Iraq, and the UAE are big players in the oil market, exporting in the direction of both Europe to the west and the Asia Pacific to the east. Asia Pacific states such as Australia and Malaysia as well as MENA countries supply the most LNG globally. This means that energy supply chains make use of seven different chokepoints: the Strait of Hormuz, Strait of Malacca, Lombok Strait, Mozambique Strait, Bab el Mandeb, Taiwan Strait, and Suez Canal. Raw materials such as cobalt and silicon are also moved across these chokepoints, as their supply chains involve four key regions: Africa, East Asia, Europe, and North America. In particular, silicon is exported from the United States, Germany, Norway and China to Europe and the Asia Pacific, while most cobalt mines are in the DRC and the extracted material travels to China for refinement before being exported to the rest of the world. Lastly, the supply chain of semiconductors spans the entire world but its major players are United States, Taiwan, South Korea, China, Japan, and Europe. While most semiconductors travel by air, the inputs necessary for fabrication and ATP processes often make use of maritime trade, passing via the straits of Malacca, Lombok, Taiwan, Korea, Luzon, Makassar, and Sunda.

Figure 1. China Dominates the entire Solar Supply Chain[1]



To assess whether the supplies of these five key economic resources are likely to be stable, we look at three dimensions that influence access: (I) political; (II) technological; and (III) physical. For each, a high-, and a low-access scenario is developed. Key political developments include trade liberalisation, human rights and/or environmental regulations, ownerships, treaties, and so on. Key technological developments include productivity or extraction gains. Key physical developments more loosely focus on the discovery or limits of oil and gas fields, or mines, or the feasibility of expanding manufacturing in a limited amount of time.

Our thinking is built on the following assumption. In a high-access world it is – all things being equal – more difficult to deny access and cut off consumers, whether through export controls

1 Johannes Bernreuter, "Polysilicon Manufacturers: Global Top 10 | Bernreuter Research," Bernreuter Research, June 29, 2022, https://www.bernreuter.com/polysilicon/manufacturers/.

or military pressures on sea lines of communication. Whenever a supply source is cut off, in a high-access world, the global market is likelier to redirect flows, with existing suppliers increasing their relative supplies, or other suppliers delivering to consumers. That redirection of flows is not necessarily cost-free, but denying an adversary access to these inputs is impossible. In a low-access world, there are few available options and therefore disruptions have higher impacts. The high- and low-access scenarios foreseeable for the year 2033 for each of these economic inputs are summarised in Table 1.

Although the scenarios show that there is significant possible variation in access due to political, economic, and technological trends for our sample of energy, raw materials, and technology inputs, upon closer inspection, less potential leeway exists to drastically reorder the physical dependencies inherent to the maritime – and sometimes air – transport of these key economic inputs. In reality, the physical transport routes are relatively fixed. Trade will continue to pass through them because it is unlikely that supply will significantly shift to different regions in the foreseeable future. Access to key resources could thus be denied through markets or through physical transport in the context of peacetime disruptions, regional conflict, and great power war.

Several threats to the relevant sea lines of communication should then be considered. Major power war between the US (and its allies and partners) on the one side, and Russia and/or China on the other side is a less likely, though steadily increasing, threat. Regional conflicts are more likely to disrupt global supply chains, as several such possible conflicts exist, for instance between Saudia Arabia and the Gulf states, and Iran, or between North and South Korea. They also do not preclude great-power involvement, and could easily escalate into a wider conflict. Finally, peacetime disruptions, including inspections by coast guards or naval vessels in disputed waters, can hamper the flow of key resources.

Table 1. High and Low Access scenarios for oil, LNG, cobalt, silicon, and semiconductors

	High Access	Low Access
Oil	Diversity of suppliers and increased global production, coupled with the expansion of cost-efficient technologies spread through major producers lead to greater access. Sanctions on oil producers are lifted and political stability allows for greater output.	Production remains concentrated in the hands of Middle Eastern countries and new technologies and extraction methods are too costly to significantly affect global production. Sanctions, political tensions, and environmental concerns do not allow for supplier diversification.
LNG	New producers enter the market, repairs to legacy plants are more efficient, and political stability improves in key producing countries.	Production remains concentrated in the hands of few states -given also complications related to LNG long-term contracts- and technical issues with legacy plants slow down production. Political tensions between exporter and importers as well as environmental concerns do not allow for greater access to LNG.
Cobalt	Cobalt production has diversified away from the DRC and technological break throughs in deep sea mining, recycling, substitution and processing methods are conducive to cost efficient extraction. Policies that incentivize diversification of suppliers are successfully implemented.	Cobalt extraction is still concentrated in the DRC. The failed materialization of technological progress as well as geopolitical competition, cartel forming and political instability undermine production of cobalt.
Silicon	New producers of silicon join the market, while technological progress in substitution and recycling also allows for diversification, dampening geopolitical threats associated with silicon extraction.	China remains the main producer of silicon and technological progress fails to materialize. At the same time, geopolitical competition between China and the West ramps up. Concerns over human rights' violation in Xinjiang further restrict exports from this region.
Semiconductors	Fabrication of advanced logic chips is diversified away from Taiwan hence reducing the threat of geopolitical disruptions to the supply chain.	Taiwan remains the main producer of advanced logic chips and geopolitical competition threatens to disrupt the production of semiconductors in North-East Asia.

As a consequence, European states have key stakes in maritime security close to and far away from Europe itself, regardless of their relationship with the United States and the latter's strategy towards China in the coming years, and regardless of their relationship with regional states. In terms of their ability to provide maritime security, these actors are, however, highly constrained. The decline of European navies since the end of the Cold War has left them with limited naval capacity, as depicted in Table 2.

Lacking their own capabilities, European states could rely on the US to ensure that the maritime transport routes from Europe to Asia remain open, and/or increase their partnerships with regional states. However, given the uncertainties surrounding the U.S. willingness and capability to manage its security commitments in multiple regions, it would be strategically sound for Europeans to take on a greater share of the provision of the public goods of maritime security along the maritime transport routes . There are three main configurations that Europe should consider when cooperating with Indo-Pacific countries for meaningful multinational operations: (1) Multilateral frameworks; (2) Minilateral frameworks; and (3) Bilateral frameworks.

Table 2. Overview of ships from key European navies[2]

	Aircraft carrier	Attack submarine	Destroyer	Frigate	Corvette	Offshore patrol vessel	Minehunter	Landing platform	Oiler	Support
France	1 (fixed wing)	10 (nuclear powered)	3	17		14	10	3	2	4
UK	2 (fixed wing)	11 (nuclear powered)	6	12		8	11	6	6	1
Germany		6 (diesel powered)	3	9	5		12		5	6
Netherlands		4 (diesel powered)		6		4	6		1	1
Italy	2 (helicopter)	8 (diesel powered)	4	11		15	10	4	4	
Spain	1	1 (diesel powered)		10		6	6	2	2	
Denmark				9		3				
Belgium				2			5			
Greece		11 (diesel powered)		13			3		4	3
Norway		6 (diesel powered)		4		10	6		1	
Portugal		2 (diesel powered)		5	2	4				

2 The overview excludes the French and British ballistic missile submarines used for their strategic deterrent.

Multilateral frameworks require more coordination and can entail longer bureaucratic timeframes given the participation of larger groups of states, but are also more suited to face recurring peacetime threats to SLOCs such as piracy, terrorist attacks, and coastguard harassment. They also allow for greater flexibility in naval deployments, as vessels can rotate in shorter periods since several states participate in multilateral naval operations. Minilateral frameworks offer instead more freedom of action as they involve a smaller number of parties. This is useful particularly in times of crisis, allowing for a more rapid response – for example when there are regional conflicts or the risk thereof. Finally, bilateral frameworks are the gateway to joint exercises and trainings as well as the sharing of military bases, equipment, and services, which would allow European states to have a forward presence and contribute (if still limitedly) to the protection of SLOCs in case of major power war or regional conflicts. Notably, these three frameworks reinforce each other: strong bilateral ties can merge into minilateral settings that can build shared interests, values, and practices, leading to the creation of multilateral frameworks.

Reinforcement of supply chains through investments in the diversification of suppliers and supplies is clearly necessary.

Following from the above considerations, this report, finally, makes two recommendations for small and middle powers in Europe and Asia. First, the reinforcement of supply chains through investments in the diversification of suppliers and supplies is clearly necessary. This would consist of: (a) investments in semiconductor manufacturing, regardless of limited benefits within timelines; (b) energy production; (c) mining and refining cobalt and silicon; and (d) lowering demand through substitution and recycling. Second, there is a need for the reinforcement of maritime security along maritime transport routes between Europe and Asia. Given Europe's limited naval capacity, especially at long distances, European naval power projection is likely to be most effective when addressing access on the Atlantic Coasts, the Strait of Bab el Mandeb and the Strait of Hormuz. For involvement in the Western Pacific, two options are plausible: (a) European states send a regular but minimal naval presence to these regions to supplement regional efforts, saving most of their naval resources for the regions closer to home; and (b) Europeans states complement regional efforts through other measure such as capacity-building.

1. Introduction

The re-nationalisation of economic interactions calls for a different set of policies.

The redistribution of power in the international system, and the intensifying geopolitical competition between the United States and its key European and Asian allies on the one hand, and Russia and China on the other, signal the end of the post-1991 global order in two ways: (1) the United States has become militarily more constrained considering its commitments in multiple regions with growing tensions,[3] which makes it more difficult to protect the global commons;[4] and (2) the Sino-American competition is not only at risk of boiling over into open war, but is already being waged through tit-for-tat economic warfare.[5] Within that deteriorating international environment, states in Europe and Asia are at risk of losing access to global markets, whether through military threats to supply chains, or by the decoupling efforts of the United States and China.

In the era of unfettered hyper-globalization between approximately 1989 and 2008, and then plateauing globalisation until 2018, key lessons of how to manage such instability were lost.[6] Globalisation had a fundamental impact on the international system and the order by removing political barriers to the movement of goods and people and allowing the full utilisation of the new technologies of transport, communication, and computation.[7] By increasing interdependence, globalisation seemed to remove many of the zero-sum incentives that had precipitated conflict between great powers in previous eras. The re-nationalisation of economic interactions, however, calls for a different set of policies.

The lessons that had been lost would have been commonly received wisdom for centuries. The access to technology matters not just for prosperity, it matters for military competitiveness, if not superiority. In turn, military superiority matters for access to technology, or

3 Hal Brands and Evan Braden Montgomery, "One War Is Not Enough: Strategy and Force Planning for Great Power Competition," *Texas National Security Review* 2, no. 3 (2020); Luis Simón, Linde Desmaele, and Jordan Becker, "Europe as a Secondary Theater? Competition with China and the Future of America's European Strategy," *Strategic Studies Quarterly* 15, no. 1 (2021): 90–115; Paul Van Hooft, "Don't Knock Yourself Out: How America Can Turn the Tables on China by Giving up the Fight for Command of the Seas," *War on the Rocks*, February 23, 2021.

4 Paul van Hooft, "All-In or All-Out: Why Insularity Pushes and Pulls American Grand Strategy to Extremes," *Security Studies* 29, no. 4 (August 7, 2020): 701–29, https://doi.org/10.1080/09636412.2020.1811461; Paul Van Hooft, Benedetta Girardi, and Tim Sweijs, "Guarding the Maritime Commons: What Role for Europe?" (The Hague, Netherlands: The Hague Centre for Strategic Studies (HCSS), February 2022).

5 Sam Kim, Eric Martin, and Bloomberg, "China's Ban on Micron Chips Is 'Economic Coercion' and Won't Be Tolerated, Says Gina Raimondo," *Fortune*, May 27, 2023, https://fortune.com/2023/05/27/china-micron-technology-chips-ban-gina-raimondo/. ; Joris Teer and Mattia Bertolini, "Reaching Breaking Point: The Semiconductor and Critical Raw Material Ecosystem at a Time of Great Power Rivalry" (The Hague Centre for Strategic Studies, October 19, 2022).

6 "Chapter 4 Geoeconomic Fragmentation and Foreign Direct Investment". In *World Economic Outlook, April 2023: A Rocky Recovery*, (USA: International Monetary Fund, 2023), https://doi.org/10.5089/9798400224119.081.CH004; Antràs, Pol. 2021. "De-globalisation? Global Value Chains in the Post-COVID-19 Age." In Central Banks in a Shifting World: Conference Proceedings—ECB Forum on Central Banking, 11–12 November 2020, edited by European Central Bank, 28–80. Frankfurt: European Central Bank. https://data .europa.eu/doi/10.2866/268938. Page 6; page 7. Goldberg, Pinelopi K. and Tristan Reed. 2023. "Is the Global Economy Deglobalizing? And if so, why? And what is next?" BPEA Conference Draft.

7 Robert O. Keohane and Joseph S. Nye, "Globalization: What's New? What's Not?(And so What?)," in *Making Policy Happen,* eds. Leslie Budd, Julie Charlesworth and Rob Paton (New York: Routledge, 2020), 105–13; "Economic Growth in a Shrinking World: The IMF and Globalization, Address by Anne Krueger, Acting Managing Director, IMF,", *IMF,* accessed February 19, 2023, https://www.imf.org/en/News/Articles/2015/09/28/04/53/sp060204. "Trade and Globalization," *Our World in Data*, accessed 26 September2022, https://ourworldindata.org/trade-and-globalization.

certainly the key economic inputs – raw materials and energy – needed to maintain production. In another case of "the more things change, the more they stay the same", whether before, during, or after globalisation, the best and most effective way to transport goods and people remains by water.[8] History has arguably been defined by the access of states to their region's – and thus the world's – rivers and seas, which brought prosperity and bought protection. Access to the rivers and seas is defined, inherently, by the boundaries of land, the coastlines, peninsulas, and islands. The unfettered access to the global maritime routes is constrained by the features of land. These constraints are colloquially referred to as chokepoints.[9]

Globalisation coincided, and not by accident, with the era of unrestricted unipolarity centred on US power. US power was arguably particularly useful for protecting the maritime commons and maintaining the openness of the commons and ensuring that the chokepoints remained unobstructed.[10] However, unipolarity is over; if not globally, at least regionally in the Western Pacific.[11] China's rise is not only a technological-economic challenge, it is also a military challenge to access through its investments in a set of land-based missile capabilities such as the DF26 and DF21-D that can target ships and airfields, an integrated air defence network, and a navy that is competitive in both qualitative and quantitative terms.[12]

Globalisation coincided, and not by accident, with the era of unrestricted unipolarity centred on US power.

Key states in Europe and Asia – especially small and middle powers – are particularly affected by this dual challenge to access. They owe their prosperity both to their advanced technology sectors and trade more broadly, and they are dependent on and thus very vulnerable to access to the global maritime commons and global markets. This includes states and actors like Japan, South Korea, Taiwan, Germany, France, UK, the Netherlands, as well as others. However, they are also crucial in reverse; their economies not only contribute to the global economy disproportionately, their technologies are also crucial to competitive military applications that thus directly shape the military balance of power. This presents them with a conundrum: they are both vulnerable and can be exploited for the vulnerabilities others have towards them.

Within this context, states in Asia and Europe must focus on ensuring access, if not alone, at least through taking on a greater share than before. How do current supply chains of key economic inputs function, and who is involved? Which routes do these supply chains take? What are feasible possibilities to reshore production, mining, or extraction? How many alternative suppliers exist? What are options to reroute? To what extent does access to advanced technology, raw materials, and energy rely on free and open maritime transport routes ? Consequently, where should naval capabilities be directed, specifically which chokepoints, and which kind of capabilities? These questions drive the different sections of the report.

The current report examines the vulnerabilities within the global networks. The second section elaborates on our overall research design and our conceptualisation of access. The

8 Ian Speller, *Understanding Naval Warfare*, 2nd ed. (Second edition. | Abingdon, Oxon ; N.Y., NY : Routledge, [2019]: Routledge, 2018), 19, https://doi.org/10.4324/9781315227818.

9 Geoffrey Till, *Seapower: A Guide for the Twenty-First Century* (Routledge, 2018), 231–33. Jeremy Stöhs, *The Decline of European Naval Forces: Challenges to Sea Power in an Age of Fiscal Austerity and Political Uncertainty* (Naval Institute Press, 2018).

10 Barry R. Posen, "Command of the Commons: The Military Foundation of US Hegemony," *International Security* 28, no. 1 (2003): 5–46.

11 Biddle and Oelrich, "Future Warfare in the Western Pacific"; Montgomery, "Contested Primacy in the Western Pacific."

12 James R. Holmes, "Defeating China's Fortress Fleet and A2/AD Strategy: Lessons for the United States and Her Allies," The Diplomat, 2016, https://thediplomat.com/2016/06/defeating-chinas-fortress-fleet-and-a2ad-strategy-lessons-for-the-united-states-and-her-allies/.

third section maps out the key suppliers, key consumers, and key transport routes, specifically the maritime transport routes. The fourth section considers future scenarios for each key material input of respectively high and low access, depending on political, technological, and economic trends. The fifth section considers weaknesses in maritime transport routes, and how these can be ameliorated. The sixth and final section summarises these threats and offers recommendations for small and middle powers in Europe and Asia.

The central thesis of the report is that access should be conceived of as depending on the interaction between the overall supply of a critical economic input and the number of suppliers, combined with the transport means available. Great powers with revisionist intentions threatening or owning one or more technological or physical chokepoints are only a risk if few or no alternatives are available. Costs may still go up, but the credibility of the threat to deny access is less pressing. In our view, if multiple access points exist, the threat emanating from any great power decreases. However, we do take the political context into account.

Access should be conceived of as depending on the interaction between the overall supply of a critical economic input and the number of suppliers, combined with the transport means available.

2. Conceptualising access: study design

The project is intended to assess the robustness of major supply chains, yet doing so for all forms of trade is unfeasible. Instead, the report looks at a cross-section of key economic inputs that includes high-end technologies, raw materials, and energy, specifically: (I) oil and liquified natural gas; (II) cobalt and silicon; and (III) semiconductors. The project is intended to assess the robustness of major supply chains, yet doing so for all forms of trade is unfeasible. Instead, the report looks at a cross-section of key economic inputs that includes high-end technologies, raw materials, and energy, specifically: (I) oil and liquified natural gas; (II) cobalt and silicon; and (III) semiconductors. Each of these three categories is crucial to industrial production, and our selections include key examples of each. Of course, we recognise that our examples are hardly exhaustive; however, we aim to highlight distinct phases that can be disrupted by hostile actions or actors. Without consistent access to energy, industrialised economies will obviously grind to a halt. Without access to raw materials, specific advanced, high-value added technologies cannot be manufactured. Finally, without access to semiconductors, economies face a clear ceiling in terms of integration to the information and data economy. With this cross-section, we can highlight a number of developments. We look at (I) the current supply chain relationships for each of these key economic inputs, as well as transport routes; and (II) the possible future scenarios to ascertain the bandwidth of changes to access to each.

The possibilities of access is key to our approach. We conceptualise access as a combination of overall supplies and the number of suppliers, with the underlying assumption that market forces can meet a high demand for a key economic input under those conditions. Second, access is conceptualised to include whether transport routes, particularly maritime transport routes but also air transport routes, are available. Chapter 4 combines both these features to conceive of two kinds of worlds, namely a high- and a low-access world, while chapter 5 looks at the availability of transport for these key economic inputs.

Simply put, in a high-access world there is both medium-to-high overall supply of a key economic input on the one hand, and a medium-to-high number of suppliers on the other hand; in contrast, in a low-access world, the interaction between both supply and suppliers is constrained as both are low-to-medium. Cutting off a supply source in a high-access world will likely lead the global market to redirect flows. Suppliers will then increase their supplies or other suppliers will begin their deliveries to consumers. If transport routes can be rerouted, then access remains possible. It goes without saying that redirecting flows means incurring costs, and thus shapes relative access, but under those circumstances there is no absolute denial that would bring production to a halt. We can look at Russia's current ability to bypass sanctions and export controls as an example of maintaining limited access at increased costs. In contrast, few options would be available in a low-access world. Disruptions would then have higher impacts.

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Oil. Oil has been fuelling the lives of billions of people around the globe for decades, given its multiplicity of applications. Notwithstanding substantial investments in renewable energy and the implementation of decarbonization policies by various states, global oil production has experienced a significant increase of 20 million barrels per day (mb/d) over the past two decades, peaking at 93.8 mb/d in 2022. Although the Covid-19 pandemic in 2020 and 2021 led to a temporary decline in global oil consumption, attributed to economic contractions and disruptions in global supply chains, global oil consumption has since rebounded and surged to 97.3 mb/d. This upward trajectory is anticipated to persist in the foreseeable future.[13]

To assess the current state of the oil industry, we rely on the data provided in the *Statistical Review of World Energy 2023* from the Energy Institute (EI). It's worth noting that the EI's definitions for oil production, consumption, and exports may exhibit slight variations compared to those utilized by the International Energy Agency (IEA) in its *World Energy Outlook* report of 2022.[14] These variations may result in discrepancies when comparing or harmonizing data between the two sources.

In the context of this report, the International Energy Agency's Stated Policies Scenario (STEPS) emerges as the most practical choice among the three forecasting scenarios

13 "Statistical Review of World Energy 2023," 15 and 23. "Oil 2021 - Analysis and Forecast to 2026" (International Energy Agency, 2021), 4, https://iea.blob.core.windows.net/assets/1fa45234-bac5-4d89-a532-768960f99d07/Oil_2021-PDF.pdf.

14 The International Energy Agency (IEA), in its forecast scenarios, defines oil as encompassing both conventional and unconventional oil production. This definition is inclusive of various petroleum products, including refinery gas, ethane, liquid petroleum gas, aviation gasoline, motor gasoline, jet fuels, kerosene, gas/diesel oil, heavy fuel oil, naphtha, white spirits, lubricants, bitumen, paraffin, waxes, and petroleum coke. In contrast, the Energy Institute (EI) offers a different definition of oil production, including crude oil, shale oil, oil sands, condensates, and natural gas liquids (NGLs), while explicitly excluding liquid fuels from other sources such as biofuels and synthetic derivatives of coal and natural gas. "Statistical Review of World Energy 2023," 56; International Energy Agency, "World Energy Outlook 2022" (IEA, 2022), 495.

provided by the IEA for indicating the future development of the oil markets.[15] In the IEA's STEPS scenario of 2022, global oil demand is projected to plateau at 102.4 mb/d by 2030, a level that is anticipated to remain consistent through 2040 and 2050. This stability is underpinned by an increase in oil consumption of more than 60% in China, India, and Southeast Asian states. This substantial rise offsets the reduction in oil consumption resulting from the energy transition in other regions, such as Europe.[16] However, in its *World Oil Outlook* report of 2022, OPEC even forecasts a global oil demand of 109.8 mb/d by 2045.[17] Despite variations between the forecasts presented by the IEA and OPEC, both scenarios affirm the prevailing consensus regarding the enduring significance of oil within the global energy supply and economy. Hence, the strategic significance of securing access to oil remains paramount for all nations in ensuring socioeconomic stability.

To put it in the words of BP's chief executive Bernard Looney, "Oil will be around for a very, very long time."[18] Notwithstanding the possibility of oil transportation through pipelines, approximately 60% of total global oil production undergoes transportation via sea.[19] Access to maritime routes in order to secure oil thus remains strategically important.

LNG. Liquefied Natural Gas (LNG) enables the transportation of natural gas over extensive distances. As LNG transactions are solely reliant on maritime transport, the analysis of LNG within the context of open maritime trade routes is essential. LNG is used as an energy source for multiple applications, including heating, industrial manufacturing processes, power generation, and as a transport fuel.[20] Recently, gas has been hailed as the bridge fuel to a low-carbon future, since it emits about 40% less CO2 than coal and 20% less than oil.[21]

Global LNG demand is projected to rise over the next 10 years, confirming a trend that has seen a steady growth in LNG trade for the past two decades.[22] In 2022, global LNG trade grew by 5.2% compared to 2021, attaining an all-time high of 393.00 million metric tonnes (mmt). The Russian-Ukrainian conflict triggered a major shift in Europe's natural gas imports. With a 35% drop in European gas pipeline imports from Russia in 2022, LNG emerged as one of the few viable alternatives, leading to a remarkable 58% surge in European LNG imports. This shift underscores the growing political importance and the projected trajectory of global LNG trade.[23]

As per the IEA's STEPS scenario, global LNG trade is projected to exhibit sustained growth, reaching 477.02 mmt by 2050. This trajectory surpasses the declining trend anticipated for

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15 The Net Zero Emissions by 2050 (NZE) Scenario presents notable implementation challenges, given its reliance on extensive energy reductions, ambitious renewable energy growth, and its design as a backtrack scenario aimed at limiting global temperature rise to 1.5 degrees Celsius. In contrast to both the NZE Scenario and the Announced Pledges Scenario (APS), which depend on the full and timely realization of government climate commitments, the STEPS scenario adopts a more cautious approach International Energy Agency, "World Energy Outlook 2022," 463.

16 International Energy Agency, 231–32.

17 Organization of the Petroleum Exporting Countries (OPEC), "World Oil Outlook 2022," 102, accessed September 17, 2023, https://woo.opec.org/pdf-download/index.php.

18 CERAWeek, "On the Future of Oil Demand," Tweet, *Twitter*, October 26, 2020, https://twitter.com/CERAWeek/status/1320684857127768065/photo/1.

19 "World Oil Transit Chokepoints" (U.S. Energy Information Administration (EIA), July 25, 2017).

20 "Uses and Benefits," Center for LNG, accessed November 25, 2022, https://www.lngfacts.org/uses-and-benefits/.

21 "REPowerEU: Affordable, Secure and Sustainable Energy for Europe," Text, European Commission, accessed December 6, 2022, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en.

22 "World Energy Outlook 2022," 369-370; "Statistical Review of World Energy."

23 "Statistical Review of World Energy 2023," 3.

natural gas pipeline trade, which is forecasted to reach 251.37 mmt by that time, nearly half the volume of LNG trade.[24] As the is the case with oil, some differences exist between the IEA's and EI's definition of natural gas and what is counted in the statistics.[25] These variations may result in discrepancies when comparing or harmonizing data between the two sources.

Silicon. Silicon is an important raw material that, apart from various chemical applications and aluminium alloys, can also be found in solar panels, li-ion batteries, fuel cells, electric traction motors, robotics, drones, 3D printing, and digital technologies.[26] Whereas silicon at lower purity levels is used in metallurgy – the majority of the volume produced –[27] higher purity silicon is used in electrical applications, such as semiconductors or solar panels. Demand for silicon is expected to grow significantly, at a rate between 2.2% and 2.6% per year,[28] depending on whether countries keep their climate pledges. Safeguarding the global silicon supply chain is key to ensuring the digitalisation and decarbonisation of society in the coming decades.

