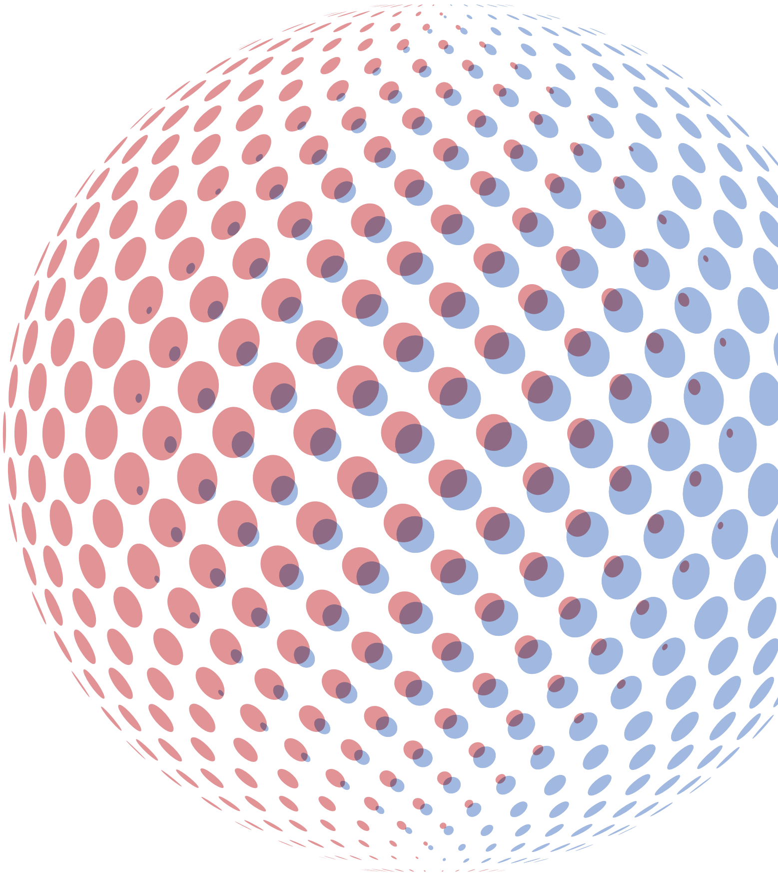
Digital Power China

A European reasearch consortium



REVERSE DEPENDENCY:

MAKING EUROPE’S DIGITAL TECHNOLOGICAL STRENGTHS INDISPENSABLE TO CHINA

MAY 2024 | EDITOR: TIM RÜHLIG

REVERSE DEPENDENCY:

MAKING EUROPE’S DIGITAL TECHNOLOGICAL STRENGTHS INDISPENSABLE TO CHINA

MAY 2024 | EDITOR: TIM RÜHLIG

A REPORT OF

Digital Power China
A European research consortium

Table of Contents

About the Digital Power China Research Consortium

The Digital Power China (DPC) research consortium is a gathering of 21 China experts, economists and engineers based in 12 European research institutions, universities, think tanks and consultancies in 10 European countries. Not all DPC researchers contribute to every report. For this report, DPC has been joined by invited guest researchers.

The group is devoted to tracking and analysing China's growing footprint in digital technologies, and the implications for the European Union. DPC offers the EU concrete policy advice based on interdisciplinary research. Tim Rühlig, Senior Research Fellow at the German Council on Foreign Relations (DGAP), is the convenor of DPC.

DPC systematically pairs technological and country expertise, which is based on rigorous academic research combined with experience of the provision of policy advice. The informal group brings together a variety of European researchers in order to combine diverging perspectives from across the continent. Responsibility for the accuracy of the views expressed remains solely with the indicated authors.

This report has been generously funded by the United Kingdom's Department for Science, Innovation and Technology, and the China Knowledge Network (CKN) of the Government of the Netherlands, with support from the EU Cost Action “China in Europe Research Network” (CHERN).

We would like to thank Carl-Friedrich Richter for layouting this report, and Andrew Mash, who has edited this and all previous reports and papers published by DPC for the exceptional cooperation.

Acknowledgments

Part of the research for and production of this report has been generously funded by United Kingdom's Department for Science, Innovation, and Technology. The other part has been conducted within the framework agreement for the China Knowledge Network (CKN). The aim of CKN is to promote strategic knowledge development about China for the national government of the Netherlands. Two workshops supporting the work underlying this report were funded by the EU COST Action “China in Europe Research Network” (CHERN), CA 18215 supported by COST (European Cooperation in Science and Technology).

All authors would like to thank the participants of both workshops for their comments and suggestions.

Responsibility for the contents and for the opinions expressed rests solely with the authors and does not constitute, nor should be construed as, an endorsement by the secretariat of the China Knowledge Network and/or the Netherlands Ministry of Economic Affairs and Climate Policy and the Ministry of Foreign Affairs or the British Government and/or its Department for Science, Innovation, and Technology.

Department for
Science, Innovation,
& Technology

CKN China Kennisnetwerk

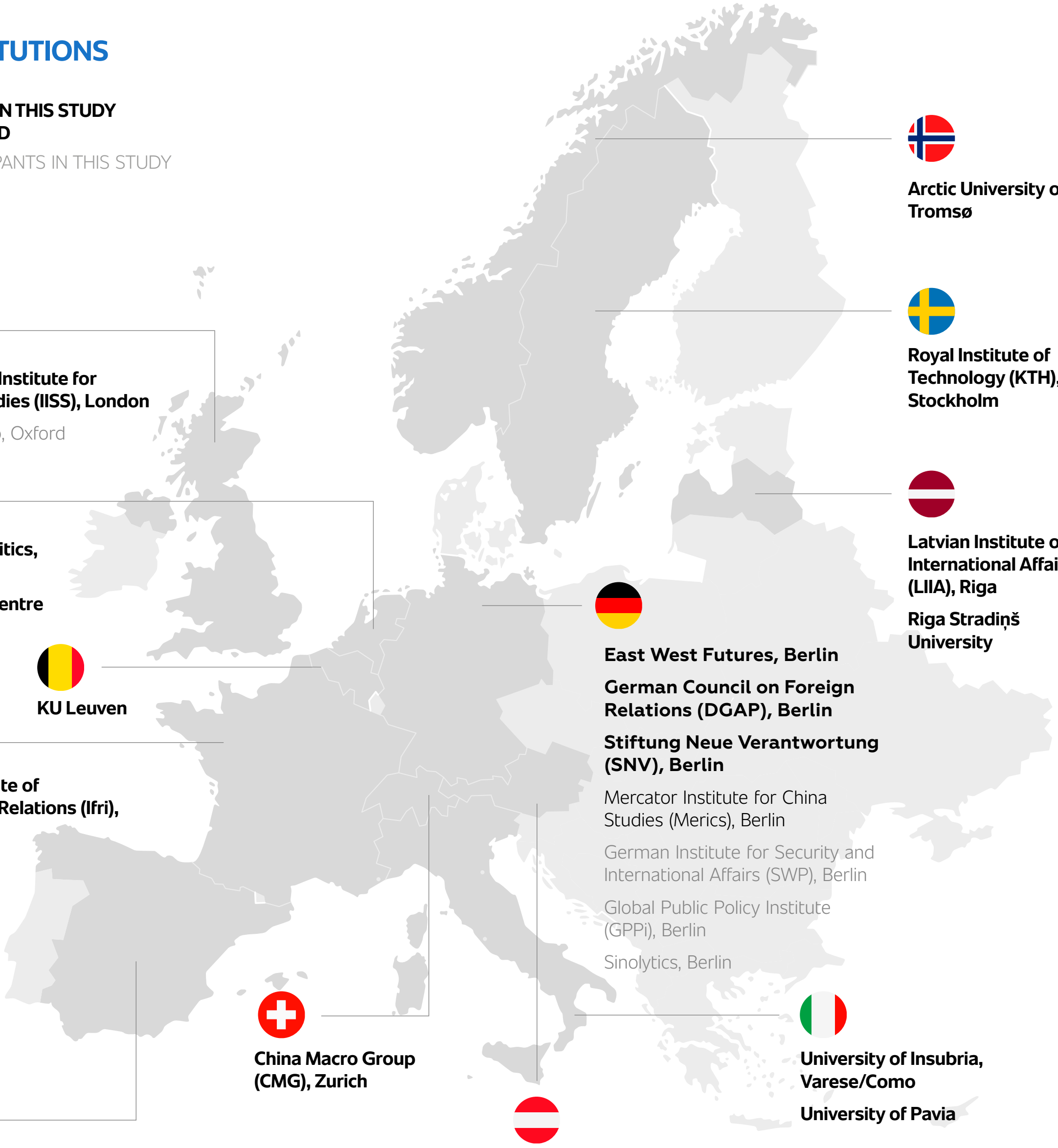
cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the European Union

CHERN
https://china-in-europe.net/

DPC INSTITUTIONS

PARTICIPANTS IN THIS STUDY
SHOWN IN BOLD
GUEST PARTICIPANTS IN THIS STUDY



Arctic University of Tromsø

Royal Institute of Technology (KTH), Stockholm

International Institute for Strategic Studies (IISS), London

SecDev Group, Oxford

China Geopolitics, Wassenaar

Leiden Asia Centre

Maastricht University

KU Leuven

Latvian Institute of International Affairs (LIIA), Riga

Riga Stradiņš University

East West Futures, Berlin

German Council on Foreign Relations (DGAP), Berlin

Stiftung Neue Verantwortung (SNV), Berlin

Mercator Institute for China Studies (Merics), Berlin

German Institute for Security and International Affairs (SWP), Berlin

Global Public Policy Institute (GPPi), Berlin

Sinolytics, Berlin

French Institute of International Relations (Ifri), Paris

China Macro Group (CMG), Zurich

University of Insubria, Varese/Como

University of Pavia

Qureca, Barcelona

European Space Policy Institute (ESPI), Vienna

Executive Summary DPC 2024

This report uses 12 case studies to analyse reverse dependencies of the People's Republic of China (PRC) on the European Union and the United Kingdom. In adapting to growing geopolitical competition over digital technology, the EU and the UK are striving for economic security and technological sovereignty. European policies focus on reducing critical over-dependencies on China. This de-risking is a necessary process of adaptation to the new geopolitical realities. The previous Digital Power China report contributed to this policy objective by differentiating between diverging risk profiles across several emerging and foundational technologies, and proposing concrete policy instruments.1

However, current de-risking policy ignores the fact that it is virtually impossible to reduce strategic dependencies to a degree that provides the economic security and technological sovereignty the EU and the UK seek. The cost of such decoupling would be enormous and, for good reason, nobody is realistically willing to pay such a price. Technological ecosystems are based on a highly transnational division of labour and all actors are likely to remain interdependent for the foreseeable future. China's technological advancement continues to rely on the outside world, including Europe.

Under these circumstances, Europe should complement its policy with policies that help to maintain reverse dependencies and keep it technologically indispensable to China. Each technological ecosystem requires a different mix of policies that aim for "autonomy" or "strategic entanglement". However, reverse dependencies on China should be more prominently factored into European policy.

It is arguable that the logic of interdependence has not prevented Russia from violating international law and attacking Ukraine. Indeed, the high technological and economic costs are no guarantee that the PRC will not act against European core interests. For this reason, Europe must reduce its strategic dependencies on China, as it is currently doing. However, in the absence of a feasible decoupling strategy, maintaining a high cost for China is the best of all imperfect policy options to complement – rather than replace – efforts to reduce strategic dependencies. The PRC is in the middle of a structural economic transformation and economic growth is still considered vital for the legitimacy of the rule of the Chinese Communist Party (CCP). Security considerations are gaining in importance relative to economic development, but this does not mean that the Chinese leadership does not consider a further deterioration in economic growth to be a threat to its power. In other words, while no guarantee, imposing economic and technological cost still has a fair chance of shaping the considerations of the CCP leadership.

In 12 concrete cases, this report assesses Europe's technological strengths and the potential leverage they might carry. The character of European technological indispensability, the degree of leverage and mechanisms for utilising this, as well as the policies that Europe should put in place all vary across the technological areas analysed in this study. However, seven patterns can be discerned across all the cases. These are summarised below.

FINDING 1: Europe's greatest source of strength is research and innovation, but intellectual property and production contribute too

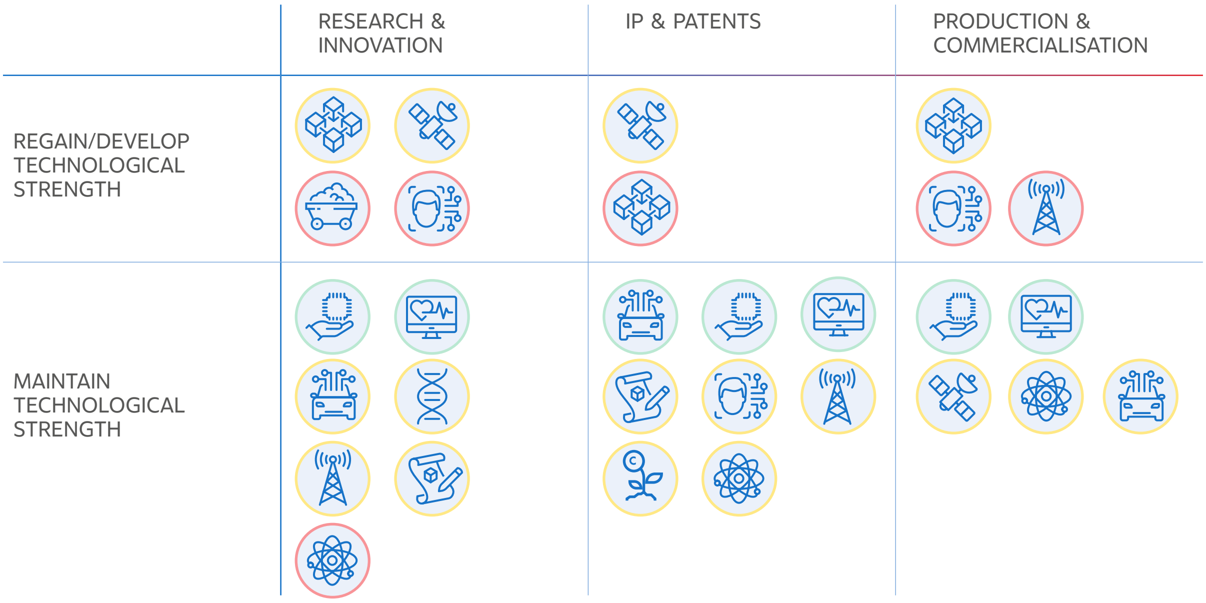
Across the case studies analysed, European strengths result from excellent research and innovation, intellectual property (IP) and patents or the production and commercialisation of the respective technologies. In many cases, Europe's potential leverage results from a combination of these sources. In some cases, Europe is well-placed to develop or regain technological strength in one or several of these three dimensions. In others, the EU should strive to maintain and consolidate the technological edge it already has (see Figure 1).

It is widely known that Europe's technological capabilities are stronger in research and innovation than in IP and production. However, the cases illustrate that this general finding on European research and innovation strength does not preclude technological excellence in critical niches resulting from IP and commercial products. European strategic indispensability, if achieved, will emerge from a combination of all three pillars.

---

1 Tim Rühlig (ed.), Europe's Strategic Technology Autonomy From China: Assessing Foundational and Emerging Technologies, Berlin, Digital Power China, 2023, accessed 28 October 2023, at https://dgap.org/en/research/publications/europes-strategic-technology-autonomy-china

FIGURE 1: Existing and potential sources of European technological strength across the analysed case studies



KEY

Green icons = highest likelihood that Europe will achieve its goals if its puts in place the right policies
Yellow icons = medium level of likelihood that Europe will achieve its goals if its puts in place the right policies
Red icons = even were Europe to put in place the right policies, it would face difficulties achieving its goals

AI – facial recognition
Critical raw materials
Quantum sensing
Space exploration
AI – medical equipment
Genomic data
Semiconductor – auto
Technical standardisation
Blockchain for smart contract
Patents – twin transition
Semiconductor lithography
Wireless – energy saving

FINDING 2: Technological superiority, as well as commercial, political and regulatory aspects, are all decisive factors in European technological indispensability

European technological strength is the result of more than just technological excellence. Depending on the technology ecosystem, economic factors such as a strong market position, better commercialisation conditions, integration of a technology into products or access to the European Single Market play a decisive role. Further factors will be political and regulatory conditions, such as legal certainty, Europe's normative power or its prioritisation of the sustainable development of technologies. In some cases, a combination of technological, economic and political factors has resulted in technology partnerships that provide a European edge over China (see Figure 2).

FIGURE 2: Sources of potential European strength across the analysed case studies

	CATEGORY	CASES
TECHNOLOGICAL EXCELLENCE	TECHNOLOGICAL	🤖 🧬 ⚛ 🔲 📜 📶 🚗 🌱
STRONG MARKET POSITION/ BETTER COMMERCIALISATION/ BETTER PRODUCT INTEGRATION	ECONOMIC	🖥 ⚛ 🌱 🔲 🛰 📶 📜
MARKET ACCESS	ECONOMIC	🌱 🧬 📜 🖥 🤖
POLITICAL/ REGULATORY FACTORS (SUCH AS LEGAL/ REGULATORY CERTAINTY, NORMATIVE INFLUENCE, POWER STATUS)	POLITICAL/ LEGAL	📦 🛒 🛰 📜 🧬 🌱
SUSTAINABILITY	POLITICAL/ REGULATORY (but also technological and economic)	🛒 🌱 📶 📦
RESEARCH PARTNERSHIPS	TECHNOLOGICAL/ ECONOMIC/ POLITICAL	🛒 ⚛ 🛰 📜 🧬 🔲

FINDING 3: Europe should calibrate its levels of ambition by technology

When considering technological indispensability and the resulting chokepoints, observers automatically think of China's reliance on European advanced semiconductor manufacturing equipment. This hard chokepoint, often associated with the Dutch vendor ASML, is a unique case of a complex technological ecosystem relying on a broad range of mostly European suppliers that it is almost impossible to replicate. No other hard chokepoint of the same quality exists in the digital technologies analysed.

Accordingly, Europe will need to adjust what it is striving to achieve. The level of ambition must vary depending on feasibility and the concrete technological ecosystem. However, the level of ambition is also a matter of political will. Europe needs to calibrate its level of ambition and be realistic about what it can achieve, and what it is seeking to gain politically from a given or potential technological strength. At least four levels of ambition can be distinguished:

- **Level 1:** Threat prevention aims to increase European security by preventing dual-use technology leakage to China, defined along the lines of the Wassenaar Arrangement and the EU dual-use export control regulation (2021/821), or the UK's Export Control Act 2002 (ECA 2002) and the associated Export Control Order 2008, SI 2008/3231.

- **Level 2:** The ability to deny is about maintaining or creating co-dependencies that constitute a high degree of economic cost for China if Europe were to leverage its strength by means of technological disentanglement. This level of ambition follows a defensive logic as Europe is simply seeking to prevent China from acting against core European interests.
- **Level 3:** The ability to act is more proactive in that it strives to maintain an edge over China. The ability to act is not purely defensive. Instead, it represents a degree of Chinese technological reliance on European strength that allows the EU to shape technological development and related policy directly or indirectly through third markets.
- **Level 4:** Curtailment is about preventing the respective other from developing certain economic and technological capabilities far beyond the security realm. The goal is to limit or freeze Chinese technological and economic development more broadly.

Of the analysed cases, curtailment is only feasible in lithography. Other levels of ambition are achievable, however, depending on the technological ecosystem. Figure 3 summarises the likelihood that the right policy choices would allow Europe to achieve the respective levels of ambition in the analysed cases. The colour code indicates the likelihood that Europe could achieve the respective level of ambition within a timeframe of 10 years if the right policies were put in place. Where an icon is not displayed in a respective box, this level of ambition is not feasible.

FINDING 4: Not every European technological strength carries the same degree of political leverage

Technological strength is a necessary but not a sufficient precondition for European leverage over China. Whether Europe can leverage a given technological strength depends on a number of factors, such as ethical considerations, the degree of difficulty substituting the respective technology and the degree of damaging spillover, among other factors. Figure 4 summarises the degree of leverage across technology ecosystems.

FINDING 5: Integrate strategic and commercial considerations for a durable technology policy

To a large extent, Europe's technological strength is the strength of commercial actors alongside publicly funded research institutions such as universities. It is in Europe's

FIGURE 3: The likelihood that the right policy choices would allow Europe to achieve its respective levels of ambition in a timeframe of 10 years

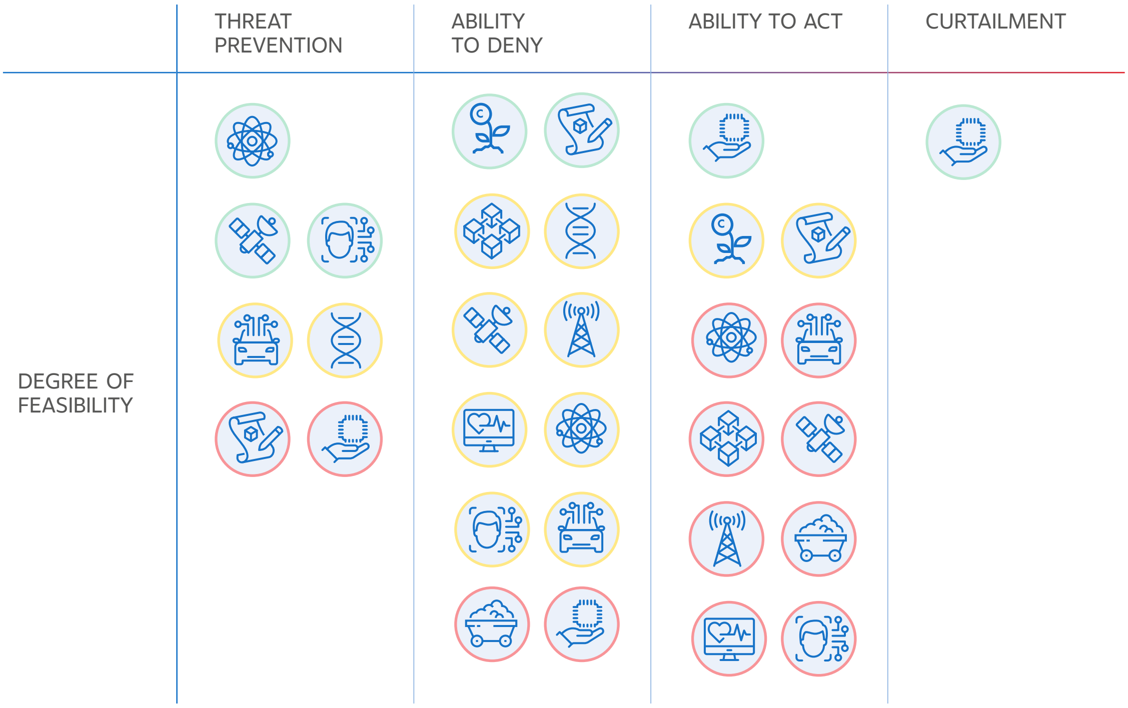
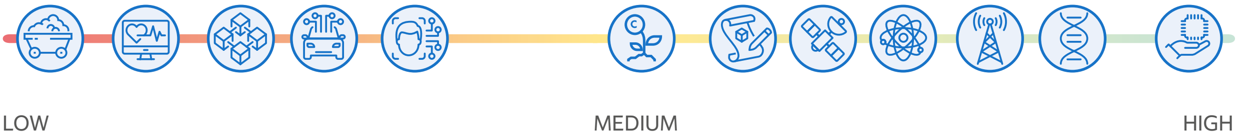


FIGURE 4: Degree of leverage



strategic interest to maintain and further develop these strengths in order to retain leverage. A durable strategy means providing a conducive environment for commercial actors to flourish. However, commercial actors do not necessarily consider strategic priorities to a sufficient degree.

Strategic objectives can also become commercial opportunities. For example, even when the uneven playing field of commercial competition between the EU and China puts European market actors at a disadvantage, if competition is solely or mostly over price, the creation of markets for trustworthy technologies can create commercial opportunities.

Europe should develop its technology policy from the starting point that it is unavoidable that companies and consumers will have to pay a premium to cover growing geopolitical risks in the medium term. EU and UK policy must start from the objective of reducing this inescapable additional cost in the medium term. Thus, in the triangle of "promote", "protect" and "partner", promote and partner tools that take technology markets into consideration require at least as much attention as protect instruments. Furthermore, such a policy should be framed as an attempt to reduce broader societal insecurity over European economic and technological development and as an explicit attempt to increase societal cohesion and trust.

FINDING 6: Balance strategic entanglement and autonomy as two elements of achieving European security

Having identified that dependence on a foreign supplier of critical technology poses a security risk to Europe, the next step is to identify the degree to which this risk can be addressed through entanglement (indispensability) or autonomy.

If European and Chinese technology suppliers are entangled in a critical technology ecosystem, Europe's long-term policy objective should be to ensure or achieve indispensability within entanglement. The goal should be for European technology to play an indispensable role in the Chinese technology ecosystem. Strategic entanglement creates security through indispensability; targeted reverse dependencies keep the cost of conflict very high for China.

Autonomy reduces dependence and vulnerability in Europe and thereby increases European security, but a technologically independent or self-reliant China also poses security challenges for Europe.

This distinction does not ignore the fact that there will still be credible economic interactions between the EU and China that do not fall into the category of strategic entanglement. However, the objective of this study is to identify under which circumstances, how much and what kind of interaction with China can increase European security, or when autonomy should be the strategy of choice. Autonomy and strategic entanglement are two poles on a continuum and need to be properly balanced. This balance will vary across technology ecosystems but also depend on the level of European ambition, as outlined above.

FINDING 7: Policy recommendations for Europe are technology-specific and vary according to level of ambition, from research promotion to knowledge security and commercialisation

European policy on developing or maintaining technological indispensability in critical technological niches requires case-specific policies. No one-size-fits-all approach can provide conducive conditions for, let alone a guarantee of, retaining technological indispensability.

The comparison of the analysed cases does illustrate, however, that policies vary depending on level of ambition. A comparison of the policy instruments proposed for the four respective levels of ambition finds several patterns, which are summarised in Table 1.

That is not to say that all of these instruments are crucial in all cases, and instruments not mentioned in this list can also be important in individual technology ecosystems. European policymakers must not neglect the specific characteristics of different technology ecosystems.

TABLE 1: Patterns of recommended policy instruments sorted by level of ambition

	THREAT PREVENTION	ABILITY TO DENY	ABILITY TO ACT	CURTAILMENT
Frequently mentioned policy instruments across the twelve analysed technology ecosystems	• Identify dual-use goods, establish a risk tracker • Export controls • Inbound investment screening • Outbound investment screening • Strengthen oversight and enforcement	• Strengthen European research (public funding, tax incentives, promotion of academic-commercial collaboration) • Deepening of Single Market/UK Market for quicker technology rollout, including tax incentives and public procurement • Increase cooperation with third countries, including Free Trade Agreements • Allow European engagement and partnership by European companies in China • Regulatory and standards engagement in Europe and internationally • Inbound investment screening • Consequent enforcement of intellectual property rights	• Strengthened European research coupled with research collaboration with third countries (public funding, tax incentives, promotion of academic-commercial collaboration) • Coordinated industrial policy and instruments to incentivise technology rollout in Europe and in like-minded third countries • Digital Free Trade Agreements • Deepening of Single Market/UK Market for quicker technology rollout, including tax incentives and public procurement • Public high-risk/high-gain investments • Active policies to attract talent • Strong commitment to setting norms and standards in the EU, internationally and in China • Strong enforcement measures of international principles including anti-dumping, anti-subsidy instruments and IP rights enforcement in cooperation with third countries • Targeted outbound investment screening • Inbound investment screening	• Export controls • Outbound investment screening • IP rights enforcement • Strategies to buffer economic losses of European companies
Policy focuses on the "Protect, Promote, Partner" triangle	• Protect	• Promote • Partner	• Protect • Promote • Partner	• Protect
Source of European technology strength in focus	• Knowledge security	• Research promotion • Commercialisation	• Research promotion • Knowledge security • Commercialisation	• Knowledge security

European policymakers need to balance protective measures with openness towards China. For example, outbound investment screening to prevent the export of innovation capabilities from Europe to China can be useful not only in a narrow security context, but also as a factor in preserving European competitiveness. However, in isolation, outbound investment screening will not resolve Europe's challenges. "Promote" and "partner" tools are the most crucial instruments and strengthening Europe will be essential. Targeted "protect" measures can help, but will not resolve Europe's problems. A further challenge will be for policies to remain technology agnostic and avoid the trap of simply protecting incumbents. European policy responses must adequately address geopolitical challenges, remain economically viable in the environment of European free market economies and take account of specific emerging or foundational technologies.

Reverse Dependencies on China: How Europe Can Remain Technologically Indispensable and Preserve its Strategic Autonomy

Jan-Peter Kleinhans and Tim Rühlig

ABSTRACT

In adapting to growing geopolitical competition over digital technology, the European Union and the United Kingdom are striving for economic security and technological sovereignty. European policies focus on reducing critical (over-)dependencies on China. However, technological ecosystems are deeply transnational and a full decoupling would result in a situation where Europe had no leverage. China's technological advancement continues to rely on the outside world, including Europe. Under these circumstances, Europe should complement its current policy with policies that help to maintain reverse dependencies and help it to remain technologically indispensable to China. In 12 concrete cases, this report assesses Europe's technological strengths and the potential leverage they might give it. Europe should calibrate its levels of ambition technology by technology across four levels: threat prevention, ability to deny, ability to act and curtailment. Not every European technological strength has the same degree of political leverage, as for example levels of substitutability and spillover damage diverge. Strengthening European security will require a balance of strategic entanglement with China and autonomy, and a combination of "promote", "protect" and "partner" tools. This chapter discusses policy patterns across technologies; but Europe will need to tailor its tools to the specific characteristics of individual technology ecosystems.

The geopolitical contestation over disruptive technologies between the United States (US) and the People's Republic of China (PRC) leaves a deep imprint on Europe.[1] Policymakers in the European Union (EU) and the United Kingdom (UK) are concerned that technological (over-)dependencies could constrain the policy choices at their disposal. Europe's reliance on Chinese technologies is a particular subject of concern.[2]

The digital technological footprint of the PRC is rapidly growing. China's party state-permeated economy has created favourable conditions for a further increase in the global market share of Chinese technology companies.[3] This undermines the competitiveness of European firms. The assumption that an authoritarian country such as China is incapable of ground-breaking innovation has turned out to be an illusion.[4] On the contrary, China has been able to subtly spread the authoritarian values inscribed in its digital technologies across the globe.[5] This goes against Europe's stated core interests. No European state is in a security alliance with the PRC and Europe and China could find themselves on

---

1 We would like to thank James Beioley, Hanna Dohmen and Hanna Zinner for their comments on a previous version of this paper. In this report, "Europe" is defined as the European Union (EU-27) and the United Kingdom (UK) unless otherwise stated.

2 Government of the UK, *Global Britain in a Competitive Age: The Integrated Review of Security, Defence, Development and Foreign Policy*, London, 2021, accessed 29 October 2023, at https://assets.publishing.service.gov.uk/media/60644e4bd3bf7f0c91eababd/Global_Britain_in_a_Competitive_Age-_the_Integrated_Review_of_Security__Defence__Development_and_Foreign_Policy.pdf; and European Commission, Joint Communication to the European Parliament, the European Council and the Council on "European Economic Security Strategy". JOIN/2023/20 final, Brussels, 2023, accessed 29 October 2023, at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023JC0020&qid=1687525961309.

3 Tim Rühlig (ed.), *China's Digital Power: Assessing the Implications for the EU*, Berlin, Digital Power China, 2022, accessed 29 October 2023, at https://dgap.org/en/research/publications/chinas-digital-power

4 Tim Rühlig, "The Roots of China's Innovativeness: Why China's Unstoppable Innovation Powerhouse Might Falter," *DGAP Analysis* no. 5, Berlin, DGAP, 2023.

5 Paul Scharre, "The Dangers of the Global Spread of China's Digital Authoritarianism", Testimony before the US-China Economic and Security Review Commission, Hearing on "Rule by Law: China's Increasingly Global Legal Reach", 4 May 2023, Washington, DC, Center for a New American Security, 2023, accessed 29 October 2023, at https://s3.us-east-1.amazonaws.com/files.cnas.org/documents/Paul_Scharre_Testimony.pdf

opposing sides of an escalating conflict. The friendship between Russia and China may not be as "limitless" as proclaimed,[6] but China's technological development could pose a direct security threat to Europe if the PRC decided to share parts of its dual-use know-how with Russia. Many fear that the possibility of the PRC leveraging its technological dependencies against Europe could constrain the strategic choices of the EU and the UK.

In response, Europe is aiming for a reduction in risk. Several policy instruments have been put in place to this end, such as the EU's investment screening mechanism or the 5G Toolbox. Other policy tools are still in the process of adoption, such as the Critical Raw Materials Act proposed by the European Commission. Most prominently, the EU has launched an European Economic Security Strategy (EESS) that it is now implementing. The Commission published the first implementation package in January 2024.[7] It outlines next steps, some of which have already begun, such as risk assessments of four critical technologies. Similarly, the UK's Integrated Review prioritises innovation in critical technologies such as artificial intelligence (AI), quantum computing, engineering biology, nuclear technology, cyber and space. Technological strength in these fields is seen not only as vital to the UK's future prosperity, but as a precondition for remaining resilient in a world shaped by the utilisation of dependencies in an intensifying power competition.[8] Consequently, the UK has tightened its own investment screening, to name just one of several policy instruments.[9]

Most of these instruments are reactive and protective in nature. Europe is striving to address its technological weaknesses and reduce its over-dependencies on technologies and raw materials that are considered critical. Such de-risking is certainly a necessary process of adaptation to the new geopolitical realities, especially if Europe can successfully differentiate between diverging risk profiles across several emerging and foundational technologies and adopt policy instruments that meet these specific profiles. In its previous report, the Digital Power China (DPC) research consortium proposed such a risk classification, assessed eight emerging and foundational technologies, and made concrete policy recommendations for Europe.[10]

However, what the current de-risking policies neglect is that it is virtually impossible to reduce strategic dependencies to a degree that provides the economic security and technological sovereignty the EU and the UK are seeking. The cost of such decoupling would be enormous and, for good reason, nobody is realistically willing to pay such a high price. The development and production of most emerging and foundational technologies – we speak of "technological ecosystems" – are based on a highly transnational division of labour. All actors are likely to remain interdependent for the foreseeable future. Technological decoupling is impossible and explicitly not desired – by either the EU or the UK.