Cobalt. Cobalt is an important raw material vital to various technologies. Global demand is expected to strongly grow through 2050 due to the energy transition, predominantly driven by demand for cobalt-rich li-ion batteries. Cobalt is a preferred material as it is highly durable and resistant to high temperatures, and used in various products ranging from jet engines to rockets. Cobalt has been increasingly used in emerging technologies. This includes the abovementioned li-ion batteries that are crucial to e-mobility and energy storage, but also fuel cells, robotics, drones, electric vehicles, 3D printing, and semiconductors. These technologies are central to a variety of industries from renewable energy, e-mobility, to defence.[29] The demand for cobalt is expected to continuously grow in the coming decades at a rate of 4% to 6% per year as production of cobalt-rich end-products increases, specifically as a consequence of the world's energy transition.[30] Demand for cobalt in the EU alone is expected to increase by up to 80% by 2030.[31] Safeguarding the cobalt supply chain is of critical importance to enable both the modern digital economy and the green energy transition.

Semiconductors. The extent to which semiconductors are geopolitically crucial is now daily frontpage news,[32] and they are currently presented as the archetypical dual-use technology with both commercial and military value. They are the backbone of the modern digital economy and play indispensable roles across multiple economic sectors, enabling the

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24 International Energy Agency, "World Energy Outlook 2022," 369; "Statistical Review of World Energy 2023," 3.

25 While the IEA's definition mainly focuses on methane-based gas occurring in deposits, encompassing both non-associated and associated gas, as well as coal mine-derived methane, it explicitly excludes natural gas liquids, manufactured gas, and quantities vented or flared. In contrast, the EI's definition incorporates derivatives of coal and natural gas consumed in gas-to-liquids transformation while excluding natural gas converted to liquid fuels. International Energy Agency, "World Energy Outlook 2022," 493; "Statistical Review of World Energy 2023," 57.

26 S. Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study" (European Commission, 2020), 17.

27 European Commission, *Study on the EU's List of Critical Raw Materials (2020): Critical Raw Materials Factsheets (Final)* (LU: Publications Office, 2020), 706, https://data.europa.eu/doi/10.2873/631546. European Commission, 706.

28 International Energy Agency, "Demand for Silicon from Solar PV by Scenario, 2020-2040," IEA, October 26, 2022, https://www.iea.org/data-and-statistics/charts/demand-for-silicon-from-solar-pv-by-scenario-2020-2040. KU Leuven, "Pathways to Solving Europe's Raw Materials Challenge," April 2022, 28, https://www.eurometaux.eu/metals-clean-energy/?5.

29 Bobba et al., "Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study," 17.

30 International Energy Agency, "World Energy Outlook 2022," 217. KU Leuven, "Pathways to Solving Europe's Raw Materials Challenge," 31. International Energy Agency, "World Energy Outlook 2022," 217.

31 Patrícia Alves Dias et al., *Cobalt: Demand Supply Balances in the Transition to Electric Mobility* (LU: Publications Office of the European Union, 2018), https://data.europa.eu/doi/10.2760/97710.

32 Chris Miller, *Chip War: The Fight For The World's Most Critical Technology*, 2022.

functionality of multiple products: smartphones, solar panels, automobiles, wind turbines, and jetfighters all require chips to ensure key functions. The average car alone already contains over 1400 chips to control everything from engines to airbags.[33] The surging demand for digital consumer products, as well as increasing demand for green energy solutions, is expected to further increase the demand for semiconductors globally. In particular, advanced logic chips (i.e., <10nm) are key to unlocking technologies that are expected to be cutting-edge, such as artificial intelligence (AI) for both civilian and the military applications, from smarter and faster missiles to better medical diagnoses. Safeguarding the global semiconductor supply chain of these chips is thus securing – and potentially exploiting – a chokepoint towards many other vital future technologies.

The selection of these five key economic inputs is not exhaustive, nor is it intended to be. However, it provides an insight into the vulnerabilities that dependencies create. Access to these inputs can be limited both by who can impede the supply itself, as well as the transport of those supplies. The more limited the overall supplies and number of suppliers, as well as the routes that the supply of those key economic inputs can take, the more states in Europe and Asia will be at risk of access denial.

The maritime transport routes, the maritime transport routes , that connect European and Asian economies include several key chokepoints: the Korea Strait, Taiwan Strait, Luzon Strait, Malacca Strait, Bab el Mandeb, and the Suez Canal. There are limited options for rerouting. For example, if both the Taiwan Strait and the Luzon Strait are disrupted, shipping between East Asia and Europe is expected to increase by multiple days. Alternatives to Bab el Mandeb and the Suez Canal would require ships to go around Africa, equally resulting in a significant increase in time and cost.[34]

The following section discusses the supply chains of producers to consumers, then discusses alternative suppliers and alternative routes.

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33 Ian King and Gabrielle Copolla, "Silicon Valley Answer to the EV Question Calls for Less Silicon," *Bloomberg.Com*, September 29, 2021, https://www.bloomberg.com/news/articles/2021-09-29/what-will-replace-silicon-chips-in-the-next-generation-of-evs.

34 Shipping companies have opted to reroute around Africa in the past when the Suez Canal was temporarily blocked. Peter S. Goodman and Stanley Reed, "With Suez Canal Blocked, Shippers Begin End Run Around a Trade Artery," *The New York Times*, March 26, 2021, sec. Business, https://www.nytimes.com/2021/03/26/business/suez-canal-blocked-ship.html.

3. Existing supply chains: high technology, raw materials, and energy

The increasing complexity of supply chains also increased their vulnerabilities, by increasing the number of points where their flows can be interrupted.

As hyper-globalization emerged after 1989 and trade barriers were lowered, specialisation became more and more possible and supply chains consequently became more and more complex. Effective maritime transport allowed a further emphasis on efficiency between disparate markets and just-in-time deliveries. This efficiency provided a boost for the global economy and sped up the rapid industrialisation of key developing countries. The most important of these was China. Ironically, given the intensification of Sino-American competition and the preparations for conflict on both sides, Chinese growth was enabled by access to the US markets.

Yet, the increasing complexity of supply chains also increased their vulnerabilities, by increasing the number of points where their flows can be interrupted. This applies to materials, energy, and technology components, as well as the physical routes that these goods cross. The following sections discuss the supply chains for each of the key economic inputs: semiconductors, silicon, cobalt, oil, and LNG. While limited, as a first cut, it shows the distinct complexity and vulnerabilities of the current global economic system.

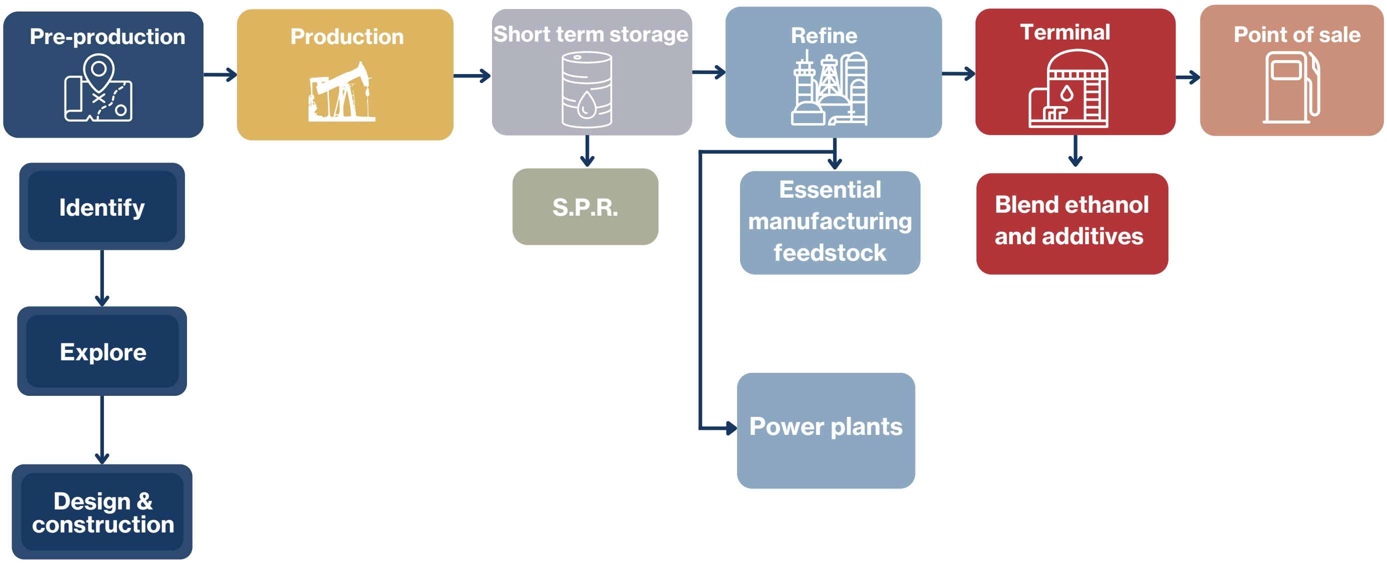
Energy: Oil

Supply chain

The supply chain for oil is extremely complex and involves a number of steps (see Figure 2). It begins with production, involving the extraction of crude oil from both land and sea through processes such as drilling and recovery. Subsequently, crude oil undergoes transportation through various modes, including trains, trucks, ships, and pipelines, to reach storage, refineries, terminals, and eventually the point of sale. Refineries play a central role in the transformation of crude oil into diverse consumer products, employing complex chemical processes to yield fuels like diesel, jet fuel, and manufacturing feedstocks. Following refinement, feedstocks are transported to manufacturing facilities, where they assume integral roles in the production of numerous goods, ranging from medical equipment to plastics and organic chemicals. Terminals, situated near transportation hubs, serve as the final staging points for refined fuel before reaching the point of sale. Ultimately, the refined fuel is transported to its final destination, encompassing fuel stations and airports, facilitated by trucking, shipping, and delivery lines, ensuring the distribution of the finished product across countries.[35]

Table 3 presents data regarding the oil supply chain, including production of crude oil by region, refining throughput/capacity, and consumption by product and region.

Figure 2. Oil supply Chain



Source: American Petroleum Institute, 'Oil Supply Chain', energyinfrastructure.org.

Table 3. Oil Supply chain

Production of oil by region as of 2022 (market share)[36]	Refining throughput/capacity as of 2022 (market share)[37]	Consumption by product as of 2022 (market share)[38]	Consumption of products by region as of 2022 (market share)[39]
1. Middle East - 32.8%	1. Asia Pacific – 36.4%/35.5%	1. Diesel/gasoil – 29.0%	1. Asia Pacific – 35.7%
2. North America - 26.9%	2. North America – 22.5%/21.2%	2. Gasoline – 24.6%	2. North America – 24.7%
3. CIS - 14.9%	3. Europe – 15.1%/14.8%	3. Naphtha – 6.8%	3. Europe – 14.5%
4. Asia Pacific - 7.7%	4. Middle East – 11.0%/10.8%	4. Fuel oil – 7.4%	4. Middle East – 9.4%
5. Africa - 7.5%	5. CIS – 8.1%/8.4%	5. Jet/kerosene – 6.4%	5. CIS – 4.6%
		6. Others – 25.9%	

35 "Energy Infrastructure: Oil Supply Chain," American Petroleum Institute, accessed September 18, 2023, https://www.energyinfrastructure.org/energy-101/oil-supply-chain.

36 "Statistical Review of World Energy 2023," 15.

37 "Statistical Review of World Energy 2023," 15.

38 "Statistical Review of World Energy 2023," 23.

39 "Statistical Review of World Energy 2023," 15.

The US emerges as the world's largest oil producer, averaging 17.8 mb/d. However, substantial oil production alone does not guarantee a nation's status as a significant oil exporter. The US domestic consumption is extremely high (19.1 mb/d in 2022), meaning that US crude oil exports to the rest of the world are lower than those of Saudi Arabia, Russia and the Commonwealth of Independent States (CIS), UAE, Iraq, and even Canada, which produces around 5.5 mb/d.[40][41] Indeed, as Emma Ashford notes, simply because a state produces oil, does not mean that it shapes global oil markets; it is about its production outstripping its domestic consumption.[42]

The international oil market is instead shaped by the Middle East and Africa through the Organization of Petroleum Exporting Countries (OPEC). This coalition consists of 13 OPEC member countries, with the central mission of managing global oil supply and price dynamics. OPEC collectively contributes approximately 30% of the world's total oil production. Among its member states, Saudi Arabia is the main producer, with an output of 12.1 mb/d as of 2022.[43] Saudi Arabia is also the largest exporter of crude oil in the world.[44] Iraq is the second-biggest Middle Eastern producer, with its output increasing by 1.7 mb/d from 2013 to 2019, the year in which it averaged 4.7 mb/d. Despite holding 8% of the world's known resources, Iraqi production is held back by constrained export infrastructures.[45] Other significant oil producers in the Middle East are the United Arab Emirates (4.0 mb/d), Iran (3.8 mb/d), and Kuwait (3.0 mb/d). They are respectively the 7th, 8th, and 10th largest suppliers of oil in the world.[46] In Africa, the biggest suppliers are Angola and Nigeria, which are also part of OPEC. They produce 1.2 and 1.5 mb/d respectively. However, technical and operational issues hamper further development of oil extraction in these two countries.[47]

In 2016, amid a backdrop of subdued oil prices, OPEC embarked on an expansion initiative, collaborating with 10 additional oil-producing nations to establish OPEC+. Among these extended alliances, Russia commands a substantial production capacity, exceeding 11 of the 14 mb/d supplied by the Eurasian region.

In addition to the shift of production from Western International Oil Companies (IOCs) to OPEC+ nations, there has been an increase in the share of National Oil Companies (NOCs) in total capital investments in oil and gas projects since 2014, rising from 40% to over 50%. These developments indicate that the influence of OPEC+ on the oil market will only continue to grow in the future.[48]

Asia Pacific contributes 7.3 mb/d to the global supply. The main producer is China, whose output amounts to 4 mb/d. China also consumes most of its domestic production, exporting no significant oil quantities.[49]

40 "World Energy Outlook 2022," 331–36.

41 "Statistical Review of World Energy 2023," 20.

42 Emma Ashford, *Oil, the State, and War: The Foreign Policies of Petrostates* (Georgetown University Press, 2022).

43 ""Statistical Review of World Energy 2023," 15.

44 "U.S. Energy Information Administration (EIA)," U.S. Energy Information Administration (EIA), accessed November 17, 2022, https://www.eia.gov/international/overview/country/SAU.

45 "U.S. Energy Information Administration (EIA)."

46 "Statistical Review of World Energy 2023," 15..

47 "U.S. Energy Information Administration (EIA)."

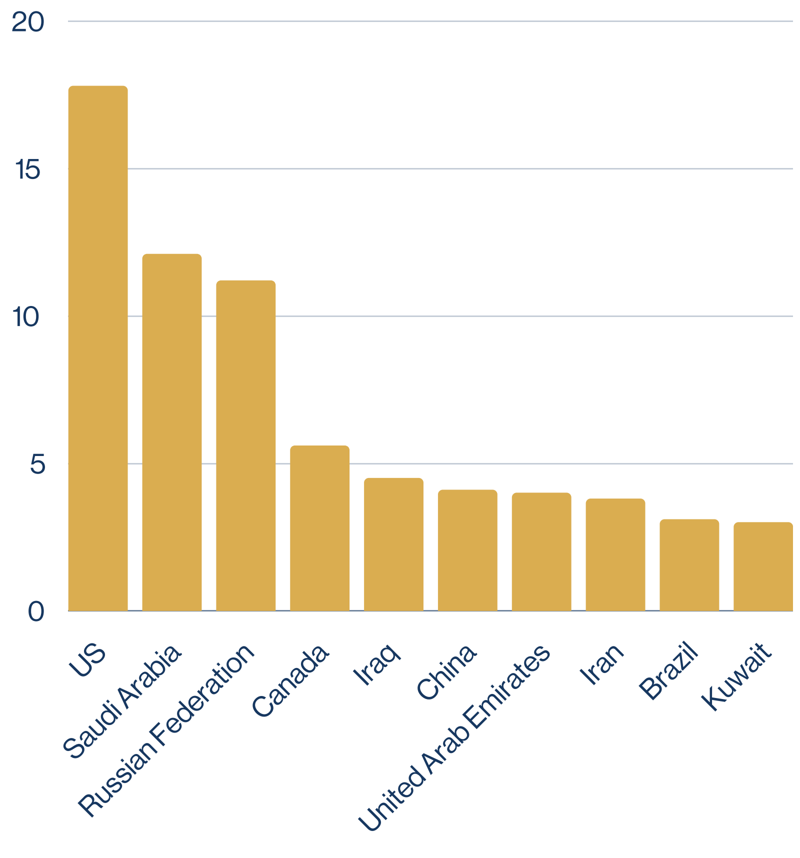
48 Gautam Jain and Luisa Palacios, "Investing in Oil and Gas Transition Assets En Route to Net Zero," Center on Global Energy Policy at Columbia University SIPA, March 2, 2023, https://www.energypolicy.columbia.edu/publications/investing-in-oil-and-gas-transition-assets-en-route-to-net-zero-2/.

49 "Statistical Review of World Energy"; "U.S. Energy Information Administration (EIA)."

Latin America and Europe close the list of oil suppliers, accounting for 6.8% and 3.3% respectively of the global production. Brazil is the 9th biggest world producer of oil with 3.1 mb/d (half of the total South and Central American production), but its levels of productivity are unmatched in the rest of the region, whose output is limited by low reserves and mismanagement of resources.[50] In Europe, the only notable producer is Norway, that, with its 1.9 mb/d, is the 11th largest producer in the world.[51]

Overall, there are several countries in the world that contribute to the global supply of oil. That said, three of them (US, Saudi Arabia, and Russia) vastly outpace the others.

Figure 3. Top 10 oil producers (mb/d), 2022[52]

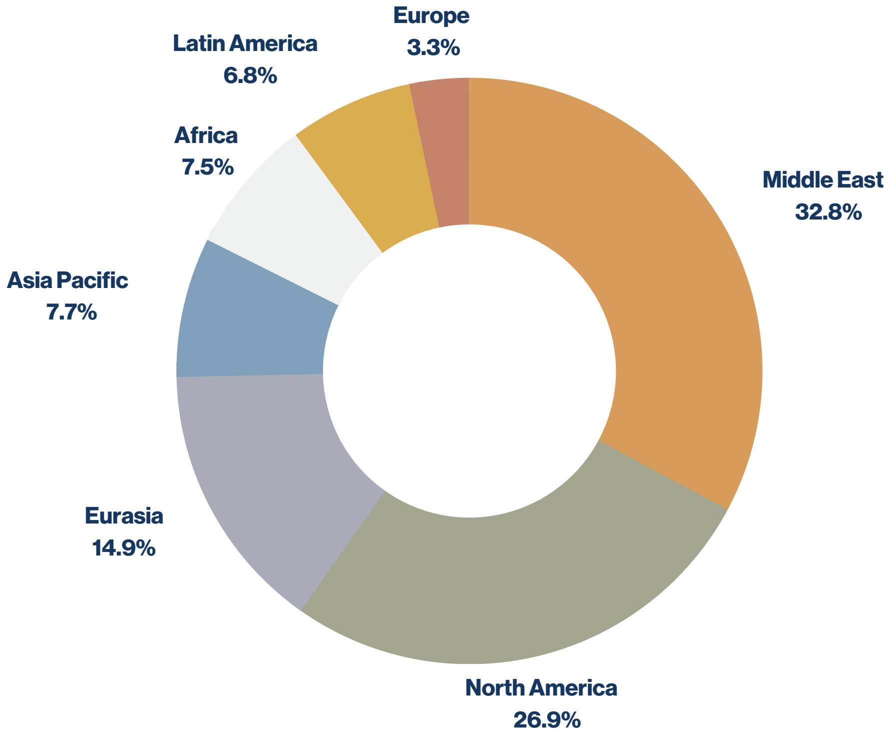


50 "World Energy Outlook 2022"; "U.S. Energy Information Administration (EIA)."

51 "Statistical Review of World Energy 2023," 15.

52 "Statistical Review of World Energy 2023," 15. For geographical definitions, see definition of Statistical Review of World Energy.

Figure 4. Percentage of oil production per region, 2022



Where does oil go? The Asia Pacific region consumes the most oil, around 36% of the world's consumption.[53] China is the largest consumer of oil (14.3 mb/d), mostly provided by Middle Eastern countries.[54] Despite China being an oil producer itself, its import dependence may reach 80% by 2030.[55] Japan, South Korea and Taiwan also import nearly all of the oil they consume from the Persian Gulf.[56]

While Europe's oil production is extremely low compared to other regions, it is home to the world's biggest importers.[57, 58] Table 4 shows the top three oil suppliers for a selection of European countries.

53 ""Statistical Review of World Energy 2023," 28.

54 "Statistical Review of World Energy 2023," 28.

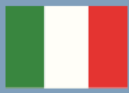
55 Lucas Myers, "China's Economic Security Challenge: Difficulties Overcoming the Malacca Dilemma," SFS, *Georgetown Journal of International Affairs* (blog), March 22, 2023, https://gjia.georgetown.edu/2023/03/22/chinas-economic-security-challenge-difficulties-overcoming-the-malacca-dilemma/.

56 The major consumer of the region is China with 15.4 mb/d, 80% of which is imported. Saudi Arabia is the largest source of crude imports to China, accounting for 17% of Beijing imports, while Russia is the second one with 15%. Other major exporters to China are Iraq (11%), Oman (9%), Angola (8%), Brazil (6%), Kuwait (6%), and UAE (6%).Japan is the 7th biggest consumer globally with 3.3 mb/d, of which it imports 36% from Saudi Arabia, 29% form the UAE, 9% from Qatar, and 8% from Kuwait. While South Korea also imports the majority of its oil from Saudi Arabia (27%), its second largest source are the US and Kuwait (14% each), followed by Iraq (11%) and UAE (8%). Taiwan imports 86% of its crude oil from the Persian Gulf. India's imports also come principally from the Middle East, more specifically from Iraq (24%), Saudi Arabia (16%), and the UAE (11%). Australia stands out among Asia-Pacific states for not importing most of its oil from the Middle East but from its neighbor Malaysia (42%), followed by Brunei (13%), the US (10%), and Gabon (5%). "Statistical Review of World Energy." "U.S. Energy Information Administration (EIA)."

57 European countries consumed 13.527 mb/d of oil in 2021, of which 13.522 were imported. "Statistical Review of World Energy."

58 "Shedding Light on Energy in the EU: From Where Do We Import Energy ?," Eurostat, accessed November 18, 2022, https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-2c.html.

Table 4. Top three oil suppliers per selected European countries before the Russian invasion of Ukraine[60]

						
1st supplier	Saudi Arabia 15%	Russia 31.5%	Azerbaijan 19.2%	Russia 30.7%	Nigeria 16.2%	Norway 36%
2nd supplier	Kazakhstan 14%	UK 11.9%	Iraq 16.7%	UK 15.3%	Mexico 13.7%	US 30%
3rd supplier	Russia 12.7%	Norway 11.3%	Russia 13.8%	Norway 11.5%	Saudi Arabia 11.9%	Libya 8%

However, with a full EU embargo on Russian crude oil entering into force from December 2022, European states have been looking elsewhere to fulfil their energy needs.[60] While betting on renewables can be the solution on the long run, in the short-term, Europe will have to look to the Persian Gulf and the US for its oil supply. This means that oil trade between Europe and the Gulf states and the US, especially Saudi Arabia and the UAE, will likely intensify.[61]

59 "U.S. Energy Information Administration (EIA)"; "The Netherlands 2020 - Energy Policy Review," n.d., 258; International Energy Agency, "France 2021 Energy Policy Review" (International Energy Agency, December 7, 2021), https://doi.org/10.1787/2c889667-en; "Crude Oil Net Imports in Italy, 2000-2020," International Energy Agency, accessed November 24, 2022, https://www.iea.org/data-and-statistics/charts/crude-oil-net-imports-in-italy-2000-2020; "Spain 2021 - Energy Policy Review" (International Energy Agency), accessed November 24, 2022, https://iea.blob.core.windows.net/assets/2f405ae0-4617-4e16-884c-7956d1945f64/Spain2021.pdf.

60 "Joint European Action for More Affordable, Secure Energy," Text, European Commission, March 8, 2022, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1511.

61 Rob Davies, "After Ukraine, How Will the World Replace Russia's Oil Products?," *The Guardian*, March 19, 2022, sec. Business, https://www.theguardian.com/business/2022/mar/19/after-ukraine-how-will-world-replace-russia-oil-products; Tsvetana Paraskova, "EU In Talks With Alternative Suppliers As It Considers A Russian Oil Ban," OilPrice.com, April 20, 2022, https://oilprice.com/Energy/Crude-Oil/EU-In-Talks-With-Alternative-Suppliers-As-It-Considers-A-Russian-Oil-Ban.html. "EU Imports of Energy Products Continued to Drop in Q2 2023," Eurostat, September 25, 2023, https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20230925-1; Alberto Chiumento, "EU Energy Imports Fall in Q2 as Russian Supplies Cut," *Reuters*, September 25, 2023, sec. Energy, https://www.reuters.com/business/energy/eu-energy-imports-fall-q2-russian-supplies-cut-eurostat-2023-09-25/.