However, if technological self-reliance is neither feasible nor Europe's goal, Europe will need to remain technologically indispensable in order to be a strategic actor in global supply chains. In other words, under conditions of persistent interdependence, Europe can only prevent being constrained by technological dependencies if it pursues two complementary strategies at the same time: reducing strategic dependencies on China where possible and ensuring that it remains technologically *indispensable* to China. Each technological ecosystem requires a different mix of policies that aims for "autonomy" or "strategic entanglement". However, reverse dependencies on China should be factored into Europe's policies more prominently. Europe will preserve its sovereignty if the PRC leadership considers the cost of going against the EU's and the UK's core interests to be too high.

It might be argued that the logic of interdependence has not prevented Russia from violating international law and attacking Ukraine. Indeed, a high technological and economic cost for China is no guarantee that the PRC will not go against European core interests, which is why Europe must reduce its strategic dependencies on China, as it is currently doing. Studies have demonstrated

---

[6] President of Russia, Joint Statement of the Russian Federation and the People's Republic of China on the International Relations Entering a New Era and the Global Sustainable Development, Moscow, the Kremlin, 2022, accessed 3 March 2024, at http://www.en.kremlin.ru/supplement/5770

[7] European Commission, "Commission Proposes New Initiatives to Strengthen Economic Security", Press release, accessed 14 April 2024, at https://ec.europa.eu/commission/presscorner/detail/en/IP_24_363

[8] Government of the UK, op. cit.

[9] Government of the UK, "National Security and Investment Act 2021", accessed 29 October 2023, at https://www.legislation.gov.uk/ukpga/2021/25/contents/enacted

[10] Tim Rühlig (ed.), *Europe's Strategic Technology Autonomy From China: Assessing Foundational and Emerging Technologies*, Berlin, Digital Power China, 2023, accessed October 28 2023, at https://dgap.org/en/research/publications/europes-strategic-technology-autonomy-china

that the economic costs of decoupling were higher for Russia before the war than they would be for China now.[11] However, in the absence of a feasible decoupling strategy, maintaining a high cost for China is the best of all imperfect policy options to complement – rather than replace – efforts to reduce strategic dependencies. The fact that Russia has acted irrationally is no evidence that China will do the same. The PRC is in the middle of a structural economic transformation and economic growth is still considered vital for the legitimacy of the rule of the Chinese Communist Party (CCP). Security considerations gain in importance relative to economic development, but this does not mean that the Chinese leadership does not consider a further deterioration in economic growth to be a threat to its power. In other words, while no guarantee, imposing economic and technological costs still has a fair chance of shaping the considerations of the CCP leadership.

Preserving European technological strengths sounds more trivial than it is, as such a policy will require a shift in perspective. It is not weaknesses alone that should be at the centre of our considerations, but also how to preserve technological strengths and maintain technological leadership.

UNDERSTANDING EUROPEAN STRENGTHS

Against most expectations, the PRC has developed into an innovation powerhouse.[12] Recent Australian research has found that China leads in 37 of 44 critical technologies, as measured by international research output.[13] The latest Cyber Power Index prepared by the Belfer Center ranks China second, falling short only of the cyber capabilities of the United States.[14] The World Intellectual Property Organisation's Global Innovation Index paints a slightly different picture: China is placed 11th, but still ahead of several industrialised economies including France.[15] These and other similar studies might be unable to grasp the full complexity and degree of China's technological advance. While only approximations, however, all these reports paint a clear picture: the PRC, through its universities, research institutes and companies, can be highly innovative.

China's emergence as a technological power presents Europe with a reality it did not anticipate. For decades, European policymakers ascribed western digital prowess to the beneficial combination of liberal democracy and free market capitalism. As a non-democratic, non-free-market state, China was believed to be unable to emulate this success.[16] This interpretation has turned out to be false. China has gone far beyond catching up with the West. The fundamental "sin" driving the PRC's growth model – the theft of intellectual property (IP) – cannot account for why China has overtaken the West in several emerging and foundational technologies. If IP theft alone had been the sole characteristic of the China model, the PRC would have run out of steam as China gained technological leadership.

As is argued in more detail elsewhere, China's formula for success comprises "Five Virtues": (a) a skilful modulation of protectionism in a large market; (b) attracting knowledge into the country; (c) liaison with western actors; (d) party-state guidance instead of control; and (e) domestic competition with Chinese characteristics. However, all these virtues are being challenged by domestic policies and deteriorating international conditions. China will remain innovative, but the extent of its success is not foretold. The West still has some leverage. The PRC may not be the copycat it has been accused of being, but its technological advancement continues to rely on the outside world, including Europe.[17]

---

[11] Jürgen Matthes, "Gegenseitige Abhängigkeiten im Handel zwischen China, der EU und Deutschland. Eine empirische Faktensammlung" [Mutual trade dependencies between China, the EU and Germany: A collection of empirical facts], IW-Report 35/2022, Köln, Institut der Deutschen Wirtschaft, 2022, accessed 14 April 2024, at https://www.iwkoeln.de/fileadmin/user_upload/Studien/Report/PDF/2022/IW-Report-2022-Gegenseitige-Abhaengigkeiten.pdf

[12] Graham Allison et al., *The Great Tech Rivalry: China vs the US* , Cambridge, MA, Belfer Center for Science and International Relations, 2021, accessed 22 October 2023, at https://www.belfercenter.org/sites/default/files/GreatTechRivalry_ChinavsUS_211207.pdf

[13] Jamie Gaida et al., *ASPI's Critical Technology Tracker: The Global Race for Future Power*, Canberra, ASPI, 2023, accessed 22 October 2023, at https://ad-aspi.s3.ap-southeast-2.amazonaws.com/2023-03/ASPIs%20Critical%20Technology%20Tracker_0.pdf?VersionId=ndm5v4DRMfpLvu.x69Bi_VUdMVLp07jw.

[14] Julia Voo et al., *National Cyber Power Index 2022*, Cambridge, MA, Harvard Kennedy School, 2022, accessed 23 October 2023, at https://www.belfercenter.org/publication/national-cyber-power-index-2022

[15] Soumitra Dutta et al., *Global Innovation Index 2022: What is the Future of Innovation-driven Growth?* Geneva, World Intellectual Property Organisation, 2022, accessed 23 October 2023, at https://www.wipo.int/edocs/pubdocs/en/wipo-pub-2000-2022-en-main-report-global-innovation-index-2022-15th-edition.pdf

[16] Regina M. Abrami et al., "Why China Can't Innovate", *Harvard Business Review*, accessed 18 September 2021, at https://hbr.org/2014/03/why-china-cant-innovate

[17] Tim Rühlig, "The Roots of China's Innovativeness", op. cit.

This general observation, however, does not provide enough insight into the ways in which China relies on Europe and how the continent can maintain its technological indispensability to the PRC. Instead, Europe needs to understand China's technological ambitions, the weaknesses and obstacles the country faces on its way to achieving them and whether the PRC depends on Europe in this regard. In fact, Europe does not possess enough knowledge of its strengths and Chinese dependencies on the EU and the UK. It is this policy-relevant knowledge gap that this report seeks to tackle. We explore how Europe can remain technologically indispensable – or at least highly relevant – to China by examining 12 concrete technology case studies.

Our starting point is an analysis of Chinese-language sources identifying technological weaknesses and dependencies in specific cases. A previous study carried out by the Center for Security and Emerging Technology (CSET) at Georgetown University analysed a series of Chinese-language articles discussing technology chokepoints.[18] This report departs from CSET's previous results, investigating case studies by analysing both academic and policy documents in the Chinese language. The aim is to identify China's relevant technology ambitions and the obstacles that Chinese companies, researchers and policymakers must overcome.

This information on Chinese weaknesses is then matched with European technology strengths. For this, a triangulation of several data points helps to verify Chinese perceptions of its own technological weaknesses and identify whether Europe can match these weaknesses with its own strengths. Depending on the concrete case studies, these data points comprise the global research landscape measured by journal articles and conference papers, patent data, equity research data, public procurement data and/or technical assessments by the technical experts of DPC.

For this purpose, the report adopts a case study approach. Rather than aiming to grasp a full but vague picture based on import data, we explore 12 specific technology niches in detail that are of strategic relevance. Table 1 summarises the strategic relevance of the respective cases in each technological area.

All the case studies explore the potential for future European technology strengths with a time horizon of 10–15 years in mind. Accordingly, the cases examined need to be technology neutral enough to avoid technological determinism and the protection of European incumbents.

TABLE 1: Summary of chapter cases

SEMICONDUCTORS: LITHOGRAPHY EQUIPMENT
Jan-Peter Kleinhans and John Lee
Lithography is the most complex of the three basic steps in wafer fabrication. It is a highly concentrated market with an EU monopoly at the cutting-edge and an EU/Japanese duopoly in older technologies. Lithography is dependent on a lot of "auxiliary" equipment that needs to be closely integrated with the lithography machine.
WIRELESS INFRASTRUCTURE AND OPERATION: TOTAL ENERGY CONSUMPTION AND GREEN RADIO NETWORKS
Tim Rühlig and Liesbet van der Perre
Total energy consumption is one of three crucial factors (alongside performance and price) determining the competitiveness and sustainability of wireless infrastructure and transmission strategies. The primary focus is on RAN's total energy consumption. RAN is one of the two major mobile network infrastructure components (alongside the Core Network). It has been identified as a major bottleneck in energy consumption in high-capacity wireless networks.

---

[18] Ben Murphy, *Chokepoints: China's Self-identified Strategic Technology Import Dependencies*, Washington DC, Center for Security and Emerging Technology, 2022, accessed 28 October 2023, at https://cset.georgetown.edu/publication/chokepoints/

QUANTUM: QUANTUM SENSING

Simon Armstrong, Markus Herrmann, Abhishek Purohit, Michael Settelen and Araceli Venegas-Gomez

Quantum technologies are quantum computing and simulation, quantum communication, and quantum sensing and imaging. The case study focuses on the latter. Applications and use cases in quantum sensing impact various sectors, such as healthcare, material sensing, environmental monitoring and defence. If more focus is not put on these applications, this could weaken China. The EU has demonstrable strengths in quantum sensing over China, backed by its rich history in quantum research, structured and strategic investments in diverse quantum sensing technologies, and a well-established ecosystem that synergises academic and industrial components effectively.

BLOCKCHAIN: SMART CONTRACTS

Cyrille Artho and Rogier Creemers

Smart contracts are small pieces of software that automatically handle assets on a blockchain. They have the potential to significantly enhance the security of transactions. This is one of the major applications of blockchain discussed in both Europe and China. Once deployed, a smart contract cannot be changed; ensuring beforehand that the software has no major flaws is therefore of key importance. Research, development and innovation of smart contracts are seeing rapid growth, but wider adoption will require better development tools and agreements on common interfaces and platforms.

CRITICAL RAW MATERIALS: CHINA’S “STRATEGIC” METALS

Raphael Danino-Perraud, John Seaman and Florian Vidal

A broad range of so-called technology metals are critical components of emerging technologies that will drive the digital and energy transitions. China remains dependent on foreign production of many metals it considers “strategic” for technological competitiveness. Such dependencies create vulnerabilities for Beijing, and there are particular concerns around supply disruption, even though China has made efforts to mitigate risks through investment and supply chain integration.

ARTIFICIAL INTELLIGENCE: MEDICAL DEVICES

Carlo Fischione, Sanne van der Lugt and Frans-Paul van der Putten

The Chinese government sees medical equipment as a sector in which it wants to be self-sufficient. Two European companies (Philips, Siemens) are among the world leaders for medical devices and deeply integrated into the Chinese medical and tech sectors.

SEMICONDUCTORS: AUTOMOTIVE CHIPS

Jan-Peter Kleinhans and John Lee

Automotive chips are sensors, power semiconductors, microcontrollers and autonomous driving chips. European chip suppliers are leaders in the first three categories. An electric vehicle (EV) has two or three times more chips than an internal combustion engine car. Chinese EV makers control more than 80% of China’s EV market, which is the largest globally.

SPACE: MOON EXPLORATION

Marco Aliberti and Angela Stanzel

The provision of communication and navigation services is indispensable to sustaining a long-term robotic and/or human presence on the Moon. Communications and navigation represent just one critical technical area to be mastered for lunar exploration, but also the one with most application potential for commercial return on investments.

ARTIFICIAL INTELLIGENCE: FACIAL RECOGNITION

Gregory Walton and Valentin Weber

Facial recognition plays a small but important part in the Chinese economy's use of AI for industrial, consumer and citizen identification purposes. The Chinese facial recognition market is expected to reach €1.42bn by 2030. Facial recognition is essential to the modern surveillance state and a sizeable security industrial complex has emerged that exports the technology. Facial recognition is key to Beijing's communist elite remaining in power by allowing efficient monitoring of the population.

ARTIFICIAL INTELLIGENCE / DATA GOVERNANCE: GENOMIC DATA

Una Berzina-Cerenkova, Elena Ferrari, Karina Palkova and Julia Voo

European Genomic data is indispensable to China's bio-tech and med-tech research and exports. Responsible data governance of genomic data is a strategic asset for the EU, especially in the case of cross-border collaborations. The Chinese government regards bio-tech as a national priority to be sustained through massive investments in technologies for genomic data analysis.

TECHNICAL STANDARDS: STANDARDS IN 5G ENERGY CONSUMPTION, AUTOMOTIVE CHIPS AND FACIAL RECOGNITION

Martin Catarata, Julian Heiss and Tim Rühlig

The analysis covers a subset of three emerging technology standards foundational to defining crucial developments in the respective technologies: (a) 5G energy consumption for the competitiveness and sustainability of future wireless infrastructure; (b) cutting-edge automotive chipsets for the development of secure and reliable autonomous driving; and (c) AI facial recognition for privacy protection in an "inherently learning" technology.

DIGITAL AND GREEN TRANSITIONS: OPPORTUNITIES AND CHALLENGES FOR EUROPE AND CHINA

Davide Bonaglia, Rasmus Lema, Mercedes Menéndez de Medina and Roberta Rabelotti

The number of digital green patents has risen sharply since 2010; 70% of digital green patents are in technologies whose purpose is to minimise the use of energy during the operation of the ICT equipment involved. The EU has technology advantage in technologies related with energy generation, transmission, and distribution and those related with wastewater treatment or waste management. China has not yet developed any are of technology advantage in digital green technologies.

FROM TECHNOLOGICAL STRENGTH TO POLITICAL LEVERAGE

China has profited greatly from technological upgrading. The PRC has been undergoing a process of technological catch-up for several decades. Legitimate and illegitimate technology transfer from Europe to China have contributed significantly to the PRC's rise to become the world's second-largest economy.[19] China's technological advance remains central to the development of the PRC, which is facing several structural challenges. As its demographic dividend and urbanisation potential draw to an end, China needs to undergo structural reform. China can no longer compete on cheap skilled labour, but needs to move up the global value chain and sustain as much productivity growth as possible. For this, technological innovation and advance will be central. In 2016, an official of the National Development and Reform Commission (NDRC) explained in an anonymous interview that "to ensure social stability, we need to achieve significant productivity gains from digital technologies. Only if we stay on top of digital technologies

---

[19] Jyh-an Lee, "Forced Technology Transfer in the Case of China", in *Journal of Science Technology Law*, vol. 26, no. 2, pp. 324–352, September 2020.

can we remain competitive and prevent the middle-income trap.[20] [...] We need to make sure that we do not grow old before we get rich".[21]

From this context, we can understand that China's leadership puts great emphasis on technological development. In his speech to the 20th CCP Party Congress, paramount leader Xi Jinping identified technological advance and self-reliance as key to the country's economic prosperity and national strength.[22] Equally, China's most recent Five-Year Plan prioritises innovation and characterises domestic self-reliance as the main objective not only for domestic development, but also as a basis for the PRC's global power.[23] It is therefore no wonder that Xi Jinping has continuously identified a strengthening of basic research as a decisive feature of the government's work.[24]

While China's persistent dependence on foreign technology, including from Europe, provides potential leverage for the EU and the UK, not every European technological strength has equal political leverage. To properly assess the political leverage of a technological strength, policymakers need to take various aspects into account.

Area of indispensability: Europe's strength could be based on superior research and innovation, intellectual property and patents, or production and commercial goods. Such a distinction is crucial if policymakers are to understand how to provide the conditions for maintaining their respective European strongholds.

Market entry barriers: What would it take for China to achieve import substitution and reduce its dependence on European technology providers? Are the barriers to successful market entry by Chinese technology providers mainly rooted in: (a) technological breakthroughs; (b) economies of scale; or (c) compliance with standards and certification? Or are there no substantial barriers to entry at all, and could the dominant market position of a European technology provider rapidly dwindle?

Technological substitutability: One technology can often be substituted with another even if that means settling for decreased performance, higher costs or lack of certain capabilities. One example would be wafer fabrication at the 7nm level, which can be achieved either with extreme ultra-violet (EUV) equipment or through the use of older deep ultra-violet (DUV) equipment. The latter, however, increases production time, cost and defects rates.

Foreign availability: Reducing dependence on a European technology provider by strengthening the domestic supplier ecosystem can take a long time. Sometimes a short- to medium-term solution might be to diversify through foreign, non-European suppliers. Thus, foreign availability dilutes the strength of a chokepoint.

Effective utilisation: Controlling a European technological strength through, for example, export controls might be ineffective or unenforceable. For instance, restricting exports is substantially harder for software and other intangible technologies than for tangible goods, such as industrial machinery. A different example would be Europe's strength in medical equipment: given that the protection of lives depends on the technology, it is questionable whether Europe should use it as a chokepoint for geopolitical purposes.

EUROPEAN AMBITIONS

Technological strengths and the degree of leverage they carry say little about the political ambitions that Europe is seeking to achieve by using them. The feasibility of different levels of ambition varies according to the concrete technological ecosystem. However, the level of ambition is also a matter of political will. Europe needs to calibrate its levels of ambition and be realistic about what it can and what it wants to gain politically from a given (potential) technological strength. At least four levels of ambition can be distinguished:

---

[20] The middle-income trap refers to the phenomenon that a middle-income country's economic development stalls below what is needed to achieve a high per capita income. This is the effect of rising labour costs and the resultant decline in competitiveness before the population has progressed to high income levels.

[21] Anonymous author interview with an official of the NDRC, Beijing, July 2016.

[22] Ministry of Foreign Affairs of the People's Republic of China, "Full Text of the Report to the 20th National Congress of the Communist Party of China", Beijing, Chinese Government, 2022, accessed 29 October 2023, at https://www.fmprc.gov.cn/eng/zxxx_662805/202210/t20221025_10791908.html

[23] Government of the PRC, "中华人民共和国国民经济和社会发展第十四个五年规划和2035年远景目标纲要" [Outline of the People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035], State Council, accessed 29 October 2023, at https://www.gov.cn/xinwen/2021-03/13/content_5592681.htm

[24] See e.g. Xi Jinping, "加强基础研究 实现高水平科技自立自强" [Strengthening basic research to realise high-level scientific and technological self-reliance and self-improvement], Qiushi, accessed 29 October 2023, at http://www.qstheory.cn/dukan/qs/2023-07/31/c_1129776375.htm?utm

- **Threat prevention** is the lowest level of ambition. It has only one goal in mind: to prevent the transfer of technology to China that could be used to threaten Europe. Threat prevention aims to increase European security by preventing dual-use technology leakage to China, defined along the lines of the Wassenaar Arrangement and the EU dual-use export control regulation (2021/821), as well as the UK's Export Control Act 2002 (ECA 2002) and the associated Export Control Order SI 2008/3231.

- The **ability to deny** is more ambitious as it is about maintaining or creating co-dependencies that constitute a high degree of economic cost for China if Europe were to leverage its strength by means of technological disentanglement. This level of ambition follows a defensive logic as Europe simply wants to prevent China from acting against core European interests. In contrast to the first level, the ability to deny considers not just dual-use goods, but economic dependencies more broadly. Resting on the assumption that China is unlikely to accept irrationally high economic costs, it seeks to use the cost of interdependencies to deter the PRC from acting against core European interests.

- The **ability to act** capitalises on the same rationale of economic cost through interdependence but is more proactive in that it strives to maintain an edge over China. The ability to act is not purely defensive. Instead, it represents a degree of Chinese technological reliance on European strength that allows the EU to shape technological development and related policy directly and indirectly through third markets. China often strives for the ability to act, for example, through controls on exporting graphite from China to Sweden.[25] Graphite exports are controlled by the PRC not for security purposes or to reactively prevent Sweden from going against Chinese core interests. Instead, the likely purpose is to hamper one of Europe's most important EV battery production sights, thereby maintaining European reliance on Chinese EV batteries.

- **Curtailment** is about preventing the respective other from developing certain economic and technological capabilities far beyond the security realm. The goal is to limit and freeze Chinese technological and economic development more broadly. US semiconductor export controls are a recent example of curtailment as they cut China off from advanced generative AI development.

In each technological ecosystem, European policymakers need to identify the level of ambition given the feasibility of the actions required to achieve a stated ambition. This report therefore structures its policy recommendations along the above four levels of ambition, outlining which policies the EU and the UK need to put in place in each case study. In this context, European policies need to start from a proper understanding of Chinese ambitions, technological ecosystems and existing strategic niches with the potential for leverage, to all of which this report strives to contribute.

FINDINGS ACROSS CASE STUDIES

The character and degree of potential European technological indispensability, the mechanisms for leveraging it and the policies that Europe should put in place vary across the technological areas analysed in this study. However, seven patterns visible across all cases are summarised below.

FINDING 1: Europe's greatest source of strength is research and innovation, but IP and production contribute too

Across the case studies analysed, European strength can result from excellent research and innovation, IP and patents or the production and commercialisation of the respective technologies. In many cases, Europe's potential for leverage results from a combination of these sources. In some cases, Europe is well placed to develop or regain technological strength in one or several of these three dimensions. In other cases, the EU is already well placed and should strive to maintain and consolidate the technological edge it currently holds.

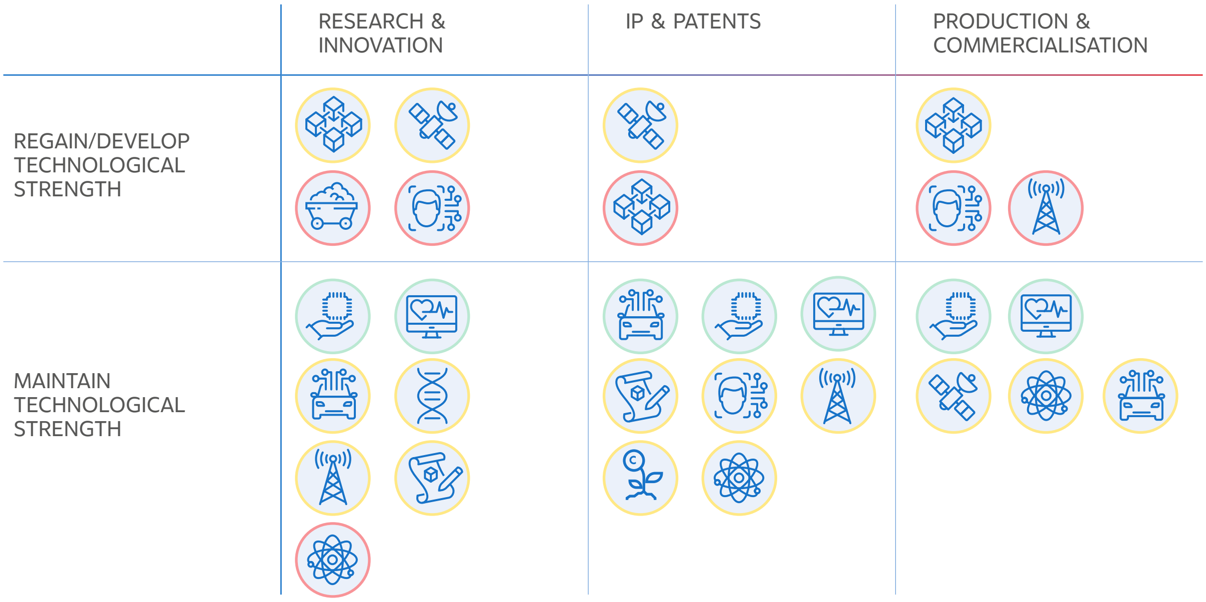
It is widely known that Europe's technological capabilities are stronger in research and innovation than in IP and production.[26] However, the cases illustrate that this general finding on European research and innovation strength does not preclude that technological excellence in critical niches can equally result from IP and commercial products. European strategic indispensability, if achieved, will emerge from a combination of all three pillars.

---

[25] Shunsuke Tabeta and Iori Kawate, "China's Graphite Export Curbs Take Effect With Uncertainty For EVs" *Nikkei Asia*, accessed 20 December 2023, at https://asia.nikkei.com/Spotlight/Supply-Chain/China-s-graphite-export-curbs-take-effect-with-uncertainty-for-EVs

[26] See e.g. the results of the first DPC report, Tim Rühlig (ed.), China's Digital Power op. cit.

FIGURE 1: Existing and potential sources of European technological strength across the analysed case studies



	RESEARCH & INNOVATION	IP & PATENTS	PRODUCTION & COMMERCIALISATION
REGAIN/DEVELOP TECHNOLOGICAL STRENGTH	🟨 Blockchain for smart contract 🟨 Space exploration 🟥 Critical raw materials 🟥 AI – facial recognition	🟨 Space exploration 🟥 Blockchain for smart contract	🟨 Blockchain for smart contract 🟥 AI – facial recognition 🟥 Wireless – energy saving
MAINTAIN TECHNOLOGICAL STRENGTH	🟩 Semiconductor lithography 🟩 AI – medical equipment 🟨 Semiconductor – auto 🟨 Genomic data 🟨 Wireless – energy saving 🟨 Technical standardisation 🟥 Quantum sensing	🟩 Semiconductor – auto 🟩 Semiconductor lithography 🟩 AI – medical equipment 🟨 Technical standardisation 🟨 AI – facial recognition 🟨 Wireless – energy saving 🟨 Patents – twin transition 🟨 Quantum sensing	🟩 Semiconductor lithography 🟩 AI – medical equipment 🟨 Space exploration 🟨 Quantum sensing 🟨 Semiconductor – auto

KEY

Green icons = highest likelihood that Europe will achieve its goals if its puts in place the right policies
Yellow icons = medium level of likelihood that Europe will achieve its goals if its puts in place the right policies
Red icons = even were Europe to put in place the right policies, it would face difficulties achieving its goals

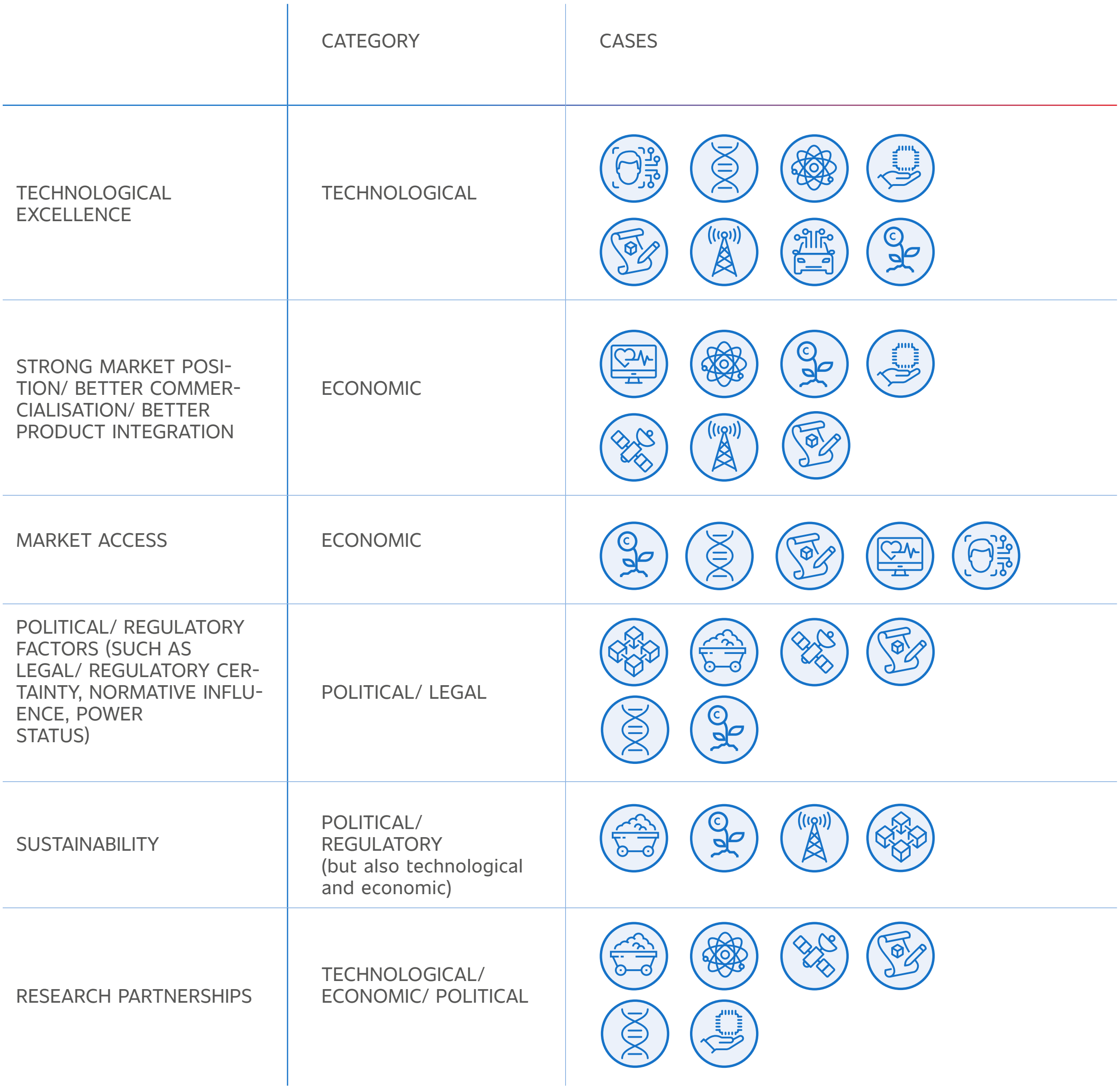
- AI – facial recognition
- Critical raw materials
- Quantum sensing
- Space exploration
- AI – medical equipment
- Genomic data
- Semiconductor – auto
- Technical standardisation
- Blockchain for smart contract
- Patents – twin transition
- Semiconductor lithography
- Wireless – energy saving

Figure 1 summarises the existing and potential sources of European technological strength across the analysed case studies. The colour coding of the icons indicates the likelihood of Europe developing or maintaining a technological edge over China within a timeframe of 10 years. Icons are not displayed in a given column if there is no realistic chance of achieving technological strength in the respective pillar.

FINDING 2: Technological superiority, and commercial, political and regulatory aspects are all decisive factors in European technological indispensability

European technological strength is the result of more than just technological excellence. Depending on the technology ecosystem, economic factors such as a strong market position, better commercialisation conditions, the integration of a technology into products or access to the European Single Market can play a decisive role. Political and regulatory conditions such as legal certainty, Europe's normative power or the priority it gives to the sustainable development of technologies are also factors. In some cases, a combination of

FIGURE 2: Sources of potential European strength across the analysed case studies



	CATEGORY	CASES
TECHNOLOGICAL EXCELLENCE	TECHNOLOGICAL	🤖 🧬 ⚛ 🔲 📜 📡 🚗 🌱
STRONG MARKET POSITION/ BETTER COMMERCIALISATION/ BETTER PRODUCT INTEGRATION	ECONOMIC	🖥 ⚛ 🌱 🔲 🛰 📡 📜
MARKET ACCESS	ECONOMIC	🌱 🧬 📜 🖥 🤖
POLITICAL/ REGULATORY FACTORS (SUCH AS LEGAL/ REGULATORY CERTAINTY, NORMATIVE INFLUENCE, POWER STATUS)	POLITICAL/ LEGAL	⧉ ⛏ 🛰 📜 🧬 🌱
SUSTAINABILITY	POLITICAL/ REGULATORY (but also technological and economic)	⛏ 🌱 📡 ⧉
RESEARCH PARTNERSHIPS	TECHNOLOGICAL/ ECONOMIC/ POLITICAL	⛏ ⚛ 🛰 📜 🧬 🔲

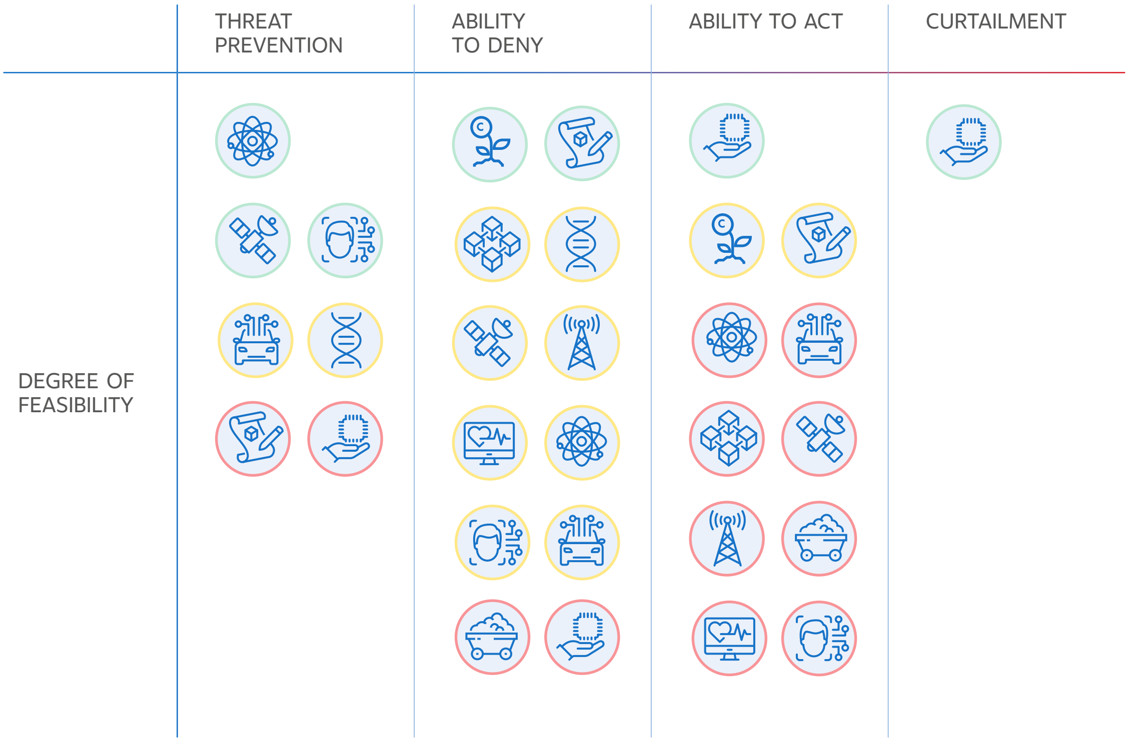
technological, economic and political factors has resulted in technology partnerships that give Europe an edge over China. Figure 2 summarises the sources of potential European strength across the analysed case studies.

FINDING 3: Europe should calibrate its levels of ambition technology by technology

When considering technological indispensability and the resulting chokepoints, observers automatically think of China's reliance on European advanced semiconductor manufacturing equipment. This hard chokepoint, often associated with the Dutch vendor ASML, is a unique case of a complex technological ecosystem that relies on a broad range of mostly European suppliers that would be almost impossible to replicate. No other hard chokepoint of the same quality exists in the analysed digital technologies.

This means that of the analysed cases, curtailment is only feasible in lithography. Other levels of ambition, however, are achievable depending on the technological ecosystem. Figure 3 summarises the likelihood that the right policy choices would allow Europe to achieve its respective levels of ambition in the analysed cases. The colour coding indicates the likelihood that Europe could achieve the respective level of ambition in a timeframe of 10 years if the right policies were put in place. Where an icon is not displayed in a respective box, this level of ambition is not feasible.

FIGURE 3: The likelihood that the right policy choices would allow Europe to achieve its respective levels of ambition in a timeframe of 10 years



When considering different levels of ambition, European policymakers face trade-offs inherent in all four levels. Some of these are technology-specific, others more general.

- **Threat prevention:** A targeted focus on dual-use items makes considerations less complex and allows for a maximum of economic and technological exchange with the PRC compared to the other levels of ambition. At the same time, Europe constrains itself to preventing technology leakage without any additional leverage beyond this narrow aim.

- **Ability to deny:** A focus on mutual dependency accepts a certain level of vulnerability inherent in interdependency while maintaining a significant degree of interaction and its resultant revenue for EU actors. This strategy assumes that China, unlike Russia, is a cost-sensitive and rational actor seeking to avoid acting against core European interests, as this would place significant constraints on China's domestic economy and technological development. If China's economic crisis deepens, however, the PRC could act irrationally. Alternatively, the EU could miscalculate the distribution of dependency and enter a stage of asymmetric dependency.

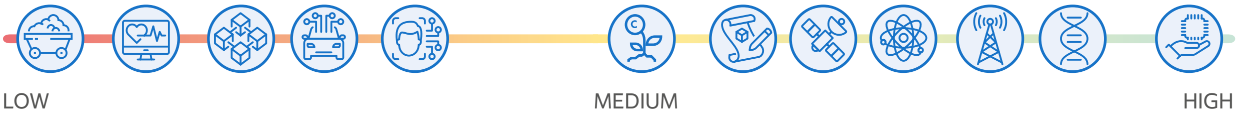
- **Ability to act:** A high degree of leverage would result from Chinese dependence on European technological input. Europe could not only shape China's calculations in a major crisis, but also influence technological and related policy developments in the PRC. At the same time, Europe would increase its economic and security risk as a high level of cooperation would strengthen Chinese capabilities.

- **Curtailment:** If successful, a relative gain in power compared to China would come at an economic cost, slowed innovation and an undermining not least of global ambitions on climate change mitigation; it also runs the highest risk of Chinese retaliation.

FINDING 4: Not every European technological strength has the same degree of political leverage

Technological strength is a necessary but not sufficient precondition for European leverage over China. Whether Europe is able to leverage a given technological strength depends on a number of factors, not least ethical considerations, the degree of difficulty substituting the respective technology and the spillover effect into other factors. For example, withholding medical technology is likely to be less acceptable and therefore politically less

FIGURE 4: Degree of leverage



feasible in European democracies. Figure 4 summarises the degree of leverage across technology ecosystems.

Figure 5 summarises the analysed case studies along two dimensions that influence the degree to which technological strength provides leverage: substitutability and expected spillover damage if ties with China were to be cut. The figure does not consider the possibility of asymmetric retaliation.[27] Note that spillover can differ; for example, the damage in auto chips would mostly be a significant decrease in European suppliers' revenues and related effects while spillover in critical raw materials would result from China's leverage and retaliatory capabilities. Figure 5 shows a correlation between the degree of difficulty in replicating or circumventing European technological strength and the expected degree of spillover.

FINDING 5: Integrate strategic and commercial considerations for a durable technology policy

To a large extent, Europe's technological strength is the strength of commercial actors and that of publicly funded research institutions such as universities. It is in Europe's strategic interest to maintain and further develop these strengths in order to retain leverage. A durable strategy requires a conducive environment in which commercial actors can flourish. However, commercial actors do not necessarily consider strategic priorities to a sufficient degree.

Strategic objectives can also be turned into commercial opportunities. For example, even when an uneven playing field of commercial competition between the EU and China puts European market actors at a disadvantage where competition is solely or mostly over price, the creation of markets for trustworthy technologies can create commercial opportunities.

Europe should develop its technology policy from the starting point that it is unavoidable that companies and consumers will have to pay a premium to cover growing geopolitical risks in the medium term. EU and UK policy need to start from the objective of reducing this inescapable price. Therefore, in the triangle of promote, protect and partner, promote and partner tools that take account of the technology markets will require at least as much attention as protect instruments. Furthermore, such a policy should be framed as an attempt to reduce broader societal insecurity over European economic and technological development, and explicitly strive to increase societal cohesion and trust.

FINDING 6: Balance strategic entanglement and autonomy as two elements for achieving European security.

Having identified that dependence on a foreign supplier of critical technology poses a security risk to Europe, the following step is to identify the degree to which this risk can be addressed through either entanglement (indispensability) or autonomy.

- **Entanglement** (Indispensability): If European and Chinese technology suppliers are entangled in a critical technology ecosystem, Europe's long-term policy objective should be to ensure or achieve indispensability within entanglement. The goal is for European technology to play an indispensable role in the Chinese technology ecosystem. Strategic entanglement creates security through indispensability. Targeted reverse dependencies keep the cost of conflict very high for China.

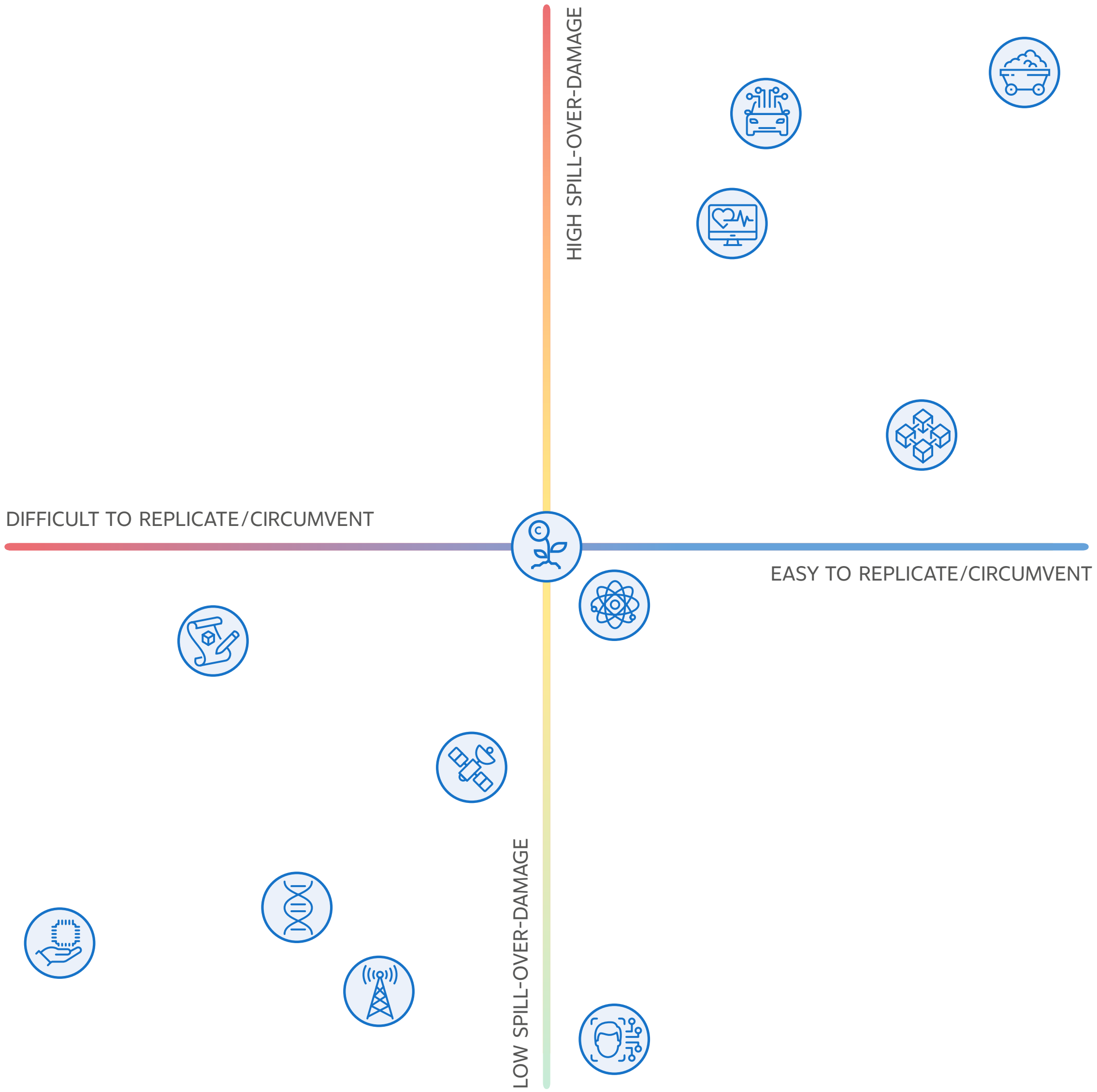
- **Autonomy:** Autonomy reduces Europe's dependence and vulnerability and thereby increases European security. However, a technologically independent or self-reliant China in turn poses security challenges for Europe.

This distinction does not ignore the fact that there will be regular economic interaction between the EU and China that does not fall into the category of strategic entanglement. However, the objective of this study is

---

[27] For example, a tightening of European semiconductor export controls could result in tighter and broader Chinese export restrictions on critical raw materials. Figure 5 considers technology-inherent spillover risks, i.e., the risk of retaliation in the very same technology. It can be hypothesised that the likelihood of asymmetric retaliation largely depends on the damage to China caused by the respective European action. Testing this hypothesis, however, is beyond the scope of this volume.

FIGURE 5: The degree to which technological strength provides leverage: substitutability and expected spillover



to identify under which circumstances, how much and what kind of interaction with China can increase European security, and when autonomy should be the strategy of choice. Autonomy and strategic entanglement are two poles on a continuum and must be properly balanced. This balance varies across technology ecosystems but also depends on the level of European ambition, as outlined above.

FINDING 7: Policy recommendations for Europe are technology-specific and vary according to levels of ambition, from research promotion to knowledge security and commercialisation

European policy on developing or maintaining technological indispensability in critical technological niches requires case-specific policies. No one-size-fits-all approach can provide conducive conditions for, let alone a guarantee of retaining technological indispensability.

The comparison of analysed cases does illustrate, however, that policies vary depending on level of ambition (as outlined in finding 3) and depending on the role of autonomy and strategic entanglement as sources of security (as outlined in finding 6). Furthermore, in all cases, a combination of policies that promote research and innovation, protect IP and patents, and provide conducive conditions for production and commercialisation are essential to increasing European security by means of strategic indispensability.

A comparison of the policy instruments proposed for the respective four levels of ambition identifies a number of patterns. To achieve *threat prevention*, an analysis and tracking of the risks of dual-use applications is often mentioned along with export controls, inbound and outbound investment screening, as well as strengthened oversight and enforcement of existing rules. These measures focus on knowledge security. Within the EU's triangle of promote, protect and partner tools, there is a heavy emphasis on protect instruments.

Achieving the *ability to deny* in the 12 technology ecosystems discussed in this report tends to require a different set of tools. Strengthening European public and private sector research by various means; deepening the Single Market/UK market to provide conditions that incentivise faster adoption and rollout of critical technologies, such as through public procurement and tax incentives; cooperation with third countries while also allowing European engagement in the Chinese market and cooperation with Chinese companies; as well as inbound investment screening and enforcement of intellectual property rights along with strong engagement to set regulatory norms and technical standards in Europe and internationally are all frequently recommended. These tools mostly focus on research promotion and support for commercialisation. Thus, promote and partner instruments are vital along with minor protect tools.

At first glance, the policy instruments to achieve the *ability to act* appear similar to those for the ability to deny. Strengthening of research and commercialisation conditions in Europe, public investment, digital free trade agreements with third countries, and strong commitment to norms and standards in the EU and internationally all read as somewhat the same even if with a bit more ambition. However, the tools far exceed those of the ability to deny. Coordinating research collaboration and coordinating industrial policies with third countries are complex and demanding. Public investment is often mentioned in the context of high-risk/high-gain constellations that call on public actors to take on the risks of default. Coupled with a call to attract talent and the aspiration to even influence domestic standard setting in China, this illustrates that this level of ambition seeks to establish Europe as a technology leader. In contrast to the ability to deny, this will require strong and proactive collaboration with third countries, but also targeted defensive measures such as anti-dumping and anti-subsidy instruments and IP rights enforcement in cooperation with third countries, targeted outbound investment screening and inbound investment screening. Comprehensive policy instruments would involve research promotion, knowledge security and commercialisation support tools. All three angles of promote, protect and partner would play an important role with a strong emphasis on partner tools.

Curtailment, finally, is about export controls, outbound investment screening, the enforcement of intellectual property rights but also strategies to buffer the economic losses that European companies and economies would face. "Protect" tools for ensuring knowledge security will be key.

This is not to say that all of these instruments are crucial in all cases or that instruments that are not mentioned in this list cannot be important in individual technology ecosystems. Table 2 summarises the patterns but European policymakers must not neglect the specific characteristics of different technology ecosystems.

Many of the policy instruments currently being widely discussed in the European Union and the United Kingdom appear in at least some of the chapters of this report: (a) continuous risk assessments; (b) increased promotion of technologies, including dual-use technologies; (c) high-risk/high-gain investments by public actors as a means of deepening the Single Market; (d) strong engagement in international norm- and standard-setting; (e) comprehensive coordination with third countries, including on research promotion but also industrial policy; (f) new and deepened existing free trade agreements; (g) tightened inbound investment screening and export controls; and (h) limitations on research collaboration with Chinese actors. Most remarkably, outbound investment screening to prevent the export of innovation capabilities from Europe to China is discussed not only in a narrow security context, but also as a factor in preserving European competitiveness.

Finally, European policymakers need to balance protective measures with openness to China. A further challenge will be for policies to remain technology agnostic and avoid the trap of simply protecting incumbents. European policy responses must adequately address geopolitical challenges while remaining economically viable in the environment of European free market economies, and take account of specific emerging or foundational technologies.

TABLE 2: Patterns of recommended policy instruments sorted by level of ambition

	THREAT PREVENTION	ABILITY TO DENY	ABILITY TO ACT	CURTAILMENT
Frequently mentioned policy instruments across the twelve analysed technology ecosystems	• Identify dual-use goods, establish a risk tracker • Export controls • Inbound investment screening • Outbound investment screening • Strengthen oversight and enforcement	• Strengthen European research (public funding, tax incentives, promotion of academic-commercial collaboration) • Deepening of Single Market/UK Market for quicker technology rollout, including tax incentives and public procurement • Increase cooperation with third countries, including Free Trade Agreements • Allow European engagement and partnership by European companies in China • Regulatory and standards engagement in Europe and internationally • Inbound investment screening • Consequent enforcement of intellectual property rights	• Strengthened European research coupled with research collaboration with third countries (public funding, tax incentives, promotion of academic-commercial collaboration) • Coordinated industrial policy and instruments to incentivise technology rollout in Europe and in like-minded third countries • Digital Free Trade Agreements • Deepening of Single Market/UK Market for quicker technology rollout, including tax incentives and public procurement • Public high-risk/high-gain investments • Active policies to attract talent • Strong commitment to setting norms and standards in the EU, internationally and in China • Strong enforcement measures of international principles including anti-dumping, anti-subsidy instruments and IP rights enforcement in cooperation with third countries • Targeted outbound investment screening • Inbound investment screening	• Export controls • Outbound investment screening • IP rights enforcement • Strategies to buffer economic losses of European companies
Policy focuses on the “Protect, Promote, Partner” triangle	• Protect	• Promote • Partner	• Protect • Promote • Partner	• Protect
Source of European technology strength in focus	• Knowledge security	• Research promotion • Commercialisation	• Research promotion • Knowledge security • Commercialisation	• Knowledge security

AUTHORS

Jan-Peter Kleinhans is the Head of Global Chip Dynamics at Stiftung Neue Verantwortung e.V. in Berlin, Germany. Contact: jkleinhans@stiftung-nv.de
Tim Rühlig is a China Fellow at the European Commission, DG I.D.E.A., seconded from the German Council on Foreign Relations (DGAP) and the chair of the Digital Power China research consortium (DPC). He is based in Germany and Belgium. The author is writing in his personal capacity and his views should not be considered as representing his employer or any EU institution. Contact: contact@timruhlig.eu

Is the EU’s Semiconductor Manufacturing Equipment a Strategic Chokepoint?

Jan-Peter Kleinhans and John Lee

ABSTRACT

This chapter examines the critical role of lithography in semiconductor manufacturing and China’s ongoing challenges in achieving technological self-reliance in this domain amid expanding European and US export controls. The paper outlines China’s dependency on European lithography equipment, notably from Advanced Semiconductor Materials Lithography (ASML), and the concerted efforts by Chinese entities to develop indigenous capabilities, which have so far seen limited success. Despite significant investments and a strategic national push for import substitution, China’s semiconductor manufacturing equipment industry, particularly in lithography tools, remains several generations behind its foreign counterparts. The analysis identifies systemic inefficiencies and limited synergies within China’s lithography ecosystem, which will potentially continue to impede the development of competitive domestic lithography systems. The paper advocates for enhanced cooperation and alignment with Europe’s allies, focused on promoting research to ensure Europe remains at the forefront of lithography innovation and thus indispensable to China’s ambitions in semiconductor technologies.

SCORECARD 1 TECHNOLOGY FIELD: LITHOGRAPHY FOR SEMICONDUCTOR FRONT-END PRODUCTION

Source of European technology strength	Research and innovation	Intellectual property and patents	Production and commercialisation
	High	High	High

Type of European technology strength	Technological excellence	Commercialisation advantage	Conditioning of market access	Regulatory, political and normative factors	Sustainability	Research partnerships with third countries
	X	X				X

Degree of European leverage: Low – Medium – ○ High

INTRODUCTION

In the 1970s, the US government had already identified export controls on semiconductor manufacturing equipment (SME) as an effective approach to controlling the transfer of “manufacturing know-how”.[1] More than 50 years later, this is still a key objective of the United States and several allied governments. The US has reportedly been negotiating with Japan and the Netherlands at least since 2020, outside of multilateral export control forums such as the Wassenaar Arrangement, to expand their export controls on advanced SME to limit China’s technological advancement in semiconductor manufacturing.[2]

---

[1] US Department of Defense, “An Analysis of Export Control of US Technology: A DoD Perspective”, 4 February 1976, accessed 10 April 2024, at https://apps.dtic.mil/sti/pdfs/ADA022029.pdf

[2] Reva Goujon, Lauren Dudley, Jan-Peter Kleinhans and Agatha Kratz, “Freeze-in-Place: The Impact of US Tech Controls on China”, Rhodium Group and Stiftung Neue Verantwortung, 21 October 2022, accessed 10 April 2024, at https://rhg.com/research/freeze-in-place/

For a long time, the Chinese government has been aware of the dangers that stem from its semiconductor industry's dependence on foreign-made SME. Even discounting earlier Chinese efforts to achieve import substitution in the semiconductor supply chain, since the mid-2000s the *02 Special Project for Integrated Circuit Manufacturing Equipment and Complete Processes* has sought to systematically reduce China's dependence on foreign inputs for semiconductor manufacturing.[3]

Various entities received support to conduct R&D and implement it in industrial production, selected according to what was supposedly a "targeted, competitive and merit-based approach".[4] In theory, this was a coordinated national effort drawing on China's historically state-administered research and development (R&D) complex and led by state fiat rather than market demand. The goal was to indigenise front-end semiconductor fabrication at progressively increasing levels of sophistication.

Two decades on, however, verifiable results in SME that are useable in industrial production under commercial conditions are still lacking. The basic problem is that SME development seems often to have been fragmented and not connected to real world production. Entities charged with developing various components and systems have done this under laboratory conditions, with limited interaction with other supply chain actors, especially the fabrication providers that are the end-users of SME.

This situation has persisted despite increasing state efforts to impose centralised coordination on the development of China's semiconductor industry. In 2014, China's State Council released the *National Integrated Circuit Industry* Development Outline, which tried to improve policy coordination and implementation by establishing a *Leading Small Group* (national steering committee) with support from an advisory expert committee.[5] Made in China 2025 was launched in 2015, accompanied by a technology roadmap from the Chinese Academy of Engineering that set relatively specific targets for the semiconductor industry, including on manufacturing equipment. The *IC Industry Technical Innovation Strategic Alliance* was established in 2017 to better coordinate research and innovation with industrial applications, again with a focus on semiconductors, including manufacturing equipment. Following the US export controls introduced in late 2022 to restrict China's access to foreign-supplied SME, a new Leading Small Group was reportedly established in early 2023 "to revamp high-level oversight [and] oversee all aspects of China's new strategy for the semiconductor industry".[6]

Despite all these top-down initiatives, China's fabrication plants (fabs) still depend heavily on foreign-made manufacturing equipment. China's domestic equipment suppliers are several technological generations behind their foreign competitors in a number of critical types of SME.[7] This, however, should not come as a surprise, mainly for two reasons.

First, Chinese semiconductor suppliers, such as Semiconductor Manufacturing International Corporation (SMIC), Yangtze Memory Technologies (YMTC) or ChangXin Memory Technologies (CXMT), do not face the same capital constraints as foreign competitors, due to the various levels and types of support they receive from the government.[8] Until recently, therefore, they were able to focus on catching up with their foreign competitors in terms of production capacity and finished products, including in the latter's technological sophistication: SMIC as a foundry[9] to the Taiwan Semiconductor Manufacturing Company (TSMC) and Samsung; YMTC in non-volatile memory chips (NAND) to Samsung and SK Hynix; and CXMT in volatile memory chips (DRAM) to Micron, Samsung and SK Hynix.

---

[3] John Lee and Jan-Peter Kleinhans, "Mapping China's Semiconductor Ecosystem in Global Context: Strategic Dimensions and Conclusions", Stiftung Neue Verantwortung and MERICS, 30 June 2021, accessed 10 April 2024, at https://www.stiftung-nv.de/sites/default/files/chinas_semiconductor_ecosystem.pdf

[4] Dongxing Securities, "关于北京华卓精科科技股份有限公司 首次公开发行股票并在科创板上市申请文件 审核问询函的回复" [Reply to the inquiry letter: Review of Beijing Huazhuo Jingke Technology Co., Ltd.'s application documents for initial public offering of shares and listing on the Science and Technology Innovation Board], accessed 10 April 2024, at https://pdf.dfcfw.com/pdf/H2_AN202206271575136026_1.pdf

[5] Ibid.

[6] Paul Triolo, "A New Era for the Chinese Semiconductor Industry: Beijing Responds to Export Controls", in *American Affairs 2024*, accessed 10 April 2024, at https://americanaffairsjournal.org/2024/02/a-new-era-for-the-chinese-semiconductor-industry-beijing-responds-to-export-controls/

[7] Jan-Peter Kleinhans and John Lee, "China Semiconductor Observatory: Baseline Report 2022", China Semiconductor Observatory, 13 December 2022, accessed 10 April 2024, at https://www.stiftung-nv.de/sites/default/files/cso_baseline_report_2022.pdf

[8] Organisation for Economic Co-operation and Development, "Measuring Distortions in International Markets: The Semiconductor Value Chain", 12 December 2019, accessed 10 April 2024, at http://dx.doi.org/10.1787/8fe4491d-en

[9] A semiconductor foundry is a contract chip manufacturer that produces chips designed by their customers.

To achieve this, Chinese fabs needed best-in-class, that is foreign-made, SME. For several years, China has been the most important sales market, alongside Taiwan and South Korea, for foreign SME suppliers. In 2017, China accounted for 14.5% of equipment sales globally,[10] and it grew that share to more than 26% in 2022.[11] If instead Chinese fabs had prioritised utilising domestic equipment to assist the development of domestic SME suppliers, this would have jeopardised the competitiveness of Chinese fabs.

Second, especially in advanced semiconductor production, SME suppliers and fabs typically form relatively close relationships to constantly improve the production process and fine-tune the equipment.[12] Since domestic fabs preferred foreign-made SME, Chinese equipment suppliers had limited opportunities to learn from real-world high-volume manufacturing in order to improve their equipment. This only started to change significantly from around 2020, when Chinese chip manufacturers began increasingly to buy domestic equipment, at least for legacy chip production.[13] The revenues of Chinese SME suppliers have soared in recent years, not least due to the increased use of export controls on SME by foreign governments. The combined annual revenue of China's five largest SME suppliers, NAURA Technology (002371), Advanced Micro-Fabrication Equipment (688012), Piotech (688072), ACM Research (688082) and KingSemi (688037), grew from RMB 5.8 billion in 2018 to RMB 24.53 billion in 2022.[14] In other words, while the global SME market grew by 67% from US$ 64.5 billion in 2018 to US$ 107.6 billion in 2022, the sales of Chinese SME suppliers quadrupled. Notably, essentially all the sales by Chinese SME suppliers are to fabs in China.

With increased sales to Chinese fabs also comes closer cooperation between Chinese chip manufacturers and domestic SME suppliers, improving the competitiveness of Chinese SME suppliers in some types of equipment. One example is YMTC's reportedly close cooperation with Chinese etching equipment suppliers AMEC and Naura – driven by YMTC's specific targeting by US export controls since 2022.[15] One wafer fabrication equipment category where China's semiconductor ecosystem seems to have made little progress on decreasing its dependence on foreign, in particular European, equipment and components, however, is lithography.

CHINA'S DEPENDENCE ON EUROPEAN LITHOGRAPHY EQUIPMENT

In wafer fabrication, during the lithography process, light or electrons are used to transfer a pattern from a mask on to the surface of a (silicon) wafer, defining the intricate structures of the semiconductor devices. The Dutch lithography equipment supplier, Advanced Semiconductor Materials Lithography (ASML), currently has a monopoly on the most advanced type of lithography tools – extreme ultra-violet (EUV) scanners. Even for older types of lithography equipment, such as deep ultra-violet (DUV) immersion tools,[16] ASML has a quasi-monopoly, controlling more than 90% of argon-fluoride immersion (ArFi) tool sales globally, while Japan's Nikon accounts for the rest of the market: ASML sold 125 and Nikon nine pieces of ArFi equipment in 2023.[17]

To build its lithography machines, ASML relies on a network of 5000 suppliers, 200 of which ASML considers "critical".[18] Roughly half of those 5000 suppliers are

---

[10] SEMI, "Semi Reports 2017 Global Semiconductor Equipment Sales of $56.6 Billion", 5 April 2018, accessed 10 April 2024, at https://www.semi.org/en/Global-Equipment-Sales-56-6-Billion

[11] SEMI, "Global Semiconductor Equipment Billings Reach Industry Record $107.6 Billion in 2022, Semi Reports", 12 April 2023, accessed 10 April 2024, at https://www.semi.org/en/news-media-press-releases/semi-press-releases/global-semiconductor-equipment-billings-reach-industry-record-%24107.6-billion-in-2022-semi-reports

[12] Jan-Peter Kleinhans and John Lee, op. cit.

[13] Douglas Fuller, "Tech War or Phony War? America's Porous Controls on Semiconductor Fabrication Equipment and China's Response", 30 November 2023, accessed 10 April 2024, at https://www.prcleader.org/post/tech-war-or-phony-war-america-s-porous-controls-on-semiconductor-equipment-and-china-s-response

[14] Authors' calculations based on companies' financial reports.

[15] Qianer Liu and Cheng Leng, "Costs of US chip curbs force China's YMTC into major fundraising round", *Financial Times*, 2 November 2023, accessed 10 April 2024, at https://www.ft.com/content/4dcaaf91-d77f-4c70-97bf-69ba6a4e94f9

[16] Also referred to as argon-fluoride immersion (ArFi) lithography equipment.

[17] Nikon, "Financial Results for the 3rd Quarter of the Year Ending March 31, 2024", 8 February 2024, accessed 10 April 2024, at https://www.nikon.com/company/ir/ir_library/result/pdf/2024/24third_all_e.pdf ; ASML, "ASML 2023 Fourth-quarter and Full-year Results", 24 January 2024, accessed 10 April 2024, at https://www.asml.com/-/media/asml/files/investors/financial-results/q-results/2023/q4/presentation-investor-relations-q4-2023-m1ttie.pdf?rev=d95dae6ecb0f4abdaf87785af87eaa54

[18] ASML, "Sourcing & Supply Chain", accessed 10 April 2024, at https://www.asml.com/en/careers/teams/sourcing-and-supply-chain

located in Europe but they accounted for 80% of ASML's supply spend in 2022.[19] ASML is best understood as a systems integrator. It builds only around 15% of the final lithography tool and most components are sourced from ASML's highly specialised supplier network, such as projection optics from Zeiss and EUV lasers from Trumpf, both German companies that are global leaders in their respective fields.

Thus, to achieve import substitution of lithography tools, it is not enough for China to simply strengthen the competitiveness of its domestic lithography tool supplier, Shanghai Micro Electronics Equipment (SMEE). SMEE, like ASML, depends on an ecosystem of component and subsystem suppliers for lenses, crystals, optics, lasers, wafer stages and much more. Based on recent data, in many cases these Chinese lithography component suppliers seem, in turn, to depend on foreign, including European, suppliers.[20] Thus, China's dependence on European technological strength in the lithography process extends substantially beyond ASML to suppliers of optical systems, lasers and many more technologies indispensable to advances in lithography.

ASSESSMENT OF DEPENDENCIES: HOW LITHOGRAPHY TOOLS ARE USED IN FABS

To assess China's past and future dependency on European lithography equipment, a variety of factors must be taken into account regarding the use of lithography equipment for wafer fabrication.

Fabs depend on all generations of lithography tools

Even cutting-edge 3nm process nodes for logic chips, such as smartphone processors, still use a mixture of DUV (KrF, ArF, ArFi) and EUV lithography tools.[21] Only certain areas of a chip depend on the most advanced lithography, while other functionalities have larger dimensions that can easily be built with older lithography technology. Since older generations of lithography tools are cheaper, less complex and tend to have a higher throughput (wafers per hour), fabs try to use them as much as possible. This is also the reason why ASML continuously releases new versions of its i-Line, KrF, ArF and ArFi tools.[22] Table 2 provides an overview of the different generations of lithography tools.

Process nodes can be built in different ways

Every fab has its own approach to combining different lithography generations in a new process node. For example, Intel, Samsung and TSMC built their first generation 7nm processes in very different ways: Intel's 7nm (equivalent) process utilised KrF, ArF and ArFi tools but no EUV; Samsung's 7nm process utilised KrF, ArF, ArFi and EUV tools; TSMC's 7nm process solely utilised KrF and ArFi tools, but neither ArF nor EUV tools were used.[23] Table 1 includes a likely estimate of SMIC's 7nm (N+1) process. Based on reputable analysis, it seems likely that SMIC's 7nm process is very similar to TSMC's first generation 7nm process. Since SMIC does not have access to EUV tools, it is likely that SMIC, just like TSMC, uses KrF and ArFi lithography tools for its 7nm process.[24]

TABLE 1: Type of lithography tools used in 1st generation 7nm processes

7nm	KrF	ArF	ArFi	EUV
INTEL	X	X	X	
SAMSUNG	X	X	X	X
TSMC	X		X	
SMIC	X	(X)	X	

---

[19] ASML, "ASML Annual Report 2022", 31 March 2023, accessed 10 April 2024, at https://www.asml.com/en/investors/annual-report/2022

[20] Eduardo Jaramillo, "China's Semiconductor Industry Can't Quit German Optics", The China Project, 1 May 2023, accessed 10 April 2024, at https://thechinaproject.com/2023/05/01/chinas-semiconductor-industry-cant-quit-german-optics/

[21] ASML, "Investor Day 2021: Technology Strategy to Drive Moore 's Law into Next Decade", 2021, accessed 10 April 2024, at https://www.asml.com/-/media/asml/files/investors/investor-days/2021/asml-investor-day-2021-technology-strategy---martin-van-den-brink.pdf?rev=cc20a678382f45fdbf89ab69916b8478

[22] ASML, "Investor Day 2021: DUV Products and Business Opportunity", 2021, accessed 10 April 2024, at https://www.asml.com/-/media/asml/files/investors/investor-days/2021/asml-investor-day-2021_business-line-duv---ron-kool.pdf?rev=eea4dec5c9384d48a21bb12f913aca90

[23] Scotten W. Jones, "LithoVision 2020: Economics in the 3D Era", 2020, accessed 10 April 2024, at https://semiwiki.com/wp-content/uploads/2020/03/Lithovision-2020.pdf

[24] TechInsights, "Comparing SMIC 7nm vs TSMC 7nm", 2022, accessed 10 April 2024, at http://nzz-files-prod.s3-website-eu-west-1.amazonaws.com/2022/08/30/ef873456-9644-4a36-b160-ec0d41853e68.pdf

TABLE 2: Different generations of lithography tools

LITHOGRAPHY TECHNOLOGY	POSSIBLE NODE DENSITY	FIRST USE	LIGHT SOURCE; WAVELENGTH	ASML	Nikon	Canon	SMEE
i-Line	350–220nm	~1985	Mercury vapor lamp; 365nm	X	X	X	X
KrF	250–80nm	~1990	Krypton fluoride (KrF) excimer laser; 248nm	X	X	X	X
ArF	130–38nm	~1998	Argon fluoride (ArF) excimer laser; 193nm	X	X		O
ArFi	40–7nm	~2005	Argon fluoride (ArF) excimer laser; 193nm	X	X		?
EUV	7nm–???	~2018	Plasma from tin droplet; 13.5nm	X			

Mixing lithography tools from different suppliers sacrifices accuracy

Even though Nikon is the only other supplier besides ASML to offer ArFi tools, its sales are minuscule. One reason is that fabs are reluctant to mix ArFi tools from different suppliers, since this substantially decreases the accuracy of the manufacturing process, negatively impacting yield. One self-described industry insider commented on X (formerly Twitter) that “this is how ASML is able to maintain its dominant market share for scanners. Nikon offers a perfectly good immersion scanner [ArFi tool] that, in some cases, performs better for overlay at an attractive price point. Despite this, an existing fab is reluctant to purchase one because of the performance impact against other ASML scanners in their fab”.[25]

Many different types of “auxiliary” tools are necessary for the lithography process

While everybody is aware of ASML’s dominance in lithography equipment, these machines depend on a variety of “auxiliary” equipment and consumables: ASML’s lithography tool shines light through (or on to) a photomask that holds part of the chip design. Transferring the chip design on to the photomask is done by mask writers, specialised lithography tools supplied by Austrian IMS Nanofabrication, among others.[26] The finished photomasks need to be checked for errors using metrology and inspection tools, such as those supplied by German Zeiss.[27] The wafer needs to be coated with photoresist, and after exposure the photoresist needs to be developed – all of this again using highly specialised equipment, for example from Tokyo Electron in Japan.[28] Mask blanks, mask writers, coater/developer tools, metrology and inspection tools, and photoresists are just some examples of critical tools and consumables indispensable to the lithography process.