Figure 5. Top 10 oil consumers (mb/d), 2022

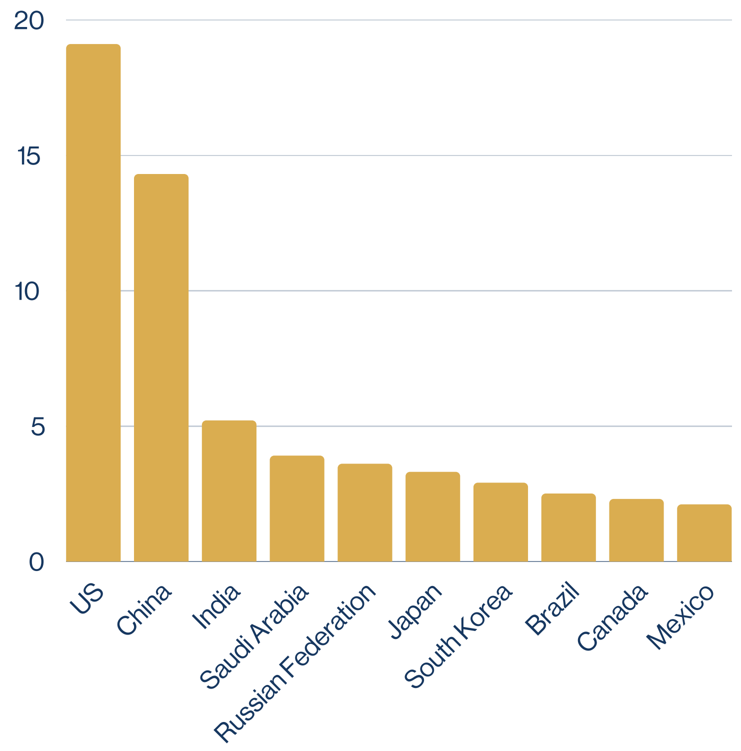


Figure 6. Top 10 oil consumers (mb/d), 2022

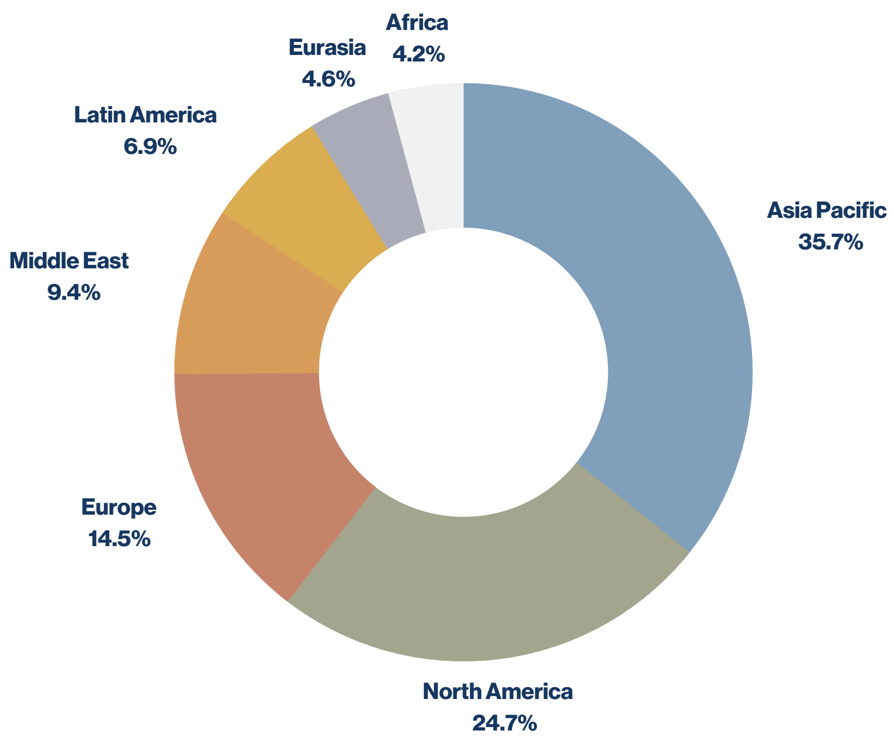
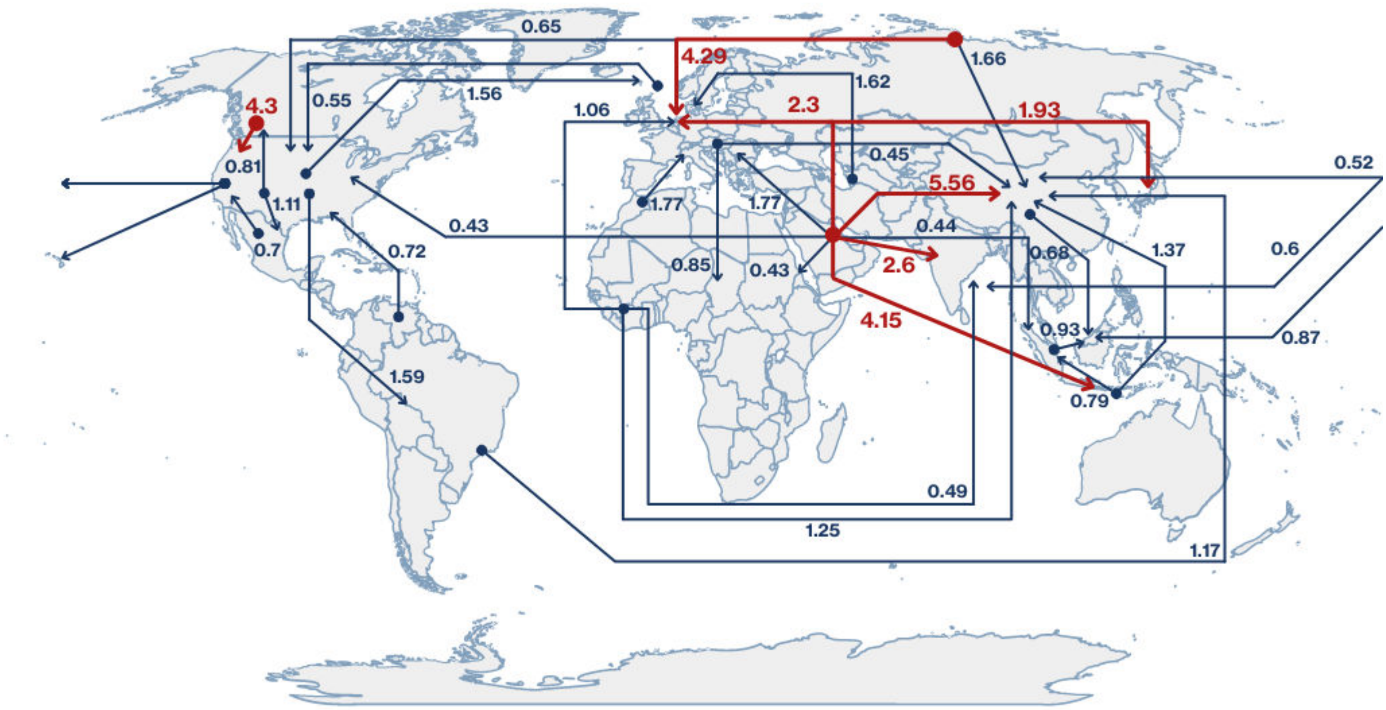


Figure 7. Major oil trade movements 2022[62]

Measured in million barrels per day



Source: BP Statistical Review of World Energy 2022

Energy: Liquefied Natural Gas (LNG)

Supply chain

The LNG supply chain consists of a comprehensive process of natural gas conversion and transport. It begins with the extraction of natural gas from subsurface reservoirs. After undergoing purification at processing facilities, the processed gas is transported to a liquefaction plant via pipelines. At the liquefaction plant, the purified natural gas undergoes a chilling process, reducing its temperature to approximately -160 degrees Celsius, thereby transforming it into liquefied natural gas with a 600-fold reduction in volume. This is then stored in cryogenic tanks before being loaded onto specially designed double-hulled tankers for international shipment.[63] Upon arrival at its destination, the LNG is transferred to a regasification plant, where it undergoes a heating process, returning it to its original gaseous state. This regasified natural gas is then delivered into the existing natural gas pipeline system, facilitating its delivery to residential, commercial, industrial, and power generation consumers.[64]

The complex processes around LNG production and transportation mean that unlike oil, which can be transported relatively inexpensively worldwide, the gas market faces higher

62 "Statistical Review of World Energy," 28.

63 "Liquefied Natural Gas (LNG)," Energy.gov, accessed November 25, 2022, https://www.energy.gov/fecm/liquefied-natural-gas-lng.

64 "Liquefied Natural Gas (LNG)."

transportation costs, making it less globally integrated. Approximately 13% of global gas consumption is transported in the form of LNG over long distances, and this percentage is gradually increasing.[65]

Moreover, the LNG market exhibits distinct characteristics that set it apart from the oil market, primarily revolving around its limited spot market presence and the prevalence of long-term contracts. These contracts often establish fixed delivery commitments, limiting the flexibility of LNG producers to quickly adjust production levels. China's strategic securing of a 25% share in the global LNG market by 2030 through these extended contractual agreements, often linked to oil or Henry Hub prices, enables it to sell profitably to parties relying on the spot market such as Europe, especially during tight market conditions.[66]

In 2022, the leading LNG exporting states were Australia (82.54 mmt), Qatar (83.86 mmt), and the United States (76.66 mmt). In Asia Pacific, Malaysia, Indonesia and Papua New Guinea are also notable LNG exporters.

When it comes to consumption, the Asia Pacific region emerged as the largest importer, receiving 255.71 of the 393 mmt of total exported LNG in 2022, followed by Europe with imports totalling 125.1 mmt during the same year.[67] Imports in the Asia Pacific are driven by Chinese, Japanese, South Korean, Indian, Taiwanese, and Pakistani demand. Asia Pacific states also acquire LNG from MENA (83.3 mmt), US (17.5 mmt), and Russia (14.9 mmt), but their biggest source comes from intra-regional trade (133.9 mmt).[68] In Europe, Spain, France, the UK, and Turkey lead LNG consumption.[69] European states import LNG mainly from MENA (47.8 mmt), US (52.21 mmt), and Russia (14.2 mmt).

Table 5 shows the breakdown of LNG trade movements by country, while Figure 8: Major gas trade movements 2021 (million metric tonnes) shows the trade movements plotted on a map, highlighting the difference between gas transported via pipeline and LNG.

65 "Statistical Review of World Energy 2023," 3.

66 IEA, "Global Gas Security Review 2023 Including the Gas Market Report Q3 2023," 2023, 18; Anne-Sophie Corbeau and Sheng Yan, "Implications of China's Unprecedented LNG-Contracting Activity," Center on Global Energy Policy at Columbia University SIPA, October 7, 2022, https://www.energypolicy.columbia.edu/publications/implications-of-chinas-unprecedented-lng-contracting-activity/.

67 "Statistical Review of World Energy 2023," 35–36.

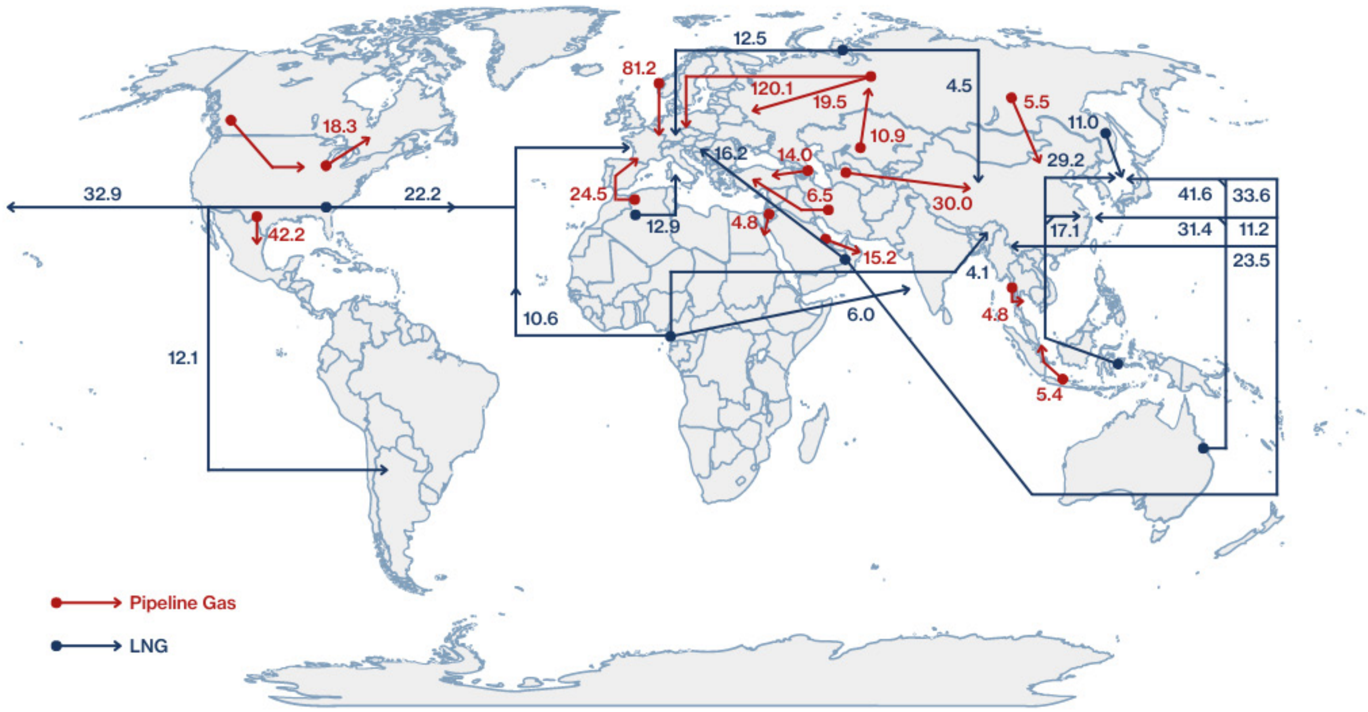
68 "Statistical Review of World Energy 2023," 30.

69 "Statistical Review of World Energy 2023," 30.

Table 5. LNG trade movements (mmt) from the world (per region) to Europe and the Asia Pacific, 2021[70]

To	From: Africa	Asia Pacific	Europe	Latin America	Middle East	Russia	United States	Total
Belgium	0,1	-	0,1	-	4,9	2,1	1,7	8,9
France	5,9	-	0,9	0,4	1,6	5,4	11,2	25,4
Italy	2,0	-	01	0,2	5,1	-	2,3	10,4
Spain	6,3	0,1	0,1	1,0	1,4	3,7	8,4	20,9
Turkey	6,2	0,1	-	0,3	0,1	0,2	3,9	10,9
United Kingdom	1,3	-	0,1	1,7	5,8	0,3	9,0	18,3
Other EU	5,1	-	1,3	1,2	1,8	2,5	15,8	28,3
Total Europe	**26,9**	**0,1**	**2,6**	**4,9**	**20,3**	**14,2**	**52,2**	**123,3**
China	1,9	39,7	-	0,7	18,9	4,4	1,9	67,5
India	2,5	0,6	-	0,1	14,3	0,4	2,4	20,6
Japan	1,4	52,2	-	0,3	6,6	6,7	4,1	71,2
Malavsia	-	2,8	-	-	-	-	-	2,8
Pakistan	0,5	0,1	-	0,1	6,4	-	0,1	7,1
Singapore	0,2	2,6	-	0,1	0,4	0,1	0,4	3,8
South Korea	1,4	21,3	-	0,8	15,1	1,9	5,7	46,3
Taiwan	0,4	10,4	-	0,1	5,8	1,1	21	19,9
Thailand	0,6	3,3	-	0,5	3,1	0,1	0,5	8,0
Other Asia Pacific	0,5	0,4	-	-	3,5	0,2	0,3	4,9
Total Asia Pacific	**9,4**	**133,2**	**-**	**2,7**	**74,1**	**14,9**	**17,5**	**251,8**

Figure 8. Major gas trade movements 2021 (million metric tonnes)[71]



Source: BP Statistical Review of World Energy 2022

70 "Statistical Review of World Energy 2023," 37.

71 "Statistical Review of World Energy," 28. Changes may have occurred since data used for this figure are from 2021.

Energy: Chokepoints and Alternative suppliers

The world's maritime transport routes are crucial for global oil markets.

The world's maritime transport routes are crucial for global oil markets. Almost 60% of the world's oil produced is transported via sea, with most of the seaborne trade happening from Persian Gulf and West African producers to European, Asia Pacific, and American consumers.[72] There are four main routes. The first one connects the Persian Gulf producers to East Asian consumers, passing via the Straits of Hormuz, Malacca, and Lombok. The second trade route is used to export oil from the Persian Gulf to Western Europe and the east coast of the Americas, where tankers need to go through the Strait of Hormuz and that of Mozambique. The third oil shipping route is the one linking producers in the Persian Gulf to consumers in Europe and North America via the Strait of Hormuz, Bab el Mandeb, and the Suez Canal. The last oil trade route in the Indo-Pacific is that between West Africa and China, which makes use of the Taiwan and Malacca straits.[73] Oil trade hence passes by seven different chokepoints in the Indo-Pacific and adjacent regions: the Strait of Hormuz, Strait of Malacca, Lombok Strait, Mozambique Strait, Bab el Mandeb, Taiwan Strait, and Suez Canal. Among these, the straits of Hormuz and Malacca are by far the busiest.[74] In 2020, 18 mb/d of crude oil transited via the Strait of Hormuz, accounting for almost 50% of the total volume of seaborne oil trade for that year, of which almost 80% flowed towards Asia.[75] In 2018, 15.7 mb/d passed through the Strait of Malacca.[76] Despite substantial Chinese efforts to reduce its dependence on the Straits of Malacca for energy imports, a challenge often referred to as the "Malacca Dilemma," progress in this regard has been minimal. While China has made partial attempts to diversify its energy imports and reduce the 80% share of total oil imports passing through the Straits of Malacca by utilizing overland routes, these endeavours have yielded limited results.[77]

LNG is also traded mainly from MENA producers to European and Asia-Pacific consumers, passing by the straits of Hormuz, Malacca, Taiwan, and the Suez Canal. However, given the strong intra Indo-Pacific trade from top global exporter Australia to China, Japan, and South Korea, other chokepoints such as the Korea Strait, Luzon Strait, Makassar Strait, Ombai Strait, and Sunda Strait are also heavily involved in LNG trade.[78]

Alternative routes to the abovementioned ones are not readily available.[79] In the event of the closure of the Strait of Malacca, the Sunda and Lombok Straits are the closest options, but the first one is too shallow to accommodate large oil tankers, while the latter lacks the infrastructures (port facilities and refuelling stations) to be a viable alternative.[80] If the Sunda and Lombok straits were also off-limits, the only alternative would be a long re-routing by the south of Australia, but this would considerably prolong shipping times. In the event of a blockade of the Strait of Hormuz, no opportunity for re-routing really exists, with the only alternatives

72 "World Oil Transit Chokepoints."

73 Giancarlo Elia Valori, "Maritime Oil Routes," *Modern Diplomacy* (blog), February 10, 2022, https://moderndiplomacy.eu/2022/02/10/maritime-oil-routes/; "World Oil Transit Chokepoints."

74 Niall McCarthy, "How Global Seaborne Oil Depends On Major Chokepoints," *Forbes*, accessed November 26, 2022, https://www.forbes.com/sites/niallmccarthy/2021/03/25/how-global-seaborne-oil-depends-on-major-chokepoints-infographic/.

75 Valori, "Maritime Oil Routes"; IEA, *World Energy Outlook 2019,* 166.

76 McCarthy, "How Global Seaborne Oil Depends On Major Chokepoints."

77 Myers, "China's Economic Security Challenge."

78 "World LNG Report 2022" (International Gas Union, 2022), https://www.igu.org/resources/world-lng-report-2022/; "World Oil Transit Chokepoints."

79 IEA, *World Energy Outlook 2019,* 166.

80 IEA, 168.

being few pipelines operated by Saudi Arabia and the UAE, the capacity of which would not be sufficient to replace the strait's traffic.[81] If the Suez Canal is not accessible, exporters to Europe and North America should re-route their tankers via the Cape of Good Hope, but this would add thousands of miles to shipments.[82] In general, re-routing is not a good option in many cases: it not only implies longer shipping times, but it also raises concerns over tanker shortages.[83]

On the one hand, securing alternative oil suppliers is a relatively straightforward process, primarily due to the global nature of the oil market. Moreover, IEA member states alone hold approximately 1.5 billion barrels of oil in strategic reserves, which can be coordinated for large-scale withdrawals among members and mitigate disruptions in supply. On the other hand, oil is available in various forms, including light, medium, and heavy crudes, each with varying sulphur content and other characteristics. These variations limit refiners' ability to switch between different oil sources. Additionally, the existence of clean tankers for refined products and dirty tankers for crude oil further complicates the flexibility of refiners to alter their source of supply. Lastly, finding viable substitutes for oil is challenging, as oil accounts for over 90% of global energy consumption for transportation, with no large-scale alternatives readily available.

Securing alternative LNG suppliers presents a more intricate challenge, mainly because gas trade is predominantly regional, governed by pipelines, and constrained in its capacity for intercontinental movement of LNG. Furthermore, lack of infrastructure continues to hinder the availability of LNG supply, with high upfront investments serving as a significant barrier for countries looking to develop such infrastructure. Moreover, countries lack substantial LNG reserves to rely on in case of a disruption, unlike the wide ranging strategic reserves of oil. Furthermore, the LNG market is fundamentally different from the oil market due to the prevalence of long-term contracts, especially in the case of China. This structure prevents LNG from behaving as a genuine spot market, which is the case with oil. Consequently, when the relatively spacious LNG market of 2022, created in response to the downturn in Chinese energy consumption, returns to a state of tight supply, Chinese companies have the capacity to resell LNG from their long-term contracts at higher prices to regions without such contracts. This manoeuvre is facilitated by the fact that consuming countries can readily substitute LNG with renewables, coal, and diesel fuel.[84] With the demand for oil and LNG not drastically curbing any time soon, and the difficulties related to finding alternative shipping routes and suppliers, the supply of these resources is inextricably connected to the upkeeping of free and open SLOCs. In fact, the trade of oil and LNG passes for several maritime chokepoints, and little to no alternatives to current shipping routes and suppliers are available at present.

81 "World Oil Transit Chokepoints, 6."

82 Valori, "Maritime Oil Routes."

83 "Oil Market Report," International Energy Agency, accessed November 19, 2022, https://www.iea.org/topics/oil-market-report.

84 Mark Finley and Anna Mikulska, "Wielding the Energy Weapon: Differences Between Oil and Natural Gas," Baker Institute, June 26, 2023, https://www.bakerinstitute.org/research/wielding-energy-weapon-differences-between-oil-and-natural-gas.

Raw material: Silicon

Supply chain

The silicon supply chain is characterised by an interaction between three key regions, namely East Asia, Europe, and North America. After silicon is mined, the raw ore is refined into various different levels of purity. Depending on its purity level, the silicon supply chain follows different paths. Whilst silicon with the highest purity levels, for example used in semiconductors, is predominantly produced in Europe and North America, and exported to East Asia, lower purity silicon is mainly produced in East Asia, and exported to Europe.[85]

Table 6. Lower and Higher Purity Silicon Characteristics

Lower purity silicon	Higher purity silicon	
Purity level: <99.99% Applications: Metallurgy	Purity level: >99.99%	
	Solar-grade polysilicon Applications: Solar panels	electronic-grade polysilicon Applications: Digital products (e.g., semiconductors);
	Dominated by: China	Dominated by: Germany, US, Japan

In 2021, the world produced over eight million metric tons of silicon, and world production is expected to increase in the coming decade. China dominates the silicon supply chain and accounts for over two-thirds of global mining output (see Figure 9: China Dominates the entire Solar Supply Chain). Other major producing countries include Russia, Brazil, Norway, and the United States.[86] China is also the key player in the refining and processing of silicon, including polysilicon used in solar panels. Seven out of the ten biggest suppliers of polysilicon are Chinese companies, including Tongwei, GCL, and Daqo New Energy, with the majority of companies based in the Xinjiang region.[87] However, the most advanced form of polysilicon, namely electronic-grade polysilicon used in semiconductor manufacturing, is predominantly produced in Germany (e.g., Wacker Chemie), the United States (e.g., Hemlock Semiconductor), and Japan (e.g., Tokuyama Corporation). Chinese companies are now increasing their capabilities to produce electronic-grade silicon as well and have the advantage of scale. Even though Chinese companies are producing mostly lower grade silicon, the sheer magnitude of the production volumes of such lower grades justifies building or expanding silicon production capacity. Once a new facility is erected or expanded, it is a relatively easier and cost effective step towards building capacity for higher or ultrahigh grade silicon as plant capital expenditures can be paid back quicker due to the economies of scale.[88]

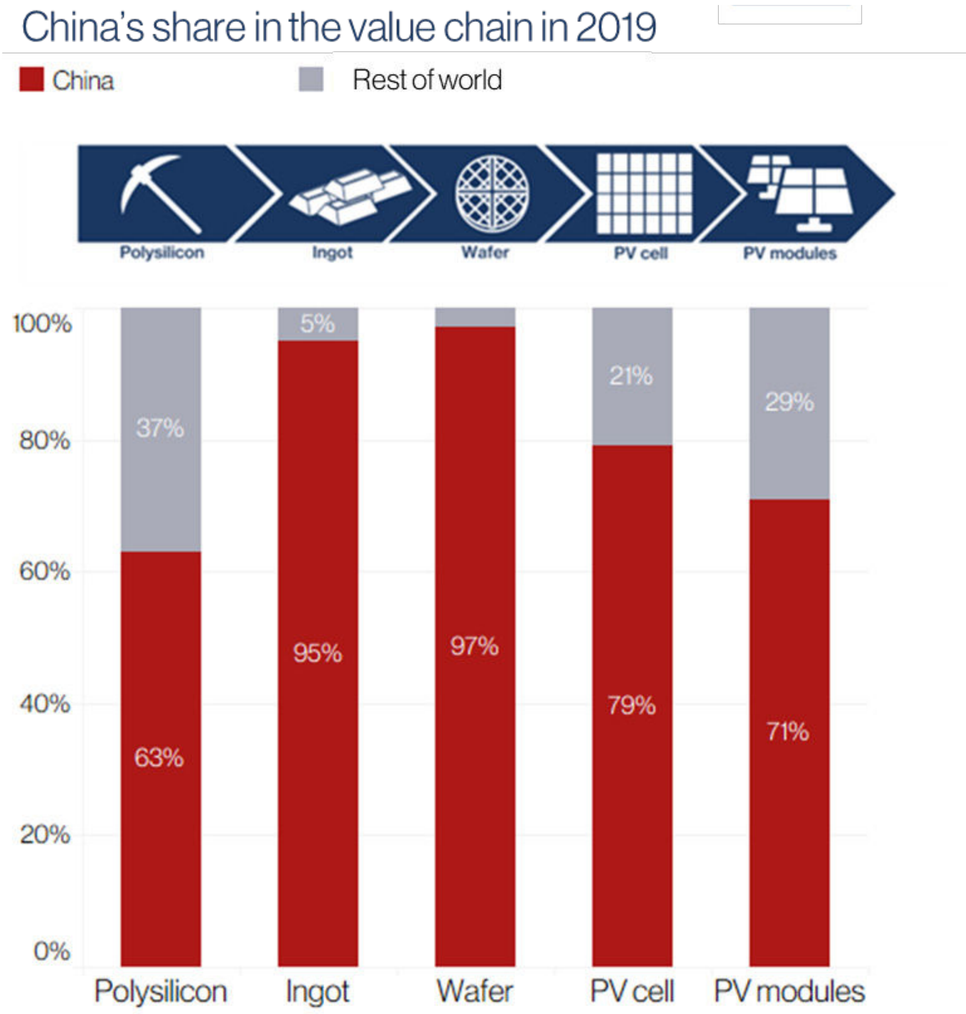
85 UN Comtrade, "UN Comtrade: International Trade Statistics," 2022, https://comtradeplus.un.org/.