Thus, to decrease their dependence on European lithography equipment, Chinese equipment suppliers would need to offer a range of lithography tools. Furthermore, fabs prefer to use ArFi tools from a single supplier to build advanced process nodes, since mixing these tools from different suppliers (i.e. ASML and Nikon) substantially reduces accuracy and yield. To gain insights from real world production, so that Chinese lithography tool suppliers can benefit from the experience and iteratively improve their equipment, Chinese equipment suppliers depend on fabs taking risks by using newly developed Chinese lithography equipment. If Chinese fabs are reluctant to take these risks and/or are under pressure to

---

[25] X, Post from @lithos_graphein, 12 Feb 2024, accessed 10 April 2024, at https://twitter.com/lithos_graphein/status/1757130934648783337

[26] Christof Klein and Elmar Platzgummer, “MBMW-101: World’s 1st High-Throughput Multi-Beam Mask Writer”, Photomask Technology 2016, accessed 10 April 2024, at https://www.ims.co.at/wp-content/uploads/2019/01/2016-10-17_BACUS-2016_IMS_MBMW-101_998505.pdf

[27] Zeiss, “Photomask Metrology Solutions”, accessed 10 April 2024, at https://www.zeiss.com/semiconductor-manufacturing-technology/products/photomask-solutions/mask-metrology.html

[28] Tokyo Electron, “Coater/Developer”, accessed 10 April 2024, at https://www.tel.com/product/act.html

ensure high yield and utilisation rates, Chinese lithography equipment suppliers will struggle to improve.

The latter dynamic in particular makes the competitiveness of SMEE, currently China's leading lithography machine systems integrator, of critical importance to China's prospects for achieving import substitution in lithography. The following section elaborates on what is publicly known about the current level of China's home-grown lithography tools.

ASSESSMENT OF DEPENDENCIES: THE COMPETITIVENESS OF SMEE

It is important not to conclude from Table 2 that Canon and SMEE are roughly at the same level technologically. Since 2020, Canon has sold between 120 and 180 i-Line and KrF tools each year, which is roughly four times more than Nikon.[29] Canon's equipment is used every day in high-volume manufacturing. In contrast, it is unclear how many of SMEE's i-Line and KrF lithography tools have been sold, let alone how many are being used successfully in high-volume front-end manufacturing.

In March 2023, the *Financial Times* quoted a manager of a Chinese chip supplier as saying that: "homegrown lithography [SMEE] was examined and verified by academics, not industrial engineers. This equipment is only theoretically usable, and no chip manufacturer has ever dared to activate such a machine in their fabs".[30] Such judgments are corroborated by detailed commentaries posted on Chinese social media from self-described industry insiders.[31] They also correspond with opinions shared with the authors by industry contacts. Since SMEE's lithography tools seem to be barely used by Chinese fabs, their technical specifications and performance on paper are ultimately of little relevance.

At the time of writing, SMEE's most advanced front-end lithography tool is the SSA600/20, an ArF-based tool supposedly capable of 90nm production. SMEE published the results of a performance test of a prototype of the SSA600/10 in 2011.[32] For comparison, ASML's PAS 5500/1150C, released for high-volume manufacturing in 2003, was ASML's first ArF-based lithography tool capable of 90nm production.[33] While SMEE has various (partially successful) lithography tools for display production and packaging, the company only advertises three tools for wafer fabrication: (a) the SSA600/20: ArF excimer laser at 193nm, capable of 90nm production; (b) the SSC600/10: KrF excimer laser, capable of 110nm production; and (c) the SSB600/10: i-Line mercury lamp, capable of 280nm.[34]

In recent years, there have been numerous media reports that SMEE would imminently be releasing a 28nm-capable ArFi (immersion) lithography tool, the SSA800-10W. It was initially reported the new ArFi-tool would be released at the end of 2021,[35] then by the end of 2022.[36] News again emerged that the SSA800-10W would be shipped by the end of 2023.[37] In December 2023, one of SMEE's state-owned shareholders posted a statement online that SMEE had successfully developed a 28nm lithography machine, but this was soon deleted

---

[29] Authors' calculations based on companies' financial reports.

[30] Qianer Liu, "China gives chipmakers new powers to guide industry recovery", *Financial Times*, 21 March 2023, accessed 10 April 2024, at https://www.ft.com/content/d97ca301-f766-48c0-a542-e1d522c7724e

[31] EEWorld China, "马上2023了, 我国光刻机发展的怎么样了? [It's almost 2023: How is the development of photolithography machines in my country?], 15 December 2022, accessed 10 April 2024, at http://news.eeworld.com.cn/mp/EEWorld/a147909.jspx.

[32] Lifeng Duan, Jianrui Cheng, Gang Sun and Yonghui Chen, "New 0.75 NA ArF scanning lithographic tool", SPIE, 22 March 2011, accessed 10 April 2024, at https://doi.org/10.1117/12.879376

[33] ASML, "Reflect & Imagine: 20 Years of ASML, Chapter 5 1999–2004", 2004, accessed 10 April 2024, at https://www.chiphistory.org/exhibits/ex_se_asml_20yr_history/chapter5.pdf

[34] Zhongtai Securities, "光刻机行业报告" [Lithography machine industry report], accessed 3 April 2023, at https://pdf.dfcfw.com/pdf/H3_AP202304061585172426_1.pdf?1680777189000.pdf ; SMEE, "SSX600系列光刻机" [SSX600 series lithography machine], accessed 10 April 2024, at http://www.smee.com.cn/eis.pub?service=homepageService&method=indexinfo&onclicknodeno=1_4_1_1

[35] Toms Hardware, "China's 28nm-Capable Chip Fabbing Tool on Track Amid Trade War", 6 December 2020, accessed 10 April 2024, at https://www.tomshardware.com/news/chinas-28nm-capable-chip-fabbing-tool-on-track-amid-trade-war

[36] Asia Financial, "China Expecting Key Native Lithography Machine this Year: SCMP", accessed 4 August 2023, at https://www.asiafinancial.com/china-expecting-key-native-lithography-machine-this-year-scmp

[37] TechWire Asia, "China is Anticipating its First 28nm Lithography Machine by the End of 2023", 4 August 2023, accessed 10 April 2024, at https://techwireasia.com/08/2023/the-first-28nm-lithography-machine-in-china-this-year/?s=31

and replaced with a reference only to SMEE's commitment to developing advanced lithography machines.[38]

Industry observers are fairly sceptical about the real-world performance and production readiness of SMEE's latest tool: "Nothing has ever come of these reports in terms of equipment in mass production fabs. Instead, SMEE has created demonstration equipment in its laboratory".[39] Another industry observer states that the new SSA800 "is now likely part of a fully domestic production line that is being tested and certified", but it remains to be seen "whether SMEE can manufacture multiple commercial versions of the SSA800".[40] Thus, releasing a lithography tool that meets the technical specifications necessary for 28nm process nodes on paper is very different from that tool being successfully and widely used in 28nm high-volume manufacturing.

Even SMEE's older SSA600/20 90nm ArF tool seems to have no market relevance. As noted above, the company released performance tests of its SSA600/10 prototype (the predecessor to the SSA600/20) in 2011.[41] Around 13 years later, however, the machine seems to have had negligible sales.[42] It is reportedly not used by Chinese fabs for high-volume manufacturing. A significant amount of online commentary, including on Chinese social media, suggests that the SSA600/20 is not ready for use in production. At the time of writing, such commentaries suggested that only a handful of SSA600/20 have been sold to SMIC, YMTC, CXMT and other Chinese entities, none of which seem to use these machines for production.[43] One self-described industry insider (outside China) notes, that "only a few [SSA600] were shipped, so [SMEE] had no chance to make the incremental improvements needed to go beyond a sub-par prototype".[44]

Another indicator that SMEE's SSA600/20 is not ready for commercial-scale wafer fabrication is ASML's growing equipment sales to China. ASML's net system sales to China grew from €1.54 billion in 2018 to €6.,36 billion in 2023.[45] Since 2019, based on SEMI data, at least 22 new fabs at 90–180nm (the intended application of SMEE's SSA600/20) were announced and/or had already started production in China.[46] It might be assumed that those Chinese fabs would eagerly source domestic lithography tools, but this does not seem to be the case. On the contrary, Nikon announced in November 2023 it would release a new i-line tool, which would be compliant with Japan's new export controls, specifically intended for the Chinese market.[47]

The apparent state of development of some of SMEE's component suppliers only reinforces the picture outlined above. For example, Beijing U-Precision Technology was established in 2012 specifically to conduct work on the 02 Special Project.[48] U-Precision has developed a dual wafer stage table for lithography equipment and supplies SMEE.[49] However, the compatibility of U-Precision's wafer table with SMEE's lithography machines has been questioned in the Chinese media.[50] This example is typical of the reported shortcomings of the siloed and

---

[38] TrendForce, "Reports of SMEE Successfully Developing 28nm Lithography Machine, Original Source Deleted Shortly After", 22 December 2023, accessed 10 April 2024, at https://www.trendforce.com/news/2023/12/22/news-reports-of-smee-successfully-developing-28nm-lithography-machine-original-source-deleted-shortly-after/ ; and Lianhe Zaobao, „上海微电子据报成功研制出中国首台28纳米光刻机" [Shanghai Microelectronics reportedly successfully developed China's first 28nm lithography machine], 20 December 2023, accessed 10 April 2024, at https://www.zaobao.com.sg/realtime/china/story20231220-1457226

[39] Douglas Fuller, "Tech War or Phony War? China's Response to America's Controls on Semiconductor Fabrication Equipment", 30 November 2023, accessed 10 April 2024, at https://www.prcleader.org/post/tech-war-or-phony-war-america-s-porous-controls-on-semiconductor-equipment-and-china-s-response

[40] Paul Triolo, op. cit.

[41] Lifeng Duan, Jianrui Cheng, Gang Sun and Yonghui Chen, "New 0.75 NA ArF scanning lithographic tool", SPIE, 22 March2011, accessed 10 April 2024, at https://doi.org/10.1117/12.879376

[42] Douglas Fuller, op. cit.

[43] EEWorld China, op. cit.

[44] X, Post from @lithos_graphein on 12 Feb 2024, accessed 10 April 2024, at https://twitter.com/lithos_graphein/status/1757130934648783337

[45] Based on ASML financial reporting

[46] Based on SEMI World Fab Forecast Q4 2023, in 200mm equivalents.

[47] Nikkei Asia, "Nikon Looks to Strike Gold in China's Low-tech Chip Device Market", 11 November 2023, accessed 10 April 2024, at https://asia.nikkei.com/Business/Tech/Semiconductors/Nikon-looks-to-strike-gold-in-China-s-low-tech-chip-device-market

[48] Ibid.

[49] Zhongtai Securities, "光刻机行业报告" [Lithography machine industry report], accessed 3 April 2023, at https://pdf.dfcfw.com/pdf/H3_AP202304061585172426_1.pdf?1680777189000.pdf

[50] EEWorld China, op. cit.

bureaucratic approach to SME development of the past two decades, which as noted above has been criticised by Chinese commentators, including managers and officials quoted anonymously in foreign media.[51] Based on U-Precision's own Initial Public Offering (IPO) documents from Q3 2023, the company's wafer table system for ArFi lithography remains in development.[52]

In essence, there is a very long way between a breakthrough in lithography technology in the lab and the successful use of that tool in high-volume manufacturing. According to one self-described Chinese industry insider, the whole approach that Chinese industry and the authorities have taken to this challenge must change, his prescription being to concentrate equipment development on one "real" production line to systematically resolve problems and progress iteratively, with the initial goal being a useable 90nm lithography machine.[53]

ASSESSMENT OF DEPENDENCIES: RESEARCH AND DEVELOPMENT

There are indications that China's R&D-industrial complex is starting to adapt and to improve synergies between the disparate actors in its lithography development ecosystem. One study of China's lithography innovation network, based on patent data and published in 2023, assesses that the frequency of patent cooperation within the network is rapidly increasing, and that the network's size is growing by orders of magnitude through the addition of new nodes.

However, the authors conclude that the new nodes are often not well connected to the existing network, and that their addition is not translating into sufficient knowledge increase for the network as a whole. Accordingly, the network's "overall knowledge absorption capacity is poor". They recommend rebalancing the network's emphasis on "core" technologies by making more effort to integrate the development of supporting elements, such as photoresists and lithography gases. Improving coordination between the lithography innovation network and the policymakers shaping the institutional and development environment was also seen as important. Essentially, the authors advocate adopting ASML's model of an "open networked collaborative innovation paradigm".[54]

Similar conclusions have been reached even by authors writing within the ideological framework of "socialism with Chinese characteristics", and specifically about the "new-type national system" declared under Xi Jinping for mobilising and directing national resources for the development of strategic technologies like lithography. One commentator describes EUV's development outside China as based not just on resource accumulation, but also on international collaboration and "a clear profit distribution mechanism based on the market economy". He concludes that the "fundamental problem in perfecting the new-type national system", and thereby achieving breakthroughs in technologies like EUV, "is coordinating it with market forces and openness to the outside world".[55]

In summary, there is a very long way from breakthroughs in lithography-related technologies in the lab to successful use of a lithography tool in high-volume manufacturing. The evidence suggests that despite the long-term commitment of significant resources, China's lithography ecosystem has yet to resolve systemic inefficiencies and is some distance from being able to replicate the R&D model through which ASML developed advanced lithography. More specifically, there are various indicators to suggest that China's key lithography system integrator, SMEE, has yet to produce competitive lithography systems even for mature node wafer fabrication, let alone cutting-edge fabrication processes.

---

[51] Qianer Liu, "China gives chipmakers new powers to guide industry recovery", *Financial Times*, 21 March 2023, accessed 10 April 2024, at https://www.ft.com/content/d97ca301-f766-48c0-a542-e1d522c7724e

[52] Dongxing Securities, "关于北京华卓精科科技股份有限公司 首次公开发行股票并在科创板上市申请文件 审核问询函的回复" [Reply to the inquiry letter review of Beijing Huazhuo Jingke Technology Co., Ltd.'s application documents for initial public offering of shares and listing on the Science and Technology Innovation Board] , accessed 10 April 2024, at https://pdf.dfcfw.com/pdf/H2_AN202206271575136026_1.pdf; Zhongtai Securities, "光刻机行业报告" [Lithography Machine Industry Report], accessed 3 April 2023, at https://pdf.dfcfw.com/pdf/H3_AP202304061585172426_1.pdf?1680777189000.pdf

[53] EEWorld China, op. cit.

[54] GU Haoran, GUO Benhai, LONG Zhuoxi and LE Wei, "Evaluation and Optimization of China's Lithography Technology Innovation Network from the Perspective of Patent Cooperation", Industrial Engineering and Management", 2023.

[55] Qu Guanqing, "The Historical Origin and Characteristics of the Times of the New National System: Also on the Research and Development of EUV Lithography Machines", *Journal of Hunan University of Technology*; (Social Science Edition), vol. 28, no. 6 (2023), pp. 7–14.

EUROPE'S AMBITION: CONTINUED CHINESE DEPENDENCY ON EUROPE

Because of the strategic relevance of decreasing its dependence on suppliers of foreign lithography tools, the Chinese government, chip manufacturers and the supplier ecosystem are eager to strengthen the competitiveness of their domestic lithography ecosystem. However, countless technological breakthroughs will be required. To that end, the Chinese government has reportedly given its leading semiconductor and equipment suppliers (Huawei, SMIC, YMTC, Naura and AMEC) privileged access to government R&D.[56] Importantly, strengthening China's domestic equipment ecosystem, including lithography, is no longer just a government effort. For example, Huawei's venture capital (VC) arm Hubble Investment invested in at least 107 companies between 2019 and 2024, the majority of which are within the semiconductor ecosystem.[57] Among these companies is RSLaser, controlled by the Microelectronics Institute of the Chinese Academy of Sciences, which is developing an excimer laser for lithography tools.[58] In November 2022, Huawei filed a patent on the EUV lithography process.[59]

It is hard to imagine a technology field of greater importance for China's policy goal of self-reliance. This makes it hugely challenging to meaningfully forecast the likelihood of technological breakthroughs in lithography equipment and provide remotely robust timelines in terms of market penetration. Apart from the undivided attention of the Chinese government, leading semiconductor companies and China's VC ecosystem, several other aspects must be taken into account when trying to forecast the future competitiveness of China's lithography ecosystem.

First, SMEE and the wider Chinese lithography innovation ecosystem now know that what they need to achieve is technologically possible and feasible, making it easier to focus R&D efforts. This is especially true in the case of EUV, which was met with huge scepticism and substantial uncertainty regarding the feasibility of the approach early on.[60]

Second, it is not just about SMEE anymore. Chinese industry and government now realise that SMEE might not be their best bet for building production-ready lithography tools. There is now a flurry of activity in China's semiconductor equipment ecosystem as established SME suppliers, such as Naura and AMEC, reportedly kick-start lithography research.[61] Like other efforts in China's semiconductor ecosystem, Huawei seems to be playing a role in China's advances in lithography technology.[62]

Third, Chinese researchers and companies already have access to foreign DUV tools and can intricately study and reverse engineer them. The latter matters since SMEE's goal is not to compete with ASML, Canon and Nikon internationally, but simply to achieve import substitution for China's domestic chip manufacturing.

Fourth, no one benefits from open communication of technological breakthroughs. Neither the Chinese government, nor Huawei, SMIC or SMEE have any incentive to publicly announce concrete technological breakthroughs. It will become increasingly difficult to confidently assess China's technological capabilities, especially in "weaponised" chokepoint technologies such as lithography tools.

---

[56] Paul Triolo, op. cit.; Gregory Allen, "In Chip Race, China Gives Huawei the Steering Wheel: Huawei's New Smartphone and the Future of Semiconductor Export Controls", 6 October 2023, accessed 10 April 2024, at https://www.csis.org/analysis/chip-race-china-gives-huawei-steering-wheel-huaweis-new-smartphone-and-future

[57] PitchBook, "Hubble Investment", accessed 10 April 2024, at https://pitchbook.com/profiles/investor/432600-22

[58] SMM, "Huawei's Latest Investment in Lithography Machine to Understand the List of Domestic Industry Chain", 7 June 2021, accessed 10 April 2024, at https://news.metal.com/newscontent/101498347/huaweis-latest-investment-in-lithography-machine-to-understand-the-list-of-domestic-industry-chain

[59] DigiTimes, "Huawei Confirms Breakthrough in EUV Lithography Process Optimization", 26 December 2022, accessed 10 April 2024, at https://www.digitimes.com/news/a20221226VL203/euv-huawei.html

[60] ASML, "Making EUV: From Lab to Fab", 30 March 2022, accessed 10 April 2024, at https://www.asml.com/en/news/stories/2022/making-euv-lab-to-fab

[61] Che Pan, "Tech War: China Quietly Making Progress on New Techniques to Cut Reliance on Advanced ASML Lithography Machines", *South China Morning Post*, 1 April 2024, https://www.scmp.com/tech/tech-war/article/3257442/tech-war-china-quietly-making-progress-new-techniques-cut-reliance-advanced-asml-lithography

[62] Yuan Gao and Debby Wu, "Huawei Tests Brute-force Method for Making More Advanced Chips", Bloomberg, 22 March 2024, accessed 17 April 2024, at https://www.bloomberg.com/news/articles/2024-03-22/huawei-tests-brute-force-method-for-making-more-advanced-chips; and Cheng Ting-Fang, "Huawei Building Vast Chip Equipment R&D Center in Shanghai", Nikkei Asia, 11 April 2024, accessed 17 April 2024, at https://asia.nikkei.com/Business/Tech/Semiconductors/Huawei-building-vast-chip-equipment-R-D-center-in-Shanghai#

Fifth, most lithography tools are not impacted by export controls. For i-Line, KrF and ArF tools, SMEE will have to continue to compete with ASML, Canon and Nikon in the Chinese market.[63] Here, it will probably continue to be challenging for SMEE to gain market share in China. Whether a Chinese fab, operated by an IDM or a foundry, will continue to source older DUV tools from foreign market leaders or SMEE is likely to depend on a variety of factors. Chinese companies on the US Entity List, for example, would probably prefer to largely depend on domestic suppliers. Of course, the story is different for advanced ArFi and EUV tools, the export of which is controlled by the US, the Netherlands and Japan.[64] Here, entirely Chinese-made tools are the only option for Chinese fabs.

Sixth, lithography depends on many auxiliary tools and materials in which China would also need to establish competitive suppliers to become fully self-reliant. While this paper's analysis concentrates solely on lithography exposure tools (stepper/scanner), the above-mentioned mask blanks,[65] mask writers,[66] photoresist coater/developer,[67] among several others, are also indispensable to the lithography process. In many of these technologies and materials, European, Japanese and US companies are among the market leaders in often highly concentrated markets.[68] As noted above, Chinese researchers have recently assessed that the lithography innovation ecosystem still gives too little emphasis to such supporting elements.[69]

Finally, continued sourcing from foreign Tier 2 and Tier 3 suppliers will speed up SMEE's efforts. SMEE and its domestic component suppliers would probably achieve production-ready lithography tools more quickly if they did not source solely from domestic technology suppliers but continued to rely on foreign Tier 2 and Tier 3 suppliers.[70]

Against this backdrop, the following assessment of the likelihood of SMEE (or another Chinese lithography system integrator) building production-ready tools should be treated with due caution.

How likely is it that by 2035 SMEE (or another Chinese lithography system integrator) will have a substantial market share in China using entirely Chinese-made lithography equipment?

- It is *highly likely* that entirely Chinese-made *i-Line tools* will have a *substantial market share* domestically by 2035.

- It is *very likely* that entirely Chinese-made *KrF tools* will have *meaningful market shares* in China by 2035. KrF lithography tools will still be important for memory chip (NAND and DRAM) production at that time.[71]

- It is *likely* that entirely Chinese-made ArF tools will have *successfully entered the Chinese market* by 2035. Since SMEE already has an ArF-based system with the SSA600/20, it seems to be only a matter of time until the company improves the tool enough to make it capable of commercial-scale wafer fabrication.

- It is *unlikely* that Chinese-made ArFi tools will have *meaningful market shares* in China by 2035. For that to happen, Chinese-made ArFi tools would need to: (a) be capable of commercial-scale throughput (wafers per hour) and reliability; (b) have the necessary overlay accuracy (dedicated chuck overlay)[72]

---

[63] Reva Goujon and Jan-Peter Kleinhans, "All In: US Places a Big Bet with October 17 Controls", 6 November 2023, accessed 10 April 2024, at https://rhg.com/research/all-in/

[64] CSIS, "The Post-October 7 World: International Perspectives on Semiconductors and Geopolitics", 28 September 2023, accessed 10 April 2024, at https://www.csis.org/analysis/post-october-7-world

[65] A mask blank in lithography is an unpatterned, precursor substrate used for creating photomasks, which contain parts of the design of the chip.

[66] A mask writer is a specialised, highly precise lithography tool that transfers the chip design on to the mask blank.

[67] Equipment to apply, develop and remove the photoresist on the wafer.

[68] SemiAnalysis, "Austria's Silent Monopolies on Advanced Semiconductor Manufacturing: EV Group and IMS Nanofabrication", 24 August 2022, accessed 10 April 2024, at https://www.semianalysis.com/p/austrias-silent-monopolies-on-advanced

[69] Gu Haoran, Guo Benhai, Long Zhuoxi and Le Wei, op. cit.

[70] Eduardo Jaramillo, op. cit.

[71] ASML, "Technology Strategy to Drive Moore 's Law into Next Decade: ASML Investor Day 2021", 2021, accessed 10 April 2024, at https://www.asml.com/en/investors/investor-days/2021. Since China's YMTC and CXMT cannot depend on US tools to upgrade and expand their fabs, there should be ample opportunity for SMEE to serve China's memory chip fabs – if their KrF tools are reliable and perform.

[72] Reva Goujon and Jan-Peter Kleinhans, op. cit.

to allow for complex multi-pattering processes to achieve ≤14nm production; and (c) be based on a fully domestic supplier ecosystem. Thus far, only two companies in the world have achieved this: ASML and Nikon, both with unrestricted access to a global supplier ecosystem.

- It is *highly unlikely* that an entirely Chinese-made EUV tool will have achieved *production-readiness* by 2035. It took ASML and its suppliers the best part of three decades to achieve that and, at the time of writing, there does not seem to be a viable alternative approach.[73]

Lastly, when looking at the more abstract level at Europe's technology strength, or better that of ASML and its suppliers, it becomes clear that it plays out across all three dimensions:

- **Research and innovation:** ASML has a long-standing R&D collaboration with imec, the leading research and technology organisation (RTO) for front-end process and transistor development.[74] However, ASML also has very close R&D partnerships with its customers, such as TSMC,[75] as well as its peers, and suppliers of auxiliary lithography equipment, such as Tokyo Electron in Japan.[76] The amount of research collaboration that ASML conducts across its entire ecosystem – from its own component and material suppliers, to other equipment suppliers and customers – has directly contributed to ASML's success.[77] Such ecosystem-spanning, collaborative R&D is one of Europe's strengths but also very much dependent on company culture and not easily built-up from scratch. That said, SMEE would not necessarily need to follow ASML's approach. Nikon and Canon are much more vertically integrated successful lithography companies. As described above, however, Chinese commentary often emphasises lack of cross-ecosystem cooperation as the key impediment to the lithography import substitution effort.

- **Patents and intellectual property (IP):** ASML, together with German optics supplier ZEISS SMT, controlled more than 750 EUV patent families as of December 2021: "Their combined family count exceeds the sum total of the next 9 ranked players combined. [...] EUV lithography is one of the most consolidated patent landscapes imaginable. This is a reflection of task complexity and the fact that the ASML/Zeiss partnership have effectively side-lined their historical competitors, Nikon and Canon".[78]

- **Commercialisation and production:** As mentioned above, whereas Nikon and Canon are substantially more vertically integrated, ASML is best understood as a system integrator, building just around 15% of the lithography tool itself. This requires a tremendous amount of knowledge not just about every single physical aspect of the tool itself, but also about the challenges of high-volume wafer fabrication and how it is deployed in a fab. As shown above, having a lithography tool that meets technical specifications on paper is very different from successfully operating lithography tools in high-volume manufacturing. ASML is not just selling tools anymore but providing critical services to fabs. The company generates around 30% of its revenue from service and maintenance contracts.[79]

In conclusion, Europe's strength in lithography technology is equally rooted in R&D, patents and IP, as well as the commercialisation and production of the tools. Thus, Europe's technology aspiration should be to further develop European technology strength.

---

[73] SemiEngineering, "Nanoimprint Finally Finds its Footing", 20 April 2023, accessed 10 April 2024, at https://semiengineering.com/nanoimprint-finds-its-footing-in-photonics/

[74] Techovedas, "How IMEC Made ASML the Biggest Company in Europe?", 21 August 2023, accessed 10 April 2024, at https://techovedas.com/imec-made-asml-the-biggest-company-in-europe/

[75] TSMC, "TSMC and ASML Reach Agreement to Develop Next Generation Lithography Technologies as an Extension of Long-Term Partnership", 5 August 2012, accessed 10 April 2024, at https://pr.tsmc.com/english/news/1734

[76] ASML, "Tokyo Electron Limited and ASML Announce Agreement", 30 November 2011, , accessed 10 April 2024, at https://www.asml.com/en/news/press-releases/2011/tokyo-electron-limited-and-asml-announce-agreement

[77] Hiroyuki Chuma, "Increasing Complexity and Limits of Organization in the Microlithography Industry: Implications for Japanese Science-based Industries", Research Institute of Economy, Trade and Industry, March 2005, accessed 10 April 2024, at https://www.rieti.go.jp/jp/publications/summary/05030000.html

[78] Mike Adel, "ASML's EUV Tool is not Just the Pinnacle of Chip Making: It is a Benchmark of IP Dominance", 28 December 2021, accessed 10 April 2024, at https://www.linkedin.com/pulse/asmls-euv-tool-just-pinnacle-chip-making-benchmark-ip-mike-adel/

[79] ASML financial reports

QUALITY OF EUROPEAN TECHNOLOGICAL STRENGTH

This section briefly considers the extent to which Europe's strength in lithography technologies could be used as political leverage vis-à-vis China. The quality of Europe's technological strength differs according to lithography generation.

Ease of circumvention/replication

The broadened export controls on ArFi lithography tools introduced by the US, the Netherlands and Japan incentivise China's SME ecosystem to achieve complete import substitution in the longer term. Using another technology instead of lithography tools for semiconductor production, or *circumvention*, is not possible at the technology level, but it is possible at the tool level – at least to some extent: Chinese fabs could order ArFi tools for older process nodes but then use them for more advanced nodes;[80] or, through multi-patterning techniques,[81] existing ArFi equipment can achieve 7nm and potentially also 5nm process levels, allowing Chinese fabs to circumvent existing EUV controls at least in the short to medium term. However, going beyond 5nm fabs would require access to EUV tools.[82] Trying to control the use of advanced ArFi tools already exported to China would be challenging and partially explains why some Chinese fabs seem to have stockpiled equipment in recent years.[83] Replication, or reverse-engineering foreign-made equipment, does not seem to have been overly successful for SMEE in the past 20 years. That said, it would be naive to believe that replication efforts have not intensified in recent years linked to the US-China technology rivalry.

Spillover damage if used as a chokepoint

Exploiting Europe's strong position in lithography tools through export controls could be done in two ways: denying the export of new tools to China; and/or denying the export of spare parts and maintenance of already installed equipment in China. The latter would have a more immediate effect and a higher chance of spillover damage. Without spare parts, fabs would have to halt production, almost certainly in a matter of months. The effects would depend on the extent to which the fab relies on personnel from ASML for servicing and maintenance. If spare parts or servicing were denied through export controls, this could hypothetically disrupt the supply of chips to European end-customer industries.[84]

DISCUSSING EUROPE'S LEVEL OF AMBITION

The previous sections have made clear that Chinese fabs will very likely continue to depend on European lithography tools in the medium to longer term. However, it is also clear that China is painfully aware of this dependency and is working hard to strengthen its domestic lithography ecosystem. The following discussion of the four levels of ambition for Europe provides a structure for thinking through Europe's strategic options in (not) engaging with China.

- **Level 1: threat prevention.** The export of semiconductor equipment, such as certain types of deposition, epitaxy, etching and lithography equipment, has been controlled under the Wassenaar Arrangement (and by extension the EU's dual-use regulation) for many years. While semiconductor equipment has limited direct military utility, it is indispensable for the production of advanced semiconductors that, in turn, enable the technological upgrading of China's military. Thus, it is arguable that Europe's ambition, until the imposition of Dutch export controls on advanced DUV lithography equipment,[85] has been one of threat prevention at the very least.

- **Level 2: ability to deny.** If Europe's ambition is to use China's dependence on European lithography tools to deter it from acting against European

---

[80] Paul Triolo, op. cit.

[81] Multi-patterning, such as Self-Aligned Quadruple Patterning (SAQP), is a method for creating finer features on chips beyond the limits of current lithography technology. By repeating the lithography and etching process multiple times, multi-patterning allows for higher density chip designs using existing equipment.

[82] SemiAnalysis, "China AI & Semiconductors Rise: US Sanctions Have Failed", 12 September 2023, accessed 10 April 2024, at https://www.semianalysis.com/p/china-ai-and-semiconductors-rise

[83] Qianer Liu, "China on Cusp of Next-generation Chip Production Despite US Curbs", *Financial Times*, 6 February 2024, accessed 10 April 2024, at https://www.ft.com/content/b5e0dba3-689f-4d0e-88f6-673ff4452977

[84] Jan-Peter Kleinhans and Julia Hess, "Understanding the Global Chip Shortages: Why and How the Semiconductor Value Chain was Disrupted", Stiftung Neue Verantwortung, 11 December 2021, accessed 10 April 2024, at https://www.stiftung-nv.de/sites/default/files/understanding_the_global_chip_shortages.pdf

[85] Government of the Netherlands, "Government Publishes Additional Export Measures for Advanced Semiconductor Manufacturing Equipment", 30 June 2023, accessed 10 April 2023, at https://www.government.nl/latest/news/2023/06/30/government-publishes-additional-export-measures-for-advanced-semiconductor-manufacturing-equipment

security interests, export controls would be kept to a minimum. The goal would be to ensure that it continues to be easier for China to depend on EU lithography equipment than to successfully develop a domestic alternative. In that case, Europe's agenda would be focused on keeping China dependent, encouraging it to continue to use European lithography tools and discouraging technological disentanglement.

- **Level 3: ability to act.** This goal would go beyond discouraging China from technological disentanglement. If China accelerates the development of its domestic lithography ecosystem, Europe will need to incentivise European lithography equipment remaining several generations ahead of the Chinese competition. To that end, lithography-related R&D and most of the supply chain would need to continue to be in Europe.

- **Level 4: curtailment.** A curtailment strategy would essentially force China to develop its own lithography tools without relying on European IP, including at the level of subcomponents, making it as challenging as possible for China to achieve import substitution even in the long-term. This is arguably, at least to some extent, the intention behind expanding US export controls.[86]

POLICY RECOMMENDATIONS

A key challenge that Europe will continue to face in following through on its own ambitions is the US government's unilateral, extraterritorial application of its export controls from October 2023.[87] The US government imposed export controls on advanced lithography equipment (specific types of ArFi tools) using a 0% de minimis threshold. This means that the US government claims jurisdiction over *entirely foreign-made* lithography tools that meet certain performance thresholds if those tools are intended to be sold to China.[88] Even if a lithography tool contains no US components or IP, it still falls under US export controls if shipped to China from a third country. Thus, reaching a common understanding with the US government about "red lines" and thresholds would appear to be crucial.[89]

Furthermore, because of the increasingly expansive US export controls, China will continue to double down on import substitution in semiconductor technologies.[90] The emergence of a technologically competitive Chinese-made lithography tool will lead to dwindling market shares in China for foreign lithography tool suppliers. Thus, Chinese disentanglement in semiconductor technologies is directly incentivised and accelerated by US export controls. This development also makes it highly likely that, at least to some extent, China will be less dependent on foreign DUV lithography tools by 2035.

In conclusion, regardless of Europe's distinctive policy ambitions in connection with lithography tools, closer coordination with the US and Japanese governments regarding export controls on lithography equipment should be considered. The more nuanced and intricate European technology controls become, the better European policymakers need to understand the global competitive market and continuously assess foreign availability. This is a challenging and resource-intensive exercise. A better understanding of which ally grants technology licences in which cases and to what extent foreign availability is established is now crucial. Against this backdrop, the following recommendations mainly focus on *promote* and *partner* strategies, since a European *protect* agenda is currently constrained by the US government.

- **Level 1:** If Europe's ambition is threat prevention, it would be in contravention of the US government's and the Dutch government's export controls on lithography equipment.

- **Level 2:** At this level of ambition, Europe would limit the expansion of export controls on equipment to ensure that China has little incentive to develop its own lithography ecosystem. That said, with US, Dutch and Japanese export controls on lithography equipment in place, it is highly unlikely that China would see any reason not to double down on import substitution in the longer term.

---

[86] Reva Goujon and Jan-Peter Kleinhans, op. cit.

[87] Ibid.

[88] Morgan Lewis, Navigating the New Export Maze: BIS Implements Additional Controls on Advanced Computing and Semiconductor Manufacturing Items, October 2023, accessed 17 April 2024, at https://www.morganlewis.com/-/media/files/publication/morgan-lewis-title/white-paper/2023/navigating-the-new-export-maze-bis-implements-additional-controls.pdf

[89] Anh Nguyen, "The Discomfort of Extraterritoriality: US Semiconductor Export Controls and why their Chokehold on Dutch Photolithography Machines Matter", *European Journal of International Law*, 1 December 2023, accessed 10 April 2024, at https://www.ejiltalk.org/the-discomfort-of-extraterritoriality-us-semiconductor-export-controls-and-why-their-chokehold-on-dutch-photolithography-machines-matter/

[90] Paul Triolo, op. cit.

- **Level 3:** If Europe wants to protect its ability to act vis-à-vis China through its dominance in lithography equipment, it will need to implement an R&D and industrial strategy focused on "running faster", not just protect. [91] Since China is likely to master i-Line, KrF and ArF in the low to long term, Europe needs to ensure that its broader lithography ecosystem continues to innovate by deepening innovation cooperation with allies,[92] expanding R&D programmes and VC funding for start-ups, such as through the European Investment Bank's accelerator programmes, and continuing to attract foreign talent and incentivise collaboration with foreign technology leaders, such as in South Korea, Japan and Taiwan.

- **Level 4:** Curtailing China's advances in lithography tools would incur substantial economic losses for European companies and only accelerate China's domestic ambitions. This would require export controls not only on tools, but also on components from European suppliers, potentially halting the servicing and maintenance of installed advanced ArFi tools in China,[93] as well as supporting European technology providers identifying IP theft in China.

SCORECARD 2 TECHNOLOGY FIELD: LITHOGRAPHY FOR SEMICONDUCTOR FRONT-END PRODUCTION

	Threat prevention	Ability to deny	Ability to act	Curtailment
Feasibility of level of ambition	Low	Low	High	High
Core policy recommendations	• Not aligned with current US extraterritorial export controls or Dutch export controls • Coordinate with US government to achieve a protect strategy solely focused on threat prevention (i.e. decrease restrictions on DUV equipment) • Incentivise pan-European R&D in lithography technologies through research frameworks, such as Horizon Europe	• Not aligned with current US extraterritorial export controls • Coordinate with US government to achieve a protect strategy focused on preventing China from acting against Europe's security interests • Strengthen Europe's indispensability in lithography technology through closer R&D with Japanese equipment and material suppliers; for example, through the EU-Japan Digital Partnership	• Incentivise continued entanglement with China's equipment ecosystem to ensure use of European lithography systems (also consider cooperation with Chinese equipment suppliers) • Make it attractive for foreign technology suppliers to engage in R&D in Europe through R&D incentives, tax breaks, skilled migration regulation	• Coordinate with US and Japan on export controls on components for lithography systems • Scrutinize R&D collaborations in relevant research areas with Chinese companies and universities • Co-develop a research agenda and technology roadmap together with the US and Japan to bolster a highly integrated, transnational lithography ecosystem

AUTHORS

Jan-Peter Kleinhans is the Head of Global Chip Dynamics at Stiftung Neue Verantwortung e.V. in Berlin, Germany. Contact: jkleinhans@stiftung-nv.de

John Lee is Director of East West Futures in Berlin, Germany. Contact: johnlee@eastwestfutures.com

---

[91] European Commission, European Economic Security Strategy, 20 June 2023, accessed 10 April 2024, at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023JC0020&qid=1687525961309

[92] Julia Hess and Jan-Peter Kleinhans, "Chip Diplomacy", 23 October 2023, accessed 10 April 2024, at https://www.stiftung-nv.de/sites/default/files/snv_chip_diplomacy_analysis_of_technology_partnerships.pdf

[93] Karen Freifeld et al., "Exclusive: Targeting Chinese Chips, US to Push Dutch on ASML Service Contracts", Reuters, 4 April 2024, https://www.reuters.com/business/us-urge-dutch-more-curbs-asml-chipmaking-equipment-china-sources-say-2024-04-04/

Energy Performance of Future Wireless Networks: Potential for New European Chokepoints?

Liesbet van der Perre, Tim Rühlig Julian Heiss

ABSTRACT

Wireless networks are the backbone of the digital revolution in both Europe and China. To untap their economic potential, a rapidly increasing number of devices and sensors will need to be connected. This fast-growing traffic has led to a massive expansion in energy demand from wireless networks – but energy is a scarce good. Traditional solutions to this challenge focus on energy efficiency. Energy efficiency measures energy consumption in relation to the maximal throughput of data (full load situations). Recent research has tackled the issue from a new approach based on the total energy consumption of wireless infrastructure technology. The advantage of this solution is that it reduces the energy consumption of base stations that are operating far below full load for most of the time. Europe is leading this shift in focus; China is well behind. This is not just a policy priority for Europe, as energysaving is likely to develop into more of a competitive advantage as power demand grows for wireless infrastructure. Europe's technological edge could result in significant revenue advantages for European vendors. The result might not be a hard chokepoint, but Europe can manifest co-dependency and shape the development of energy-saving technology in the wireless infrastructure technology of the future.

SCORECARD 1 TECHNOLOGY FIELD: ENERGY PERFORMANCE OF FUTURE WIRELESS NETWORKS

Source of European technology strength	Research and innovation	Intellectual property and patents	Production and commercialisation
	● Medium	● Medium	● Low

Type of European technology strength	Technological excellence	Commercialisation advantage	Conditioning of market access	Regulatory, political and normative factors	Sustainability	Research partnerships with third countries
	X	X			X	

Degree of European leverage	Low	Medium	High

INTRODUCTION

Wireless networks constitute critical infrastructure that is likely to become the backbone of increasingly digitalised economies and societies. Equally, 5G, advanced 5G and future 6G infrastructure are seen in China as having key enabling roles in achieving at least three strategic objectives defined as central by the leadership of the Chinese Communist Party (CCP):

1. accelerated economic reform by putting pressure on incumbent industries through platform economy solutions;[1]
2. increased industrial efficiency through breakthroughs in advanced robotics and massive machine type communications, and massive sensor data feeding (generative) artificial intelligence (AI), as well as developments in automated commercial

---

[1] In December 2022, the Central Economic Work Conference signalled party-state support for the platform economy after two years of slow-down. The political adjustment of the sector may have come to an end.

and private mobility by means of ultra-low latency; and[2]

3. accelerated expansion of digital authoritarianism by means of increased compute power and AI reliant on high-performance wireless infrastructure.

These objectives have ambitious rollout targets and require application of 5G+ infrastructure.[3] It is no wonder that the 14th Five-Year Plan (FYP, 2021–2025) identifies large-scale deployment and a user penetration rate of 56% for 5G, as well as technology reserves for the future deployment of 6G networks as the backbone of the technological transformation. A particular emphasis is placed on 5G-based applications in industrial, transport, energy and healthcare ecosystems.[4] Similarly, the FYP on Informatisation focuses on public and private sector deployment for the purpose of developing industrial applications and their integration into a number of other technologies, such as cloud computing, AI and blockchain, among others.[5] Previously, the Set Sail Action Plan had set out concrete quantitative (and a few qualitative) targets to be met by the end of 2023, such as a 5G individual subscriber penetration rate of 40%, a 50% share for 5G networks in all internet access traffic, a 5G penetration rate in large industrial enterprises of 35%, 3000 5G industry virtual private networks and at least 200 5G demonstration application models in key industries, to name just a few.[6]

However, meeting such ambitious targets presents a number of challenges, chief among them being the rapidly growing energy consumption of wireless networks. For a country in which energy shortages have caused significant industrial fallouts, the large-scale, high-performance rollout of 5G+ networks increases the need to constrain the overall energy consumption of the network. Mobile data traffic volume grew by a factor 300 in the period 2010–2020.[7] A basic calculation shows that if mobile traffic volume grows by 50% annually between 2020 and 2030, a factor of 100, energy efficiency would need to improve by two orders of magnitude just to stay on a par with total consumption. Against this backdrop, it is little surprise that the 14th FYP explicitly states that China "will [...] promote increased energy efficiency in emerging fields such as 5G".[8] Further work carried out by the National Development and Reform Commission (NDRC) confirms the importance of energy efficiency and China's focus on energy consumption unit of information traffic. Despite a reduction per information unit in the communications industry of up to 42% in the past three years, the NDRC identifies the need for further efficiency gains. Digital infrastructure is explicitly named as one of the NDRC's priorities.[9]

One critical trade-off relates to the centralisation of data processing,[10] which requires sufficient energy. While centralising data in centres close to a green energy supply can help to tackle the problem, many of the most innovative applications of 5G+ networks demand data

---

[2] According to an anonymous NDRC official in November 2019 "We apply an entirely different logic of efficiency to 5G. This is not about short-term commercial rollout; this is about the future of our economic prospects. The only chance to meet the gravitational forces of demography and the logic of slowing productivity growth is the automation of production and industrial AI. This transformation is doomed without a reliable standalone 5G network throughout China". This illustrates the commercial centrality of wireless infrastructure.

[3] By 5G+, we refer to 5G, 5G advanced and any future generation of wireless infrastructure technology.

[4] Xinhua, "中华人民共和国国民经济和社会发展第十四个五年规划和2035年远景目标纲要" [The 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and the Outline of Long-term Goals for 2035], accessed 3 April 2021, at http://www.xinhuanet.com/2021-03/13/c_1127205564.htm.

[5] Central Commission for Cybersecurity and Informatisation, "中央网络安全和信息化委员会印发《"十四五"国家信息化规划》" [The Central Cybersecurity and Informatization Commission issued the "14th Five-Year Plan National Informatization Plan"], accessed 30 May 2023, at https://www.gov.cn/xinwen/2021-12/28/content_5664872.htm.

[6] Ministry of Industry and Information Technology, "5G 应用"扬帆"行动计划 (2021–2023 年)" [5G Application "Sail" Action Plan (2021-2023)], accessed 3 July 2023, at https://www.miit.gov.cn/api-gateway/jpaas-web-server/front/document/file-download?fileUrl=/cms_files/filemanager/1226211233/attach/20214/70d5f6c5d5d5456495daada2fb070e98.pdf.

[7] Ericsson, "Ericsson mobility report November 2021", accessed 30 May 2023, at https://www.ericsson.com/4ad7e9/assets/local/reports-papers/mobility-report/documents/2021/ericsson-mobility-report-november-2021.pdf.

[8] Xinhua, op. cit.

[9] National Development and Reform Commission, "十四五'新型基础设施建设专家谈之七: 数字化与绿色化深度融合 推动新型基础设施低碳发展" [Expert talk on new infrastructure construction during the 14th Five-Year Plan Part 7: Deep integration of digitalization and greening to promote low-carbon development of new infrastructure], accessed 3 April 2021, at https://www.ndrc.gov.cn/fggz/fgzy/xmtjd/202112/t20211221_1308845.html.

[10] We define data processing in line with the broad understanding of EU Regulation 2016/679, better known as the General Data Protection Regulation (GDPR), as encompassing the collection, recording, organisation, structuring, storage, adaptation, alternation, retrieval, consultation, use disclosure by transmission, dissemination alignment or combination, restriction and erasure of data.

processing close to the application at the edge and at the base station. In China, the most renewable energy resources are located not close to the industrialised regions along the Pacific coast, but in the land-locked western provinces. In other words, China faces an energy deficit where most of the energy for wireless networks will be required. Any centralisation would interfere with the use cases – and long-distance data transfer in itself is highly energy intensive. In short, the global value chains of wireless infrastructure heavily rely on Chinese suppliers and China is active in energy saving research.

As is discussed below, however, Europe might have comparative advantages in its approach to energy performance as a result of Europe's long track record and leading role in both wireless technological innovation and putting constraints driven by ecological considerations on the agenda. We therefore have solid expertise rooted in our culture in tackling this challenge and driving innovation. Europe also has a political strategy on the "twin transition" (digital and energy), which makes it a top priority to consider both together on an equal levels. This can be differentiated from the "growth-driven" strategy of other regions of the world, where energy and ecology come only as second thought optimisation steps following performance and capacity upgrades.

All the above puts Europe in a good position to lead innovation on reducing energy consumption in future wireless networks. These are clearly not hard facts, however, and nor is European advantage in the development of energy consumption-reducing technologies for future wireless networks a given. Europe needs to commit to these goals if it wants to gain a competitive advantage in products. Several key conditions will have to be met by both private and public sector actors in the European Union (EU) and the United Kingdom (UK).

ASSESSMENT OF POTENTIAL REVERSE DEPENDENCIES

Traditionally, research on the sustainability and energy performance of wireless infrastructure technology has focused on energy efficiency. Energy efficiency measures energy consumption in relation to the maximal throughput of data (full load situations). In short, if the performance of equipment increases while the energy consumption of a device remains the same, energy efficiency improves. Historically, transmit energy was considered the main constraint on optimisation. Initiatives such as Greentouch (concluded in 2015) and the EU-FP7 EARTH project (2010–2012) contributed to an understanding of the broader problem and proposed improvements.[11] It should be noted that energy efficiency has improved spectacularly with each new generation of mobile network. However, as traffic has increased even faster, the overall consumption of the networks has increased. In recent years, the deployment of 5G networks in combination with the energy crisis has raised the criticality: mobile networks consume too much energy.

Recent research has turned to a different approach to the energy consumption of wireless infrastructure technology: total energy consumption should be the new key metric. Instead of measuring energy against the maximum performance of a device, actual energy consumption over a representative period and space is considered. In other words, whether networks can independently reduce energy consumption when not used to their maximum performance is crucial to decreasing total energy consumption. It was found that 2G/3G/4G base stations operate at <50% of their maximum load for ~50% of the time, and even <10% load for ~20% of the time, while their energy consumption does not drop to <50% of the maximum.[12] A key point is that there is a high static power that is independent of load, and that is always present and stable. This proves the inadequacy of the energy efficiency at maximum load metric and reveals opportunities for energy reduction. The average relative 5G network load will logically be much lower still but while the technology inherently provides better energy efficiency, it is anticipated that deployment will lead to an overall increase in energy consumption.[13] To improve energy consumption versus load, researchers are focusing on the development of self-scalable and self-rescalable networks, through the introduction of gradual sleep modes. Furthermore, the scope of the research is broadening from the use/operation phase to a total Life Cycle Assessment (LCA) to account, among other things, for the non-negligible and increasing impact of the production of electronics.

---

[11] Two widely cited papers that are representative of this research strand are Gunther Auer et al., "How Much Energy is Needed to Run a Wireless Network?," in *IEEE Wireless Communications*, vol. 18, no. 5, pp. 40–49, October 2011, doi: 10.1109/MWC.2011.6056691; and Luis M. Correia et al., "Challenges and Enabling Technologies for Energy Aware Mobile Radio Networks," in *IEEE Communications Magazine*, vol. 48, no. 11, pp. 66–72, November 2010, doi: 10.1109/MCOM.2010.5621969.

[12] Esteban Selva et al., "The Impact of Networks in the Greenhouse Gas Emissions of a Major European CSP", in *International Conference on Electrical, Computer and Energy Technologies* (ICECET), 2023, pp. 1–6, doi: 10.1109/ICECET58911.2023.10389498.

[13] Louis Golard et al., "Evaluation and Projection of 4G and 5G RAN Energy Footprints. The Case of Belgium for 2020–2025", Annals of Telecommunications, vol. 78, pp. 313-327, November 2022, accessed 30 April 2024, at https://link.springer.com/article/10.1007/s12243-022-00932-9.

Research on such scalable networks began only recently and the resulting solutions are awaiting actual and gradual deployment in the coming years. These are likely to hit the market primarily in 5G-advanced and 6G networks. However, the importance of scalable networks is also particularly relevant in moving to 6G as these networks will provide for a broader range of industrial applications. The scale and diversity of data processed at low latency lead to high energy requirements and make scalable energy performance particularly advantageous. Strikingly, such industrial use cases are at the heart of the Chinese leadership's 5G+ ambitions, as is briefly summarised above.

A reduction in total energy consumption is generally possible in both the Core Network (CN) and at the edge in the Radio Access Network (RAN). The advantage of energy saving in the CN is that in an increasingly virtualised network, many of these functions are performed in centralised data centres. In theory, these data centres can be built close to renewable energy sources, in China's case mostly in the less developed western landlocked provinces. However, this option has four disadvantages.

First, such solutions require the long-distance transfer of data, which in itself demands energy and comes at the cost of the latency required for the growing number of use cases. In addition, more infrastructure capacity will need to be built to accommodate the transfer of large amounts of data over long distances. This has a financial cost, but the buildout of such infrastructure also demands energy.

Second, the most energy-intensive component of the network is not the CN, but the base stations, which account for no less than 94% of the network's total energy consumption.[14] Hence, while such centralised options for energy saving might reduce total energy consumption, they ignore the most energy-intensive part of the network.

Third, it will be more challenging, if not impossible, to meet stringent Quality-of-Service (QoS) demands, in particular for applications and services that require (ultra) low latency and/or high reliability. Moreover, security and in particular privacy concerns grow with the number of links in a communication chain and when resources are shared. Decentralised approaches and private networks by their nature are a better fit for supporting specific QoS and security/privacy needs.

Fourth, at least for the time being, even renewable energy is only available at limited scale and the installation of ever larger data centres could have a drastic impact on the power grid.[15] Even regions that are energy rich could face shortages if the massive demand from more industrialised and digitised regions is effectively outsourced to these geographic localities.

All this highlights the need to focus on reducing total energy consumption in the servers and in the base stations, through heterogeneous architectures that contain decentralised solutions. However, this is technologically more demanding because it requires not "just" the transfer of data to regions with a high concentration of renewable energy sources, but an actual reduction in energy consumption despite the growth in data traffic. It is also more promising because the growing range and diversity of industrial applications mean that 5G advanced and 6G networks will become increasingly decentralised.

We have analysed various sources to track the state of European and Chinese developments in scalable green networks: Chinese-language academic articles, the materials of Chinese vendors and operators, Chinese and European contributions to international journals and relevant academic articles published by the Institute of Electrical and Electronics Engineers (IEEE).[16] We have also made technical assessments and conducted informal interviews with European experts to confirm our analysis. Our findings, which are discussed in more detail below, draw two main conclusions.

First, while both European and Chinese actors have identified the advantages of total energy consumption over energy efficiency, Europe has a stronger track record and appears not to prioritise performance over energy optimisation to the same degree as China. However, to take advantage of Europe's strong starting point, the EU and the UK must align their focus more rapidly and further prioritise energy performance, ideally at the same level as next generation service requirements.

---

[14] Esteban Selva et al.. op. cit.

[15] Anders S. G. Andrae and Tomas Edler, "On Global Electricity Usage of Communication Technology: Trends to 2030", in *Challenges*, vol. 6, no 1, pp. 117–157, 30 April 2015. https://doi.org/10.3390/challe6010117.

[16] The IEEE is the reference publisher of highly cited papers in the domain of electrical engineering as a whole and wireless communications more specifically. The strict peer-review process of the IEEE's highest impact journals means that the process from submission to publication typically spans many months. Hence, one limitation is that these papers often do not discuss the most recent results.

Second, Chinese solutions tend to adopt a more centralised approach to data processing, which might provide advantages for heterogeneous architectures including decentralised solutions in Europe. This could open a window to technological advantage for Europe.

CHINESE APPROACHES TO ENERGY SAVING IN WIRELESS NETWORKS

Improving energy efficiency is a policy priority area for the Chinese government. For example, energy efficiency in information and communication technology (ICT) features prominently in the "Action Plan for Green and Low-carbon Development of the Information Industry (2022–2025)" jointly issued by eight key decision making agencies, among them the NDRC and the Ministry of Industry and Information Technology (MIIT).[17] More explicitly, the MIIT's "Industrial Energy Efficiency Improvement Action Plan" mentions 5G as one of its priorities.[18] However, these policy documents still use the concept of energy efficiency rather than energy consumption.

This is in line with Chinese tech-giant Huawei's advocacy of energy efficiency over energy consumption. Instead of considering total energy consumption, Huawei wants service, including coverage and experience among other factors, to be considered integral components of energy efficiency.[19] While representing a change to the traditional approach, this falls short of a paradigmatic shift to considering energy consumption.

However, other actors in the Chinese wireless industry, such as the China Communications Standards Association (CCSA), acknowledge the need to reduce total energy consumption. The CCSA also admits that the growing energy consumption of the ICT industry will inevitably lead to a growth in electricity demand.[20] More concretely, China Unicom and China Mobile, two of the country's three largest mobile operators, have issued papers outlining concrete technological techniques for reducing total energy consumption that largely resemble the European discourse.

For example, in a three-year roadmap that ended in 2021, China Unicom listed measures for all parts of the network, including base stations. The company advocated work to upgrade application-specific integrated circuits (ASICs), as well as new materials and software-enabled solutions such as signal, channel and cell shut-off, deep sleep and amplifier voltage regulation. AI solutions were also seen as generating energy-saving effects through increased flexibility and scalability.[21] Proposed routes to *operational* energy savings included the introduction of more dedicated and optimised hardware components (such as replacing FPGAs with ASICs), and taking advantage of further scaled semiconductor technology. It is important to note that the latter might not bring about an overall ecological improvement, as it is known that scaling comes with an increased ecological footprint linked to the production of electronics.[22] While improving hardware implementation can reduce operational energy consumption, these can be considered "first level" measures or good engineering practices that are reactive in nature at the implementation phase. More proactive approaches to system and network design have far greater potential. Equally, the proposed AI approaches are a double-edged sword. AI solutions can drastically increase the computational complexity of a network and might simply move the problem of energy consumption to the CN.

---

[17] Chinese Government, "关于印发信息通信行业绿色低碳发展行动计划（2022-2025年）的通知 工信部联通信〔2022〕103号" [Notice on Issuing the Action Plan for Green and Low-Carbon Development of the Information and Communications Industry (2022-2025). Ministry of Industry and Information Technology Communications [2022] No. 103], accessed 21 December 2023, at https://www.gov.cn/zhengce/zhengceku/2022-08/26/content_5706914.htm,

[18] Ministry of Industry and Information Technology, "工业能效提升行动计划" [Industrial energy efficiency improvement action plan], accessed 21 December 2023, at https://www.gov.cn/zhengce/zhengceku/2022-06/29/5698410/files/e5be6f181bce4f89acb0b60d-18d1acf6.pdf.

[19] Huawei Technologies, "2022 Sustainability Report", accessed 15 December 2023, at https://digitalpower.huawei.com/attachments/index/30a6fe3914de47a3bddd88fa87b80b88.pdf; and Huawei Technologies, "Green 5G White Paper", accessed 13 December 2023, at https://www-file.huawei.com/-/media/corp2020/pdf/tech-insights/1/green_5g_white_paper_en_v2.pdf?la=en.

[20] CWW, "中国通信标准化协会发布《ICT产业碳达峰碳中和白皮书》" [China Communications Standards Association releases "White Paper on Carbon Neutralization of ICT Industry Carbon Peak"], accessed 14 December 2023, at http://www.cww.net.cn/article?id=565889.

[21] China Unicom, "中国联通5G智能节能技术白皮书（2019)" [China Unicom 5G Intelligent Energy Saving Technology White Paper (2019)], accessed 8 December 2023, at http://www.bomeimedia.com/China-unicom/MWC19/08.pdf.

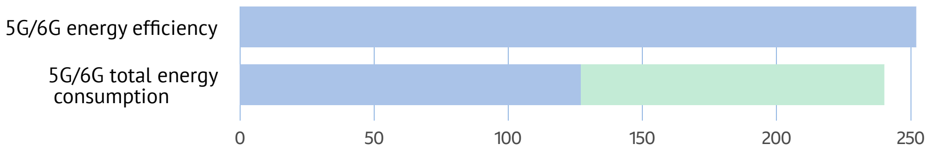
[22] Thibault Pirson et al., "The Environmental Footprint of IC Production: Meta-analysis and Historical Trends", IEEE 52nd European Solid-State Device Research Conference (ESSDERC), ESSDERC 2022, pp. 352–355, doi: 10.1109/ESSDERC55479.2022.9947198.

In contrast to China Unicom, China Mobile is less specific about its ambitions. It does not explicitly discuss total energy consumption in its strategies, but acknowledges its responsibility for ecological and environmental protection. In rather broad terms, the company advocates the use of new technologies such as cloud computing, cloud-network integration, cloud-edge device collaboration and software controls on energy efficiency in the network, not least by means of AI, as well as new materials. Strikingly, while base stations are mentioned, a large proportion of the measures discussed by China Mobile concern the CN.[23]

This mirrors a White Paper published by China's second largest mobile infrastructure vendor, ZTE, which mainly focuses on the control plane of the CN. This focus implies a rather centralised vision of wireless networks, as discussed above.[24] In the context of the cost of future networks, ZTE also acknowledges the importance of energy saving in base stations as advances enabling more use cases could increase energy consumption in base stations by 70–80%. Like China Unicom, ZTE advocates a combination of hardware and software solutions, including slot, channel and carrier shut down as well as deep sleep mode. The company also suggests that AI-enabled prediction models of energy optimisation should reflect divergent performance requirements across use cases.[25] On the role of AI in future networks, the jury is still out on whether this will be a blessing or curse. A recurring theme is further energy saving through improved cooling systems. For example, the CCSA is leading a study on 5G base station power supply and cooling technology research.[26] Ultimately, a proactive design with lean solutions could avoid the need for cooling in many base stations.

While some Chinese actors have shifted their focus from energy efficiency to total energy consumption, others resist this trend. This finding is equally reflected in the qualitative analysis of Chinese-language academic articles that discuss the issue of energy in wireless networks. Chinese academic articles consider increased energy consumption linked to large scale deployment and divergent use cases. Quantitative results from a comprehensive analysis of Chinese-language academic articles shows that both total energy consumption and energy efficiency solutions are discussed in the PRC. In the period 2018–2023, slightly more academic articles discuss the concept of energy efficiency (see Figure 1). The profile of energy efficiency-related articles becomes even more obvious if the concept of "green communication" (绿色通信) is excluded (displayed in light green in Figure 1). In fact, "green communication" is by far the least precise of all the terms and concepts that were searched for as proxies to identify articles referring to energy efficiency or total energy consumption.[27]

Figure 1: Quantitative comparison of Chinese-language academic articles discussing 5G/6G energy efficiency and total energy consumption concepts



Source: own graphic

---

23 China Mobile, "中国移动 2022 可持续发展报告" [China Mobile 2022 Sustainability Report], accessed 13 December 2023, at https://www.10086.cn/download/csrreport/cmcc_2022_csr_report_full_cn.pdf.

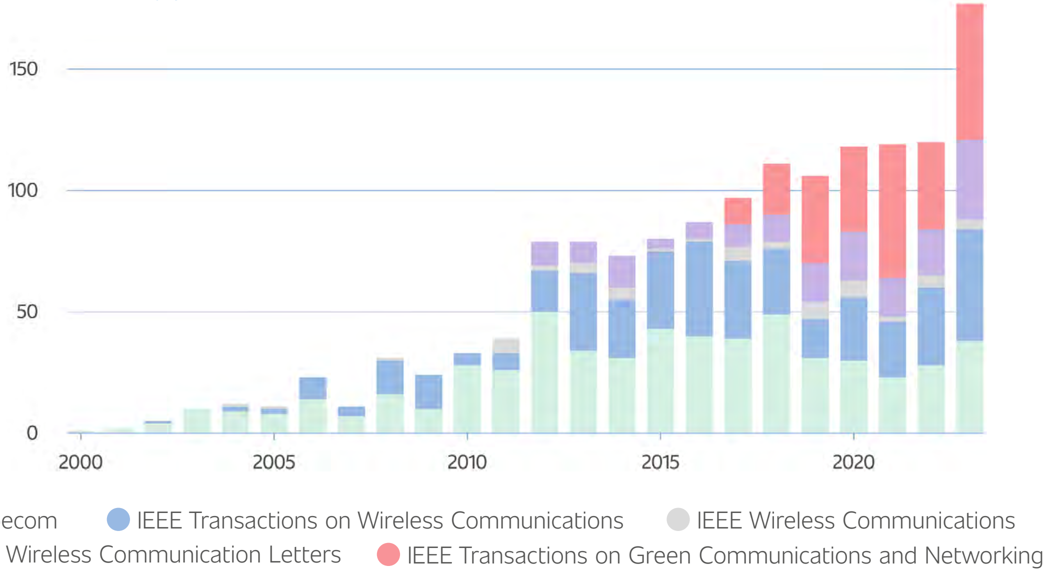
24 ZTE Corporation, "绿色5G核心网白皮书" [Green 5G Core Network White Paper], accessed 13 December 2023, at https://www.zte.com.cn/content/dam/zte-site/res-www-zte-com-cn/green_lowcarbon/pdf/ZTE_Green_5G_Core_White_Paper_CN1.pdf.

25 ZTE Corporation, "4G/5G网络节能降耗技术白皮书" [4G/5G Network Energy Saving and Consumption Reduction Technology White Paper], accessed 13 December 2023, at https://www.zte.com.cn/content/dam/zte-site/res-www-zte-com-cn/green_lowcarbon/pdf/Power_Pilot.pdf.

26 China Communications Standards Association, "5G基站供电和制冷技术研究" [Research on power supply and cooling technology of 5G base station], accessed 10 December 2023, at https://www.ccsa.org.cn/standardDetail/?standardNum=SR%20287-2020&title=5G%E5%9F%BA%E7%AB%99%E4%BE%9B%E7%94%B5%E5%92%8C%E5%88%B6%E5%86%B7%E6%8A%80%E6%9C%AF%E7%A0%94%E7%A9%B6.

27 The concepts indicating that articles refer to "energy efficiency" were power efficient/power efficiency (功率效率/高效能), energy efficient/energy efficiency (能效/能源效率), transmit power reduction (发射功率较低), and low-power transmission/low transmission power (低功率传输/低功耗传输, 低发射功率/低传输功率). The concepts serving as proxies for "total energy consumption" were deep sleep (深度休眠), sleep mode (休眠状态), energy saving in network (网络节能) and green communication (绿色通信).

FIGURE 2: Number of papers on energy saving technology in wireless networks sorted by journals over time



ENERGY SAVING STRATEGIES IN IEEE PUBLICATIONS

An analysis of papers published by five core journals and conferences of the IEEE demonstrates that papers related to the concept of energy efficiency far outnumber those discussing the concept of total energy consumption. (See Figure 2 for a count of the collective papers on energy saving technology and figures 3 and 4 for the subset of papers concerning only energy efficient technology or only total energy consumption respectively)[28]

Using origin measured by the geolocation of the authors' institutional affiliation, where co-authored papers were attributed an equal share to all contributing authors at their respective institutions), China is ahead of contributions from EU and British institutions combined. Of the small number of papers that discuss a reduction in total energy consumption, however, a mixed picture emerges without a clear lead region (See Figures 5, 6 and 7).

The IEEE dataset was further investigated to track cooperation between researchers from different geographical entities. This time, each cooperation was counted as "1" instead of a contribution share. No EU/UK co-authored papers with Chinese entities were found in the IEEE databases investigating total energy consumption until 2022. The number of co-authored papers discussing energy efficiency in China has increased in recent years. One remarkable feature is the high share of UK-China collaborations among the contributions of British researchers (See Figures 8, 9 and 10).