86 USGS, "Silicon Statistics and Information | U.S. Geological Survey" (USGS, 2022), https://www.usgs.gov/centers/national-minerals-information-center/silicon-statistics-and-information.

87 Bernreuter, "Polysilicon Manufacturers: Global Top 10 | Bernreuter Research."

88 "Electronic Grade Polysilicon Market Share 2022 Global Trend, Industry News, Industry Demand, Business Growth, Top Key Players Update, Business Statistics and Research Methodology by Forecast to 2028 -," Market Watch, May 12, 2022, https://www.marketwatch.com/press-release/electronic-grade-polysilicon-market-share-2022-global-trend-industry-news-industry-demand-business-growth-top-key-players-update-business-statistics-and-research-methodology-by-forecast-to-2028-2022-05-12.

Figure 9. China Dominates the entire Solar Supply Chain[89]



Bron: Bernreuter Research (polysilicon), Bloomberg New Energy Finance (ingot), China Photovoltaic Industry Association (wafer/cell/module)

Major consumers of global silicon, as well as its end products, are located in North America, Europe, and East Asia. Chinese refined silicon is used in metallurgy or for solar cells and, subsequently, either consumed in the Chinese domestic market or shipped overseas to consumer markets in Europe, in particular Germany and the Netherlands, or East Asia, including Japan, and North America.[90] Higher purity silicon, on the other hand, is mostly exported from North America and Europe to consumer markets in East Asia, including China, Japan, and South Korea.[91] This silicon is integrated into high-purity end-uses, such as semiconductor manufacturing, after which it is re-exported to markets in Europe and North America. The table below lists the key countries in each segment of the silicon supply chain.

89 Bernreuter, "Polysilicon Manufacturers: Global Top 10 | Bernreuter Research."

90 UN Comtrade, "UN Comtrade: International Trade Statistics."

91 UN Comtrade.

Table 7. Global Producers and Consumers of Silicon

Silicon Mining (2020)[92]	Silicon Refining and Conversion (2020)[93]	Silicon Consumption (2020)[94]	Key Application: Solar PV Production (2020)[95]
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% World total: 8,120	By absolute value exported, in USD: Lower purity silicon (<99.99%): 1. China: $1.1 billion 2. Norway: $453 million 3. The Netherlands: $193 million Higher purity silicon (>99.99%): 1. Germany: $819 million 2. US: $819 million 3. Japan: $349 million	By absolute value imported, in USD: Lower purity silicon (<99.99%): 1. Germany: $478 million 2. Japan: $353 million 3. The Netherlands: $220 million Higher purity silicon (>99.99%): 1. China: $1 billion 2. Japan: $599 million 3. South Korea: $241 million	Share: 1. China: 70%-89% 2. Rest of Asia: 1%-8% 3. Europe: 0%-1%

Raw material: Cobalt

Supply chain

The cobalt supply chain, from mining to end-product, spans the entire globe and it is characterised by a limited number of players, in particular the Democratic Republic of Congo (DRC) and China. First, the raw cobalt ore is mined as a by-product of copper or nickel ore. This is followed by a refining process, after which the refined cobalt is processed into various chemicals, including cobalt sulphate and other metals. These processed chemicals and metals are eventually integrated into various end uses, such as battery cathodes, superalloys, and magnets, which are subsequently used in end-products.[96]

Cobalt is predominantly mined in the DRC, which is responsible for over two-thirds of global production in 2020. However, the refining and conversion of cobalt into metals and chemicals predominantly takes place in China.[97] Moreover, the majority of mines in the DRC are owned by Chinese (state-owned) companies, including China Molybdenum, Zhejiang Huayou Cobalt, and Jinchuan group. As of 2020, Chinese companies were involved in 15 out of the DRC's 19 cobalt mines.[98] One other major cobalt mine operator in the DRC is Swiss-based Glencore.[99] Other producers include Russia, Australia, and the Philippines.[100] The (partially

[92] USGS, "Silicon Statistics and Information | U.S. Geological Survey."

[93] UN Comtrade, "UN Comtrade: International Trade Statistics."

[94] UN Comtrade.

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

[96] Amrish Ritoe, "The New Great Game: Securing Critical Minerals Today for a Clean Energy System Tomorrow," HCSS, 17, accessed March 21, 2022, https://hcss.nl/report/the-new-great-gamesecuring-critical-minerals-to-dayfor-a-clean-energy-system-tomorrow/.

[97] USGS, "Cobalt Statistics and Information," Professional Paper, Professional Paper (USGS, 2022), https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-cobalt.pdf.

[98] 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. 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."

[99] Melissa Pistilli, "5 Largest Cobalt Mines in the World," INN, June 30, 2021, https://investingnews.com/daily/resource-investing/battery-metals-investing/cobalt-investing/largest-cobalt-mines/.

[100] USGS, "Cobalt Statistics and Information."

refined) cobalt ore mined in the DRC is subsequently shipped elsewhere, through various ports in Southern Africa, to be refined and converted into relevant metals and chemicals.[101] China is the world's leading producer of refined and processed cobalt (65% of global production), such as cobalt sulphate, which is essential for most electronic technologies.[102] Other countries holding a smaller stake in the refining and processing of cobalt are Finland (10%) and Belgium (5%).[103]

Table 8. Global Producers and Consumers of Cobalt

Cobalt Mining (2020)[104]	Cobalt Refining and Conversion (2019)[105]	Consumption (2020)[106]	Key Application: Battery Cells Production (2020)[107]	Key Application: EV Sales (2021)[108]
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 World total: 142,000	World share: 1. China: 65% 2. Finland: 10% 3. Belgium: 5%	World share: 1. China: 32% 2. Europe: 23% 3. Asia ex. China: 18% 4. North America: 18% 5. Rest of the world: 9%	Annual production capacity in GWh and share: 1. China: 465; 74% 2. Europe: 57; 9% 3. United States: 56; 9%	In millions and share: 1. China: 3.2; 49% 2. Europe: 2.4; 37% 3. US: 0.7; 11% 4. South Korea: 0.1; 0.02% 5: Canada: 0.1; 0.02%

Asia is by far the largest consumer of cobalt, due to the high concentration of battery production in East Asia. China accounts for over 30% of global cobalt consumption to manufacture components and end-products, in particular li-ion batteries. In fact, China controls 74% of global battery cell manufacturing as of 2020, followed by Japan and South Korea.[109] China is also dominant in the production of other cobalt-rich end uses, such as tool materials, magnets, and pigments. In Europe and North America cobalt is predominantly used in batteries, nickel-based alloys, and tool materials. These products are subsequently consumed by a domestic market or exported to major sales markets in East Asia, North America, and Europe.[110]

101 Tom Daly, "China Moly Shrugs off South Africa Port Disruption as DRC Cobalt Sales Rise," *Reuters*, April 30, 2020, sec. Commodities, https://www.reuters.com/article/us-cmoc-cobalt-drc-idUSKBN22C1KG; Melvin Goh et al., "South Africa's Lockdown to Hit Cobalt Exports: Sources | S&P Global Commodity Insights," SP Global, March 27, 2020, https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/032720-south-africas-lockdown-to-hit-cobalt-exports-sources.

102 USGS, "Cobalt Statistics and Information."

103 Amrish Ritoe, "The New Great Game," 17.

104 USGS, "Cobalt Statistics and Information."

105 "Share of Top Three Producing Countries in Total Processing of Selected Minerals and Fossil Fuels, 2019," IEA, accessed March 28, 2022, https://www.iea.org/data-and-statistics/charts/share-of-top-three-producing-countries-in-total-processing-of-selected-minerals-and-fossil-fuels-2019. "Share of Top Three Producing Countries in Total Processing of Selected Minerals and Fossil Fuels, 2019."

106 Roskill Consulting Group, "'State of the Cobalt Market' Report" (Cobalt Institute, May 2021), 8.

107 Jakob Fleischmann et al., "Unlocking Growth in Battery Cell Manufacturing for Electric Vehicles," McKinsey, 2021, https://www.mckinsey.com/capabilities/operations/our-insights/unlocking-growth-in-battery-cell-manufacturing-for-electric-vehicles.

108 BloombergNEF, "Electric Vehicle Outlook 2022" (BloombergNEF, 2022), https://about.newenergyfinance.com/electric-vehicle-outlook/.

109 Jakob Fleischmann et al., "Unlocking Growth in Battery Cell Manufacturing for Electric Vehicles," McKinsey, 2021, https://www.mckinsey.com/capabilities/operations/our-insights/unlocking-growth-in-battery-cell-manufacturing-for-electric-vehicles.

110 Roskill Consulting Group, "'State of the Cobalt Market' Report," 8.

Raw materials: Chokepoints, Alternative suppliers, Alternative supply lines

The silicon supply chain is defined by an interaction between three regions, namely East Asia, Europe, and North America. Cobalt is instead mined in the DRC, refined and processed mainly in China and consumed either domestically by China or exported to consumer markets in Europe, East Asia, and North America. The primary chokepoints in the maritime transportation routes of cobalt and silicon are the Taiwan Strait, Luzon Strait, Malacca Strait, the Six Degree Channel, Bab el Mandeb in the Horn of Africa, and the Suez Canal. Secondary chokepoints, with a more limited amount of goods transported, are the Mozambique Strait (for cobalt) and the Korea Strait (for cobalt and silicon). Few alternatives to these chokepoints exist in case of disruptions. The Taiwan Strait and the Luzon Strait can act as a substitute for one another for traffic between the South China Sea and the East China Sea. However, if both of these chokepoints are disrupted, shipping between East Asia and Europe is expected to increase by five to six days. Shipping through the Malacca Strait could be rerouted through the Lombok and Sunda Straits, but will add significant shipping time.[111] Alternatives to Bab el Mandeb and the Suez Canal are more limited as ships would have to go around Africa resulting in a significant increase in time and cost.[112]

As for alternative suppliers, the dependency on China for silicon and cobalt is likely to persist throughout the next decade.[113] As a substitute to Chinese silicon, operations in Brazil, Norway, and the United States could be scaled up and provide alternative maritime transportation routes. However, it must be noted that expanding or setting up mining operations elsewhere will take a significant amount of time, from seven up to twenty years, complexifying the diversification to other countries in the short to medium term.[114] In addition, China dominates the supply chain of various end products of silicon, such as solar panels, making dependency on maritime transportation routes to China through, for example, the Malacca Strait, unlikely to change. Cobalt can be sourced elsewhere to create alternative trade flows in the supply chain, but these come with significant challenges. As an alternative to the DRC, vast cobalt reserves can be found in nickel-bearing laterite deposits in Australia and Cuba, and magmatic nickel-copper sulphide deposits in Australia, Canada, Russia, and the United States. Moreover, over 120 million tons of cobalt reserves have been identified in polymetallic nodules on the floor of the Pacific, Indian, and Atlantic Oceans, but will most likely – due to international agreements under the International Seabed Authority – only become a viable alternative in the early 2030s.[115] In addition, it must be noted that to set up onshore mining operations from exploration to exploitation can take 7 to 20 years, limiting short-term relocation of cobalt mining.[116] Finding alternative suppliers to China is unlikely in the short-to-medium term.

111 ChinaPower, "How Much Trade Transits the South China Sea?," *ChinaPower Project* (blog), August 2, 2017, https://chinapower.csis.org/much-trade-transits-south-china-sea/.

112 Goodman and Reed, "With Suez Canal Blocked, Shippers Begin End Run Around a Trade Artery."

113 USGS, "Silicon Statistics and Information | U.S. Geological Survey."

114 IEA, "The Role of Critical Minerals in Clean Energy Transitions" (Paris: IEA, 2022), https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary.

115 USGS, "Cobalt Statistics and Information."

116 IEA, "The Role of Critical Minerals in Clean Energy Transitions."

Figure 10. Silicon supply chain

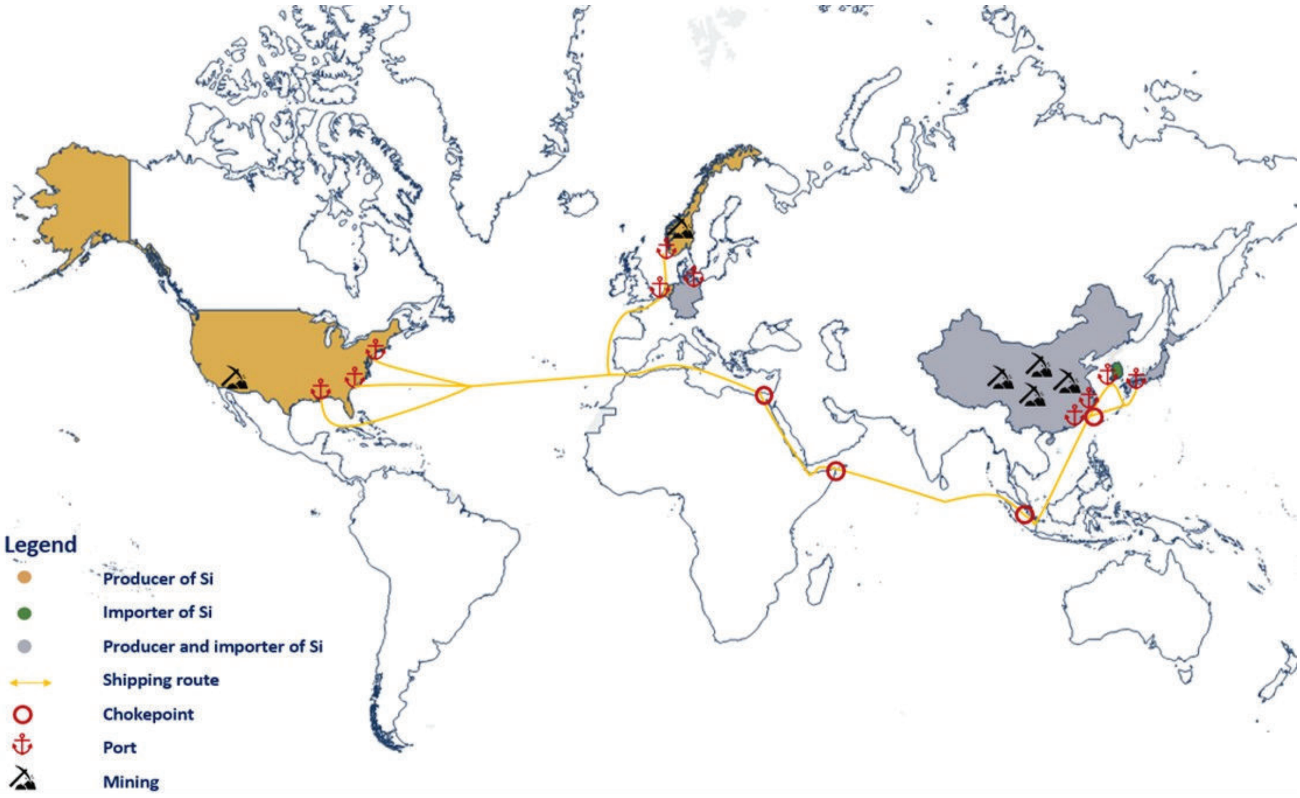
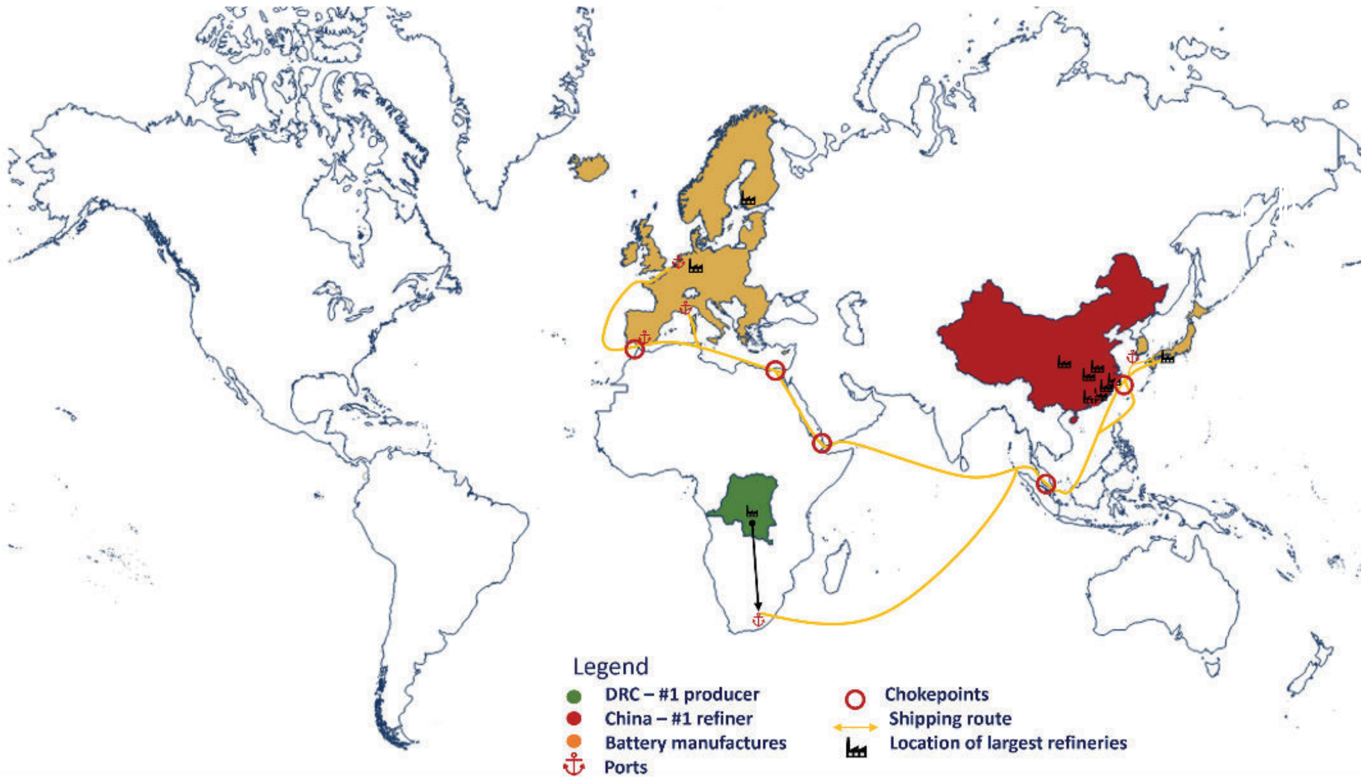


Figure 11. Cobalt supply chain

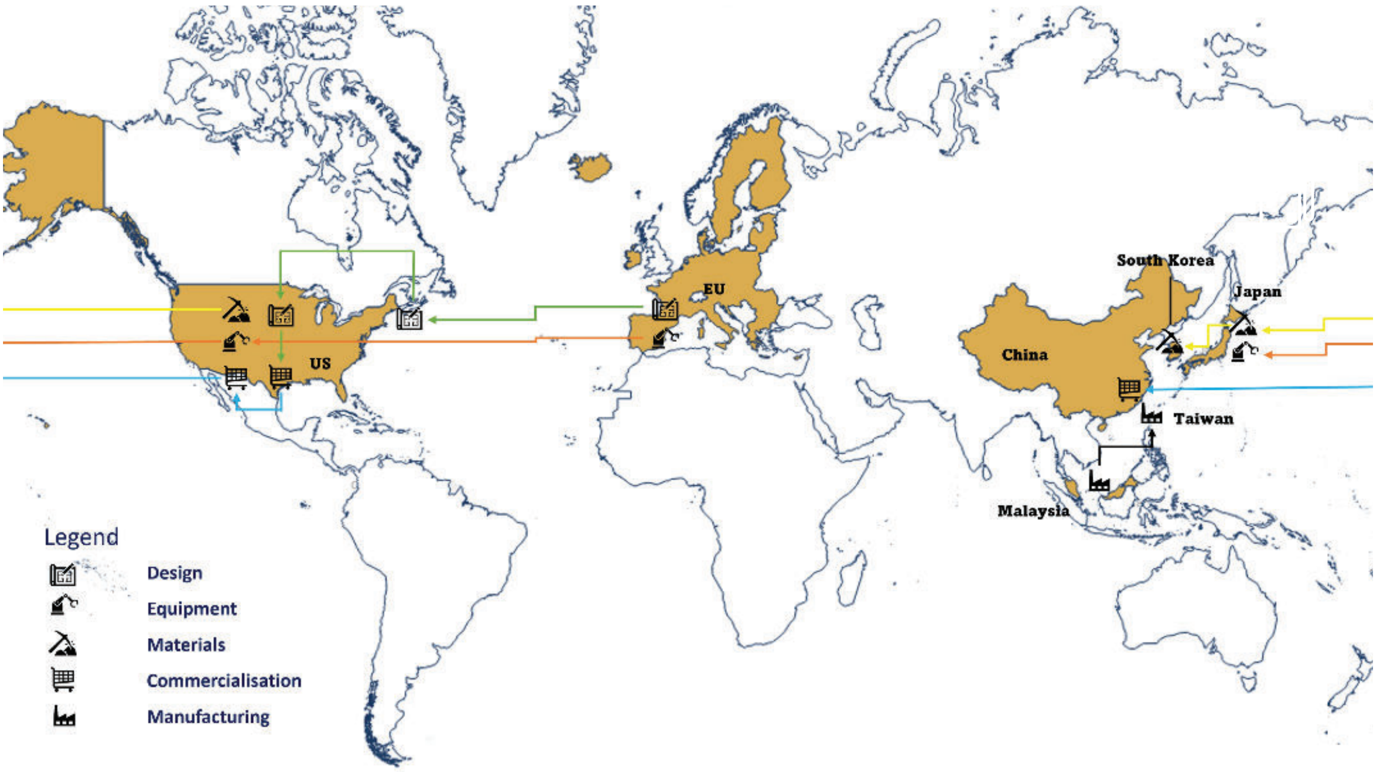


High technology: Semiconductors

Supply chain

The semiconductor supply chain is the most extreme example of the consequences of the increased complexity of global supply chains, as it is characterised by a high global division of labour and strong interdependencies. The supply chain can be divided into three main steps, namely (1) design, (2) fabrication, and (3) assembly, testing, and packaging (ATP). We focus on the latter two steps to highlight vulnerabilities. The fabrication of chips and ATP of semiconductors (respectively front- and back-end manufacturing), rely on their own supply of wafers, equipment, and processed chemicals. The finished "cutting-edge" semiconductors are subsequently commercialised into end products, such as computers and smartphones. The semiconductor supply chain spans the entire world across various regions, including important players such as the United States, Taiwan, South Korea, China, Japan, and Europe (see Figure 12). For example, one company in The Netherlands, Advanced Semiconductor Manufacturing Lithography (ASML), supplies key manufacturing equipment to companies in East Asia, including Samsung and Taiwan Semiconductor Manufacturing Company (TSMC), which fabricate the chips, whilst companies in China and Malaysia are important to the back-end of the supply chain. There are hence multiple chokepoints in the supply chain of semiconductors.

Figure 12. A Highly Globalised Supply Chain[117]



117 Kjeld van Wieringen, "Global Semiconductor Trends and the Future of EU Chip Capabilities" (ESPAS, 2022), 5.

High technology: Chokepoints, Alternative suppliers, Alternative supply lines

The semiconductor supply chain is characterised by a high global division of labour, with East Asian nations playing a major role in the production process, as well as the commercialisation into end-products. The United States, China, and Europe are the three key consumers of products containing advanced logic chips, such as computers and smartphones. The high concentration of digital component and end-product production in specific localities, such as China for manufactured digital products and Taiwan for the production of semiconductors, makes these regions "high value" sources that are not easily replaceable. However, unlike the transport routes for oil, LNG, and critical raw materials, which are primarily maritime, semiconductor transport routes are not. The supply chain of key digital products that run on one or more advanced logic chips relies on transport first and foremost via air,[118] which can also be disrupted. Yet, the supplies of material inputs for the production of semiconductors does take place over water, including trade of materials via the straits of Malacca, Lombok, Taiwan, Korea, Luzon, Makassar, Ombai, and Sunda. The extremely localized nature of the different stages of the semiconductor supply chains, makes diversification of suppliers difficult and vulnerability to geopolitical turmoil high. When it comes to front-end processes, the most obvious example is Taiwan, where over 90 percent of the advanced logic chip front-end manufacturing is located. Taiwan Semiconductor Manufacturing Cooperation's lead is relatively fixed for the foreseeable future, given the extremely high entry-barriers.[119] Building a cutting-edge fabrication plant costs around 20 billion USD, requires thorough and highly specialised knowledge of the semiconductor fabrication process, and it could easily take five years to set up. As of yet, there are no locations outside of Taiwan and South Korea with the capacity to manufacture the most advanced semiconductors in significant numbers.

Other steps in the supply chain, including ATP and the assembly of electronic devices, are less concentrated and characterized by lower entry barriers. While continued reliance on China is likely, alternatives such as Taiwan, the United States, Singapore, Malaysia, and Vietnam exist.[120] Companies are already gradually seeking alternative locations to move the production of electronic devices away from China, driven among other things by lasting fears of China's economic direction following Xi Jinping's ZERO-Covid policy and because of the intensifying US-China rivalry.[121] For example, Apple has recently started to shift some iPhone

118 Akira Kitado, "Japan's Airlines Eye Catering to Semiconductor, e-Commerce Shipments," Nikkei Asia, August 2023, https://asia.nikkei.com/Business/Transportation/Japan-s-airlines-eye-catering-to-semiconductor-e-commerce-shipments. Adam Satariano, "Apple transports newly released iPhones entirely by air. The IPhone's Secret Flights From China to Your Local Apple Store," *Bloomberg*, September 11, 2013; Kitado. Adam Satariano, "Apple transports newly released iPhones entirely by air. The IPhone's Secret Flights From China to Your Local Apple Store," *Bloomberg*, September 11, 2013, https://www.bloomberg.com/news/articles/2013-09-11/the-iphone-s-secret-flights-from-china-to-your-local-apple-store#xj4y7vzkg; Jan van Casteren, "How the New IPhone Could Drive Up the Shipping Cost of Everything," VentureBeat, September 13, 2017, https://venturebeat.com/commerce/how-the-new-iphone-could-drive-up-the-cost-of-everything/#:~:text=Apple%20ships%20its%20iPhones%20around,reasons%3A%20speed%20and%20working%20capital.