All these qualitative and quantitative indicators generally suggest that China – while striving to achieve energy savings in future wireless networks, not least for reasons of cost and reducing power shortages – has not fully committed to changing its approach from energy efficiency to total energy consumption, let alone full life cycle assessments that also consider the energy and ecological footprint of the production of electronics. This provides a window of opportunity for Europe to maintain and reinforce its technological leadership. Such leadership is not necessarily restricted to R&D. Especially where large vendors, notably Ericsson and Nokia, are involved, it could translate into effective patents. Energy saving is likely to become more of a competitive advantage as power demand grows for wireless infrastructure. Intellectual property (IP) could result in significant revenue advantages for European vendors. Whether such advantages could translate into superior products, however, will depend not least on the degree to which energy saving methods deviate across single vendor solutions, or international standards are specified in a way that the respective technologies can implement them adequately. This issue is further discussed in chapter 12 in this volume.

---

[28] The data was gathered through API from the IEEE's service IEEE Xplore, using journal and conference identifiers. The data includes information on IEEE publications at the author level. The country affiliations of papers are derived from the authors' institutions as provided in the data. We would like to thank SNV for providing us with access to the code base for their project, "Who is developing the chips of the future?", see https://www.stiftung-nv.de/de/publication/who-developing-chips-future#analysis, and especially Laurenz Hemmen for his help and advice.

FIGURE 3: Number of papers on energy efficiency technology in wireless networks sorted by journals over time

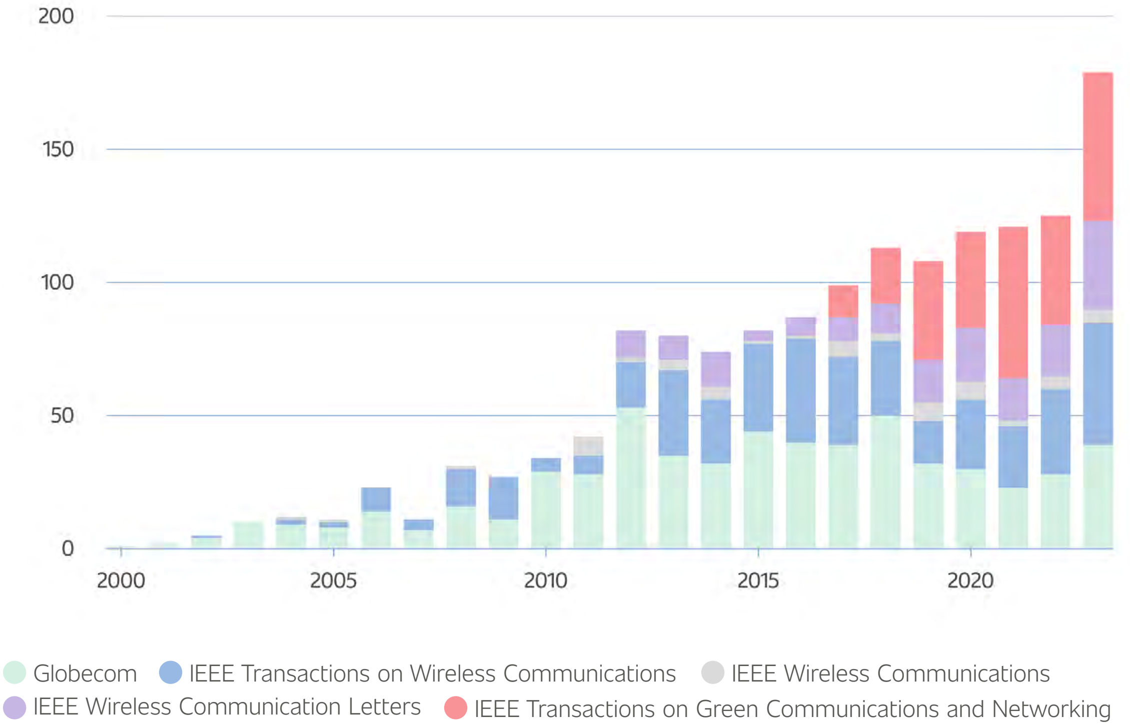


FIGURE 4: Number of papers on total energy consumption technology in wireless networks sorted by journals over time

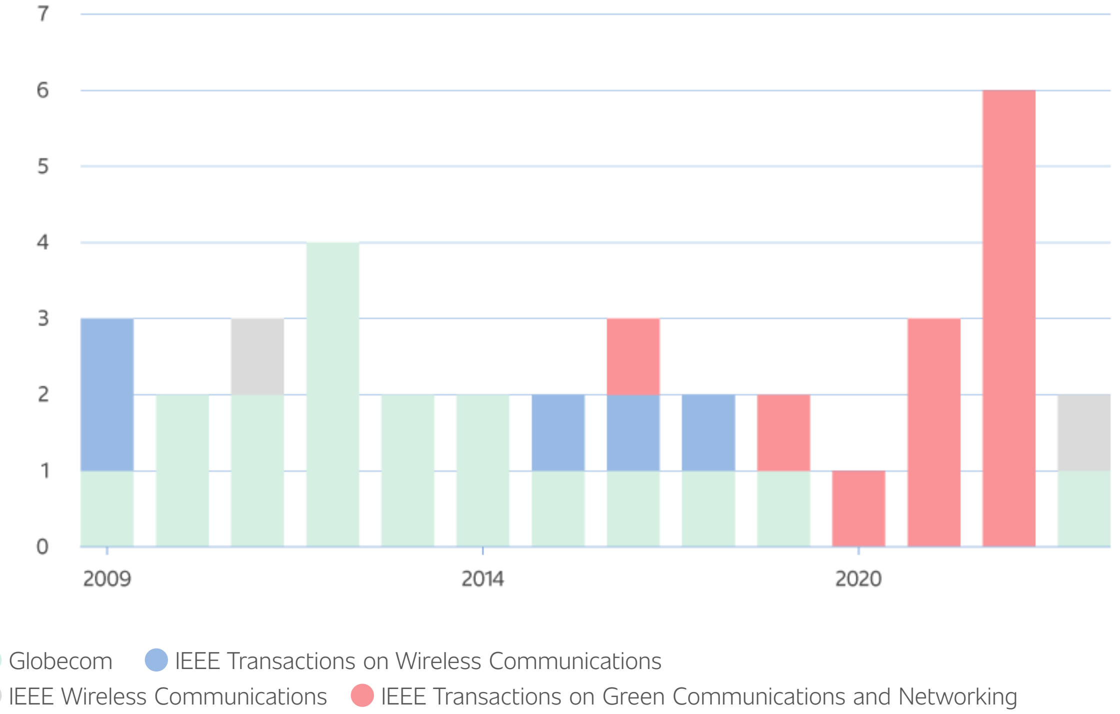


FIGURE 5: Number of papers on energy saving technology in wireless networks sorted by country over time

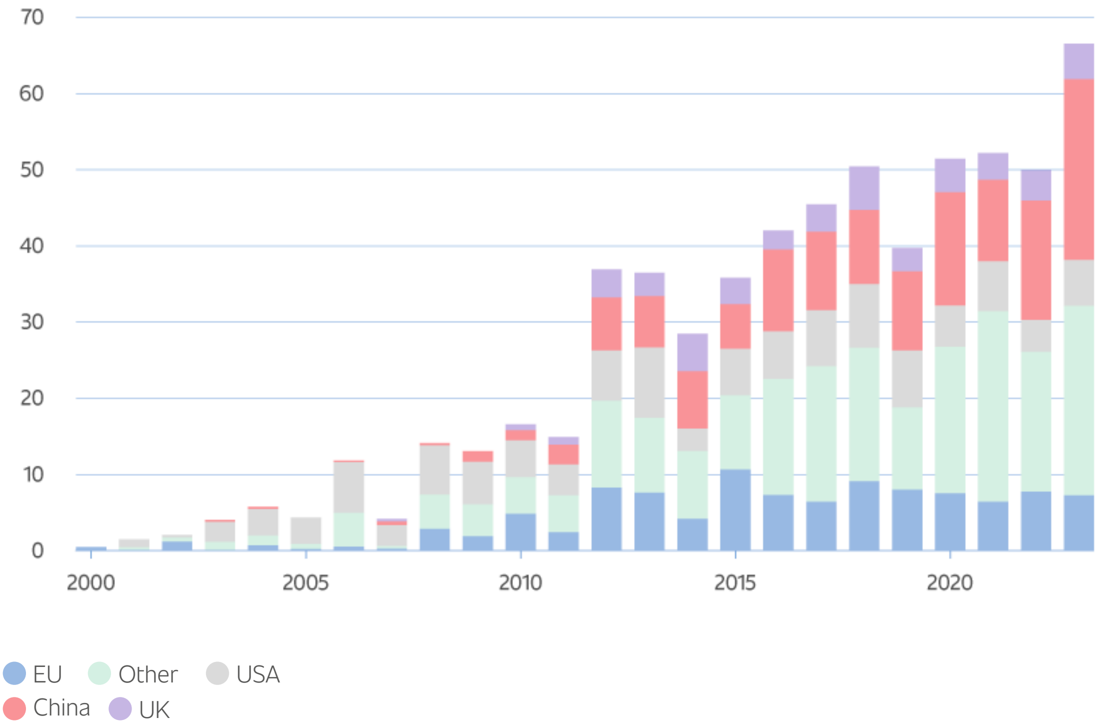


FIGURE 6: Number of papers on energy efficiency technology in wireless networks sorted by country over time

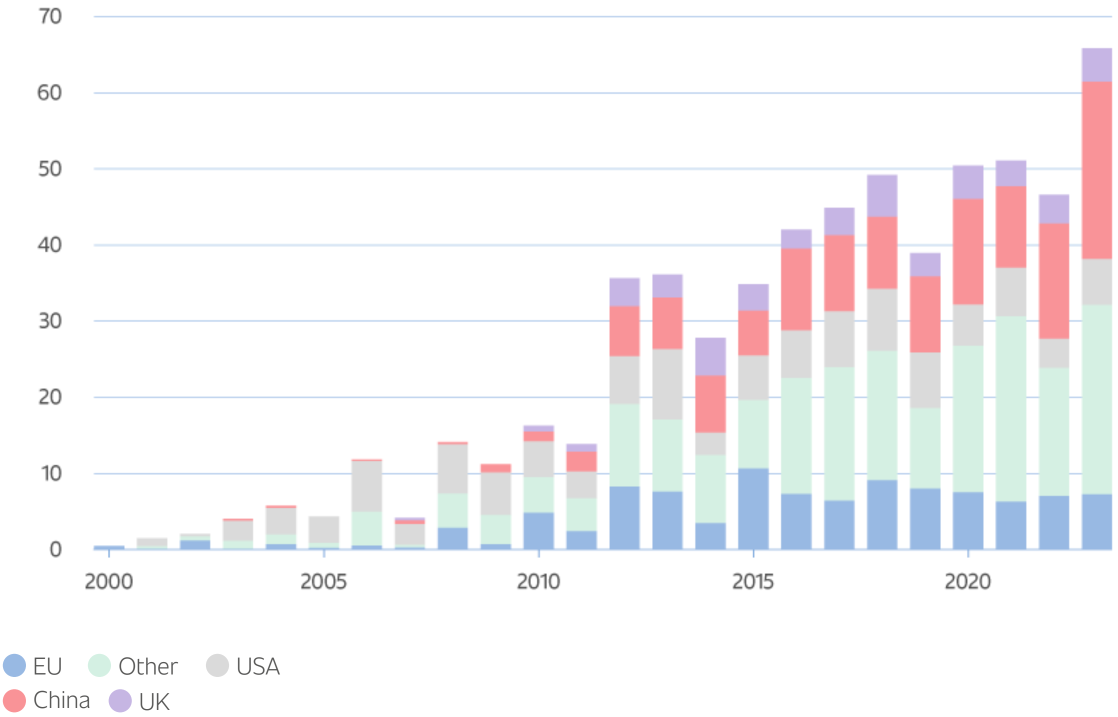


FIGURE 7: Number of papers on Total energy consumption technology in wireless networks sorted by country over time

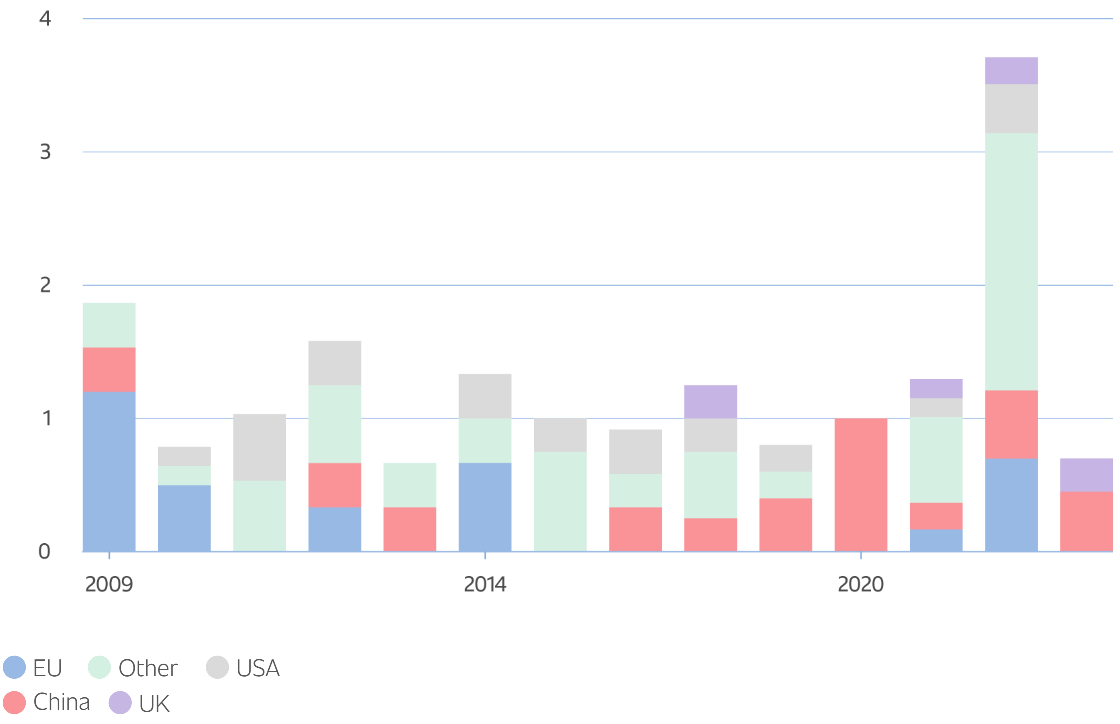


Figure 8: Number of papers resulting from research collaboration on energy saving technology in wireless networks sorted by country over time

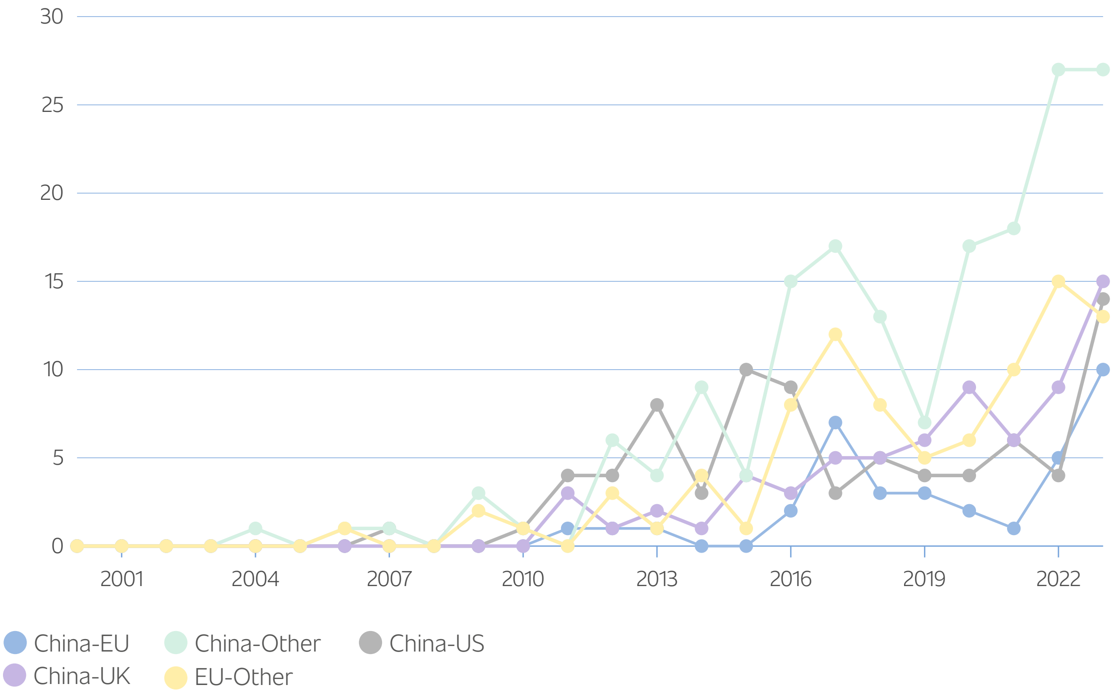


FIGURE 9: Number of papers resulting from research collaboration on energy efficiency technology in wireless networks sorted by country over time

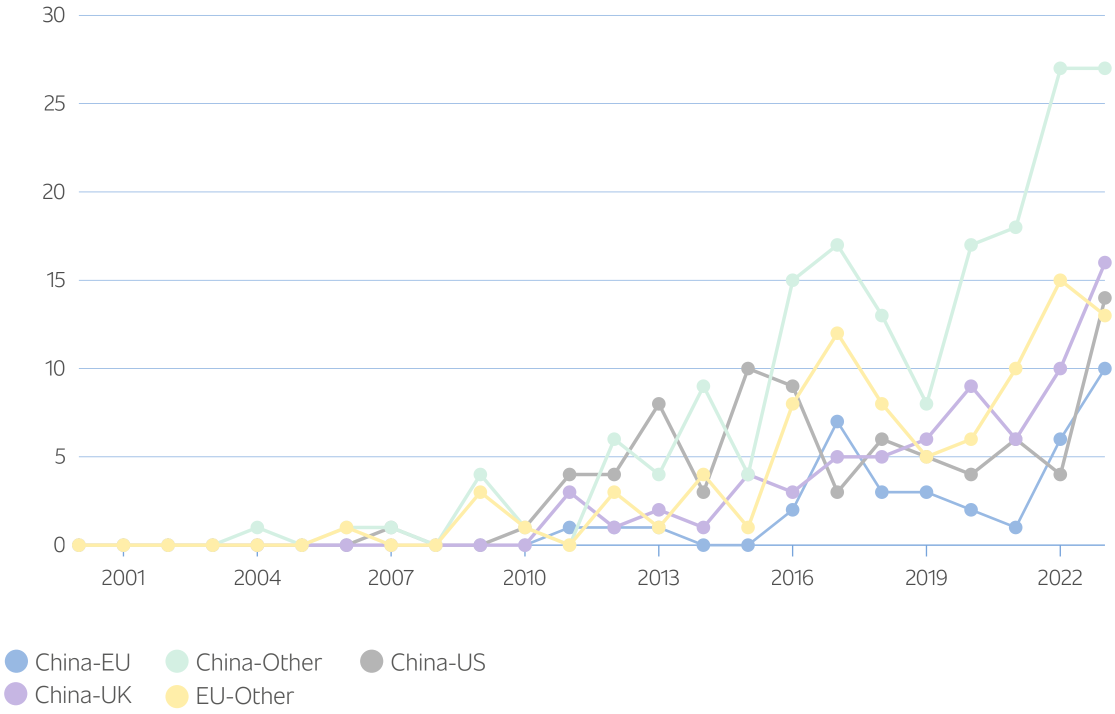
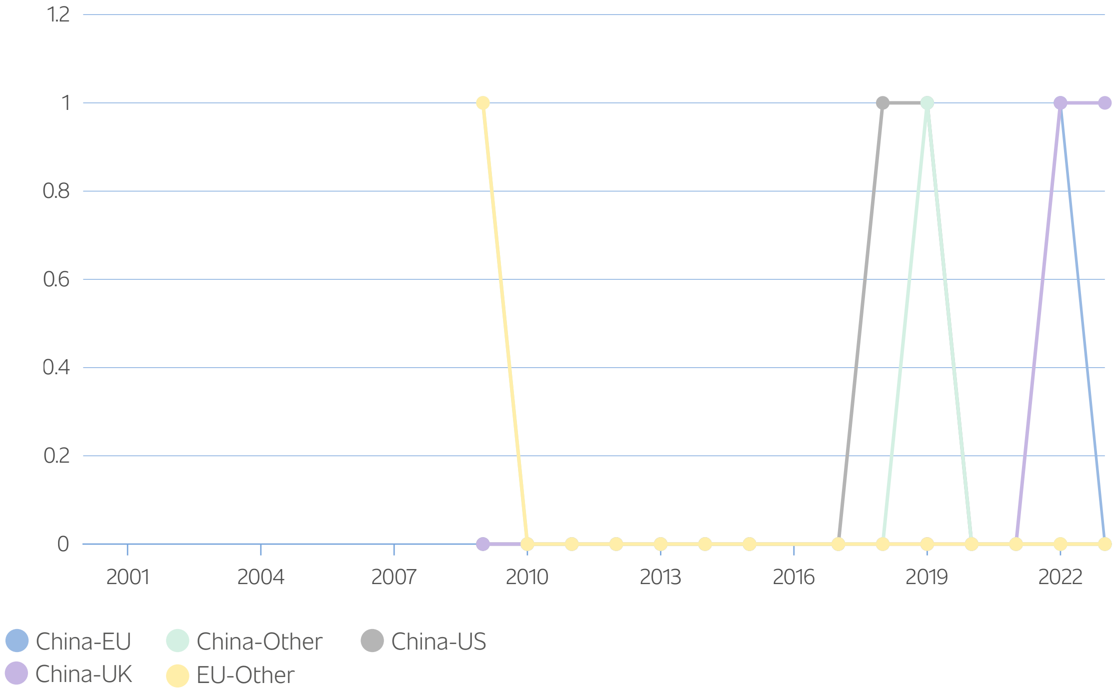


FIGURE 10: Number of papers resulting from research collaboration on total energy consumption technology in wireless networks sorted by country over time



LEVEL OF AMBITION AND POLICY RECOMMENDATIONS

Europe probably only has a short window of opportunity to develop a technological advantage in wireless energy-saving technologies. The PRC prioritises a reduction in total energy consumption less than Europe. This provides Europe with a head start. However, China's policy preferences make it highly probable that the shift in technology development currently visible in only a small share of companies and researchers will accelerate.

Any European advantage originates primarily from a technological superiority that evolved from a greater prioritisation of sustainability over other performance criteria compared to the PRC, coupled with the resulting early mover advantage. However, the potential this unfolds stems from future cost savings that make the reduction of total energy consumption attractive not only for Europe, but also for China and third countries. Hence, European advantage does not simply result from a normative preference to contribute to energy saving and a smaller ecological footprint. Instead, the stronger focus on sustainability coupled with rising energy demand and high energy prices could make the European approach economically appealing and advantageous in commercial competition with the PRC.

Theoretically, European advantages could emerge in three broad categories: China could rely on European research, patented IP from the EU and the UK, and/or technology imports from Europe. Advantages in research and IP are feasible if public and private sector actors in Europe undertake the right actions. Chinese import dependencies are less likely, but it might be worth exploring, in the wake of promoting research and IP, whether niche import dependencies could emerge in the medium term. We discuss this further while differentiating between the four levels of ambition outlined in the introductory chapter.

Threat prevention

Threat prevention is about avoiding the export of technology to China that could be used in a way that is counter to Europe's security interests. This level of ambition focuses on export controls on dual-use items.

While energy-saving technology in future wireless networks might include technologies that could serve dual-use purposes, requiring a thorough analysis of exports, this is of minor importance. Energy type and use are certainly security relevant. However, energy-saving technologies are distinct from energy supply and do not carry an immediate security risk. Therefore, the case of energy saving technologies for future wireless networks does not lend itself to the ambition of threat prevention.

The ability to deny

The ability to deny, as understood in this report, is about the creation of co-dependencies that are significant enough for China to consider before going against core European interests. In other words, this level of ambition strives to create economic costs resulting from mutual dependencies that the PRC would consider significant at a moment of conflict. We argue that such co-dependency in energy-saving technologies for future wireless networks is achievable for Europe. To achieve this, the following policies should be considered to strengthen research, IP and the production of respective technologies.

First, any significant role for Europe in energy-saving technologies for future wireless networks will depend on maintaining and expanding Europe's strong role in *research*. Public actors play a significant role in the allocation of R&D funds, and thereby influencing the direction of innovation in the EU and the UK. European R&D allocation should focus less on those technologies where China already has an advantage or that will soon enter the stage of standardisation, and instead systematically invest in future technologies where the PRC has not already gained a strong role. In the case of energy-saving technologies, this will mean doubling down on total energy consumption instead of energy efficiency. In the light of the significant collaboration between Chinese researchers and their counterparts in the EU and the UK, public funds should not exclude such cooperation but prefer inter-European research projects. Cautious policies should be adopted on the inclusion of Chinese researchers in publicly funded projects and a negative list of areas should be established on which research cooperation with China in publicly funded projects would require specific justification.

Second, since the most likely method for achieving co-dependency appears to leverage the R&D dependencies of Chinese actors and their reliance on *European IP*, Europe should focus on the development of fundamental patents and their inclusion in international standards. As we outline in chapter 12 in more detail, there is currently a strong mutual interest in international technical standards on wireless networks. Reasons range from the global character of the wireless market and the extraordinary consumer demand for interoperability in wireless technology, to the reusability of knowledge due to the global spread of Chinese researchers and company labs in multiple locations around the globe. This could of itself provide some "guarantee" that no region in the world will obtain a dominant position in terms of IP in the next 10–15 years. European public actors should therefore focus not on incremental patents for specific applications for the sake of numbers, but rather on fundamental patents to encourage and incentivise the transition of research to IP. Incentivising active participation in international standardisation has enormous potential to create co-dependency by means of standard essential patents (SEPs). In the light of Chinese attempts to gain control over SEPs pricing, Europe must stay firm in defending established practices of IP enforcement.

Third, for the ability to deny, Chinese *import dependencies* on Europe will be difficult but not completely impossible to achieve. In third markets, however, less energy-intensive solutions provide a competitive advantage for European vendors' equipment compared to technologies produced in China. To incentivise commercialisation, Europe will need to speed up its own deployment of energy-saving alternatives. Europe should not aim to provide funding for industry production in Europe. Instead, technology partnerships or even digital trade agreements make it cheaper for European vendors to diversify supply chains at low cost. Europe's success requires European suppliers to remain efficient and commercially successful. Low price non-Chinese alternatives are crucial to reducing dependencies on the PRC. Lowering deployment barriers at home, incentivising sustainable network deployment and reducing barriers to diversified sourcing would all be helpful.

The ability to act

The ability to act goes a step further than the ability to deny as it aims to shape the technological and wider commercial and political contexts in which China can develop future technologies. In other words, it aims to develop more proactive capabilities that result in stronger Chinese reliance on Europe. We argue that Europe would be able to achieve this level of ambition, but it would require more action in terms of research promotion, knowledge protection and support for production than in the lower levels of ambition. All the policy recommendations mentioned above would apply in addition to the following.

Generally speaking, Europe's *research promotion* strategies for gaining the ability to act would not fundamentally diverge from those outlined above. However, if the EU and the UK seek a higher degree of Chinese unidirectional dependence, they will need to target more ambitious goals in pursuing disruptive innovation. For example, Europe could explore whether the network side can be built with hardware that is as "lean" as the handsets. This might exclude the need for cooling, and reduce weight and the costs of transportation and installation. In other words, Europe should promote targeted innovation programmes aimed at high-risk, high-gain research on "best in class" solutions regarding energy performance and the broader ecological footprint of wireless networks. This would also imply that public R&D is not primarily driven by new applications and use cases that have higher performance requirements. Instead, novel technological solutions could bring about joint ecological-economic benefits. Alongside the reduced costs of energy consumption described above, economic gains would result from reduced materials, no need for cooling, lower transport and installation costs, and consideration of whole lifecycle costs. In such research, publicly funded R&D would by default not involve Chinese partners (a "positive list approach"). Research would be strictly limited to European institutions and individuals, as well as like-minded partners. Funding from the Chinese Scholarship Council should be entirely prohibited for research on wireless networks in Europe, while the sources of other Chinese funding would need to be carefully investigated. This would require substitution of existing funding from Chinese sources and thus an increase in public R&D spending.

Patented IP is central to *protecting* European advantage derived from its research promotion. Technical standards remain a crucial way to lock the PRC into certain solutions and thereby create co-dependencies. An ambition to maintain or expand Europe's ability to act, however, would require a delicate balance. On the one hand, standards and their underlying SEPs manifest dependencies. As chapter 12 discusses in more detail, where domestic Chinese and international standards deviate – even only in detail – European influence on domestic Chinese standard-setting can help to shape the technological ecosystem in which the PRC's technological solutions emerge. On the other hand, especially if European vendors strive for competitive advantage in third markets, the balance between proprietary and standardised technology needs to be carefully considered. As in the previous level of ambition, Europe should defend established practices of IP enforcement against Chinese attempts to gain control over this process. To avoid unwanted leakage of technological innovation, not only should Europe restrict academic research, but outbound investment screening could also help to prevent the transfer of innovation capabilities from Europe to China by means of Joint Ventures and European investment in the PRC.

Chinese *import dependencies* would massively increase Europe's ability to act. However, national security concerns make it unlikely that European vendors will gain much beyond the current market share in China of around 5–8%. Even an insistence on reciprocity is unlikely to have much of an effect because China considers 5G+ infrastructure a matter of national security and an increasing number of EU member states are gradually reducing their dependence on Chinese equipment for the same reason. Manufacturers from both sides will increasingly need to accept that they are effectively excluded from their respective other's market. Any import dependencies will only be for niche technologies. Given the maturity of the Chinese wireless industry and growing geopolitical rifts, Europe will not be able to develop a hard chokepoint. Such a hard chokepoint would imply that reverse engineering were impossible, which, as far as can be assessed at this stage of technology development, is unlikely. To stimulate European production or diversification away from China, Europe should create guidelines, directives and procurement tools to help to assess "low initial cost" versus "durable investments" that emphasise the commercial benefit of energy-saving technology. In so doing, Europe should actively coordinate its efforts with like-minded partners. The main target of such a strategy would be to increase European market share in third markets, especially in the Global South and North America. Digital free trade agreements should accompany calculation of the long-term commercial effects of equipment that requires less energy to operate even if it is a more expensive investment. If Europe wants to strengthen production, a stronger role must be played by Central and Eastern Europe due to the persistence of lower labour costs there.

Curtailment

The fourth and final level of ambition, which is referred to as curtailment in this study, is not feasible for Europe in the field of energy-saving technologies for future wireless networks. To achieve curtailment, Europe would need to cease almost all interaction with China in the respective technologies and thereby stall China's development. However, even if Europe ended all interactions with China, which is highly unlikely as it would greatly harm Europe itself, the PRC would still be able to develop future wireless networks, even if not at the same level of sustainability. In other words, while the cost for Europe would be high, the impact on China would be negligible.

In sum, Europe must generally choose between two levels of ambition: the ability to deny or the ability to act, and then align its policies in terms of research promotion, knowledge protection and facilitation of reshoring and diversification. These options also relate to the fundamental question of whether to increase European security through strategic entanglement or greater autonomy. Each level of ambition will require a mixture of both. Europe needs to reduce technological interactions and reliance on China while at the same time keeping targeted entanglement alive in order to ensure that the PRC would have to pay a price if it decoupled from Europe altogether in a situation of geopolitical conflict.

Whatever the political choice, a fundamental precondition will be to rethink other performance criteria than green networks and sustainability. Only if Europe continues to shift, and further shifts, its focus to total energy consumption will it have a chance to maintain and develop a competitive advantage over the PRC. It is not just performance in new use cases, but energy consumption that must be prioritised.

SCORECARD 2 ENERGY PERFORMANCE OF FUTURE WIRELESS NETWORKS

	Threat prevention	Ability to deny	Ability to act	Curtailment
Feasibility of level of ambition	○ Not feasible	● Medium	● Low	○ Not feasible
Core policy recommendations	• None	• Increase public R&D support for green communication • Restrict research collaboration with China based on a negative list • Provide financial support for fundamental patents (SEPs) and participation in international standardisation • Conclude digital Free Trade Agreements with third countries	• High risk/high gain public investments in R&D • Restrict research collaboration with China based on a positive list • Establish outbound investment screening • Incorporate guidelines, directives and procurement tools into European policies and digital Free Trade Agreements that support “durable investments” over “low initial cost” • Set up industrial policy to expand production capacity in Europe, especially in Central and Eastern European countries	• None

AUTHORS

Tim Rühlig is a China Fellow at the European Commission, DG I.D.E.A., seconded from his post as Senior Research Fellow at the German Council on Foreign Relation. The author is writing in his personal capacity and his views should not be considered as representing his employer or any EU institution. Contact: contact@timruhlig.eu
Liesbet van der Perre is a Professor in the DRAMCO lab of the Electrical Engineering Department of the KU Leuven in Belgium. Contact: liesbet.vanderperre@kuleuven.be
Julian Heiss is a Non-resident Fellow of the Global Public Policy Institute with a background in data science and international affairs. Contact: jheiss@gppi.net
With contributions by **Oscar Shao**, German Council on Foreign Relations

Quantum Sensing Applications in Healthcare

Michael Settelen, Dr Araceli Venegas-Gomez, Abhishek Purohit and Simon Armstrong

ABSTRACT

Quantum technologies have emerged as a pivotal area of geopolitical competition. Part of the enormous transformative potential of quantum technologies are the quantum sensing technology applications to healthcare. In its pursuit of high-quality development and national security, China attaches great strategic importance to quantum as a new technology frontier and is attempting to lead this "second quantum revolution". However, China does not have a dedicated policy focus on quantum sensing for healthcare. Nor has it made particular progress beyond basic research. We find that European quantum sensing technological capabilities – in general and in healthcare – are far more mature than China's. Given this "first-mover advantage", which Europe has especially in terms of commercialisation, the European Union and the United Kingdom have a real opportunity to maintain their lead. Whether this can be turned into an area of strategic indispensability will depend on policy prioritisation in Beijing. Key to this will be measures to curb unwanted technology outflow, as well as investments in maintaining Europe's research and market edge.

SCORECARD 1	TECHNOLOGY FIELD: QUANTUM SENSING FOR HEALTH CARE		
Source of European technology strength	Research and innovation	Intellectual property and patents	Production and commercialisation
	● Low	● Low	● Medium

Type of European technology strength	Technological excellence	Commercialisation advantage	Conditioning of market access	Regulatory, political and normative factors	Sustainability	Research partnerships with third countries
		X	X	X	X	

Degree of European leverage: Low — Medium ○ — High

INTRODUCTION

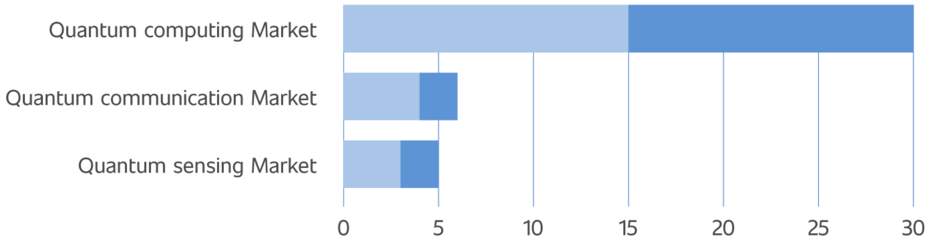
Quantum technologies have emerged as a pivotal area in the geopolitical competition, particularly between the United States and China. This is due to quantum's highly sought-after capabilities and the potential market that arises from their diverse applications, which resulted in record-high private sector investment of US$ 2.35 billion in 2022. In the past decade, thanks to advances in theoretical understanding and engineering capabilities, certain quantum technologies have seen a pronounced graduation into marketable devices. This has resulted in the rapidly advancing quantum technologies market attracting interest from industry and policymakers, and a market size estimate of $20 billion to $40 billion by 2030,[1] and $106 billion by 2040.[2] Quantum technologies can be broadly categorised into three main subgroups: quantum computing and simulation, quantum communication and quantum sensing.

---

[1] BCG, "Making Sense of Quantum Sensing", accessed 27 March 2023, at https://www.bcg.com/publications/2023/making-sense-of-quantum-sensing

[2] McKinsey & Company, Quantum Technology Monitor, 2023.

FIGURE 1: Market share of different quantum technology pillars by 2030 (estimate range minimum to maximum, in billion US$)

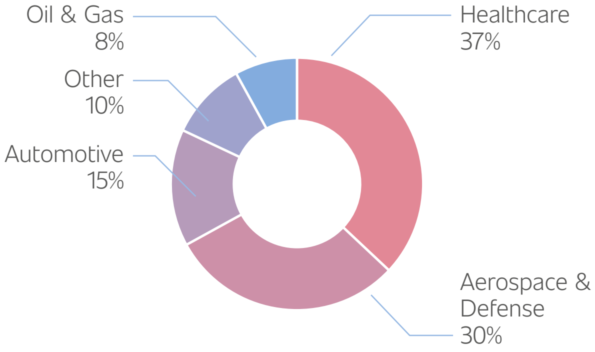


Note: Light blue = minimum estimated value, Dark blue = maximum estimated value

Source: BCG, "Making Sense of Quantum Sensing", accessed 27 March 2023, at https://www.bcg.com/publications/2023/making-sense-of-quantum-sensing

Quantum technologies have the potential to revolutionise a nation's cybersecurity infrastructure, healthcare and medical innovations, as well as the defence sector through advanced sensing and computational capabilities, potentially reshaping global dynamics and dependencies. Overall, however, it is still at a nascent stage of development.

FIGURE 2: DISTRIBUTION OF GLOBAL QUANTUM SENSOR APPLICATIONS



Source: 4 Grand View Research, "Quantum Sensor Market Size & Trends", accessed 27 March 2023, at https://www.grandviewresearch.com/industry-analysis/quantum-sensor-market-report.

Quantum sensors enable transformative applications: in healthcare, for advanced medical diagnostics; in defence and space exploration, for advanced navigation and surveillance; and in energy and environmental science, for accurate geological surveys and monitoring, while also contributing to fundamental science. The quantum sensor market was estimated at almost $800m globally in 2022, of which the EU claimed 35%. The EU and China are at the forefront of projected growth.[3] According to McKinsey, the market will grow to $6 billion by 2040. Of the various companies around the world developing quantum sensors for various potential applications, healthcare represents the largest market (see Figure 2).

Given the heterogeneity of quantum technologies and application areas, this chapter focuses on the application of quantum sensors to healthcare. It compares technology readiness levels for such devices across the EU and China, as well as China's ambitions and current weaknesses in quantum technology against the EU's strengths and competitive advantage.[4] Finally, it outlines opportunities for the EU to achieve quantum sensing indispensability.

Quantum tech in Europe

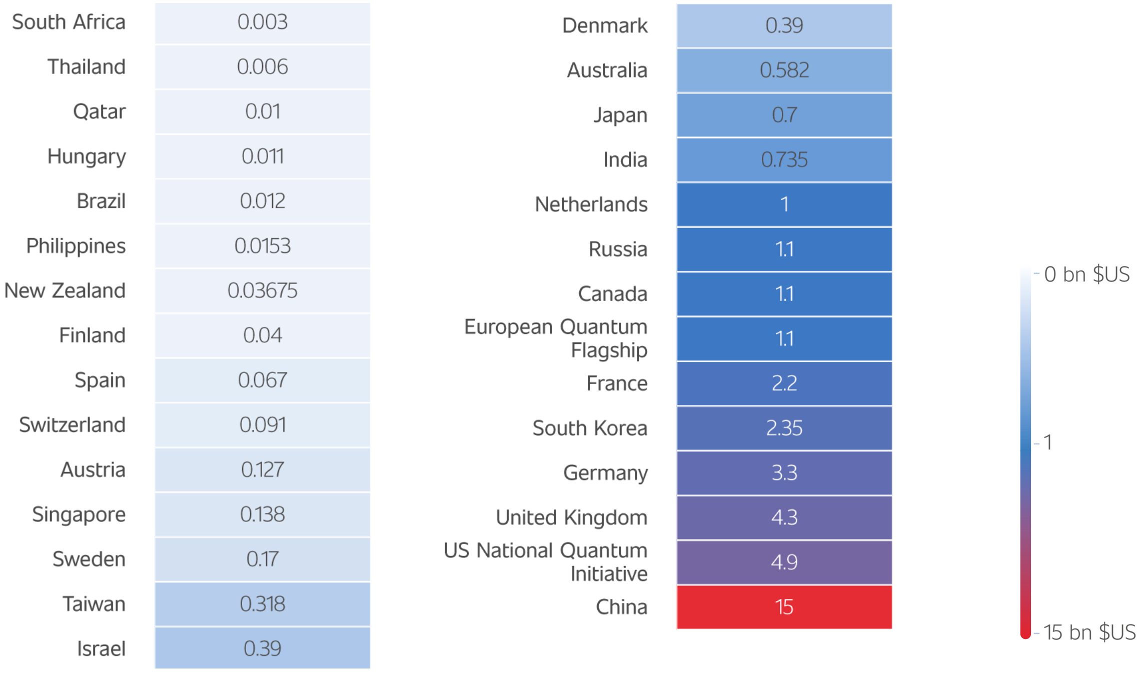
European advances in R&D and commercial deployment of quantum technologies over the past decade demonstrate a strong commitment to advancing the field. There have been significant investments, collaborations and strategic initiatives across various European countries, each of which has contributed to the continent's quantum technology landscape, particularly in quantum sensing. There are dedicated national initiatives in 15 European states and five countries have active financial mechanisms to support quantum technologies. Table 1 shows these national quantum initiatives. European countries have spent approximately one-third of

---

[3] Grand View Research, "Quantum Sensor Market Size & Trends", accessed 27 March 2023, at https://www.grandviewresearch.com/industry-analysis/quantum-sensor-market-report.

[4] Abhishek Purohit et al., "Building a quantum-ready ecosystem", in IET Quantum Communication, vol. 5, no. 1, pp. 1–18, 2024, doi: 10.1049/qtc2.12072.

TABLE 1: Overview of national initiatives (in billion $US)



South Africa	0.003
Thailand	0.006
Qatar	0.01
Hungary	0.011
Brazil	0.012
Philippines	0.0153
New Zealand	0.03675
Finland	0.04
Spain	0.067
Switzerland	0.091
Austria	0.127
Singapore	0.138
Sweden	0.17
Taiwan	0.318
Israel	0.39
Denmark	0.39
Australia	0.582
Japan	0.7
India	0.735
Netherlands	1
Russia	1.1
Canada	1.1
European Quantum Flagship	1.1
France	2.2
South Korea	2.35
Germany	3.3
United Kingdom	4.3
US National Quantum Initiative	4.9
China	15

Source: QURECA, "Overview of Quantum Initiatives Worldwide 2023", accessed 27 March 2023, at https://qureca.com/overview-of-quantum-initiatives-worldwide-2023/

the estimated $40 billion invested globally.[5] China is said to have invested $15 billion, but this amount has never been confirmed (see below).

The ongoing projects and future plans of the Quantum Flagship are integral to Europe's quantum strategy. Its main aim is to consolidate and expand European scientific leadership and excellence in this research area in order to kick-start a European quantum industry.[6] Numerous start-ups and spin-offs have been established as a result of these joint efforts in an attempt to commercialise solutions for communication, computation, simulation, sensing and metrology.[7]

Overall, the European quantum technologies landscape presents a competitive and growing market to the world.

- **Focused Investment:** European countries are investing heavily in quantum technologies, and significant proportions are being allocated specifically to quantum sensing. This demonstrates Europe's ambition to become a leader in the field. Although the overall investment in quantum science and technology seems to be substantially larger in China, the details of this budget are not clear. The EU has a larger number of projects dedicated to quantum sensing, and some even specifically for healthcare applications, while China's projects are more focused on general quantum science and technology, which may or may not be developed further into quantum sensing applications.[8]
- **Collaboration and Innovation:** The establishment of national initiatives and laboratories across Europe

---

[5] QURECA, "Overview of Quantum Initiatives Worldwide 2023", accessed 27 March 2023, at https://qureca.com/overview-of-quantum-initiatives-worldwide-2023/.

[6] Further updates to the Strategic Research and Industry Agenda (SRIA) and the Strategic Industry Roadmap (SIR) highlight the focus on developing quantum infrastructures and technologies. The Flagship aims to consolidate and expand Europe's scientific leadership in quantum technologies, including sensing. The QuantERA project supported this growth through the provision of €88.9 million.

[7] The Quantum Insider, "New Report Shows Quantum Technologies Thriving in Europe", accessed 27 March 2023, at https://thequantuminsider.com/2023/02/10/new-report-shows-quantum-technologies-thriving-in-europe/.

[8] It is also possible that China is not displaying its technology use cases in public.

demonstrates a collaborative approach to innovation in quantum sensing. These initiatives aim to consolidate resources and expertise to advance the field.

QUANTUM TECHNOLOGY AND SENSING IN CHINA

China's policies on, and ambitions and strategic goals for quantum technology

China attaches great strategic importance to quantum as a new technology frontier in its pursuit of high-quality development and national security, and is attempting to lead this "second quantum revolution".[9] In the eyes of Beijing, quantum technologies could be a crucial technology for the country's future national competitiveness. This is part of a broader push for technological leadership and to become a global "great power in science and technology" (科技强国),[10] which has further intensified amid US-China tensions over strategic technologies.

China's ambition to strengthen domestic quantum capabilities became particularly urgent in the wake of Edward Snowden's revelations of US intelligence activities in June 2013, and heightened worries about the security of the existing communications infrastructure. In recent years, quantum technologies have been given increasing political attention at the highest level. According to Pan Jianwei, often called China's "father of quantum", this trend is expected to accelerate further.[11]

Beijing has also started to more clearly articulate China's high-level ambition, and quantum technology has been declared a "new frontier of the industrial and technology revolution" (科技革命和产业变革的前沿领域) that is critical to China's "high-quality development" (高质量发展) and to "ensuring national security" (保障国家安全).[12] Xi Jinping wants China to occupy the "highland of the international quantum competition" (量子科技国际竞争制高点),[13] and to better handle global (geopolitical) risks, requiring the country to be more self-reliant (自主可控) in quantum technology and secure the key supply chains via breakthroughs in core technologies.[14] This new ambition is reflected in the 14th FYP (2021–2025), where quantum technologies are listed along with other strategic priorities such as AI or advanced semiconductor manufacturing.

Therefore, while there is to date no quantum-specific industrial policy or plan, quantum technologies – especially on communication and computing – have received significantly greater policy attention in recent years.

China's overall position in quantum sensing

Starting from the position of a latecomer, China has ramped up its policy plans and funding to mobilise resources for the development of quantum technologies, including sensing. In 2016, in line with its new Innovation Driven Development Strategy (IDDS),[15] support for quantum sciences was kick-started by the National Key Research and Development Plan, which among other things sought to advance "indigenous innovation" (自主创新) for China to become a leader in "basic innovation" (源头创新). This essentially introduced a new paradigm of innovation. This work is continued in China's "S&T Innovation 2030" major projects as part of the 14th FYP. Thus far, however, there has been no dedicated plan for quantum sensing.

To support implementation of the objectives of the National Key R&D Plan in developing cutting-edge research and development, China has established a number of new institutions in recent years, such as the Quantum Information and Quantum Science and Technology Research Institute of the Chinese Academy of Sciences (CAS), or the National Laboratory for Quantum Information Science at the University of Science and Technology of China (USTC), in Anhui province, which has

---

[9] "The quantum technology revolution is a major historical opportunity" (量子科技改革是重大历史机遇), Global Times, 17 January 2021, accessed 27 March 2023, at https://tech.huanqiu.com/article/41Y8oTNbqKs.

[10] Elsa B. Kania, "China's Quest for Quantum Advantage: Strategic and Defense Innovation at a New Frontier", in *Journal of Strategic Studies*, vol. 44, no. 6, pp. 922–952, 27 December 2021, doi: 10.1080/01402390.2021.1973658

[11] Pan Jianwei (潘建伟), "Better Promote the Development of My Country's Quantum Technology" (更好推进我国量子科技发展), Red Flag Manuscript (红旗文稿), 8 December 2020, accessed 27 March 2024, at https://news.ustc.edu.cn/info/1056/73476.htm.

[12] 'During the 24th collective study session of the Political Bureau of the CPC Central Committee, Xi Jinping emphasised the importance of deeply understanding the significance of promoting the development of quantum technology and strengthening the strategic planning and systematic layout of quantum technology development', (习近平在中央政治局第二十四次集体学习时强调深刻认识推进量子科技发展重大意义 加强量子科技发展战略谋划和系统布局), Xinhua, accessed 27 March 2024, at http://www.xinhuanet.com/politics/2020-10/17/c_1126623288.htm.

[13] Ibid.

[14] Ibid.

[15] See the official strategy, "The CCP Central Commission and State Council Release the 'National Innovation-Driven Development Strategy Outline'" (中共中央国务院印发"国家创新驱动发展战略纲要"), Xinhua, 19 May 2016, accessed 27 March 2024, at http://www.xinhuanet.com//politics/2016-05/19/c_1118898033.htm.

$1 billion in initial funding, arguably the world's largest quantum research facility.[16]

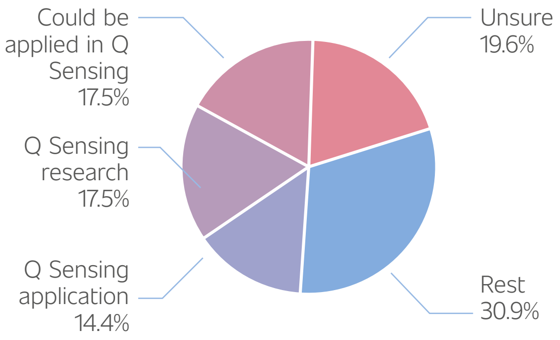
Overall, at an estimated $15 billion (see Table 1), China is investing more than any other country in developing and scaling-up quantum technologies. While this amount is unconfirmed, taking account of various sources of information and publications on specific quantum projects in China, it is clear that China is investing heavily.

An original bottom-up analysis conducted for this report of all the public quantum S&T projects – in the period 2016–2020, according to China's Ministry of Science and Technology (MOST), shows that one-third of the projects are either quantum sensing research or application projects – possibly indicating an increased focus on quantum sensing technologies. R&D efforts in quantum sensing and measurement have been directed largely at key technological areas such as chip-based atomic clocks, space quantum imaging technology, and high-precision atomic magnetometers.[17] Details of funding per project are not fully available, however, but collectively would not come near the above-mentioned $15 billion.

At the same time, China lags behind on private sector investment. Between 2001 and 2022, Chinese quantum start-ups received only $304 million from the private sector. This pales in comparison with the $3.3 billion that US start-ups get from non-public sources.[18] This means that practically all quantum R&D in China is government-controlled.

The Chinese government has also been trying to attract talent with plans such as the Thousand Talents Plan (千人计划). Chinese postgraduate students are the largest group of foreign students in US quantum sensing programmes and the second-largest in European programmes, behind US students. In terms of postgraduate employment, Chinese quantum sensing researchers are the second largest foreign group in both the US (behind EU researchers) and the EU (behind US researchers).[19]

FIGURE 3: CHINESE QUANTUM S&T PROJECTS, 2016-2020



Source: Ministry of Science and Technology (MOST), China Macro Group analysis

Performance

China is now the country with the second most advanced industrial base in quantum after the US, having closed the technology gap on quantum considerably. Like the US, China has a high research output in every application domain of quantum technology. In quantum sensing, China also lags behind both the US and Europe in terms of demonstrated technical capability. Most research remains at the laboratory stage.[20] Looking particularly at high-quality research, however, some conclude that the US, the EU and China are already on a par.[21] Nonetheless, Tang et al. find that research strength in imaging and other aspects is still weak, and currently lags behind Europe and the US as a whole – a disadvantage in terms of long-term competition.[22] They also identify an issue with government research funding and support not being in line with the rapid

---

[16] Elsa B. Kania, op. cit.

[17] Yang, Kuangjunyu, Xu Jing and Tang Chuan "Trend Observation: Strategic Deployment and Research Hotspot in Field of International Quantum Sensing and Measurement.", in Bulletin of Chinese Academy of Sciences, vol. 37, no. 2, pp. 259–263, October 2022.

[18] McKinsey & Company, Quantum Technology Monitor, 2023.

[19] Jaime Gaida, Jennifer Wong-Leung, Stephan Robin and Danielle Cave, "ASPI's Critical Technology Tracker: The Global Race For Future Power", Policy Brief, Report no. 69/2023, Australian Strategic Policy Institute, Canberra, 2023.

[20] Edward Parker et al., "An Assessment of the US and Chinese Industrial Bases in Quantum Technology", RAND Corporation, 2 February 2022, accessed 16 April 2024, at https://www.rand.org/pubs/research_reports/RRA869-1.html; and Brian Hart et al., "Is China a Leader in Quantum Technologies?", China Power, accessed 27 March 2024, at https://chinapower.csis.org/china-quantum-technology/.

[21] Jamie Gaida, Jenny Wong-Leung and Stephan Robin, '"Critical Technology Tracker': Who is Leading the Critical Technology Race?", Australian Strategic Policy Institute, 2023, accessed 27 March 2024, at https://techtracker.aspi.org.au

[22] Tang Chuan, Fang Junmin, Wang Lina and Zhang Juan, "The Development Trend and Planning Analysis of Quantum Information Technology", in World Science and Technology Research and Development, vol. 39, no. 5, pp 448–456, 2017

multidisciplinary development and long-term support needed to develop the relevant quantum technologies.

On the other hand, while substantially fewer in number than for communications or computing, Chinese patent applications on quantum sensing have trumped US and EU applications in terms of quantity (cf. Figure 4).[23]

This is also reflected in publications. China issued 7050 publications on quantum computing and 6440 on communications between 2011 and 2020, but only 1539 publications were produced on quantum sensing. Similarly, research capacity and the number of highly cited publications in quantum sensing are also considerably lower than in the other two areas. Interestingly, 41.4% of China's quantum sensing publications have a focus on quantum imaging.[24]

In terms of commercialisation, moreover, studies conducted have thus far not identified any quantum sensing technologies in which China has made substantial breakthroughs or is a leader. Pan Jianwei has affirmed that "China started late in quantum sensing, and there is a certain gap with developed countries".[25] Only very few Chinese companies seem to be doing meaningful R&D in quantum technology.[26] Most of these – both large and small – focus on communications or computing applications. None of the large companies and only one among the eight identified Chinese quantum start-ups focus on sensing.[27] Indeed, Yang et al. (2022) identify a need for China to support the application and transformation of quantum sensing and measurement technology in the long term. They call on China to set out its research and development priorities in a hierarchy, and to strive to create market demand – often a necessary precondition for private capital to enter the game.[28]

Weaknesses and path dependencies

China has been rapidly emerging as a key player in quantum technologies but still faces a number of challenges.

A number of quantum *technology clubs* have emerged that prohibit members from engaging with China. The US Quantum Consortium,[29] for instance, includes companies from 36 countries, but excludes Chinese companies. Under the framework of the US-EU Trade and Technology Council (TTC), Washington and Brussels are also seeking to accelerate technology cooperation in quantum technologies.[30] Such measures not only threaten China's supply of quantum R&D, but also affect China's academic exchanges with the rest of the world.

According to Xue Qikun, one of China's top quantum scientists from the prestigious Tsinghua University, China is not yet fully self-sufficient and hence *relies on imports of core components* and advanced materials and equipment, such as helium dilution refrigerators for computing.[31] As no discussion could be identified in Chinese academic sources and no granular analysis of supply chain interdependencies exists, it is unclear what the true extent of import dependencies for quantum sensing are – either in general or with regard to the EU.

---

[23] Brian Hart et al., op. cit.; Edward Parker et al., op. cit.; Nigel Clarke et al., European Patent Office, Landscape Study on Patent Filing, Quantum Metrology and Sensing, Brussels, 2019; McKinsey & Company, Quantum Technology Monitor, 2023; and China Academy of Information and Communications Technology, 量子信息技术发展与应用 研究报告 [Quantum information technology development and application research report], Beijing, 2022.

[24] Edward Parker et al., op. cit.

[25] Pan Jianwei (潘建伟), "Better Promote the Development of My Country's Quantum Technology" (更好推进我国量子科技发展), Red Flag Manuscript (红旗文稿), 8 December 2020, accessed 27 March 2024, at https://news.ustc.edu.cn/info/1056/73476.htm.

[26] In 2022, RAND identified 8 quantum-focused start-ups (Ciqtek, Kunfeng, Origin Quantum, Qasky, QuantumCtek, QuDoor, Shenzhou Quantum Communication Technology and SpinQ) and 5 large technology companies with quantum research groups (CAS-Alibaba Quantum Computing Laboratory, Baidu Quantum Computing Laboratory, Huawei HiQ, TenCent and ZTE). Edward Parker et al., op, cit.

[27] Elsa B. Kania, "China's Quest for Quantum Advantage: Strategic and Defense Innovation at a New Frontier", in *Journal of Strategic Studies*, vol. 44, no. 6, pp. 922–952, December 2021, doi: 10.1080/01402390.2021.1973658

[28] Yang Kuangjunyu, Xu Jing and Tang Chuan "Trend Observation: Strategic Deployment and Research Hotspot in Field of International Quantum Sensing and Measurement.", in *Bulletin of Chinese Academy of Sciences*, vol. 37, no. 2, pp. 259–263, October 2022.

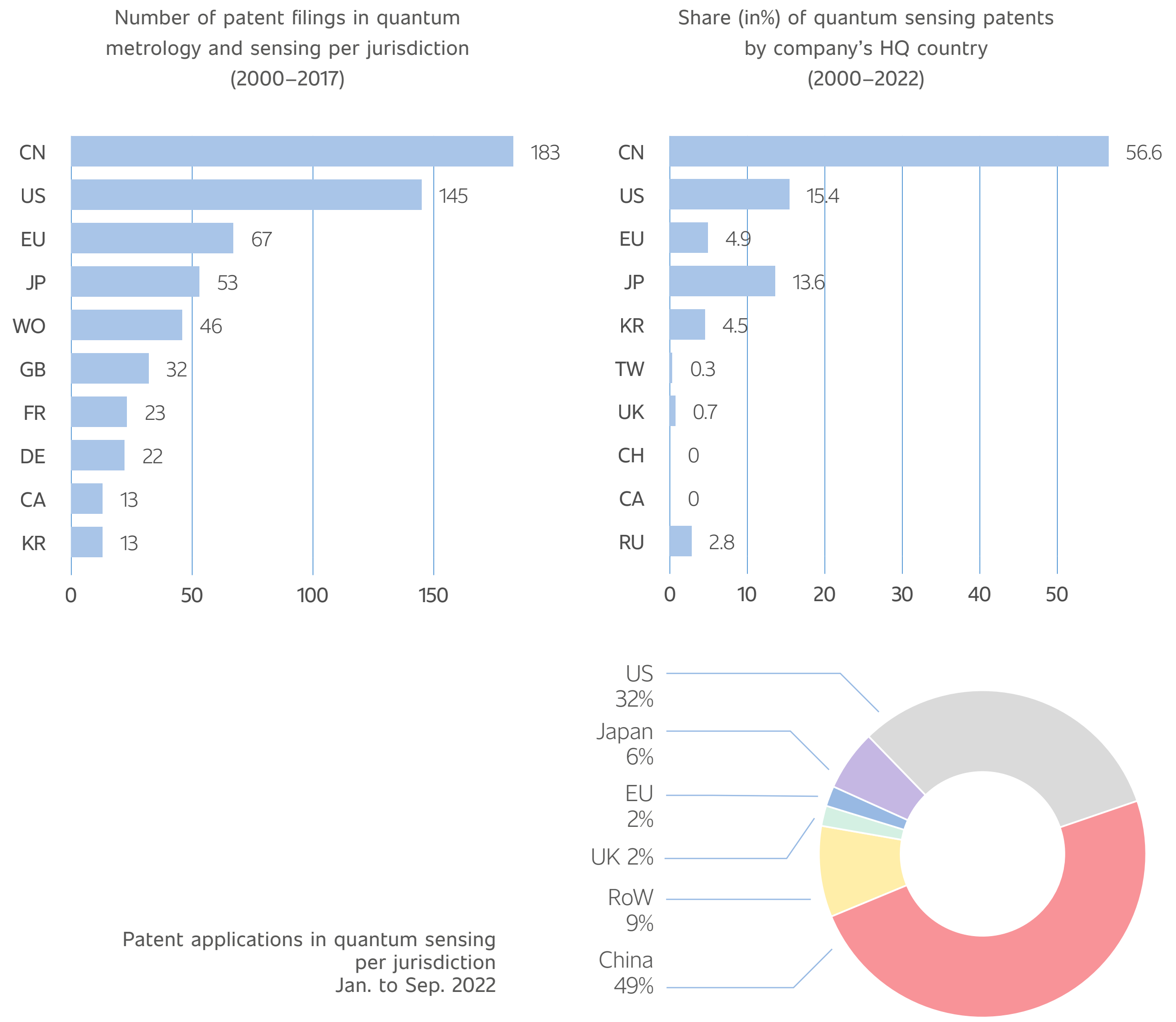
[29] The Quantum Economic Development Consortium, QED-C members, accessed 27 March 2024, at https://quantumconsortium.org/members/.

[30] The White House, "US-EU Joint Statement of the Trade and Technology Council", 31 May 2023, accessed 27 March 2024, at https://www.whitehouse.gov/briefing-roo m/statements-releases/2023/05/31/u-s-eu-joint-statement-of-the-trade-and-technology-council-2/.

[31] Li Huashan (李华山), "The reporter interviewed Xue Qikun, Vice President of Tsinghua University and Academician of the Chinese Academy of Sciences, how to grasp the general trend and make good first moves in developing quantum technology?" (记者专访清华大学副校长 中国科学院院士薛其坤 发展量子科技如何把握大趋势、下好先手棋?), School of Humanites, Tsinghua University, 21 October 2020, accessed 27 March, at https://www.rwxy.tsinghua.edu.cn/shssen/info/1001/1016.htm.

China only began its efforts to develop R&D capabilities in quantum technology in the 2000s. The country therefore *lacks a sufficient talent pool* (see Figure 5).[32] China produced 57,693 graduates in quantum technology in 2020, well behind the EU's 135,511 but ahead of the 45,087 US graduates.[33] According to the National Bureau of Statistics (NBS), China only has around 100 professionals working in quantum.[34] The pool of overseas talent is also shrinking, amid measures especially by the US to limit the flow of technology and knowledge to a strategic adversary.

FIGURE 4: Quantum sensing patent applications


Number of patent filings in quantum metrology and sensing per jurisdiction (2000–2017)

Share (in%) of quantum sensing patents by company's HQ country (2000–2022)

Patent applications in quantum sensing per jurisdiction Jan. to Sep. 2022

Source: CAICT = China Academy of Information and Communication Technology, an organization subordinate to the Ministry of Industry and Information Technology (MIIT)

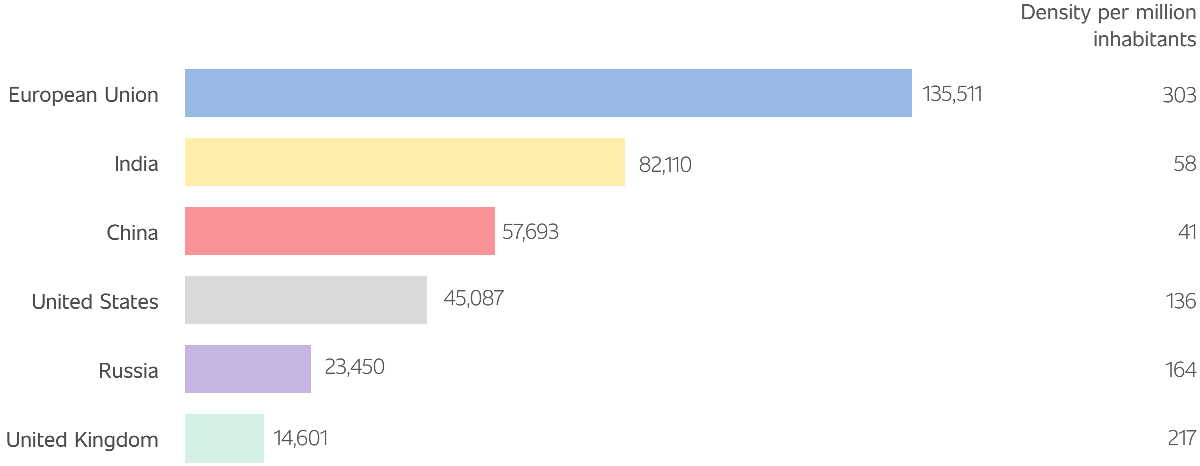
---

32 "China has joined the 'first echelon' of quantum computing: Why is it a battleground for hard technology?" (中国跻身量子计算"第一梯队", 为何它是硬科技必争之地), OFweek, 6 March 2023, accessed 27 March, at https://m.ofweek.com/ai/2023-03/ART-201712-8440-30589599.html.

33 McKinsey & Company, Quantum Technology Monitor, 2023.

34 Wang Yanbin (王延斌), "Quantum talents have become a 'scarce resource', and experts call for increased training efforts" (量子人才成"稀缺资源", 专家呼吁加大培养力度), *Science and Technology Daily*, 10 October 2023, accessed 27 March, at http://www.stdaily.com/index/kejixinwen/202312/fae98e95bb1b4164bc4db0aeb1c88f13.shtml.

FIGURE 5: Quantum technology graduate distribution by nation



Source: National government websites; OECD

1 Graduates of master's level or equivalent in 2019 in biochemistry, electronics and chemical engineering, information and communications technology, mathematics and statistics, and physics.
2 High-level estimates.
3 The actual talent pool for the United States may be larger, as bachelor's programmes are longer and master's programmes are less common

China has not established a comprehensive *framework for quantum technologies* and its relevant application areas. As a result, in quantum computing for instance, many patents focus on areas where China does not necessarily have synergies with regard to quantum R&D projects.[35] The same is true of quantum sensing, where Yang et al. call for a more coordinated approach to R&D.[36]

Private sector involvement in quantum is extremely low. China's less advanced financial system and limited engagement by the private sector in early R&D make it difficult to attract private sector investment in the commercialisation of quantum technology.[37]

China does not currently have an established system of *standardisation and certification*. This is critical for clients, especially with regard to their security requirements.[38]

EUROPE'S STRENGTH IN QUANTUM SENSING AND ITS APPLICATION FRAMEWORK

Europe has established itself as a leader in quantum sensing innovation and commercialisation, leveraging its robust academic and research infrastructure and fostering an environment conducive to public-private collaboration.

Europe's ambition, policies and strategic goals for quantum sensing technology

Europe has been at the forefront of quantum sensor technology, driven by robust research programmes, significant funding and collaborations among universities, research institutions and industry. EU quantum sensing now benefits from decades of R&D, making it an invaluable asset for countries such as China that are

---

[35] "Stories from the Frontier of Innovation, Hefei has a 'Quantum Avenue' (来自创新前沿的故事】合肥有条"量子大道), *Anhui Daily*, 20 January 2020, accessed 27 March, at http://m.xinhuanet.com/ah/2020-01/20/c_1125483844.htm.

[36] Yang Kuangjunyu, Xu Jing and Tang Chuan "Trend Observation: Strategic Deployment and Research Hotspot in Field of International Quantum Sensing and Measurement.", in *Bulletin of Chinese Academy of Sciences*, vol. 37, no. 2, pp. 259–263, October 2022.

[37] Shanghai Municipal Commission of Economy and Informatisation, "Representative members focus on the 'digital economy': How to upgrade in the mainstream?" (代表委员聚焦"数字经济": 风口之上如何提档升级?), 13 March 2023, accessed 27 March, at https://www.sheitc.sh.gov.cn/yjbg/20230313/840027d51139495c8bfe4707335c1abd.html.

[38] Ye Lingzhen (叶玲珍), "Yin Hao, Academician of the Chinese Academy of Sciences: Accelerate the introduction of quantum network certification standards to guide industry promotion and development (中科院院士尹浩: 加速出台量子网络认证标准 指导产业推广及发展), *Securities Times*, 18 March 2021, accessed 27 March, at https://company.stcn.com/gsxw/202110/t20211018_3770729.html.

seeking to rapidly advance their capabilities. European public actors regularly underline the strategic importance of quantum.[39]

There are, however, challenges with regard to adoption, mainly linked to the initial upfront costs, high operating costs and uncertainty around performance in the nascent stages of technology development. While sensitivity is quantum sensors' biggest attraction, it is also their biggest drawback due to the potential for unsuppressed background noise to drown out the desired readings. There are other technology challenges regarding their integration with other processes, such as production-scale miniaturisation, customisation and production scalability. Continuous developments are being made on all fronts, in both academia and industry, as well as increased general awareness among education experts.