119 Jan-Peter Kleinhans and Nurzat Baisakova, "The Global Semiconductor Value Chain: A Technology Primer for Policy Makers," October 2020, https://www.stiftung-nv.de/sites/default/files/the_global_semiconductor_value_chain.pdf

120 Jan-Peter Kleinhans and John Lee, "China's Rise in Semiconductors and Europe" (SNV & MERICS, 2021), 15.

121 "Significantly, as a result of China's COVID-19 policy, 23% of respondents are now considering shifting current or planned investments out of China to other markets—more than double the number that were considering doing so at the beginning of 2022, and the highest proportion in a decade—and 7% are considering the same due to the war in Ukraine." "China's Covid-19 Policy and Russia's War in Ukraine Cause Severe Disruptions to European Business in China," European Chamber, May 5, 2022, https://www.europeanchamber.com.cn/en/publications-flash-survey-2022.; Adam S. Posen, "The End of China's Economic Miracle," *Foreign Affairs*, August 2, 2023, https://www.foreignaffairs.com/china/end-china-economic-miracle-beijing-washington.; Brenda Goh and Yimou Lee, "Huge Foxconn iPhone Plant in China Rocked by Fresh Worker Unrest," *Reuters*, November 24, 2022, https://www.reuters.com/technology/foxconns-zhengzhou-plant-hit-by-fresh-worker-unrest-social-media-livestreams-2022-11-23/.

Concerns related to violation of human rights and the environment, high costs of production and shipping, hyper-specialisation of production processes, sanctions, and high market entry barriers hinder the possibility of significantly diversifying the supply chains from those states that are currently the main producers of oil, LNG, silicon, cobalt, and semiconductors.

14 production from China to India.[122] Finding alternative suppliers for back-end operations is thus technologically easier than relocating front-end processes away from Taiwan and South Korea.

Summary

The supply chains of all five key economic inputs - oil, LNG, silicon, cobalt, and semiconductors - are inextricably linked to a limited number of sea lines of communications and related maritime chokepoints. The trade of crude oil and LNG inevitably passes by the Asia Pacific, Middle East and Europe. Middle Eastern countries such as Saudi Arabia, Iraq, and the UAE are big players in the oil market, exporting in the direction of both Europe to the west and the Asia Pacific to the east. Asia Pacific states such as Australia and Malaysia as well as MENA countries supply the most LNG globally. This means that energy supply chains make use of seven different chokepoints: the Strait of Hormuz, Strait of Malacca, Lombok Strait, Mozambique Strait, Bab el Mandeb, Taiwan Strait, and Suez Canal. Raw material such as cobalt and silicon are also moved across these chokepoints, as their supply chains involve four key regions: Africa, East Asia, Europe, and North America. In particular, silicon is exported from the United States, Germany, Norway and China to Europe and the Asia Pacific, while most of cobalt mines are in the DRC and the extracted material travels to China for refinement before being exported to the rest of the world. Lastly, the supply chain of semiconductors spans North America, Europe and East and Southeast Asia but its major players are the United States, Taiwan, South Korea, China, Japan, and Europe. While most of semiconductors travel by air, the inputs necessary to fabrication and ATP processes often make use of maritime trade, passing via straits of Malacca, Lombok, Taiwan, Korea, Luzon, Makassar, and Sunda.

Finding alternative suppliers for all these key resources is difficult. Concerns related to violation of human rights and the environment, high costs of production and shipping, hyper-specialisation of production processes, sanctions, and high market entry barriers hinder the possibility of significantly diversifying the supply chains from those states that are currently the main producers of oil, LNG, silicon, cobalt, and semiconductors. The growing complexity of key resources' supply chains hence makes them more vulnerable to disruptions, given the difficulties related with finding alternative suppliers and maritime routes for transport.

122 Alex Hern, "Apple Shifts Some IPhone 14 Production from China to India," *The Guardian*, September 27, 2022, sec. Technology, https://www.theguardian.com/technology/2022/sep/27/apple-shifts-some-iphone-14-production-from-china-to-india.

4. Future scenarios: how much access to expect?

The current complexity and vulnerability of supply chains of key economic inputs is clear; we look to explore the possibilities for diminishing those threats to access and mitigating the risks of them worsening. The chapter looks at future political, physical, and technological trends that push towards greater or diminished access.

In the following sections we assess future scenarios that we conceive of as high-access and low-access. First, as noted in the study design, access is conceptualised as a combination of overall supplies and the number of suppliers. An economic input that is crucial and in high demand but has either high overall supplies or a high number of suppliers allows for market forces to reorder the supply of economic inputs. Second, access is conceptualised as the availability of transport routes, particularly maritime transport routes. The combination of these two features offers two types of access worlds. This chapter discusses the first two kinds of high- and low-access, while chapter 5 looks at the impact on physical access through maritime and other transport. Simply put, in a high-access world there is both medium-to-high overall supply of a key economic input on the one hand, and a medium-to-high number of suppliers on the other hand; in contrast, in a low-access world, the interaction between both supply and suppliers is constrained as both are low-to-medium.

Our thinking is built on the following assumption. In a high-access world it is – all things being equal – more difficult to deny access and cut off consumers, whether through export controls or military pressures on sea lines of communication. Whenever a supply source is cut off, in a high-access world, the global market is likelier to redirect flows, with existing suppliers increasing their relative supplies or other suppliers delivering to consumers. That redirection of flows is not necessarily cost-free, but denying an adversary access to these inputs is impossible. In a low-access world, there are few available options and therefore disruptions have higher impacts.

In the chapter's first cut of high- and low-access worlds, the research deliberately does not focus on who the suppliers are. Given the volatility in political relations, our working assumption is that limited access – *even* if the access is controlled by more aligned states – still increases the vulnerability to disruption, if not through market measures such as export controls or sanctions, then through militarily impeding physical access. Focusing on the existence of overall available supplies and suppliers is more robust. Our subsequent assessment in chapter 5 addresses the political context of disruptions.

The objective of this approach is to offer a systematic and comparative approach to the analysis of key economic inputs that transcends the idiosyncrasies of individual supply chains. It consciously simplifies the complexities of supply chains and emphasises the relative presence of chokepoints at the initial stages of a supply chain. The approach links the (1) overall supply and (2) suppliers to (3) the sea- or other routes over which the critical economic inputs are transported.

To assess whether supply and supplies are likely to be higher or lower access, we look at three dimensions of drivers towards higher and lower access: (I) political; (II) technological; and (III) physical. Key political developments include trade liberalisation, human rights and/or environmental regulations, ownerships, treaties, and so on. Key technological developments include productivity or extraction gains. Key physical developments more loosely focus on the discovery or limits of oil and gas fields, or mines, or the feasibility of expanding manufacturing in a limited amount of time.

In designing the scenarios, we stress that the high-access and low-access future scenarios are not intended as predictions of what *will* happen. Rather, we use the scenarios to scope the extent to which the supply or number of suppliers can change in the coming decades, and the fragility or sensitivity of the system to disruption. They are intended to give feasible bounds and examine how robust or malleable the focus on certain maritime hotspots around choke-points is.

Energy: Oil Scenario

Oil is the world's most used energy source, accounting for around 40% of the global energy consumption.[123] It is employed in a variety of products, such as gasoline, kerosene, diesel, and propane. Oil fuels the lives of billions of people globally and, as of 2019, it was used for 43% in road transport, 19% in industry and petrochemicals, 12% in aviation and shipping, 13% in buildings and power, and 12% in other sectors.[124] We consider the physical, technological, and political trends regarding oil up to 2033 that will define whether we are more or less likely to be in a high-access or a low-access world.

Physical Trends

High Access Scenario

In a high access scenario, a higher level of global oil production and a greater supplier diversity ensure diversified access to crude oil.

Most of the anticipated growth in oil production is expected to come from OPEC members in the Middle East, the United States, Brazil and Guyana, some of which may translate into larger exports.

123 "Final Consumption – Key World Energy Statistics 2021 – Analysis," IEA, 2022, https://www.iea.org/reports/key-world-energy-statistics-2021/final-consumption.

124 "World Energy Outlook 2019" (International Energy Agency, November 2022), 133.

Saudi Arabia is starting 11 oil projects that will boost its production to 13 mb/d.[125] The UAE increase their production by 1 mb/d through new major discoveries and investments in the Upper Zakum oil field.[126] Iraq's oil output also slightly increases by 2030, year in which the Middle East will account for 33.9 mb/d, over 1/3 of global production.[127] The physical developments in these countries will contribute to a world of higher access, with greater overall oil production and various suppliers.

The United States could augment its oil output by approximately 4 mb/d. This growth can be attributed primarily to the increased emphasis on deepwater projects, tight oil, and shale oil, driven by International Oil Companies (IOCs) prioritizing ventures with rapid investment recovery rates. This high-access scenario entails a notable shift in the United States' role in the global oil landscape. Rather than predominantly catering to domestic consumption, the country would have to pivot towards larger-scale oil exports, channelling substantial quantities of its increased production to the international market.[128]

Brazil has made significant investments to develop their deepwater fields with plans to double their annual investments in the next few years. Petrobras is investing up to $16B to revitalize some of their existing oil fields as well as plans to start exploiting new offshore discoveries in Central Alto de Cabo Frio & Aram.[129] These investments contribute to Brazil's expansion, with potential production levels up to 4.4 mb/d by 2030, accounting for more than 40% of global deepwater oil production.[130]

Guyana has also made large discoveries in recent years. The feasibility of extraction appears to be relatively high, with production in the Liza field starting in 2019, only four years after discovery.[131] ExxonMobil is investing heavily in Guyana's offshore fields in the Stabroek bloc.[132] These sites are full of potential extractable oil that contributes to increasing Guyana's production of crude oil by 1.5 mb/d by 2030.[133]

Low Access Scenario

In a low-access scenario, pledged investments in major oil countries face a number of difficulties with the economic viability and priorities of companies and do not generate substantial added production.

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125 Nishant Ugal, "Saudi Aramco Nears Decision for up to 11 Coveted Offshore Contracts," Upstream Online | Latest oil and gas news, January 11, 2023, https://www.upstreamonline.com/exclusive/saudi-aramco-nears-decision-for-up-to-11-coveted-offshore-contracts/2-1-1385614.

126 Martyn Wingrove, "US$470Bn Planned in Middle East Offshore Oil Investment," Riviera, May 2, 2020, https://www.rivieramm.com/news-content-hub/news-content-hub/over-us470bn-planned-in-middle-east-offshore-oil-investment-57894.

127 "World Energy Outlook 2022," 336.

128 Jilles van den Beukel, "Over de Klimaatzaak En de Emissies van Broeikasgassen Door Olie- En Gasbedrijven," energeia.nl, June 14, 2021, https://energeia.nl/trilemma/40093702/over-de-klimaatzaak-en-de-emissies-van-broeikasgassen-door-olie-en-gasbedrijven. "World Energy Outlook 2022," 338.

129 Melisa Cavcic, "Petrobras Unveils Plans to Invest $16 Bln in 'Largest Revitalization Project in the Offshore Industry Worldwide,'" Offshore Energy, May 9, 2022, https://www.offshore-energy.biz/petrobras-unveils-plans-to-invest-16-bln-in-largest-revitalization-project-in-the-offshore-industry-worldwide/.

130 "World Energy Outlook 2022," 339.

131 "World Energy Outlook 2022," 339.

132 Melisa Cavcic, "ExxonMobil's New Oil Discovery off Guyana Could Underpin Future Development," Offshore Energy, January 26, 2023, https://www.offshore-energy.biz/exxonmobils-new-oil-discovery-off-guyana-could-underpin-future-development/.

133 "World Energy Outlook 2022," 339.

IOCs may shift their strategic focus from expansion initiatives to prioritize disbursing dividends to their shareholders. This leads to a noticeable reduction in investments directed towards geological exploration and the development of new oil fields, which would impede the potential for future capacity expansion significantly.[134] This is compounded by an elevated level of political risk associated with investments in new oil production sites. This heightened risk factor casts doubt on the feasibility of well development, primarily due to the substantial development costs involved, which amount to approximately $90.9 million per offshore oil drilling well.[135]

These developments lead to a more limited expansion in additional production capacity within the United States in the low-access scenario as compared to the high-access scenario. It is conceivable that in countries like Suriname, Final Investment Decisions (FID) could face potential postponements or even cancellations. The full realization of Guyana's oil field potential might be hindered due to changing priorities. This situation is exemplified by major private entities like ExxonMobil and other influential corporations involved in the development of Guyana's oil resources, which have been observed to alter their final investment decisions.

In the Middle East, certain OPEC members face several issues related to shortages in natural resources and infrastructural barriers necessary for the extraction of oil. In this scenario, Iraq's potential oil fields are not exploited and instead, the issue of water scarcity worsens, which affects their ability to extract crude oil.[136] Iran's spare capacity and vast oil reserves run into infrastructural issues since the country lacks the expertise to maximise its potential production as it has faced sanctions since 1979. The abovementioned developments hence play a role in stagnating global oil production and increase supplier concentration to the Middle East, giving rise to a world of low access.

Technological Trends

High Access Scenario

There are several technological advancements and techniques that could lead to a world of higher access as a result of their effects on added capacity.

First, fracking is a drilling technique that involves cracking a rock to allow the oil to come to the surface.[137] The US, Canada, China, and Argentina use this technique to extract volumes of shale oil adequate enough to market them.[138] In a high-access scenario, the further advancement and global dissemination of fracking technology enable increased oil extraction. Houston stands as the epicentre of technological innovation in oil production, particularly shale oil, serving as a knowledge-sharing hub for other regions. However, extracting shale oil presents intricate technical challenges compared to shale gas, primarily due to the complexities involved in recovering oil from low-permeability reservoirs.

134 Geoffrey Morgan, "Big Oil Is Paying Out Years of Dividends in One Day," Bloomberg.com, August 5, 2022, https://www.bloomberg.com/news/articles/2022-08-05/big-oil-is-paying-out-years-of-dividends-in-one-day.

135 Mark J. Kaiser, "A Review of Exploration, Development, and Production Cost Offshore Newfoundland," *Natural Resources Research* 30, no. 2 (April 1, 2021): 1259, https://doi.org/10.1007/s11053-020-09784-3.

136 Dorith Kool, Laura Birkman, and Bianca Torossian, "Interprovincial Water Challenges in Iraq: Initial Analysis of an Urgent and Under-Researched Crisis" (Water, Peace and Security, August 2020).

137 "Fracking Explained | Oilandgasinfo.Ca," accessed January 31, 2023, https://oilandgasinfo.ca/all-about-fracking/fracking-explained/.

138 "In What Countries Is Fracking Done? – SGK-Planet," SGK Planet, 2021, https://sgkplanet.com/en/in-what-countries-is-fracking-done/.

Second, Brazil and Angola are currently heavily investing in deepwater exploitation. The development of their expertise creates further progress that allows for drilling in deeper waters, making it possible to exploit new fields and opening up access to crude oil.[139]

Third, transfers of technical know-how in Light Tight Oil (LTO) production also boost oil supply over the next decade. There is significant potential in Argentina, China, and Russia.[140] The spread of expertise allows other countries to reap the benefits and increase their supply capacity.

Companies are also increasingly applying IoT, data analytics, autonomous machines, and remote sensor imaging to exploration and extraction processes. The use of these technologies cuts costs and emissions as well as improves the potential of new site discoveries. It is estimated that these techniques could save up to $73B for European upstream oil companies.[141] While the technological expertise is limited to a number of countries and companies, these methods could become more widespread over the next decade and contribute to a world of higher access. Low Access Scenario

Low Access Scenario

In a low-access world, the previously mentioned technological advancements and techniques encounter severe challenges due to a negative cost-opportunity balance.

Geological constraints are increasingly significant for the US, given that the most lucrative shale oil reserves have already been identified, resulting in a slower expansion of shale oil production, despite comparable or higher oil prices. While annual growth reached approximately 2 mb/d in 2018, as of 2023 it hovers around 1 mb/d.[142]

Major producers like Saudi Arabia, UAE, Iran, Kuwait, Algeria, Oman etc. do not need to use these techniques to boost their oil supply.[143] The oil in this region is easily extractable and using such methods would only increase the costs of production and drive profits down. Consequently, it is not economically advantageous for these nations to embrace these new techniques, particularly considering the higher levels of investment required to maximize both their added capacity and economic viability. Furthermore, the dissemination of these technologies faces constraints, particularly regarding expertise, as exemplified by the case of LTO.[144]

139 Tatiana Costa, "Angola and Brazil Strengthen Cooperation in the Field of Hydrocarbons," VerAngola, September 29, 2022, https://www.verangola.net/va/en/092022/Energy/32754/Angola-and-Brazil-strengthen-cooperation-in-the-field-of-hydrocarbons.htm.

140 Tim Gould and Christophe McGlade, "Could Tight Oil Go Global? – Analysis," IEA, February 1, 2019, https://www.iea.org/commentaries/could-tight-oil-go-global.

141 Scarlett Evans, "What Can Digitalisation Do for the Oil and Gas Supply Chain?," *Offshore Technology* (blog), February 10, 2022, https://www.offshore-technology.com/features/oil-gas-digitalisation-supply-chain/.

142 Jilles van den Beukel, "Fossiel in de VS: Verleden, Heden En Toekomst," https://energeia.nl/trilemma/40106356/fossiel-in-de-vs-verleden-heden-en-toekomst, May 24, 2023, https://archive.ph/mpVS8.

143 William Beinart and Lotte Hughes, "Oil Extraction in the Middle East: The Kuwait Experience," in *Environment and Empire*, ed. William Beinart and Lotte Hughes (Oxford University Press, 2007), 0, https://doi.org/10.1093/oso/9780199260317.003.0020.

144 Gould and McGlade, "Could Tight Oil Go Global?"

Environmental concerns limit the potential benefits from fracking. The UK has already banned fracking and the government is unlikely to change direction in the near term.[145] In a low access scenario other states ban the technique and access to crude oil through fracking is hence limited.

In a low access scenario, the aforementioned technologies and methods will not be used to substantially increase production as major producers will choose not to invest in them, rendering them economically unviable for other oil-producing entities.

Political Trends

High Access Scenario

In a high access scenario, sanctions on major potential producers are lifted, which allows them to increase both output and exports; at the same time, political instability in major supplier countries diminishes significantly.

First, sanctions on several oil-producing states limit overall global supply but tricks to beat them, and thus enhance production, exist.[146] Iran has been hit by sanctions since 1979 which have limited its production capacity. Currently, it produces around 4 mb/d. In the next decade, it could increase its output by upwards of 2 mb/d.[147] China's Sinopec and CNPC are becoming involved in Iran's oil sector in their southwest fields. If relations with Western countries normalise, Iran could have a greater contribution to global oil production. Venezuela, which has been subject to US-imposed harsh sanctions since 2019, could follow a similar path to Iran. The instability caused by Russia's invasion of Ukraine and oil price volatility pushed some talks regarding softening the sanctions on Venezuela, though this development remains quite unlikely.[148] While the effects of political instability and sanctions in Venezuela would not allow the country's input to drastically increase, access to Venezuelan oil would still improve.

Second, Nigeria and Iraq are large producers that already suffer from political instability.[149] If the domestic situation were to improve in these states as well as in other producers in the region, oil production could increase.

Low Access Scenario

In a low access scenario, producers may struggle to make the necessary investments, climate legislation following mass public protests like Extinction Rebellion puts pressure on oil producers, decreasing their output, the effect of sanctions on producers limits their

145 Prime Minister Sunak has stated his continued support for the policy as it requires enormous amounts of water that could strain local communities. Andrew Jeong, "Rishi Sunak Is Keeping the U.K.'s Fracking Ban: What to Know," *Washington Post*, October 27, 2022, https://www.washingtonpost.com/world/2022/10/27/uk-fracking-ban-meaning-rishi-sunak/. Prime Minister Sunak has stated his continued support for the policy as it requires enormous amounts of water that could strain local communities.

146 "Iran Teaches Russia Its Tricks on Beating Oil Sanctions," *POLITICO* (blog), November 9, 2022, https://www.politico.eu/article/iran-russia-cooperation-dodging-oil-sanctions/.

147 Aresu Eqbali in Tehran, "Iran Plans to Boost Oil Output Capacity to Pre-Sanctions Levels by March 2022," November 28, 2021, https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/oil/112821-iran-plans-to-boost-oil-output-capacity-to-pre-sanctions-levels-by-march-2022.

148 Jennifer Jacobs et al., "US to Lift Some Sanctions on Venezuelan Oil, Ease Chevron PDVSA Talks - Bloomberg," Bloomberg, May 17, 2022, https://www.bloomberg.com/news/articles/2022-05-17/us-to-lift-some-sanctions-on-venezuelan-oil-ease-chevron-talks.

149 "Fragile States Index | The Fund for Peace," Fragile State Index, 2022, https://fragilestatesindex.org/.

production even further, and political instability hinders the production of oil and consequentially access to this resource.

The bulk of oil production revolves around OPEC and its members. The organisation has claimed that $12.1 trillion dollars must be spent on upstream, midstream, and downstream production to increase supply by 2045, roughly $500 million per year.[150] OPEC members are currently struggling to reach this investment goal in recent years because of COVID-19 and industry downturns. Increasing focus on Environmental, Social, and Governance (ESG) related issues and global decarbonization policies will push IOCs to reassess their investments.[151] Even if relations are normalised with Iran, its impact on global oil production will be rather limited as the country has not had access to extraction technology that permit it to significantly increase its output due to the imposed sanctions. Additionally, Iran faces internal stability issues that will negatively impact its oil production in the next decade.[152] Nigeria struggles with oil theft and corruption issues.[153] The internal situation and ageing infrastructure will discourage future foreign investments in its oil sector. In Iraq, oil production still requires a lot of water, which in Iraq is increasingly scarce. Moreover, the increasingly frequent and damaging natural disasters may push for more investments in renewables rather than oil. Therefore, in a low access scenario, climate legislation and regional instability in major producers negatively affects production and does not lead to a diversified access of oil.

	High Access	Low Access
Physical	Most investments are in the Middle East but supplier diversity increases as new fields are exploited in emerging markets. Global production increases.	The market remains heavily reliant on the Middle East. Investments in emerging markets are too costly and do not provide a significant level of supplier diversity. Global production largely stagnates.
Technological	New technologies spread in major producing countries, driving their cost down and improving their effectiveness. This leads to higher levels of production and access to new fields.	Dominant producers do not require the techniques to increase their output, so they choose not to adopt them. New technologies and extraction methods remain too costly.
Political	Sanctions on major potential producers are lifted, contributing to higher production. The domestic situation and regional stability ameliorates in some producing countries, allowing for a greater output.	ESG and climate legislation puts pressure on oil producers and decreases their output. Instability and lack of incentives push major oil companies away from certain markets due to high risk, decreasing global output.

150 "OPEC Launches 2022 Edition of the World Oil Outlook at ADIPEC," Organization of the Petroleum Exporting Countries, October 31, 2022, https://www.opec.org/opec_web/en/press_room/7042.htm.

151 Mark Leonard et al., "The Geopolitics of the European Green Deal" (European Council on Foreign Relations, August 2, 2021), 7, https://iorj.hse.ru/en/2021-16-2/484917422.html.

152 "A Turbulent Year for MENA in 2023: Economic Stresses, Political Instability, and the Need for Decisive Leadership," Middle East Institute, accessed February 1, 2023, https://www.mei.edu/publications/turbulent-year-mena-2023-economic-stresses-political-instability-and-need-decisive.

153 Nduka Orjinmo, "Nigeria's Stolen Oil, the Military and a Man Named Government," *BBC News*, October 22, 2022, sec. Africa, https://www.bbc.com/news/world-africa-63314545.

Energy: LNG Scenario

LNG is used as an energy source for a multiplicity of applications, among which heating, manufacturing processes, power generation, and fuel.[154] Recently, LNG has been hailed as the bridge fuel to a low-carbon future, since it emits about 40% less CO2 than coal and 20% less than oil.[155] We consider the physical, technological, and political trends regarding LNG up to 2033 that will define whether we are more or less likely to be in a high-access or a low-access world.

Physical Trends

High Access Scenario

In a high access scenario, the supplier diversity of LNG is enhanced by the expansion of liquefaction capacity given that amore certain investment business environment in the aftermath of the war in Ukraine would push for the approval of new investments in the sector. As a consequence of the Russian aggression on Ukraine, gas prices soared to an all-time high, with the value of global LNG trade doubling in 2022 to $450 billion.[156] Thus, the LNG market is an extremely lucrative venue that attracts further investments.

Several international and national gas companies have already announced new projects to expand their liquefaction capabilities. In 2022, companies from leading LNG exporters US, Australia, and Qatar announced new investments in their national territories that will add a total capacity of 84 bcm/year by 2026.[157]

Smaller LNG exporters concentrated especially in Africa also join the party. Italian company Eni announced investment in floating liquefaction units in the DRC. Following the successful inauguration of Mozambique's very first LNG production site, Coral Sul, in 2022, the company is now considering the possibility of investing in additional floating LNG projects in the coast of Mozambique.[158] Sonangol in Angola partnered with BP, Eni, Chevron, and Total Energies to invest in the Quiluma and Maboqueiro offshore fields. The LNG export plant will be online in 2026 with a capacity of 4 bcm/yr. [159] The Tanzanian government is in the process of signing $40 Billion LNG-Project Accords with Shell and Equinor to start the construction of an LNG export terminal.[160] Given that the LNG market is largely driven by long-term contracts, the expansion of LNG production will translate into higher access if all main consumers are able to access some of this supply.[161]

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154 "Uses and Benefits."

155 Kenneth B. Medlock, Steven R. Miles, and Marcia Hook, "'Green LNG' – A Pathway For Natural Gas In An ESG Future?," Forbes, accessed November 25, 2022, https://www.forbes.com/sites/thebakersinstitute/2020/10/26/green-lng--a-pathway-for-natural-gas-in-an-esg-future/.

156 "Gas Market Report, Q1-2023," IEA, February 2023, 17, https://www.iea.org/reports/gas-market-report-q1-2023.

157 "Gas Market Report Q4 2022 Including Global Gas Security Review 2022" (International Energy Agency, 2022).

158 Melisa Cavcic, "Following Coral-Sul Inauguration, Eni Eyes More FLNG Developments off Mozambique," *Offshore Energy* (blog), November 23, 2022, https://www.offshore-energy.biz/following-coral-sul-inauguration-eni-eyes-more-flng-developments-off-mozambique/.

159 "Gas Market Report Q4 2022 Including Global Gas Security Review 2022."

160 "Tanzania to Sign Key $40 Billion LNG-Project Accords Next Month," *Bloomberg.Com*, November 7, 2022, https://www.bloomberg.com/news/articles/2022-11-07/tanzania-to-sign-key-40-billion-lng-project-accords-next-month.

161 IEA, "Global Gas Security Review 2023 Including the Gas Market Report Q3 2023," 17–18.

Low Access Scenario

In a low access scenario, the supply of LNG remains concentrated in the hands of few states who already have long-term contracts with few consumers. For instance, China has already concluded a lot of such contracts, meaning that other consumers may still face insecurity of supply.[162] The production of LNG is a costly process and setting up LNG facilities can take a long time. Even announced projects are often not finalised. Despite several countries planning to join the LNG market, investments do not materialise and the production of LNG in newcomer countries is not sufficient to boost production and grant diversified access to LNG resources. While some projects are planned to become operational by 2026, the uncertain investment environment discourages new players to fund LNG projects.[163] Rising construction costs and widespread engineering as well as procurement and construction contract renegotiations hamper the development of new LNG capacity and make potential buyers reluctant to commit to new LNG contracts. The access to LNG is thus limited.

Technological Trends

High Access Scenario

Technical issues related to liquefaction technologies are a frequent occurrence especially in legacy plants, particularly in major LNG producers such as Nigeria, Malaysia, and Australia, considerably slowing down LNG production.[164] In a high access scenario, these technical issues are dealt with swiftly and the performance of legacy plants is enhanced, contributing more significantly to the LNG market.

Low Access Scenario

Given the complexity of LNG plants, sites regularly undergo maintenance and unexpected technical problems emerge frequently, causing unplanned shutdowns.[165] In a low access scenario, the occurrence of these shutdowns is frequent and has lengthy consequences aggravated by the scale of necessary repairs.

Political Trends

High Access Scenario

In a high access scenario, favourable political conditions contribute to continued investments and expansion of LNG production. Political instability is reduced in the supplier economies. For instance, Malaysia, which has changed four prime ministers over the last five years, finds stability under Prime Minister Anwar Ibrahim and tensions in the United Malays National Organization (UMNO), the leader of the ruling coalition, are defused.[166] Higher political stability allows Malaysia to invest more consistently in its LNG capabilities, resulting

162 IEA, 18.

163 "Gas Market Report, Q1-2023," 9.

164 "Gas Market Report, Q1-2023," IEA, February 2023, https://www.iea.org/reports/gas-market-report-q1-2023, 9.

165 International Energy Agency and Korea Energy Economics Institute, "LNG Market Trends and Their Implications: Structures, Drivers and Developments of Major Asian Importers" (IEA, June 27, 2019), https://doi.org/10.1787/90c2a82d-en.

166 "Political Risk Index Winter 2022/2023," Willis Tower Watson, 2023, https://willistowerswatson.turtl.co/story/political-risk-index-winter-2022-2023-gated/.

in increased export of LNG. Moreover, in a high access scenario, Russian gas circulates in the market. In fact, Europe is still a key export market for Russian LNG, despite reducing its imports from Moscow. Russia could also expands its exports towards China and India. While most of this exports would be done via pipeline and not through maritime routes, Russian contributions would still provide higher access to LNG.[167]

Low Access Scenario

In a low access scenario, the access to LNG is limited by political factors such as instability and environmental concerns. In the US, environmental concerns restrict the expansion of liquefaction plants. In particular, political partisan divisions on environmental issues hamper the possibility of gaining higher access to gas reserves and limit access to this resource.[168] Tensions between Europe and Qatar heightened when Qatari officials threatened to reconsider their LNG deals at the end of 2022 in response to investigations conducted by European states into allegations of the country's corruption.[169] Additionally, Qatar's support for Islamist groups such as the Muslim Brotherhood hinders its relations with other states, as it already happened in the past and its ties with Iran could also become problematic.[170] Such political instabilities in key supplier countries will reduce the access to LNG.

	High Access	Low Access
Physical	New players, especially from Africa, enter the market and contribute to the diversification of the supply. New long-term contracts are concluded with a variety of consumers.	Market concentration remains the same due to the non-materialization of announced and planned investments, while most of the existing LNG supply is already locked into long-term contracts.
Technological	Repairs to legacy plants are faster and more efficient.	Maintenance to legacy plants and technical issues slow down exports.
Political	Political stability improves in key exporting countries such as Malaysia. Russia is not completely cut out from the global market but still actively contributes to LNG supply.	Political tensions between exporter and importer states undermines supplier diversity. Political instability in export countries and environmental concerns of LNG also affect production.

Raw materials: Silicon Scenario

Silicon is a material key to the energy transition as well as the modern digital economy with applications in Solar PV technologies and digital technologies, such as semiconductors, SSDs, and microelectronics.[171] Whereas solar panel-grade silicon is almost exclusively produced in China, semiconductor-grade silicon is produced in Western states too, including

167 Emily Pickrell, "Russia-Ukraine War Reinforces LNG's Role In Global Energy Security," Forbes, February 23, 2022, https://www.forbes.com/sites/uhenergy/2022/04/19/russia-ukraine-war-reinforces-lngs-role-in-global-energy-security/.

168 Corey Paul and Bill Montgomery, "Political Challenges Send Chill through US Gathering of LNG Interests," SP Global, October 15, 2019, https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/natural-gas/101519-political-challenges-send-chill-through-us-gathering-of-lng-interests.

169 "Qatar Threatens EU Corruption Accusations Could Impact Gas Deals," www.euractiv.com, December 18, 2022, https://www.euractiv.com/section/energy/news/qatar-threatens-eu-corruption-accusations-could-impact-gas-deals/.

170 "Qatar Crisis: Saudi Arabia and Allies Restore Diplomatic Ties with Emirate," *BBC News*, January 4, 2021, sec. Middle East, https://www.bbc.com/news/world-middle-east-55538792.

171 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/.

the United States. We consider the physical, technological, and political trends regarding silicon up to 2033 that will define whether we are more or less likely to be in a high-access or a low-access world.

Physical Trends

High Access Scenario

In a high-access scenario, world silicon mining and refining would diversify away from China to include major production centres in other countries, such as the United States, Brazil, Norway, and Russia, but physical limitations remain. In the case of silicon, overall supply is not the major constraint. Existing world reserves are extensive and would sustain world requirements for many decades.[172] Moreover, new projects are underway in various countries, including the United States, Norway, and Australia, which could indicate an expansion of their mining, refining, and conversion and processing capacity in the next decade.[173] Diversification of the silicon supply chain is constrained by significant time investments for setting up mining operations. The timespan from exploration to full-scale production can vary from seven to fifteen years, with the International Energy Agency (IEA) even indicating it could take up to twenty years.[174] Although setting up refining and conversion and processing facilities would take significantly less time, it can still take several years, with the qualification process for a conversion and processing plant alone taking up to 18 months.[175] Therefore, although geological limitations for silicon diversification are lower, it will require a significant time investment as capacity expansion will take a multitude of years.

Low Access Scenario

In a low-access scenario, world silicon mining, refining, and conversion and processing will continue to be largely dominated by a single country, namely China. Currently, the entire silicon supply chain from mining to the application into end-products, such as solar panels, is conducted in China, as it holds over 68% of global silicon mining capacity and holds 70% to 97% of each step in the production of solar cells.[176] In a low-access scenario, China would maintain and even expand its dominance throughout the supply chain. The significant physical limitation of time needed from exploration to full-scale production of silicon mining could hamper

172 USGS, "Silicon" (USGS, 2023).

173 See, for example: Andy Szal, "Canadian Silicon Metal Producer to Open $150 Million Facility in Tennessee," Thomas Insights, January 18, 2022, https://www.thomasnet.com/insights/canadian-silicon-metal-producer-to-open-150-million-facility-in-tennessee/; "HiTest Silicon Project," Pend Oreille County, n.d., https://pocedc.org/hitest-silicon/; "Silicon Project, Kemerton and Mine at Moora – Addition of a Fourth Submerged Arc Furnace at the Kemerton Smelter: Report and Recommendations of the Environmental Protection Authority" (Perth, Australia: Environmental Protection Authority, April 2009), https://www.epa.wa.gov.au/sites/default/files/EPA_Report/2913_Rep%201317%20Simcoa%20ARI%20310309.pdf; "WACKER Prepares to Expand Its Silicon Metal Production in Norway," Wacker Chemie AG, May 25, 2022, https://www.wacker.com/cms/en-us/about-wacker/press-and-media/press/press-releases/2022/detail-171648.html. See, for example:

174 IEA, "The Role of Critical Minerals in Clean Energy Transitions"; 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; Nicholas LePan, "Visualizing the Life Cycle of a Mineral Discovery," Visual Capitalist, n.d., https://www.visualcapitalist.com/visualizing-the-life-cycle-of-a-mineral-discovery/; University of Arizona, "Copper Mining and Processing: Life Cycle of a Mine," University of Arizona, July 13, 2020, https://superfund.arizona.edu/resources/modules/copper-mining-and-processing/life-cycle-mine.

175 Ritoe, "The New Great Game."

176 USGS, "Silicon"; Bernreuter Research, "Polysilicon Manufacturers: Global Top 10," Bernreuter Research, April 27, 2022, https://www.bernreuter.com/polysilicon/manufacturers/#the-top-ten-ranking-of-the-world-s-largest-polysilicon-manufacturers.

expanding silicon production capacity elsewhere.[177] China's existing capabilities and extensive outstanding resources put it in a position it could capitalise on throughout the next decade.

Technological Trends

High Access Scenario

In a high access scenario, silicon recycling efforts would be ramped up following a technological breakthrough making it economically viable, and demand would be reduced as substitutes for silicon in key end-products would be found. The current recycling rate of silicon is 0%, as "most chemical applications [of silicon] are dispersive, thus not allowing for any recovery".[178] However, there is research conducted on the recycling of silicon wafers, which could materialise in the next decade.[179] Some substitutes for ferrosilicon do exist, including aluminium, silicon carbide, and silicomanganese, and gallium arsenide and germanium are key substitutes for silicon in semiconductors and microelectronics.[180] However, China's announced export restrictions on germanium and gallium, two materials that are respectively predominantly (68%) or almost exclusively (98%) mined in the PRC, shows that even these possible substitutes go hand in hand with the same geopolitical risks.[181]

Low Access Scenario

In a low access scenario, technological advancements will fail to increase silicon recycling and substitution rates, upholding demand for silicon metals. Existing research on recycling silicon "have not yet materialised in marketable solutions".[182]

Political Trends

High Access Scenario

In a high-access scenario, the various diversification strategies issued by governments would significantly increase the political impetus to expand and diversify silicon production capacity, whilst political relations with China would be upheld so as to prevent the weaponisation of Chinese silicon following geopolitical tension. There are several ambitious plans to secure the supply of critical raw materials, including by the United States, the European Union, the Netherlands, Australia, Canada, Japan, and China – first and foremost the US Inflation Reduction Act (IRA). The United States has pledged to heavily invest in domestic production through public-private partnerships, the opening of new mining facilities, and investing in recycling capacity.[183] The European Union has introduced various plans (e.g., EU Critical Raw

177 IEA, "The Role of Critical Minerals in Clean Energy Transitions"; Ritoe, "The New Great Game"; Nicholas LePan, "Visualizing the Life Cycle of a Mineral Discovery"; University of Arizona, "Copper Mining and Processing."

178 Magnus Gislev and Milan Grohol, "Report on Critical Raw Materials and the Circular Economy" (European Commission, 2018), 72, https://op.europa.eu/en/publication-detail/-/publication/d1be1b43-e18f-11e8-b690-01aa75ed71a1.

179 Gislev and Grohol, 72.

180 USGS, "Silicon."

181 Isaiah Schrader and Mc Nicholas Aaron, "The New Metal Battleground - The Wire China," July 2023, https://www.thewirechina.com/2023/07/09/the-new-metal-battleground-gallium-germanium/.

182 USGS, "Silicon."

183 "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/.

Materials Act) to reduce its dependency on third countries and diversifying its supply chain, including by establishing strategic partnerships with countries, such as Canada and Ukraine.[184] The Netherlands, Australia, Canada, and Japan have also put forth various strategies to increase the security of supply of key critical raw materials.[185] China is building on its extensive existing mining and refining capacity to drive further development of the industry in resource-rich regions, including Western China, as well as continuing its search for new material concessions around the world.[186] These plans could significantly expand silicon production capacity.

Low Access Scenario

In a low-access scenario, relations with the top silicon producing country, namely China, would deteriorate to the point where China weaponizes the silicon supply chain. China has a history of using economic coercive measures.[187] For example, China has put forth a plan to curb exports of technology and machinery used to produce solar panel components, thus protecting its dominant position in the supply chain and obstructing establishing production capacity elsewhere.[188] It has also put restrictions on the export of gallium and germanium.[189] Western human rights standards could also disrupt the supply of silicon from Xinjiang , considering the treatment of Uyghurs in the region. In 2022, the United States enacted the Uyghur Forced Labor Prevention Act, which bars imports from China's Xinjiang region over forced labour concerns.[190] The European Parliament, too, has repeatedly called out human rights concerns in China, with regulation similar to the United States not unlikely.[191] Deteriorating political relations with China, in short, could significantly disrupt supplies.

184 See, for example: "New Industrial Strategy," European Commission, 2020, https://ec.europa.eu/growth/industry/strategy_en; 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; 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; European Commission, "EU and Ukraine Start Strategic Partnership on Raw Materials," Text, European Commission, 2022, https://ec.europa.eu/commission/presscorner/detail/en/IP_21_3633; European Council, "Verklaring van Versailles, 10 en 11 maart 2022," European Council, March 11, 2022, https://www.consilium.europa.eu/nl/press/press-releases/2022/03/11/the-versailles-declaration-10-11-03-2022/.

185 "The Canadian Critical Minerals Strategy - from Exploration to Recycling: Powering the Green and Digital Economy for Canada and the World" (Ministry of Natural Resources of the Government of Canada, 2022), https://www.canada.ca/content/dam/nrcan-rncan/site/critical-minerals/Critical-minerals-strategyDec09.pdf; "2022 Critical Minerals Strategy" (Department of Industry, Science, Energy and Resources of the Government of Australia, March 2022), https://www.industry.gov.au/sites/default/files/2022-09/2022-critical-minerals-strategy_0.pdf; Ana Elena Sancho Calvino, "What Policies Have Governments Adopted to Secure Critical Materials?" (Global Trade Alert, November 30, 2022); "Grondstoffen voor de grote transities," Ministerie van Algemene Zaken (Ministerie van Algemene Zaken, December 9, 2022), https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/kamerstukken/2022/12/09/bijlage-nationale-grondstoffenstrategie/bijlage-nationale-grondstoffenstrategie.pdf.

186 The State Council of the People's Republic of China, "Plan to Drive High-Quality Development in Resource-Rich Regions Announced," The State Council of the People's Republic of China, November 12, 2021, http://english.www.gov.cn/statecouncil/ministries/202111/12/content_WS618e290cc6d0df57f98e4dbc.html.

187 Joris Teer and Mattia Bertolini, "Reaching Breaking Point: The Semiconductor and Critical Raw Material Ecosystem at a Time of Great Power Rivalry," 47.

188 Lisa Jucca, "China Ban Would Slow, Not Halt, Western Solar Push," Reuters, February 4, 2023, https://www.reuters.com/breakingviews/china-ban-would-slow-not-halt-western-solar-push-2023-02-03/.

189 Ministry of Commerce of the People's Republic of China, "Announcement No. 23 of 2023 of the Ministry of Commerce and the General Administration of Customs on the Implementation of Export Control on Gallium and Germanium Related Items," July 3, 2023, 23, http://www.mofcom.gov.cn/article/zwgk/gkzcfb/202307/20230703419666.shtml.

190 U.S. Congress, "Uyghur Forced Labor Prevention Act," legislation, U.S. Congress, December 8, 2021, 2021/2022, https://www.congress.gov/bill/117th-congress/house-bill/1155; Nichola Groom, "Exclusive: U.S. Blocks More than 1,000 Solar Shipments over Chinese Slave Labor Concerns," *Reuters*, November 11, 2022, sec. China, https://www.reuters.com/world/china/exclusive-us-blocks-more-than-1000-solar-shipments-over-chinese-slave-labor-2022-11-11/.

191 Finbarr Bermingham, "European Parliament Passes Landslide Vote on Alleged Xinjiang Rights Abuses," South China Morning Post, June 9, 2022, https://www.scmp.com/news/china/diplomacy/article/3181076/chinas-rights-abuses-xinjiang-hold-serious-risk-genocide-says.

	High Access	Low Access
Physical	Silicon production has diversified away from China and expanded in the United States, Brazil, Norway, and Russia	Silicon production remains largely reliant on China
Technological	Technological breakthroughs in recycling and substitution reduce silicon demand	Technological breakthroughs fail to materialize upholding demand for silicon
Political	Policy initiatives to diversify silicon production have been successful, reducing the threat of geopolitical disruptions to the supply chain	Geopolitical competition between China and the West threatens the supply chain of silicon and its end-products, whilst restrictions due to human rights considerations disrupt silicon exports from Xinjiang

Raw materials: Cobalt Scenario

Cobalt is a key economic input, specifically due to its crucial role in end-products needed in the energy transition, such as battery cells production for electric vehicles, Carbon Capture and Storage (CCS), for semiconductors and across vital sectors such as the medical and defence industry.[192] We consider the physical, technological, and political trends regarding cobalt up to 2033 that will define whether we are more or less likely to be in a high-access or a low-access world.

Physical trends

High Access Scenario

In a high-access scenario, world cobalt production would diversify away from Congolese mining and Chinese refining to include major production centres in other countries, such as Australia, Indonesia, Cuba, Canada, and Finland. Moreover, cobalt would also be extracted from polymetallic nodules and crusts on the seafloor of the Pacific, Indian, and Atlantic Oceans. Physical constraints remain, as cobalt production is geologically bound and requires an extended period of time before one can reach full-scale production. However, new mining projects have now been initiated in Canada, Finland, Australia, and the United States.[193]

Low Access Scenario

In a low-access scenario, cobalt mining remains largely reliant on DRC production and cobalt refining predominantly takes place in China, as geological limitations and time constraints limit production elsewhere. Over 120 million tons of cobalt resources have been found in polymetallic nodules and crusts on the seafloor of the Pacific, Indian, and Atlantic Oceans. Yet, due to international agreements under the International Seabed Authority, these could only become

192 Patrahau et al., “Securing Critical Materials.” Patrahau et al. Joris Teer, Mattia Bertolini, and Benedetta Girardi, “Great Power Competition and Social Stability in the Netherlands: The Risks of Russian Gas, Chinese Raw Materials and Taiwanese Chips to Vital Sectors” (HCSS, August 2023), IX, https://hcss.nl/wp-content/uploads/2023/08/Great-power-competition-and-social-stability-in-the-Netherlands-HCSS-2023-V1-1.pdf.

193 In Canada four new cobalt mining operations are ongoing, including an attempt to expand Canada’s cobalt refining capacity. In the European Union, most ongoing projects to expand cobalt operations are in Finland, with a significant focus on expanding Finland’s existing cobalt refining capacity. Other significant investments in cobalt mining and refining are in Australia and the United States.

a viable alternative in the early 2030s.[194] Aside from the geological limitations to cobalt production, setting up mining activities also takes a significant time investment. The diversification of the cobalt supply chain in the next decade therefore remains limited.

Technological Trends

High Access Scenario

In a high-access scenario, technological breakthroughs in deep-sea mining, recycling, reduction of cobalt use in end-products, and cobalt processing methods, could significantly increase the supply and reduce the demand for cobalt into 2033. Almost no deep-sea mining has been carried out to date as current technological capabilities for full-scale extraction and production are still under development and environmental impact assessments are still being conducted. However, exploitation regulations are being codified, preparing the way for the initiation of deep-sea mining activities, with the potential of enhancing access to cobalt. Besides deep-sea mining, technological advancements in the recycling of cobalt could increase the supply of the critical mineral. Current recycling rates for cobalt stand at 35%: the material is extracted from used parts, including spent batteries and catalysts. Further technological development could increase the recycling rate of cobalt in the next decade.[195] Lastly, technological advancements could also increase cobalt recovery by maximising processing methods. The IEA has suggested stepping up R&D efforts to develop new processing method, which will increase cobalt yield.[196] Simply put, a range of possible technological solutions exist to increase access.

Low Access Scenario

In a low-access scenario, technological advancements fail to significantly increase cobalt supply. Crucially, the United States Geological Survey (USGS) projects that 35 to 45 per cent of critical raw material demand could come from deep-ocean mines by 2065, indicating that it would take multiple decades before deep-ocean mining could become a significant share of cobalt production.[197] Moreover, various technological hurdles remain in place to increasing recycling of cobalt and reducing cobalt use in end-products. In a low access scenario, technological developments would not suffice to boost supply in a foreseeable period of time to meet demand.

Political Trends

High Access Scenario

In a high-access scenario, governments pursue a series of ambitious plans to diversify the cobalt supply chain. These governments include the United States, European Union, the Netherlands, Australia, Canada, Japan, and China. Strategies such as the EU Critical Raw

[194] USGS, "Cobalt Statistics and Information."

[195] Gislev and Grohol, "Report on Critical Raw Materials and the Circular Economy," 70–72.

[196] IEA, "The Role of Critical Minerals in Clean Energy Transitions."

[197] Alfonso Ascencio-Herrera and Myron H. Nordquist, eds., "Deep-Ocean Polymetallic Nodules and Cobalt-Rich Ferromanganese Crusts in the Global Ocean: New Sources for Critical Metals," in *The United Nations Convention on the Law of the Sea, Part XI Regime and the International Seabed Authority: A Twenty-Five Year Journey* (Brill | Nijhoff, 2022), 177–97, https://doi.org/10.1163/9789004507388_013.

Materials Act, the Canadian Critical Minerals Strategy, Australia's 2022 Critical Minerals Strategy, and the Netherland's Raw Materials for the Big Transitions are successfully implemented, enabling the discovery of alternative cobalt suppliers.[198] In a high-access scenario, states implement policies that aim at reinforcing and advancing recycling activities as well as opening of new mining facilities in alternative supplier states.

Low Access Scenario

In a low-access scenario, Human rights issues in DRC cobalt mining operations could lead countries and companies to restrict their supply of DRC-mined cobalt. Currently, 15 to 30% of cobalt mined in the DRC is produced by artisanal and small-scale mining (ASM), which has been repeatedly flagged by human rights groups following severe human rights violations, such as child labour, unsafe working conditions, and violent clashes between miners. Continued conflict and instability in the DRC and Southern Africa also threaten cobalt supply routes.[199] Additionally, China's dominance over the cobalt's supply chain means Beijing could weaponize cobalt as geopolitical competition heats up. Lastly, suppliers of cobalt could initiate an OPEC-style cartel, which could severely influence the supply of cobalt.[200] In summary, political developments could severely disrupt the cobalt supply chain, including increased regulation of cobalt from the DRC due to human rights violations, social unrest and political instability affecting cobalt mining operations in the DRC, the weaponization of the cobalt supply chain by China through a resource embargo or quota imposition, and cartel forming amongst suppliers of cobalt.

	High Access	Low Access
Physical	Cobalt production has diversified away from the DRC and China to include Australia, Indonesia, Cuba, Canada, and Finland	Cobalt production remains largely reliant on DRC mining and Chinese refining
Technological	Technological breakthroughs in deep-ocean mining, recycling, substitution, and processing methods would increase supply and reduce demand	Technological breakthroughs fail to materialize upholding cobalt scarcity
Political	Policy initiatives to diversify cobalt production have been successful, reducing the threat of geopolitical disruptions to the supply chain	Geopolitical competition, cartel forming, and social and political instability threaten the supply chain of cobalt and its end-products

198 "The Canadian Critical Minerals Strategy - from Exploration to Recycling: Powering the Green and Digital Economy for Canada and the World"; "2022 Critical Minerals Strategy"; Ana Elena Sancho Calvino, "What Policies Have Governments Adopted to Secure Critical Materials?"; "Grondstoffen voor de grote transities."

199 RULAC, "DRC: A Mapping of Non-International Armed Conflicts in Kivu, Kasai and Ituri," RULAC, February 5, 2019, https://www.rulac.org/news/democratic-republic-of-the-congo-a-mapping-of-non-international-armed-confl; Concern Worldwide, "Timeline: Democratic Republic of Congo's Crisis at a Glance," Concern Worldwide, February 8, 2020, https://www.concernusa.org/story/drc-crisis-timeline/. Although social and political instability in the DRC have had a limited impact on cobalt mining in southern Congo, deadly rioting at a South African port through which cobalt is exported, power outages, and worsening environmental conditions have repeatedly disrupted the supply of cobalt in the region. See, for example: Teboho Sebetlela, "Cobalt contagion: The effects of Covid-19 on cobalt supply chain risk," May 3, 2020, https://www.linkedin.com/pulse/effects-covid-19-cobalt-supply-chain-risk-teboho-sebetlela; 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; IEA, "The Role of Critical Minerals in Clean Energy Transitions"; USGS, "Platinum-Group Elements," Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply (USGS, 2017), https://www.usgs.gov/centers/national-minerals-information-center/platinum-group-metals-statistics-and-information.

200 Indonesia announced it was studying establishing one such cartel for producers of battery metals. Harry Dempsey and Mercedes Ruehl, "Indonesia Considers Opec-Style Cartel for Battery Metals," *Financial Times*, October 31, 2022. Indonesia announced it was studying establishing one such cartel for producers of battery metals.

High technology: Semiconductor Scenario: Advanced Logic Chips

In recent years, the semiconductor supply chain has received global attention due to the importance of chips to the modern digital economy and green transition, prompting many governments to invest large amounts in the industry in an attempt to increase their foothold in the supply chain. Governments and companies that seek to achieve a technological-edge vis-à-vis rivals seek to increase their foothold in the fabrication of advanced logic chips (i.e., <10nm) as they are vital to modern technologies, such as smartphones and computers, as well as key to unlocking future technologies, such as Artificial Intelligence applications. We consider the physical, technological, and political trends regarding advanced logic chips up to 2033 that will define whether we are more or less likely to be in a high-access or a low-access world.

Physical Trends

High Access Scenario

In a high-access scenario, advanced logic chip fabrication will diversify away from Taiwan to include the United States, South Korea, and Europe as well. TSMC with support of the US government has already announced an investment of $40 billion to build two fabs in Arizona of 5nm and 3nm chips to be completed in 2024 and 2026 respectively, with a projected output of over 50,000 wafers per month.[201] The two fabs in Arizona will only start production throughout the next couple of years and are not capable of replacing dependence on Taiwan, as current announced capacity is less than 5% of TSMC's total production capacity. At the same time, the fabs struggle with high production costs -leading to higher prices for TSMC-fabricated chips than those produced on Taiwan- and different working cultures and skilled labour shortages.[202] TSMC's announced fab in Japan will still open in 2024, but will product non leading-edge chips (12-16nm and 22-28nm).[203] TSMC is currently negotiating the construction of a second TSMC fab in Japan that may produce the most advanced chips, meaning those under 10nm.[204] Moreover, TSMC is also opening a factory in Dresden.[205]

In a high access scenario, a larger share of TSMC's production would be moved to the US (perhaps including the construction of additional fabs in Arizona), Japan, or maybe even to the EU, supplementing or even replacing a significant portion of TSMC's advanced logic chip production capacity – even if TSMC's main operations will remain in Taiwan. With 5 billion EUR in support by the German government, TSMC together with European partners has announced that it will set-up chip production in Germany, but not for advanced logic chips.[206]

[201] TSMC, "TSMC Announces Updates for TSMC Arizona," TSMC, December 6, 2022, http://pr.tsmc.com/english/news/2977. TSMC.

[202] Michael Sainato, "'They Would Not Listen to Us': Inside Arizona's Troubled Chip Plant," *The Guardian*, August 28, 2023, sec. Business, https://www.theguardian.com/business/2023/aug/28/phoenix-microchip-plant-biden-union-tsmc.

[203] Chiang Taipei Jen-Chieh, DIGITIMES Asia, "TSMC's Japan Fab Progresses Smoothly as Employees Move In," DIGITIMES, September 6, 2023, https://www.digitimes.com/news/a20230905PD212/ic-manufacturing-japan-tsmc.html.

[204] Gorin Chris, "Proposed second TSMC fab in Japan would be partially subsidized - Rti," RTI Radio Taiwan International, accessed September 10, 2023, https://en.rti.org.tw/news/view/id/2009758.

[205] "Taiwan's TSMC to Build Semiconductor Factory in Germany – DW – 08/08/2023," dw.com, accessed October 9, 2023, https://www.dw.com/en/taiwans-tsmc-to-build-semiconductor-factory-in-germany/a-66469463.

[206] Ben Blanchard and Thomas Escritt, "Germany Spends Big to Win $11 Billion TSMC Chip Plant | Reuters," August 2023, https://www.reuters.com/technology/taiwan-chipmaker-tsmc-approves-38-bln-germany-factory-plan-2023-08-08/.

In addition, memory chipmaker Samsung has been building a $17 billion fab in Texas and has floated a further investment of $192 billion for perhaps even 11 fabs in the state in the decades to come.[207] Even though Samsung primarily produces memory chips, spill-over effects of moving skilled personnel to the US as well as capital investments may eventually lead to a larger manufacturing capacity for advanced logic chips in the US too. US company Intel is also attempting to breakthrough in the production of advanced chips of 2nm and 1.8nm.[208] In a high-access scenario, such investments succeed and become profitable, enhancing the number of suppliers that could provide access to semiconductors, specifically advanced logic chips, though primarily by adding the United States.

Low Access Scenario

In a low-access scenario, advanced logic chip fabrication will continue to (nearly) exclusively rely on TSMC's production in Taiwan, South Korea's Samsung playing a secondary role, and US company Intel attempting to catch up.[209] Two key factors severely constrain the proliferation of advanced logic chip fabrication: the near insurmountable entry barriers for companies to enter and compete on the market, and the time necessary to set up production capacity. In fact, the fast-moving and continuous innovation leads to extremely high capital investments needed for companies looking to enter the advanced chip fabrication market.[210] Additionally, building just one cutting-edge wafer fabrication plant would cost around 20 billion USD, requires highly specialised knowledge of the complex production process, and takes up to six years. Lack of skilled labour and differences in working cultures may further complicate expansion of TSMC and Samsung fabs in the US and Europe. Finally, higher costs, for instance for labour, risks making semiconductor manufacturing in the US commercially more expensive – requiring a constant stream of state-incentives to continue production. Therefore, in a low-access scenario, physical limitations related to the fabrication of ever-smaller semiconductor transistor as well as the increasing relative costs prevent higher access to a variety of suppliers.

Technological Dimension

High and Low Access Scenarios

In the technological sphere, distinctions between high- and low-access are more difficult. Technological entry barriers into the advanced logic chip market remain high due to the high levels of specialisation, and there are currently no definitive technological trends that suggest production would become simpler and therefore more accessible. Beyond manufacturing being a complicated process, the number of systems with which the most advanced can be

207 Ed Sperling, "Where All The Semiconductor Investments Are Going," Semiconductor Engineering, November 17, 2022, https://semiengineering.com/where-all-the-semiconductor-investments-are-going/. Bob Sechler and Kara Carlson, "With Tax Breaks Locked in, Will Samsung Really Build 11 More Austin-Area Semiconductor Plants?," Austin American-Statesman, February 2023, https://www.statesman.com/story/business/2023/02/06/taylor-austin-texas-samsung-plant-tax-breaks-will-company-build-11-new-semiconductor-plants/69844457007/.

208 Intel, "Intel in Ohio," Intel, 2023, https://www.intel.com/content/www/us/en/corporate-responsibility/intel-in-ohio.html; Intel, "Intel in Arizona," Intel, 2023, https://www.intel.com/content/www/us/en/corporate-responsibility/intel-in-arizona.html.

209 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/.

210 Jan-Peter Kleinhans and Nurzat Baisakova, "The Global Semiconductor Value Chain: A Technology Primer for Policy Makers" (Stiftung Neue Verantwortung, October 2020), 14–15, https://www.stiftung-nv.de/sites/default/files/the_global_semiconductor_value_chain.pdf.

produced is highly limited; with ASML's extreme ultraviolet lithography equipment being the most obvious example and facing production capacity constraints.[211] There is thus a further steady decline in companies able to produce the most advanced semiconductors; only two companies have the technological capability to produce the most advanced logic chips whereas at the turn of the century more than 20 companies were still able to produce the most advanced chips.[212] Intel has repeatedly postponed the release of its most advanced chips to enter the market.[213] Innovations that would make advance logic production more accessible are thus unlikely.

Political Dimension

High Access Scenario

In a high-access scenario, political initiatives to increase domestic advanced semiconductor fabrication capacity that multiple states are now pursuing will diversify the supply chain. The United States has passed the CHIPS and Science Act, committing $52 billion to expand US semiconductor fabrication capacity and spur research and development of advanced chips.[214] The European Union committed €43 billion through the European Chips Act, with the objective to possess at least 20% of world production of cutting-edge and sustainable semiconductors by 2033.[215] Other countries have also set forth various policies and initiatives to incentivise and support the fabrication of advanced chips. Japan is planning to spend $6.8 billion, whilst South Korea and Taiwan have provided ample tax incentives and subsidies to retain and develop their local manufacturing capacity.[216] China has ramped up its efforts to indigenise the fabrication of advanced chips through its leading semiconductor company SMIC, by issuing various policy initiatives, such as the 02 Special Project, the 2014 National Integrated Circuit Industry Development Outline, and Made in China 2025.[217] However, its efforts are hampered by the export restrictions imposed by the United States, as well as its European and Asian allies and partners, on China .[218]

211 Kleinhans and Baisakova, 15.

212 Jean-Christophe Eloy et al., "Chip Shortages: A 5 Nm European Fab Is Not the Answer," i-Micronews, March 10, 2021, https://www.i-micronews.com/chip-shortages-a-5-nm-european-fab-is-not-the-answer/.

213 Miller, *Chip War: The Fight For The World's Most Critical Technology*.

214 The White House, "CHIPS and Science Act," The White House, August 9, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china/.

215 European Commission, "European Chips Act," European Commission, 2022, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en#the-need-for-eu-action.

216 See, for example: Yuki Furukawa and Takashi Mochizuki, "Japan Approves $6.8 Billion Boost for Domestic Chip Industry," *Bloomberg*, November 26, 2021, https://www.bloomberg.com/news/articles/2021-11-26/japan-approves-6-8-billion-boost-for-domestic-chip-industry; Kim Jaewon, "South Korea Plans to Invest $450bn to Become Chip 'Powerhouse,'" *Nikkei Asia*, May 13, 2021, https://asia.nikkei.com/Business/Tech/Semiconductors/South-Korea-plans-to-invest-450bn-to-become-chip-powerhouse; Lai Yu-chen et al., "Taiwan's Semiconductor Sector Welcomes Proposal to Raise Tax Break," Focus Taiwan, November 17, 2022, https://focustaiwan.tw/business/202211170020.

217 John Lee and Jan-Peter Kleinhans, "Mapping China's Semiconductor Ecosystem in Global Context" (Berlin: MERICS, June 2021), 12–15, https://merics.org/sites/default/files/2021-06/China%E2%80%99s%20Semiconductor%20Ecosystem_0.pdf.

218 Bureau of Industry and Security, "Commerce Implements New Export Controls on Advanced Computing and Semiconductor Manufacturing Items to the People's Republic of China (PRC)" (U.S. Department of Commerce, October 7, 2022).

Low Access Scenario

In a low access scenario, TSMC consolidates its near-monopoly position on leading-edge chips and does not geographically diversify advanced logic chip production beyond current fab construction in Arizona. Diversification of TSMC activities to other continents further is stalled by a lack of skilled labour in the US, Japan and the EU as well as business culture differences between TSMC and its new employees in the US and the EU – and higher production costs, leading to commercial unviability.

Diversification of chip production to China is further limited by export controls on semiconductor manufacturing equipment and targeted sanctions against specific Chinese chip producers. China and the US already have export controls that limit access to semiconductor machinery and chips. The US has greatly expanded the reach of its controls on October 7 2022 as well as introduced Outbound Investment Screening in August 2023. China, on the other hand, maintains controls like the 'Catalogue of Technologies Subject to Export Bans and Restrictions'[219] and 'Export Control on Gallium and Germanium Related Items.'[220] However, considering the EU's increasing participation on the side of the US in its great power technology rivalry with China, it is unlikely that a larger concentration of chip production in China would actually expand European guaranteed access to chips.

	High Access	Low Access
Physical	Advanced logic chip fabrication has diversified away from Taiwan to include the United States, South Korea, Japan and Europe	Advanced logic chip fabrication remains (nearly) exclusively reliant on Taiwanese production
Technological	Technological barriers to enter the advanced chip fabrication market remain high	Technological entry barriers to enter the advanced chip fabrication market remain high
Political	Policy initiatives to diversify advanced chip fabrication have been successful reducing the threat of geopolitical disruptions to the supply chain	Geopolitical competition threatens advanced chip production in East Asia and policy initiatives to diversify fabrication capacity elsewhere have had little effect; a maritime blockade of Taiwan disrupts TSMC's production and war between North and South Korea does the same to Samsung's production

[219] Ministry of Commerce of the People's Republic of China, "Ministry of Commerce and Ministry of Science and Technology Publish the Revised Catalogue of Technologies Subject to Export Bans and Restrictions -," accessed August 4, 2023, http://english.mofcom.gov.cn/article/newsrelease/significantnews/202009/20200902998221.shtml.

[220] Ministry of Commerce of the People's Republic of China, "Announcement No. 23 of 2023 of the Ministry of Commerce and the General Administration of Customs on the Implementation of Export Control on Gallium and Germanium Related Items," 23.

Summary

Physical, technological, and political trends influence higher or lower access to key resources. On the one hand, higher access scenarios presuppose a larger pool of suppliers as well as of overall supply of key resources. Physical availability of new mines, oil/gas fields, semiconductor fabrication plants in a host of different countries all contribute to higher access. The same goes for the spread of technologies that enable producers to augment their production capacity and diversifying extraction/manufacturing sites. Lifting sanctions, improved political stability, and policies incentivising investment in key resources are also political factors conducive to a world of higher access. On the other hand, when production of key resources is scarce and concentrated in the hands of few suppliers, access to key resources is restricted. In low access scenarios, diversification of suppliers and technological advancements that allow for higher production levels do not materialise. Additionally, restrictive policies such as sanctions and export controls, as well as conflict and environmental and human rights concerns hinder access to key resources. Table 9 below summarizes high and low access scenarios for all the key resources considered.

Table 9. High and Low Access scenarios for oil, LNG, cobalt, silicon, and semiconductors

	High Access	Low Access
Oil	Diversity of suppliers and increased global production, coupled with the expansion of cost-efficient technologies spread through major producers lead to greater access. Sanctions on oil producers are lifted and political stability allows for greater output.	Production remains concentrated in the hands of Middle Eastern countries and new technologies and extraction methods are too costly to significantly affect global production. Sanctions, political tensions, and environmental concerns do not allow for supplier diversification.
LNG	New producers enter the market, repairs to legacy plants are more efficient, and political stability improves in key producing countries.	Production remains concentrated in the hands of few states and technical issues with legacy plants slow down production. Political tensions between exporter and importers as well as environmental concerns do not allow for greater access to LNG.
Cobalt	Cobalt production has diversified away from the DRC and technological break throughs in deep sea mining, recycling, substitution and processing methods are conducive to cost efficient extraction. Policies that incentivize diversification of suppliers are successfully implemented.	Cobalt extraction is still concentrated in the DRC. The failed materialization of technological progress as well as geopolitical competition, cartel forming and political instability undermine production of cobalt.
Silicon	New producers of silicon join the market, while technological progress in substitution and recycling also allows for diversification, dampening geopolitical threats associated with silicon extraction.	China remains the main producer of silicon and technological progress fails to materialize. At the same time, geopolitical competition between China and the West ramps up. Concerns over human rights' violation in Xjijiang further restrict exports from this region.
Semiconductors	Fabrication of advanced logic chips is diversified away from Taiwan hence reducing the threat of geopolitical disruptions to the supply chain.	Taiwan remains the main producer of advanced logic chips and geopolitical competition threatens to disrupt the production of semiconductors in North-East Asia, particularly in Korea.

5. Vulnerabilities of supply chains and transport routes

Access to key economic inputs - as conceived here - functions as the interaction between overall supply, number of suppliers, and transport of said supplies. As the scenarios show, there is significant possible variation in access in the first two elements due to political, economic, and technological trends for our sample of energy, raw materials, and technology inputs, though clear constraints exist in terms of time and financial resources needed. Upon closer inspection, however, less potential leeway exists to drastically reorder the physical dependencies inherent to the maritime – and sometimes air – transport of these key economic inputs. The sections below assess the implications for potential denial of access to the key economic inputs, whether through the markets or through physical transport; this denial of access can be set in the context of peacetime disruptions, regional conflict, and great power war. The chapter then looks at the possibilities European and Asian states have to provide maritime security. It concludes that a mixture of supplier diversification and investment in bilateral, minilateral, and multilateral frameworks between European states and Indo-Pacific states to provide maritime security in key hot spots is necessary, with a clear European focus on the chokepoints in the Western Indian Ocean.

Supply chain security

Supply security for the coming decade depends on whether investments could increase access – whether through overall supply or number of suppliers – as well as on whether supplies remain tied to specific physical chokepoints. Together, these offer a sense of whether potential adversarial states can deny market or physical access. The section below assesses the potential for denial for oil, LNG, cobalt, silicon, and semiconductors.

Access to oil remains vulnerable to disruption and denial. Even in the most optimistic high-access scenario, states in Europe and Asia would remain largely dependent on the same maritime chokepoints, specifically the Strait of Hormuz, the Suez Canal, and the Strait of Malacca. The centrality of the Middle East, particularly the Persian Gulf, ensure that these basic facts of geography do not significantly change. OPEC estimates that the maritime flows of crude oil between the Middle East and Asia Pacific will be the most important by 2045.[221] Should the United States increase production and if investments in Latin America yield results, then the Panama Canal and the Cape of Good Hope become more relevant in the oil market. However, in the 2030-2035 period the most critical maritime routes for oil would remain the Straits of Hormuz, Malacca, and the Suez Canal in the high-access scenario and to an even greater extent in the low-access scenario as dependence on the Middle East would then increase.

221 "OPEC Launches 2022 Edition of the World Oil Outlook at ADIPEC."

Access to LNG remains vulnerable to disruption and denial. In both the high- and low-access scenarios, the bulk of LNG passes through the main chokepoints identified, namely the Cape of Good Hope, Malacca Strait, Tsugaru Strait, Sunda Strait, Makassar Strait, Taiwan Strait, Korea Strait, and Luzon Strait. In fact, even with the opening up of the market to new exporters from Africa, the bulk of the production would still be concentrated in Qatar, Australia, and the United States; additional producers from Africa could provide some relief for European consumers. The relative inflexibility of these maritime transport routes, is due to the complexity of and expenses required to build liquefaction plants, which ensures an extended timeline before newcomers would actually significantly contribute to the market.

Access to cobalt remains vulnerable to disruption and denial. While increasing the number of producers in North America and Europe would improve overall access, many of the transport routes would still pass through the Indo-Pacific, unless refinement facilities in North America and Europe are also expanded. Reliance on chokepoints such as the Taiwan Strait, Luzon Strait, Malacca Strait, and the Six Degree Channel could be reduced as China's share in the supply chain would become less significant. However, chokepoints in the Middle East such as Bab-Al Mandeb in the Horn of Africa and the Suez Canal would remain central as cobalt for trade between the Indo-Pacific and the North Atlantic. However, chokepoints in the Middle East such as Bab el Mandeb in the Horn of Africa and the Suez Canal would remain central as cobalt for trade between the Indo-Pacific and the North Atlantic. In a low-access scenario, the entire cobalt supply chain remains highly reliant on the DRC and China, thus continuing reliance on maritime chokepoints across Asia (see Table 9).

Silicon has potential to be made less vulnerable to disruption and denial. Should production of high-grade silicon move to North America and Europe and the Atlantic Ocean, the reliance on chokepoints such as the Taiwan Strait, Luzon Strait, Malacca Strait, Bab-Al Mandeb in the Horn of Africa, and the Suez Canal would be reduced. Should production of high-grade silicon move to North America and Europe and the Atlantic Ocean, the reliance on chokepoints such as the Taiwan Strait, Luzon Strait, Malacca Strait, Bab el Mandeb in the Horn of Africa, and the Suez Canal would be reduced. Should investments fail to materialise, the entire silicon supply chain continues to rely on China, which means that the maritime chokepoints across East Asia, South Asia, and the Middle East continue to be essential (see Table 9).

Despite being manmade and not a physically fixed resource like energy or a raw material, the manufacturing of advanced logic *semiconductors* is relatively static despite the efforts to diversify, and therefore vulnerable to disruption. While the number of companies would remain limited, in a high-access scenario, production would be spread outside of East and Northeast Asia, and thereby reducing the risk of potential supply chain disruptions as a consequence of conflict; either to supplies or to maritime and air transport. However, in a low-access scenario the world continues to (nearly) exclusively rely on Taiwan – and specifically TSMC - for the fabrication of advanced logic chips (see Table 9). Manufacturing operations elsewhere remain at least one generation behind Taiwanese production. In both scenarios, due to the outsized role of Taiwan, disruptions to key maritime chokepoints, such as the Korea Strait, Taiwan Strait, Luzon Strait, and Malacca Strait threaten manufacturing; while semiconductors might be flown out, other inputs critical to manufacturing process arrive by water, preventing the fabrication of chips. Moreover, during any major conflict, both sea *and* air routes will be disrupted. To illustrate, China has increased the military incursions and the conduct of live-fire drills in the Strait and around Taiwan.[222]

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[222] Robert D. Blackwill and Philip Zelikow, "Three Scenarios for a Military Conflict Over Taiwan," The United States, China, and Taiwan: (Council on Foreign Relations, 2021), https://www.jstor.org/stable/resrep28673.10; Bradley Martin et al., "Implications of a Coercive Quarantine of Taiwan by the People's Republic of China" (RAND Corporation, February 24, 2022), https://www.rand.org/pubs/research_reports/RRA1279-1.html.

Maritime security

The concerning reality evident from the brief overview of supply chains for these key economic inputs is that the physical transport routes are relatively fixed. Consequently, despite potentially immense investments in new fields, mines, and productions capacity – though even these are uncertain – the same maritime chokepoints will continue to remain crucial. The implicit threat to these chokepoints during peacetime moments of high-intensity confrontation and the explicit threat to them during regional or major power war remains a serious threat to the continued functioning of major economies.

Major power war

Major power war is the less likely threat, though one that is steadily increasing, and that could reveal the vulnerabilities of the complex supply chains. We would define great power war here as taking place between the United States (and its allies and partners) on the one side, and Russia and/or China on the other side.

Same maritime chokepoints will continue to remain crucial.

A Sino-American war could be triggered by the conflict between China and Taiwan over Taiwan's status. Conflict would likely be precipitated by growing Chinese pressure to cut off Taiwan from the outside world through cyber-attacks; the sabotage of undersea cables;[223] intrusions of its air force into Taiwan's Air Defence Identification Zone (ADIZ); intrusions into its territorial waters with the People's Liberation Army Navy (PLAN);[224] and the People's Liberation Army Rocket Force (PLARF) firing long-range precision fires and launch ballistic missiles into the Taiwan Strait.[225] Quarantining Taiwan is a more likely scenario than invasion, [226] or at least, the preliminary step of an invasion. [227] Such a conflict would quickly involve all regional powers, whether they would want to be involved – like Japan - or not, and affect the Taiwan Strait, Strait of Malacca, Tsugaru Strait, Korea Strait, and the approaches to these maritime spaces. However, beyond massive disruptions of maritime trading routes, a conflict of this scale between the United States, China, and others throughout the Western Pacific would threaten transport through air as well. Similarly, the Russian-Ukrainian War could escalate into wider conflict between NATO and Russia. Russia does not have the means to command the maritime commons near Europe, but it could threaten the SLOCs with its submarines.[228]

223 "After Chinese Vessels Cut Matsu Internet Cables, Taiwan Seeks to Improve Its Communications Resilience," accessed April 26, 2023, https://thediplomat.com/2023/04/after-chinese-vessels-cut-matsu-internet-cables-taiwan-shows-its-communications-resilience/.

224 Michael E. O'Hanlon, "But CAN the United States Defend Taiwan?," *Brookings* (blog), June 1, 2022, https://www.brookings.edu/blog/order-from-chaos/2022/06/01/but-can-the-united-states-defend-taiwan/.

225 Russell Hsiao, "A Preliminary Assessment of PLARF's 2022 August Missile Tests," Global Taiwan Institute, August 11, 2022, https://globaltaiwan.org/2022/08/a-preliminary-assessment-of-plarfs-2022-august-missile-tests/; Erica D. Lonergan and Grace B. Mueller, "What Are the Implications of the Cyber Dimension of the China-Taiwan Crisis?," Council on Foreign Relations, accessed February 9, 2023, https://www.cfr.org/blog/what-are-implications-cyber-dimension-china-taiwan-crisis; Adrian Ang U-Jin and Olli Pekka Suorsa, "The 'New Normal' in PLA Incursions Into Taiwan's ADIZ," accessed February 15, 2023, https://thediplomat.com/2022/09/the-new-normal-in-pla-incursions-in-to-taiwans-adiz/.

226 Mark F. Cancian, Matthew Cancian, and Eric Heginbotham, "The First Battle of the Next War: Wargaming a Chinese Invasion of Taiwan," January 9, 2023, https://www.csis.org/analysis/first-battle-next-war-wargaming-chinese-invasion-taiwan.

227 Blackwill and Zelikow, "Three Scenarios for a Military Conflict Over Taiwan"; Martin et al., "Implications of a Coercive Quarantine of Taiwan by the People's Republic of China."

228 Anna Davis and Ryan Vest, "STRATEGY for the Development of Maritime Activities of the Russian Federation until 2030" (Newport, RI: U.S. Naval War College Russia Maritime Studies Institute, August 30, 2019), https://digital-commons.usnwc.edu/cgi/viewcontent.cgi?article=1005&context=rmsi_research.

Regional conflicts

Regional conflicts are likelier threats to global supply chains, as several such possible conflicts exist. They also do not preclude the involvement of a great power. Moreover, regional conflicts could easily escalate into a wider conflict that would involve more than one great power.

In terms of access to energy, a conflict in the Persian Gulf between Saudi Arabia and the Gulf States on the one side, and Iran on the other, presents a significant risk. In such a conflict, the United States is likely to back the former, but also Iran could be supported by outside powers. The conflict and its aftermath would affect the Strait of Hormuz and Bab el Mandeb Strait.[229] A reemergence of conflict between India and Pakistan – for example over Kashmir – could at the least impede passage through the Indian Ocean, possibly sending ships further away from the subcontinent. Moreover, China might provide support to the Pakistan.[230] The choke-points surrounding the East China Sea and beyond – such as the Taiwan Strait, Strait of Korea, Tsugaru Strait – would be disrupted by a conflict in the Korean Peninsula between North and South Korea, which would also quickly involve the United States, Japan, and China.[231] A conflict between the South China Sea littoral states would likely involve China, if not initiated by China. China has territorial disputes with multiple littoral states. Its "nine dash line" intrudes on Vietnamese, Filipino, Bruneian, Malaysian, and Taiwanese island claims.[232] These confrontations over claims particularly focus on the land features of the Paracel Islands, the Spratly Islands chain, and the Scarborough reef/shoal.[233]

Peacetime disruptions

Conflict between regional and/or major powers would disrupt these supply chains, but peacetime operations to disrupt or threaten them are also possible.[234]

These disruptions could take the form of inspections by coast guards or naval vessels in disputed waters.[235] The Chinese People's Liberation Army Navy (PLAN) uses so-called hybrid or grey zone tactics with military exercises or paramilitary vessels to intimidate, harass, and coerce the civilian and coast guard vessels of the countries it is involved in disputes

229 Charles Louis Glaser and Rosemary A. Kelanic, *Crude Strategy: Rethinking the US Military Commitment to Defend Persian Gulf Oil* (Georgetown University Press, 2016).

230 Robert Einhorn and W P S Sidhu, "The Strategic Chain: Linking Pakistan, India, China, and the United States," Paper, Arms Control and Non-Proliferation Series (Washington D.C., US: Brookings Institution, March 2017), https://www.brookings.edu/wp-content/uploads/2017/03/acnpi_201703_strategic_chain.pdf.

231 Ronald O'Rourke, "U.S.China Strategic Competition in South and East China Seas : For Congress" (Washington D.C: Congressional Research Service, Library of Congress, January 2022); Nabel Akram and Komal Tariq, "Xi Jinping's Policy Towards Japan: Continuity And Development In The East China Sea – Analysis," *Eurasia Review* (blog), March 26, 2022, https://www.eurasiareview.com/26032022-xi-jinpings-policy-towards-japan-continuity-and-development-in-the-east-china-sea-analysis/; Vasco Becker-Weinberg, "South Korea Boundary Disputes in the East China Sea and the Yellow Sea," *Asia-Pacific Journal of Ocean Law and Policy* 5, no. 2 (December 21, 2020): 303–29, https://doi.org/10.1163/24519391-05020004.

232 "Maritime Claims of the Indo-Pacific," Asia Maritime Transparency Initiative, accessed March 7, 2023, https://amti.csis.org/maritime-claims-map/.

233 Shuxian Luo, "Provocation without Escalation: Coping with a Darker Gray Zone," *Brookings* (blog), June 20, 2022, https://www.brookings.edu/opinions/provocation-without-escalation-coping-with-a-darker-gray-zone/; Benjamin J. Sacks, "The Political Geography of the South China Sea Disputes: A RAND Research Primer" (RAND Corporation, October 2022), 23, https://www.rand.org/pubs/perspectives/PEA2021-1.html.

234 See the accident with the Ever Given container vessel in 2021.

235 Reuters, "China to Inspect Ships in Taiwan Strait, Taiwan Says Won't Cooperate," *Reuters*, April 6, 2023, sec. Asia Pacific, https://www.reuters.com/world/asia-pacific/china-inspect-ships-taiwan-strait-taiwan-says-wont-cooperate-2023-04-06/.

with.[236] In fact, China's Coast Guard has become a daily presence after the passing of a new law in 2021.[237] Harassment by coast guards would add delays to maritime transport, and the existence of the threat of conflict could lead to preliminary and costly re-routing, as well as rising insurance rates to maintain certain maritime transport routes. Other peacetime disruptions could be non-state actors such as pirates, working alone or sponsored by states, attacking ships.

Impact of maritime insecurity on access

Of our sampling of key economic inputs, the maritime security of the following chokepoints Strait of Hormuz, Malacca Strait, Tsugaru Strait, Sunda Strait, Makassar Strait, Taiwan Strait, Korea Strait, and Luzon Strait, Ombai Strait, Suez Canal, Bab el Mandeb would be threatened.

Access to energy: Additional oil and LNG producers would prevent leveraging access to consumers through price increases; however, in higher-intensity conflict scenarios, access to seaborne energy would remain vulnerable to denial. In all scenarios, for small and middle powers in both Europe and Asia, due to dependencies on the Middle East and the Gulf for energy, the Strait of Hormuz remains a key vulnerability. Yet, arguably, Asian states – and economies – are particularly vulnerable as there is more potential for disruption along a series of maritime chokepoints, certainly for states in Northeast Asia: Strait of Hormuz, Malacca Strait, Tsugaru Strait, Sunda Strait, Makassar Strait, Taiwan Strait, Korea Strait, and Luzon Strait for all East Asian States. In contrast, European states are vulnerable in the Suez Canal, as well as obviously Strait of Hormuz and Bab el Mandeb. However, these vulnerabilities to disruption are not only a consequence of hard physical limits of where oil and gas can be found but also the limited incentives to invest in new infrastructure, both for reasons of economic return on investment and political stability. Even with the political will and economic incentives to invest, new infrastructure would take time.

Raw materials. For silicon and cobalt, more leeway may exist to increase the number of suppliers – whether mining or refining – that would redirect maritime transport. Options to improve refinement are available, though require significant investments of time and finance for which the economic incentives may be absent. In current conditions, vulnerabilities exist along multiple maritime transport routes , both from the mines in DRC and elsewhere, to the refineries in China, and back to end consumers. With increased mining and refining, some of the weight would shift to the Atlantic coasts of Western Africa, but it is likely that the Malacca Strait, Tsugaru Strait, Sunda Strait, Makassar Strait, Taiwan Strait, Korea Strait, and Luzon Strait remain central due to the needs for refining capacity in Asia.

236 Alexander Lott, *The Implications of Hybrid Threats to the Maritime Domain* (Brill Nijhoff, 2022), 3 ff., https://doi.org/10.1163/9789004509368_002; Brahma Chellaney, "China's Global Hybrid War," The Strategist, December 9, 2021, https://www.aspistrategist.org.au/chinas-global-hybrid-war/; Kunal Sharma, "How China Uses Geoengineering to Pursue a Hybrid Warfare Strategy," The Diplomat, January 31, 2023, https://thediplomat.com/2023/01/how-china-uses-geoengineering-to-pursue-a-hybrid-warfare-strategy/; Gisela Grieger, "China Tightens Its Grip over the South China Sea," *European Parliamentary Research Service*, February 2021, 1–2; Luo, "Provocation without Escalation."

237 Nguyen Thanh Trung, "How China's Coast Guard Law Has Changed the Regional Security Structure," Asia Maritime Transparency Initiative, April 12, 2021, https://amti.csis.org/how-chinas-coast-guard-law-has-changed-the-regional-security-structure/. "Flooding the Zone: China Coast Guard Patrols in 2022," Asia Maritime Transparency Initiative, accessed March 21, 2023, https://amti.csis.org/flooding-the-zone-china-coast-guard-patrols-in-2022/.

High technology. For semiconductors, though a technology and not tied to physical locations in the way that deposits of ore, oil, or gas are, the limits are in many ways, ironically, even more rigid. Despite significant investments and political will to persist in diversifying manufacturing away from East Asia, the prodigiously high costs and complexity of expanding cutting edge production remain. As long as Taiwan is the manufacturing hub, European and Asian access to advanced logic chips – global access in fact – will remain highly vulnerable to disruption as a consequence of Taiwan's exposed geographic position and its unsettled status in the eyes of the Chinese leadership. Access to and from Taiwan could easily be disrupted; even without direct attacks on the island, the increasing frequency of Chinese intrusions into the Taiwanese ADIZ, into territorial waters, the disruptions of internet cables, and the missile barrages in the maritime approaches to Taiwan, all impede access and raise the costs of doing business.

European solutions

There are no easy or straightforward solutions.

European states thus have key stakes in maritime security close to and far away from Europe itself, regardless of their relationship with the United States and the latter's strategy towards China in the coming years, and regardless of their relationship with regional states. In terms of their ability to provide maritime security, European states are, however, highly constrained. The decline of European navies since the end of the Cold War has left them with limited naval capacity.[238] The number of ships suited for higher intensity SLOC protection, deterrence, and warfighting is limited – not only for individual ships but also for Europeans (EU+UK and others) as a collective.[239] The absolute numbers even tell an incomplete story; due to demands for maintenance, repairs, and crew rest and recuperation, arguably only one in four are available for deployments. This is not only a lack of naval vessels. It is also a matter of logistics and infrastructure being weak, or dependent on the United States.

The increases in defence spending in the wake of the Ukraine War are unlikely to significantly alter the limited European naval capabilities, as the focus of the European defence build-up is primarily on land and air assets. European naval needs in Europe are likely to be centred on anti-submarine warfare, where Russia may present a threat to some maritime approaches to Europe as well as land-based assets. Also taking into account the long lead-times for shipbuilding and the limited European shipbuilding capacity, the war in Ukraine is unlikely to lead to sharp increase in long-range power projection assets for European navies in the years up to 2033.

There are no easy or straightforward solutions. Lacking their own capabilities, European states can rely on the United States to ensure that the maritime transport routes from Europe to Asia remain open, and/or increase their partnerships with regional states. However, given the uncertainties surrounding the U.S. willingness and capability to manage its security commitments in multiple regions, it would be strategically sound for Europeans to take on a greater share of the provision of the public goods of maritime security along the maritime transport routes .

238 Stöhs, *The Decline of European Naval Forces*.

239 Jeremy Stöhs, *How High? The Future of European Naval Power and the High-End Challenge* (Kobenhavn: Djof Publishing ; In cooperation with Centre for Military Studies, 2021); Van Hooft, Girardi, and Sweijs, "Guarding the Maritime Commons: What Role for Europe?"

Table 10. Overview of ships from key European navies[240]

	Aircraft carrier	Attack submarine	Destroyer	Frigate	Corvette	Offshore patrol vessel	Minehunter	Landing platform	Oiler	Support
France	1 (fixed wing)	10 (nuclear powered)	3	17		14	10	3	2	4
UK	2 (fixed wing)	11 (nuclear powered)	6	12		8	11	6	6	1
Germany		6 (diesel powered)	3	9	5		12		5	6
Netherlands		4 (diesel powered)		6		4	6		1	1
Italy	2 (helicopter)	8 (diesel powered)	4	11		15	10	4	4	
Spain	1	1 (diesel powered)		10		6	6	2	2	
Denmark				9		3				
Belgium				2			5			
Greece		11 (diesel powered)		13			3		4	3
Norway		6 (diesel powered)		4		10	6		1	
Portugal		2 (diesel powered)		5	2	4				

There are three main configurations that Europe should consider when cooperating with Indo-Pacific countries for meaningful multinational operations: (1) Multilateral frameworks; (2) Minilateral frameworks; and (3) Bilateral frameworks.

European regional partnerships

The limited naval capacity of European states should not be equated to a total incapacity to contribute to the providing security for the SLOCs. Rather, it means that European states should take a comprehensive approach to maritime security in the Indo-Pacific and play to their strengths by forming meaningful partnerships with regional states. There are three main configurations that Europe should consider when cooperating with Indo-Pacific countries for meaningful multinational operations: (1) Multilateral frameworks; (2) Minilateral frameworks; and (3) Bilateral frameworks.

Multilateral frameworks

Multilateral frameworks allow European states to cooperate with larger numbers of Indo-Pacific partners while contributing to the common good in a way that is beneficial equally for all parties involved, as multilateral frameworks dampen brute power politics. Multilateral naval operations would be particularly useful to protect SLOCs against peacetime disruptions such as piracy, terrorist attacks, and harassment by coast guards. European states are already engaged in this kind of operations, especially in the Indian Ocean. Under the EU

240 The overview excludes the French and British ballistic missile submarines used for their strategic deterrent.

flag, operations ATLANTA and IRINI are an example of joint multilateral naval operations in which European states cooperate with one another and deploy their naval assets on a rotational basis to fight piracy off the coast of Somalia and Libya. Operations ATLANTA and IRINI also entail the training of coast guard personnel in the states that are most affected by piracy attacks.[241] The Indian Ocean Rim Association (IORA) and the EU's Enhancing Security Cooperation In and With Asia (ESIWA) initiative are other examples of multilateral frameworks in which European states cooperate with Indo-Pacific partners. While the IORA has so far focused mainly on technology transfers and fisheries protection, maritime security is one of the main objectives of the association. Reinforcing both the European presence within IORA and the association's capacity and effectiveness to conduct multilateral naval operations would be highly desirable.[242] Under ESIWA, the EU has already individuated a series of Indo-Pacific priority countries (India, Indonesia, Japan, Republic of Korea, Vietnam) with which to strengthen cooperation in the field of counter-terrorism, cyber security, maritime security, and crisis management, allocating 8.5 million euros to this multilateral effort.[243] European states such as Belgium, Denmark, France, Germany, Greece, Italy, the Netherlands, Norway, Portugal, Spain, and the UK also cooperate with several Indo-Pacific countries, among which Australia, India, Japan, South Korea, Malaysia, New Zealand, the Philippines, Singapore and Seychelles, through the Combined Maritime Forces (CMF) initiative. CMF is a multinational naval partnership that aims at "defeating terrorism, preventing piracy, encouraging regional cooperation, and promoting a safe maritime environment."[244]

These existing multilateral frameworks represent existing venues of naval cooperation between European and Indo-Pacific states and offer a cue on how new ones could function. Multilateral naval operations with European and Indo-Pacific states would see the deployment of vessels such as corvettes, patrol boats, frigates and avisos from both European and Indo-Pacific states. These types of vessels are also usually available to states with less naval capacities, offering Europeans the chance to partner up with a wide range of Indo-Pacific states and allowing for better coverage of the Indo-Pacific region. In such multilateral frameworks, European states could take care of deployments closer to home in the Indian Ocean while Indo-Pacific partners could focus on the Pacific Ocean. Joint trainings, information sharing, and mechanisms for sharing maritime awareness would complement naval activities and reinforce multilateral operations.

Minilateral frameworks

Minilateral frameworks for the protection of SLOCs would see European and Indo-Pacific states interact in smaller configurations, as minilateralism entails cooperation of a small group of interested parties tackling a certain issue.[245] There is always a trade-off between effectiveness and legitimacy; where multilateralism prioritises legitimacy, minilateralism prioritises effectiveness. On the one hand, the more limited nature of minilateral partnerships

241 "Operation Atlanta," Eunavfor Atlanta, 2023, https://eunavfor.eu/; "Operation Irini," Eunavfor Med Irini, 2023, https://www.operationirini.eu/.

242 "IORA - Indian Ocean Rim Association," IORA, 2023, https://www.iora.int/en.

243 "Enhancing Security Cooperation In and With Asia," European External Acion Service, 2019, https://www.eeas.europa.eu/sites/default/files/factsheet_eu_asia_security_october_2019.pdf.

244 "Combined Maritime Forces," US Naval Forces Central Command, 2023, https://www.cusnc.navy.mil/Combined-Maritime-Forces/.

245 European Union Institute for Security Studies., "Effective Minilateralism for the EU: What, When and How." (LU: Publications Office, 2016), https://data.europa.eu/doi/10.2815/20196.

allows for faster reactions in times of crisis,[246] which could be vital in responding to regional conflicts and, to some extent, major power wars threatening the openness of SLOCs. On the other hand, smaller configurations have less legitimacy in the international arena. France has been cooperating in various minilateral settings with Indo-Pacific states, such as the France-India-UAE trilateral on defence, energy, and technology and the India-France-Australia trilateral on maritime security.[247] In 2021, Italy-Japan-India dialogues were also set up, albeit a clear agenda was never defined.[248] The EU has also been involved in minilateral settings that aim at the promotion of maritime security and maritime domain awareness, such as the setup of regional maritime architecture based on information fusion and operation centres in Madagascar and Seychelles.[249]

Given its own scarce naval capabilities, Europe should focus on South and East Asian states with military capabilities when it comes to minilateral frameworks of cooperation. This would allow for better coordination and a more strategic coverage of SLOCs and related chokepoints. An EU-Japan-Australia trilateral would be an effective way to work with states that share not only similar interests, but also values with Europe.[250] Such a minilateral setting would also mean working closely with two states that depend on the US for their security provision, which could create the impression that it is part of US balancing efforts. This might not always be desirable. On the other hand, joining naval forces with two likeminded and capable states like Australia and Japan could also present a strategic move for European states. Other minilateral settings including European states and India and South Korea are also desirable.

Bilateral frameworks

Cultivating bilateral state-to-state relations allows European states to play into their diplomatic and institutional strengths while forming meaningful partnerships with individual Indo-Pacific states. Several European states already have diplomatic ties to Indo-Pacific countries through the presence of embassies and consulates in the region. Bilateral frameworks are also useful to establish military cooperation and resource pooling. France, Germany, Italy, the Netherlands, Spain and the UK have used their bilateral ties to various Indo-Pacific states such as Singapore, Brunei, Djibouti, UAE, Qatar and Bahrain to establish defence agreements that include the use of military bases in the region in close proximity to the Strait of Hormuz, Gulf of Aden, Strait of Malacca, and various other straits in the South China Sea. European states also have bilateral status of forces agreements and military logistics agreements with Australia, South Korea, Japan, and India which allow for mutual access to each other's naval bases, joint trainings and exercises as well as facilitating the exchanges of troops, equipment,

246 "Minilateralism: A Concept That Is Changing the World Order," Gulf News, April 13, 2023, https://gulfnews.com/opinion/op-eds/minilateralism-a-concept-that-is-changing-the-world-order-1.95096716.

247 "Minilateralism"; Delphine Alles, "Multilateralisms and Minilateralisms in the Indo-Pacific. Articulations and Convergences in a Context of Saturation of Cooperative Arrangements," Foundation for Strategic Research FRS, 2023, https://frstrategie.org/en/publications/recherches-et-documents/multilateralisms-and-minilateralisms-indo-pacific-articulations-and-convergences-context-saturation-cooperative-arrangements-2023.

248 Alles, "Multilateralisms and Minilateralisms in the Indo-Pacific. Articulations and Convergences in a Context of Saturation of Cooperative Arrangements."

249 "Joint Communication to the European Parliament and the Council on the Update of the EU Maritime Security Strategy and Its Action Plan 'An Enhanced EU Maritime Security Strategy for Evolving Maritime Threats'" (High Representative of the Union for Foreign Affairs and Security Policy, 2023), https://doi.org/10.1093/law-oeeul/e66.013.66.

250 Elena Atanassova-Cornelis and Eva Pejsova, "Minilateralism: An Opportunity for the EU's Engagement in the Indo-Pacific" (CSDS, n.d.).

and services.[251] This type of bilateral agreements favours the deepening of diplomatic and institutional ties while offering European states a farther positioning in the region, which is vital to better contribute to the security of SLOCs in the case of regional or major power conflicts.

While bilateral ties between European and Indo-Pacific states already exist, there is much space for improvement, especially with some of the major players in the region. For instance, European bilateral cooperative relationships with India could be strengthened by developing closer collaboration with the Indian Navy's Information Fusing Centre. This would help support maritime domain awareness in times of peace and ease potential wartime cooperation. India also has an increasingly regional marine protected areas (MPA) base network, the use of which would be beneficial to European states. France has already started dialogues with India in this regard.[252] Bilateral frameworks can play a vital role in strengthening cooperation with specific Indo-Pacific states and contribute to a better understanding of each other's priorities.

Summary

A comprehensive European approach to regional partnerships would include multilateral, minilateral, and bilateral frameworks. Building relations through these three different types of frameworks allows European states to not only deepen ties with regional actors, but also to make more efficient use of their scarce naval capacities. By acting in different configurations according to need and interest, European states would also manage to partly balance uncertainties surrounding the U.S. willingness and capability to manage its security commitments in multiple regions. Notably, these three frameworks reinforce each other: strong bilateral ties can merge into minilateral settings that can build shared interests, values, and practices leading to the creation of multilateral frameworks.

Multilateral frameworks require more coordination and can entail longer bureaucratic times given the participation of larger groups of states, but are also more suited to face recurring peacetime threats to SLOCs such as piracy, terrorist attacks, and coastguard harassment. They also allow for greater flexibility in naval deployments, as vessels can rotate in shorter periods since several states participate in multilateral naval operations. Minilateral frameworks offer instead more freedom of action as they involve a smaller number of parties. This comes in handy particularly in times of crisis and allows for a more rapid response – for example when there are regional conflicts or the risk thereof. Finally, bilateral frameworks are the gateway to joint exercises and trainings as well as sharing of military bases, equipment, and services, which would allow European states to have a forward presence and contribute (if still limitedly) to the protection of SLOCs in case of major power war or regional conflicts.

As the freedom of SLOCs is threatened by different risks and the extent of US involvement cannot be taken for granted, it is important that European states take a holistic approach to their engagement with Indo-Pacific actors, deepening their partnerships along all three levels of engagement. Such an approach, together with Europe's economic counterweight to China, would grant European states a better chance of contributing to the provision of the public goods of maritime security along the maritime transport routes .

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251 Paul Van Hooft, Benedetta Girardi, and Tim Sweijs, 'Guarding the Maritime Commons | What Role for Europe in the Indo-Pacific', The Hague Centre for Strategic Studies, February 2022, 63, https://hcss.nl/report/guarding-the-maritime-commons-europe-in-indo-pacific/.

252 Stephan Frühling, 'Multilateralizing Maritime Security in the Indo-Pacific' (The Hague Center for Strategic Studies, March 2022), 8.

6. Conclusions and recommendations: Suppliers, Ships, and Partnerships

Access is far from guaranteed given the current intensification of geopolitical competition and tensions, which could have significant impact on the access to key economic inputs – as our selection of inputs such as oil, LNG, cobalt, silicon, and semiconductors shows.

Summary

Taking into account current supply chains, the challenges to access remain considerable both in terms of suppliers and supplies, as well as physical maritime transport routes, the so-called maritime transport routes .

Energy

Access to both oil and LNG remains vulnerable to disruption and denial. In a high-access scenario, new supplies of oil come online as well as new oil-producing states. For example, investments in Brazil, the US, and Guyana have significant yields, and slightly increase supplier diversity, while new technologies augment the efficiency of petroleum petroleum extraction techniques. The partial lifting of sanctions, combined with improvements in the domestic politics of oil-producers, could further raise access. In contrast, in a low-access scenario, oil production and supplier diversity remain limited. Private International oil companies prioritise economic efficiency, and forego investments that would expand their production capacity. We see no strong evidence for a high-access scenario; oil remains available within the same limits as currently exist. In high-access scenario, the supply of LNG diversifies as a result of consistent investments in liquefaction capacity, especially in emerging LNG markets in Africa. This supply is furthermore distributed across multiple consumers through long-term contracts. A reduction in the time needed to carry out repairs will augment exporting capacities, which helps decrease the concentration of supply in few states by avoiding the shutdown of legacy liquefaction plants. Lastly, political stability in supplier states increases access to LNG. In contrast, in a low-access scenario, investments in new liquefaction plants fail to materialise, or at least require considerable costs and time, while political instability further hinders increases in supplier diversity. The existing LNG supply is already concentrated in the hands of a few consumers that concluded long-term contracts. Moreover, due to the high concentration of energy resources in the Gulf region, the maritime transport of energy remains vulnerable to disruptions in both high- and low-access scenarios.

Raw materials: silicon and cobalt

Access to raw materials is more differentiated, as cobalt remains vulnerable to disruption and denial, but access to silicon could be made less vulnerable to disruption. A high-access scenario for cobalt means diversification away from mining in DRC and refining in China towards cobalt producing countries, such as Australia, Indonesia, Cuba, Canada, and Finland (see Table 9), while improvements in mining and recycling increase the overall availability of cobalt. In a low-access scenario, these other states fail to invest to produce sufficient amounts of cobalt, or increase relative yields, while production in the DRC is undermined by internal instability and miners' clashes. While increasing the number of producers in North America and Europe would improve overall access, many of the transport routes would still pass through the Indo-Pacific, unless refinement facilities in North America and Europe are also expanded. For silicon, diversification may be more feasible, and with diversification of suppliers, the vulnerabilities to maritime transport routes may decrease.

First, the reinforcement of supply chains through investments in the diversification of suppliers and supplies is clearly necessary.

High technology: advanced logic chips

Despite being manmade and not a physically fixed resource like energy or a raw material, the manufacturing of advanced logic semiconductors is relatively static despite the efforts to diversify, and therefore vulnerable to disruption. In a high-access scenario the production of advanced logic chips has successfully diversified away from Taiwan to include other countries, such as particularly the United States, South Korea, and even the European Union (see Table 9). Even though a majority of TSMC's advanced chip manufacturing still takes place on the island of Taiwan, the company has extended operations to the United States, Japan and Europe. Non-American companies like Samsung also invest in production capacity in the United States, and Intel has managed to break into the manufacturing of the most advanced logic chips. Given the weight of Taiwan in semiconductor manufacturing, it is difficult to diversify access, and consequently, the vulnerability to the maritime (and air) access routes to Taiwan remains fundamental.

Recommendations

Preventive reinforcement of supply chains and maritime security is recommended; while complete attempts at denial are unlikely unless the Sino-American competition escalates into open warfare – in which case, most bets are off - disruptions remain likely as a consequence of political tensions or attempts to pressure actors like Taiwan through grey zone actions. These recommendations for small and middle powers in Europe and Asia consist of two parts.

First, the reinforcement of supply chains through investments in the diversification of suppliers and supplies is clearly necessary. While in the short-term of the coming 5-10 years, the pay-off to these investments will be insufficient, it does create more access points. Decreasing dependency on single points of access ensures that it becomes more difficult to split alliances or coalitions as less leverage exists to blackmail single or several states within those alliances or coalitions. As the political support of multiple states and actors in Europe and Asia – many of which are vulnerable small and middle powers - will be fundamental for maintaining stability during periods of bloc formation, increasing access is a robust strategy. Supply chain reinforcement would consist of investments in: (a) investments in semiconductor manufacturing, regardless of limited benefits within timelines; (b) energy production; (c) mining and refining cobalt and silicon; and (d) lowering demand through substitution and recycling.

Second, the reinforcement of maritime security along the maritime transport routes between Europe and Asia is clearly necessary. This would require investments in ships and inter-regional partnerships. However, given Europe's limited naval capacity, especially at long distances, potential naval power must be discerningly leveraged. This means that (I) in terms of effectiveness/credibility, European naval power projection is likely to be most effective when addressing access on the Atlantic Coasts, the Strait of Bab el Mandeb and the Strait of Hormuz. The benefits of increasing capacity here mostly accrue to the supply security of raw materials, but would matter for access – especially if silicon / cobalt production is diversified. An increased European security role around the Horn of Africa and the Gulf has benefits for the access of Asian economies as it improves their access, but also diminishes pressure on the United States that will want to deploy its resources further into the Pacific. Consequently, beyond the direct benefits to Europeans themselves, this could also be part of a distribution of labour/responsibilities with partners in other regions, such as East Asia. At the same time, (II) European states can invest in partnerships near key chokepoints. These can take multilateral, minilateral, and bilateral forms. The importance of the Strait of Malacca, Sunda Strait, and Makassar Strait for access to the entire Western Pacific suggests the value of partnerships close to these chokepoints. Two options suggest themselves: (a) European states send regular but minimal naval presence to these regions to supplement regional efforts, saving most of their naval resources for the regions closer to home; and (b) Europeans states complement regional efforts through other measure such as capacity-building. After all, further afield, the credibility of European naval power projection diminishes; beyond their limited capacity, military power declines over distance in any case.[253] It is thus unlikely that European states can project power to the Taiwan Strait, Korea Strait, Tsugaru Strait, and Luzon Strait to make any military difference at all. Moreover, these attempts would probably not reassure most regional states outside of Japan. The choices for European states can therefore not be cauterised from the context of the intensifying geopolitical competition between the United States and China.

The reinforcement of maritime security along the maritime transport routes between Europe and Asia is clearly necessary.

These recommendations also include choices for Asian states and actors that would partner with Europe. Clearly, they have more limited options without the United States. States in Southeast Asia have limited naval capacities, but can project power towards their nearby chokepoints. They could do so through multilateral arrangements – like via ASEAN – that include European partners, or on a minilateral or bilateral basis. In East Asia, they face choices regarding deepening their ties with primarily the United States, but also Japan. However, European and Asian states are incapable of improving maritime security near Taiwan on a minilateral or bilateral basis; Taiwan's investments in self-defence and maritime security in its proximity are thus required. Diminishing economic dependencies on China, while not entirely decoupling, could provide non-military incentives to dissuade it from escalation. Conversely, should there be an absence of access to key economic inputs, the political will to sustain a multilateral order based on rules where might does not make right is likely to crumble.

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[253] Kenneth Boulding argued that military power declines over distance, the so-called Loss of Strength Gradient. Kenneth Ewart Boulding, *Conflict and Defense: A General Theory* (Pickle Partners Publishing, 2018). Kenneth Boulding argued that military power declines over distance, the so-called Loss of Strength Gradient.

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