Quantum sensing is critical for applications like medical imaging and navigation. Europe strategically emphasises quantum technology to secure its global advantage, aiming to strengthen supply chains, boost product exports and create workforce opportunities through the commercialisation of these technologies, while at the same time enhancing national security. Alongside focused investment and a collaborative approach to accelerating innovation and commercialisation, other factors make Europe's quantum sensing landscape strong.

First, there is a *focus on indigenous development*. Europe prioritises developing homegrown quantum technologies, reducing reliance on external suppliers and enhancing supply chain security by fostering local expertise and industry. However, over-dependence within the EU could lead to vulnerabilities, especially if intra-EU relations are strained or if specific member states face economic or political instability.

Europe benefits from its *strong scientific infrastructure* and skilled professional talent pool in its leading universities and research institutions, working towards acceleration and miniaturisation of quantum sensing technologies. National governments also provide critical funding and policy support for quantum sensing technologies, such as through Germany's Federal Ministry of Education and Research.

European tech companies are increasingly investing in quantum sensing, assisting in research and the translation of technologies into market-ready products. The increasing number of start-ups, companies and organisations are among the biggest contributors to the global quantum sensing supply chain.

Europe's focus on quantum technologies includes efforts at *standardisation* and coordination.[40] Quantum metrology, sensing and imaging are among the areas of quantum technology standardisation on which the European Committee for Standardisation (CEN) and the European Committee for Electrotechnical Standardisation (CENELEC) have collaborated. These initiatives seek to plan and organise European standardisation initiatives in order to strengthen Europe's position as a leader in this area.

Quantum sensing technology framework and deployment in Europe

The focus of European quantum sensing is not only basic research, but also applications and prototypes for industrial use. Several applications have transferred to European industry, resulting in a growing number of quantum start-ups and spin-offs. The total landscape of companies working in quantum sensing is distributed across Europe (see Figure 6). The UK and Germany have the most start-ups, probably because their significant national quantum initiative budgets have led to tech spinout.

There is an emphasis on the significance of quantum technologies for a wide range of applications that are already experimentally feasible today, along with the need to make Europe increasingly cutting-edge and autonomous from a research perspective and its impact on the industrial sector.[41]

---

[39] The European Commission's Digital Compass 2030 vision contains ambitious objectives for Europe's digital transformation. Quantum technology plays a significant role with the goal of positioning the continent at the forefront of quantum capabilities by 2030. In 2020 the Commission also created its own industrial strategy to support the transition to a digital economy. Quantum technologies are mentioned as "key enabling technologies that are strategically important for Europe's industrial future", and in 2023 the EU launched a European Economic Security Strategy to address vulnerabilities in its economy, maximise the benefits of openness while minimising risks associated with economic interdependencies, with quantum technologies as one of four technology areas on which to do a risk assessment. Losing control of intellectual property and technological advantage in quantum sensing capabilities could compromise the strength of the Single Market. The European Space Agency's (ESA) Director General. Josef Aschbacher, defines quantum technology as a strategic priority in the ESA's Agenda 2025. The ESA has been working on quantum technologies for over 25 years, contributing to advances in quantum communications and sensing.

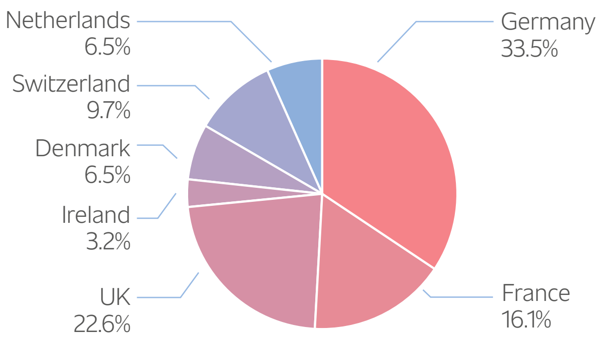
[40] van Deventer, O., Spethmann, N., Loeffler, M. et al., "Towards European Standards for Quantum Technologies", in *EPJ Quantum Technology*, vol. 9, no. 33 (2022), https://doi.org/10.1140/epjqt/s40507-022-00150-1

[41] For example, actual quantum space gravimetry missions are expected to be launched by 2040, enabling Europe to gath-

In Europe, the quantum sensing landscape is making progress with addressing societal and technological demands across a wide array of sectoral developments . This is driven by many factors, ranging from economic gain to civil motivations. The health and well-being of citizens play a fundamental role in the attraction to medical applications, while recent announcements on China's advances in quantum radar, if true, will drive motivations to stay defensively competitive.

The commercialisation of quantum sensors varies by application area, each of which presents unique challenges, notably the demands on device engineering with regard to size, weight and power (SWAP), the cost of development and resulting consumer costs, as well as measurement capabilities and robustness. As a result, most of the funding has been focused on developing proofs of concept that will lead to marketable technologies, growing sensing capabilities and creating a supply of products. Developments in recent years highlight Europe's strategic approach to harnessing quantum sensing as a catalyst for both scientific advancement and economic competitiveness.

FIGURE 6: European quantum technology start-ups overview in quantum sensing



Source: QURECA's proprietary database of quantum sensing companies.

CASESTUDY: EUROPE VS CHINA

This section assesses European strengths in quantum sensing technologies in the healthcare sector as a case study for assessing Europe's indispensability to China.

Europe's strategic goals for quantum sensing technology in healthcare

Quantum sensing is poised to revolutionise healthcare by improving diagnostic methods and patient care. They can potentially enhance diagnostic precision, enabling early and accurate detection of diseases, and facilitating non-invasive medical procedures. Its ability to monitor biological processes at the quantum level will pave the way for personalised medicine. Techniques such as nitrogen-vacancy centre imaging allow non-invasive diagnostics, reducing the risk of harm to patients and leading to faster recovery times. In addition, it promises advances in drug development and delivery monitoring, ensuring optimal therapeutic outcomes. These techniques can track the movement and concentration of drugs within the body in real time, optimising outcomes and reducing side-effects. Continuous monitoring of physiological parameters using quantum sensors can lead to a more preventive approach to health, predicting and averting illnesses before they manifest.

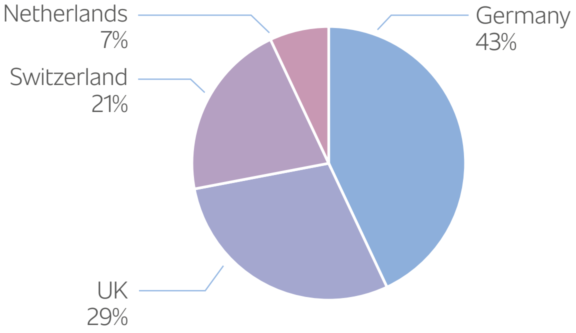
Europe recognises the importance of fostering healthcare innovation to tackling global health challenges. Quantum technologies, such as quantum sensing, are deemed vital for preserving Europe's standing in the global pharmaceutical market and its leadership in healthcare. These technologies are key to achieving supply chain sovereignty and addressing the economic vulnerabilities exposed by recent events such as the Russia-Ukraine conflict and the Covid-19 pandemic. They also offer significant commercial and workforce opportunities. By pioneering quantum-enhanced imaging and diagnostics, making them portable, cost-effective, non-invasive and increasingly sensitive, Europe is positioning itself to lead the next generation of medical technologies powered by quantum sensing. These advances promise not only to revolutionise patient care through more precise and earlier disease detection, but also to reinforce Europe's competitive edge in the global healthcare market. Strategically, the development and commercialisation of quantum sensing in healthcare align with Europe's goals to drive innovation, support high-tech industries and achieve autonomy in critical health technologies. Furthermore, healthcare offers a unique competitive advantage due to its broad market potential and the universal demand for health innovations. In addition, Europe's commitment to ethical standards in technology development, particularly in healthcare, reinforces its position as a moral leader setting global benchmarks for ethically developed healthcare technologies.

---

er high-precision gravimetric data fully autonomously. The CARIOQA Pathfinder mission, with a planned launch by 2030, aims to demonstrate the functioning of a quantum accelerometer in space using a technology called cold atom interferometry (CAI), which measures the acceleration of free-falling independent atoms by manipulating them with laser light.

Europe's approach to healthcare is influenced not only by commercialisation, but also by national security and geostrategic considerations. The Covid-19 pandemic exposed weaknesses in healthcare supply chains. Strategies such as dual sourcing and strategic stockpiling, and sustainable market frameworks for off-patent sectors are part of efforts to rebalance global supply chains. Geopolitical factors also have an impact on Europe's leadership in healthcare, especially when it comes to competition for important technology, innovation, intellectual property and medical personnel. Maintaining the EU's capacity to deliver efficient health security depends on member states' collaboration and commitment to health sovereignty. The Covid-19 pandemic brought to light the significance of European initiatives aimed at providing a platform for collaboration and standard-setting, thereby enhancing national endeavours. The United Kingdom has played a pivotal role in the commercialisation of quantum sensing for healthcare in the European context, leveraging its strong scientific research base, supportive government policies and strategic collaborations to drive innovation and market introduction of quantum technologies. It has 29% of the quantum sensing for healthcare market, second only to Germany (see Figure 7), and 22.6% of the quantum sensing market in general with a strong emphasis on translating laboratory research into practical, market-ready products and services that can enhance healthcare delivery, along with demonstrated integration into healthcare systems such as Cerca Magnetic's first commercial OPM-MEG [Optically Pumped Magnetometers- Magnetoencephalography (OPM-MEG)] system installation in hospitals.

FIGURE 7: Distribution of companies in quantum sensing for healthcare in Europe



Source: QURECA's proprietary database of quantum technology companies.

Europe's indispensability to China in quantum sensing for healthcare

In an era of geopolitical competition, maintaining strategic autonomy in critical technologies such as healthcare is vital. Furthermore, healthcare technology is an area where ethical considerations and regulations play a significant role, which allows the EU to set global standards that align with its values, and reinforce its moral and strategic leadership. Unlike sectors with limited commercial application or few ethical constraints, healthcare offers expansive market potential. The universal need for healthcare services ensures a constant demand for innovation, making it a lucrative area for investment and development, and quantum sensing presents opportunities for Europe to capture a substantial market share, driving competitiveness in the global healthcare technology market. This would ultimately give Europe a first mover advantage that is of great strategic importance for influencing technology and policy standardisation in quantum technologies for healthcare. Finally, technological advances in healthcare can spur economic growth by fostering new industries, creating high-value jobs and stimulating R&D activities.[42]

Europe has invested markedly more than China in quantum sensing applications and research at the academic level. Our research shows that the EU invested over €650 million in direct quantum sensing applications in the five-year period 2018–2023.

There is a well-established base of quantum sensor research throughout Europe on a variety of healthcare

---

[42] Quantum sensing, for instance, opens up new markets in medical technology, offering opportunities for start-ups and established companies alike. Moreover, core quantum sensing healthcare technologies such as atomic magnetometers, initially designed for neuroimaging through magnetoencephalography (MEG), have the potential to revolutionise environmental monitoring and geological exploration by detecting subtle variations in the Earth's magnetic field that will indicate underground structures or mineral deposits, or can be repurposed for military surveillance and reconnaissance. They could be used to detect stealth submarines, map underground bunkers or monitor troop movements without detection, offering a strategic advantage in intelligence gathering. Similarly, quantum dots, pivotal in healthcare for high-resolution imaging and diagnostics, extend their utility beyond medicine into quantum computing, display technologies and even enhanced security measures through their application to security inks for currency and official documents. They can also be adapted for use in advanced targeting and weapon guidance systems to improve the accuracy and efficiency of these systems, potentially leading to advances in precision-guided munitions and other smart weaponry. This dual-use nature of quantum sensing technologies underscores their transformative potential not only in advancing healthcare outcomes, but also in opening up new avenues for innovation in environmental science, technology and security, thereby amplifying their strategic importance and utility across sectors.

applications. With regard to the number of companies and the number of unique applications in those companies, the EU is way ahead of China in quantum sensing for healthcare.

Cutting-edge research involving real-time data collection on neurological and psychiatric conditions, such as dementia; rapid decreases in diagnosis times for bacterial infections from days to minutes, leading to fewer misdiagnosed antibiotics and helping to prevent antimicrobial resistance; new roles for CT scanners in early detection and therapy planning; non-invasive three-dimensional imaging of biological tissues; as well as numerous other advances in imaging techniques are just a few examples of the previously inaccessible medical tools that quantum sensing technologies have enabled. Our research shows that EU quantum sensing technological capabilities are far more mature than those of China, and an increasing knowledge gap has the potential to create technological indispensability vis-à-vis China. More application areas will emerge as the Technological Readiness Levels (TRLs) of products continually improve and more technologies move from laboratory research to consumer use. This is probably a consequence of Europe's early-bird approach to quantum sensing research investment, which is now leading to commercially ready products that could in turn lead to brand supremacy on the global market.

Europe is currently in a leading position vis-à-vis China to maintain levels of development of the technology. No dedicated plan to develop quantum sensing technologies for healthcare could be identified for China. Chinese academics are aware that computing and communications are receiving substantially more funding, but they see quantum sensing as playing a key role not only in China's military, but also in its healthcare ambitions.[43] The vast majority of the "quantum sensing" academic discourse, however, is non-strategic and deals with technical aspects of the respective sub-technologies.

Following our research and based on our knowledge, and in the absence of a detailed supply chain analysis, the security risk to Europe in terms of dependence on a specific supplier is minimal. However, should quantum sensing for healthcare become a high priority in China, Europe could continue with its current considerable autonomy in the field to avoid any additional risks.

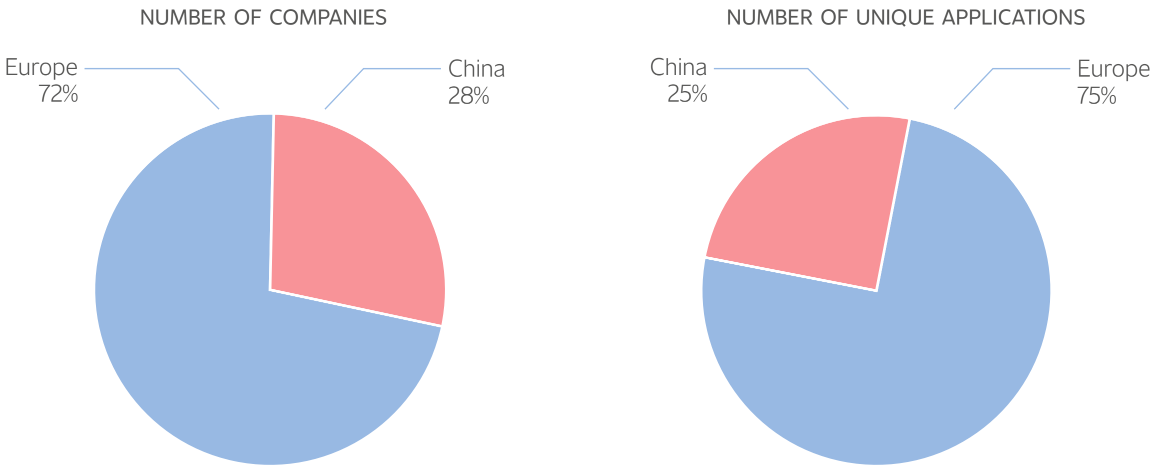
To summarise, from the above evidence and results:

- In quantum sensing for healthcare, Europe is host to a significantly higher number of companies and unique technologies compared to China and demonstrates a wider range of applications, indicating a more diverse and advanced sector.
- The companies working on quantum sensing for healthcare in Europe have a stronger commercialisation profile, indicating a more developed and advanced supply chain.
- The number of unique technologies in quantum sensing for healthcare is greater in Europe than in China, giving Europe a strategic advantage in the new technology and creating a knowledge gap.
- China does not see healthcare as a priority market for quantum sensing technologies, as evidenced by the absence of policies, funding and overall progress, as well urgency identified in the academic discourse.
- Europe has a clear advantage in commercial readiness, indicating a more market-ready sector and giving it first mover advantage.
- Europe's strong commercialisation profile, along with its reputation for manufacturing high-quality and reliable medical technology, positions it well for broader global healthcare market penetration compared to Chinese quantum sensing technologies, especially in western markets where European technologies are preferred due to their perceived quality and safety.
- Europe has a stronger R&D base and its robust intellectual property laws mean that it can leverage more IP rights and publications to widen the knowledge gap and moderate technology transfer. It also attracts more investment.
- The higher number of unique technology and larger niche applications make Europe a global leader able to set global standards on quantum sensing for healthcare applications and influence international market trends and practices.
- Europe can leverage trade policies to facilitate European quantum sensing technologies' entry into new markets.

---

[43] Yang Kuangjunyu, XU Jing and Tang Chuan, "Trend Observation: Strategic Deployment and Research Hotspot in Field of International Quantum Sensing and Measurement.", in *Bulletin of Chinese Academy of Sciences*, vol. 37, no. 2, pp. 259–263, October 2022.

FIGURE 8: Distribution of quantum sensing companies per region (left) and unique applications of those technologies per region (right)



Source: Data derived from QURECA's proprietary database of quantum companies specialising in healthcare applications.

DISCUSSING EUROPE'S LEVEL OF AMBITION

Given Europe's advances in quantum sensing for healthcare applications and China's thus far low to non-existent policy focus on this particular application area, there appears to be a window of opportunity for Europe to strengthen its technological indispensability in the next 10–15 years.

Level 1: threat prevention

Given the EU's advantage over quantum sensing "latecomer" China, in terms of research, application and talent development, as well as overall market maturity, and bearing in mind both the dual-use applications described above and the considerable upfront costs involved in developing such technologies, the EU should seek to prevent unwanted technology transfers to a potential strategic adversary.

At the time of writing, China's ambitions in quantum technologies overall and in quantum sensing mainly focus on areas with military applications, and no co-ordinated approach has been identified to develop or obtain the respective technologies. However, this does not mean that China is not trying to obtain critical information in order to develop its own sector.

In addition to combating industrial espionage, more attention should be paid to Chinese students, researchers, research collaborations and foreign investment (and those of other nationalities) that could facilitate such technology transfer. This also applies to (dual-use) export controls on basic research, and application level and outward foreign direct investment (FDI) by European companies that locate some of their core technology in China.

Feasibility: High. Under the European Economic Security Strategy, the EU is currently undertaking a risk assessment of four technology areas to avoid technology leakage detrimental to its national security. Quantum is one of them.[44] Measures to strengthen research security are also on the way.[45]

Level 2: ability to deny

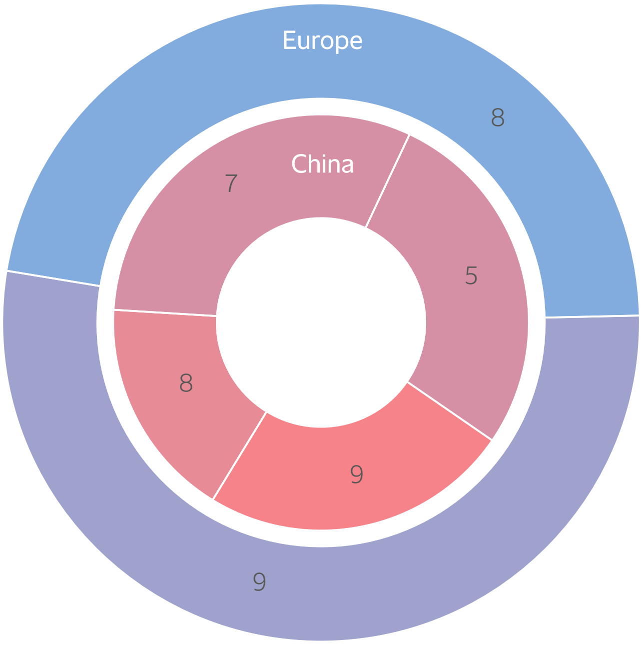
China acknowledges its gap to the technology frontier. The policy focus thus far, however, has been largely on military technologies and applications, and no dedicated healthcare ambitions could be identified.

---

[44] European Commission, "Commission recommends carrying out risk assessments on four critical technology areas: advanced semiconductors, artificial intelligence, quantum, biotechnologies", Press release, accessed 27 March 2024, at https://ec.europa.eu/commission/presscorner/detail/en/ip_23_4735.

[45] European Commission, "Proposal for a Council Recommendation on enhancing research security", 24 January 2024, accessed 27 March, at https://research-and-innovation.ec.europa.eu/document/download/e82a2fd9-ac12-488a-a948-87639eef10d4_en.

FIGURE 9: TRL levels for products in quantum sensing for healthcare



Source: Data derived from QURECA's proprietary database of quantum companies specialising in healthcare applications..

Note: In the EU all the products from companies in quantum sensing for healthcare are at TLR 8 or 9, whereas in China more products at lower TRLs (from 5 to 7) have been identified. Data taken from independent research analysis.

China also recognises a certain dependence on imports of foreign technology in pursuit of development in its quantum sector. It remains unclear, however, exactly where these dependencies lie in terms of either concrete inputs, or from where these inputs are currently sourced. Another, somewhat more obvious, dependence is knowledge. Chinese quantum sensing researchers are the second largest foreign group in both the US (behind EU researchers) and the EU (behind US researchers), and therefore reliant to a large extent on Europe's technology advantage vis-à-vis China. A third dependence is Europe's advanced market maturity. China concedes that its current quantum sensing market is still limited. Given the substantial upfront costs involved in developing these technologies at this still nascent stage, a sizeable downstream market for their respective applications is a key criterion in ultimately scaling-up production and bringing down the variable costs to a bearable level for the market. In this sense, Europe's advantages in terms of both commercialisation and standardisation could make it a key market for Chinese applications too. At the research level, there seem to be no clear dependencies as yet, something which might evolve in the coming years. At the same time, Europe does not seem to have any dependencies on China in terms of basic research, talent, the supply chain or downstream market commercialisation.

Feasibility: Medium. Building on its advantages, Europe is in a good position to further strengthen its position vis-à-vis China, perpetuating the respective Chinese dependencies on Europe. Given that quantum sensing in healthcare is not a policy priority for China, and the uncertainty about actual supply chain interdependencies, whether Europe could actually use this as leverage vis-à-vis Beijing remains unclear.

Level 3: ability to act

Europe's ambition should be high in terms of staying ahead of China and other challengers with regard to market applications for quantum sensing technologies in healthcare. The biggest two levers the EU has for increasing China's dependence are its large Single Market combined with the advanced market acceptance of healthcare applications (and respective standards), and China's dependence on EU knowledge.

Therefore, while the EU may avoid unwanted technology leakage and increase China's dependence on it, industrial policies and public-private collaborations will need to be continually assessed and further refined to maintain and expand Europe's technology edge over China. Policies on enabling R&D collaborations can crowd-in further private funding for developing quantum sensing technologies for healthcare at this early stage.

At the same time, the value and supply chains of this sensing sub-sector need to be studied further to improve understanding of the respective interdependencies, thereby allowing a more nuanced assessment of whether these interdependencies could also be preserved or further expanded for strategic purposes.

That said, China has shown in the past that its centrally steered political economy can mobilise substantial resources if it becomes top-level policy to rapidly catch up and build up technological sectors, regardless of financial efficiency. Thus far, this does not seem to be the case for healthcare. In addition, the EU now possesses a more elaborate toolkit for responding to such attempts than it had in the past, increasing the likelihood it can successfully maintain its edge.

Feasibility: Low. While the EU is likely to be able to maintain its technology edge vis-à-vis China given its predominant commercial advantage, if China decides this should become a priority sector, it might still be able to mobilise substantial resources and catch up. Until then, however, the EU can continue to leverage its market and knowledge/talent advantage.

Level 4: curtailment

The EU could intensify the inclusion of these technologies in its efforts to pluri-laterally prevent China from rapidly developing its own competitive quantum sensing sector by more closely aligning its technology supply chains and through standardisation efforts with like-minded countries, such as under the EU-US Trade and Technology Council (TTC). In addition, the EU could raise the threshold of all the measures mentioned above to avoid unwanted technology leakage, thereby at least slowing China's technology catch-up and thus ensuring that the EU and its like-minded partners stay ahead in this competition.

Feasibility: This is more difficult because alignment with like-minded partners may not be so straightforward, and the EU/European Commission may not have a legal basis for taking such measures if competence is with the EU member states. Furthermore, should China decide to treat this as a priority technology, it might simply be very hard to prevent it from developing its own competitiveness. As in the field of AI, for instance, it may be necessary to find a way to collaborate with China on aspects such as setting standards.

RECOMMENDATIONS FOR EU POLICYMAKERS

Based on the above analysis, we propose consideration of the following key policy recommendations.

Level 1: Threat prevention

- Establish a more granular understanding of quantum sensing supply chain(s) to shed light on the various interdependencies with China and thus allow industrial and trade policies to be drafted, for example to ensure continued access to critical materials.

- Raise the spectre and increase overall awareness of the risks of unwanted technology outflow; work with universities and Higher Education Institutions to develop research/knowledge security policies, due diligence guidelines and compliance mechanisms for technology collaborations; and establish an overview of quantum projects in Europe with foreign funding/involvement (e.g. foreign investments, collaborations, researchers etc.).

- Clarify the dual-use risks that quantum sensing present, and adjust the respective export control mechanisms and lists.

- Establish a "risk tracker" for strategic technologies.

- Tighten/consolidate the EU's approach to inbound investment screening.

- Prohibit funding from the Chinese Scholarship Council and investigate Chinese funding from other sources of critical technology development in Europe; substitute the funding reduction with increased spending on innovation.

- Tighten export controls.

- Consider looking into outward FDI that might currently allow/facilitate unwanted technology outflows.

- Make a commitment to international IP enforcement

- In healthcare, prioritise the safeguarding of personal or medical data. At the very least, national legislation must incorporate provisions that establish a legal framework for processing personal data for specific research objectives.

Level 2: Ability to deny

- Increase public high risk/high gain R&D investment to create (tax) incentives that crowd-in private sector investment to critical areas of an industry with traditionally high barriers to standardisation (e.g. industrial policy, demand-side policies, public investment). This should be available only to actors in the EU or like-minded countries.

- Deepen innovation cooperation, not least by means of increased funding for strategic technology development among like-minded countries and the EU.

- Continue to facilitate academic/industry collaboration.

- Identify the critical success factors that help drive the industry or technology, such as the research base (talent), funding, fair competition standards, market commercialisation, technology miniaturisation and portability.

- Knowledge creation will be an important element. Create new training programmes and university partnerships to develop expertise and human capital in partner countries, as well as talent policies/regulations to continue to attract and retain the brightest and the best.

- Ensure continued funding for research on and development of technologies and tools that prevent key vulnerabilities, ensuring that Europe will maintain or strengthen its place as a technology and service provider for quantum sensing and preventing dependence on communities that are dominated by the US or China.

Level 3: Ability to act

- Deepen the digital Single Market, for example through the creation of common data pools, harmonisation of regulations and standards, and deregulation.

- Further refine industrial policies as required to crowd-in private capital.

- Drive standardisation efforts that aim to protect knowledge with promising standardisation strategies, cementing the EU's first-mover advantage and strategic leverage.

- wIncrease policy coordination among like-minded digital industrial entities.

- Conclude digital free trade agreements.

- Strengthen resilience by investing in key partners, starting with Europe's neighbourhood, given the numerous industrial initiatives in Europe, but also in the context of the EU-US TTC, for instance by driving the discussion on global quantum technology standards.

SCORECARD 2 QUANTUM SENSING FOR HEALTH CARE

	Threat prevention	Ability to deny	Ability to act	Curtailment
Feasibility of level of ambition	High	Medium	Low	Not feasible
Core policy recommendations	• Invest in supply chain analysis for quantum sensing technologies, ensuring strategic autonomy and reduced reliance on non-European components and knowledge • Establish a "risk tracker" for strategic technologies • Tighten/consolidate the EU's inbound investment screening approach and export controls, and consider outbound FDI screening	• Increase public high risk/high gain R&D investment to create incentives (e.g. tax) to crowd-in private sector investment • Deepen innovation cooperation – not least by means of increased funding – for strategic technology development among like-minded countries and the EU • Continue to facilitate academic/industry collaboration	• Deepen the digital Single Market (e.g., create common data pools, harmonisation of regulations and standards, deregulation) • Further refine industrial policies as needed to crowd-in private capital • Drive standardisation efforts that aim to protect knowledge through promising standardisation strategies • Develop testbeds for rapid prototyping and testing of quantum sensing technologies in healthcare settings	• None

AUTHORS

Michael Settelen is Senior Consultant with China Macro Group, a specialised research-based European consultancy focused on China. Contact: msettelen@chinamacro.ch

Dr Araceli Venegas-Gomez is the founder and CEO of QURECA, a company leader in quantum education offering professional and consultancy services in the UK and Spain. She is based in Spain. Contact: araceli.venegas-gomez@qureca.com

Abhishek Purohit is a doctoral researcher at the Advanced Research Center (ARC) at the University of Glasgow, and works as a Technology and Strategy Associate at QURECA in the UK. Contact: abhishek.purohit@qureca.com

Simon Armstrong works as Quantum Educational Content Development Manager at QURECA in the UK. Contact: simon.armstrong@qureca.com

Dependencies in Blockchain and Smart Contracts: Technologies, Markets and Policy

Cyrille Artho and Rogier Creemers

ABSTRACT

Blockchain technologies and related smart contract applications are areas in which particular characteristics lead to interdependence between Chinese and European players. In contrast to, for instance, semiconductor manufacturing equipment or strategic raw materials, the applications themselves are largely defined by software and programming capabilities, the vast majority of which are available in open source. Blockchain applications do not usually require specialised hardware as off-the-shelf equipment is sufficient. This chapter therefore explores the dependencies that could result from "soft factors", such as trust, market acceptance, supporting human talent and policy support. It finds that European options for leveraging Chinese dependencies are limited in many areas. Nonetheless, European policymakers and stakeholders could build on their inherent strengths to enhance European strategic autonomy in several areas.

SCORECARD 1	TECHNOLOGY FIELD: BLOCKCHAIN FOR SMART CONTRACTS		
Source of European technology strength	Research and innovation	Intellectual property and patents	Production and commercialisation
	● Medium	● Low	● Medium

Type of European technology strength	Technological excellence	Commercialisation advantage	Conditioning of market access	Regulatory, political and normative factors	Sustainability	Research partnerships with third countries
				X	X	

Degree of European leverage	Medium
	Low ——○—————— High

INTRODUCTION

To understand the possible impact European measures could have on China's blockchain ecosystem, it is necessary to first understand how Beijing is attempting to incorporate such technologies into its development trajectory. The Chinese government is famously ill-disposed towards cryptocurrencies. In 2015, the authorities prohibited banks from using them in transactions, and from mining them to use them. In 2021, mining was banned completely. They have considerably more enthusiasm for the underlying blockchain technology, however, which stems from blockchain use cases beyond cryptocurrencies, such as for smart contracts. These are computer programs that enable automatic generation of outcomes once particular predetermined conditions have been met. The decentralised nature of blockchain allows these contracts to be more accurate, timely and tamper-proof. Other applications of blockchain lie in supply chain monitoring and tracing – a key element of China's manufacturing-led economic strategy – as well as enhancing the transparency of the financial system.

In 2021, the Chinese government published a series of development plans as part of the 14th five-year planning cycle. These outlined shifts in priorities in industrial policy in response to both domestic and international structural change. The new policy recognises that export-oriented manufacturing and investment-driven growth have resulted in significant developmental imbalances and have little future growth potential, and prioritises the role of strategic digital technologies. Blockchain is one such technology that is mentioned as a critical enabler in the overall plan for national informatisation, as well as the policy blueprints for the digital economy,[1] government digitisation[2] and the fintech sector, albeit at a high level of abstraction.[3]

Chinese policy actors have identified several areas in which progress is required to achieve their ambitions. The 2023 Blockchain White Paper from the China Academy of Information and Communications Technologies, a think tank affiliated with the Ministry of Industry and Information Technology (MIIT), lists the following:[4]

- Shortcomings in independent research and development capabilities hinder deep innovation in applications, particularly in areas such as consensus algorithms and data storage. This is demonstrated by the lack of core patents and a relatively weak global voice.

- Shortcomings in supporting technologies, such as cybersecurity, authorisation management, identity verification and biometrics.

- Shortcomings in effective governance and industrial scale.

  A lack of overall planning in blockchain infrastructure construction, leading to regional and sectoral stove piping, as well as a lack of unified technical standards and interconnection of nodes and data flows across regional and sectoral boundaries.

Professionals in the field echo these assessments, identifying regulatory uncertainty, talent scarcity and barriers to data access, as well as reliable integration of blockchain platforms with physical objects as major obstacles to growth. They also signal a need to further develop technologies in areas that demand high speed and bandwidth, and to reduce computing and data storage costs.

A range of policy responses to these issues is already under way. The National Blockchain Technology Innovation Centre opened in Beijing in the spring of 2023, with the aim of enhancing domestic research and development capabilities, and addressing the human resources deficit. The institute plans to train 500,000 blockchain experts.[5] It is supported by the Beijing Academy of Blockchain and Edge Computing, which played a leading role in the development of Chang'an Chain, China's first homegrown open-source blockchain platform.[6] The National Blockchain and Distributed Accounting Technology Standardisation Technical Committee (TC590) published its first set of standards for blockchain architectures in May 2023, followed later in the year by standards for systems testing, certificate deposits, smart contract lifecycle management, terminology and APIs. At the time of writing, at least 12 other standards are at the drafting stage.[7] In October 2023, the MIIT published a plan to develop integrated computing infrastructure,[8] with the intention of reducing the costs of artificial intelligence and blockchain applications. Chinese researchers and institutions have taken a clear lead over the global competition in internationally recognised blockchain research publications, as is discussed below.

However, China has not achieved its ambitions. Despite China's lead in academic publications on blockchain

---

[1] State Council, ““十四五”数字经济发展规划” [“14th Five Year Plan” for the Development of the Digital Economy], accessed 25 March 2024, at https://www.gov.cn/zhengce/content/2022-01/12/content_5667817.htm

[2] National Development and Reform Commission, ““十四五”推进国家政务信息化规划” [The “14th Five-Year Plan” promotes the central government's informatization planning]. accessed 25 March 2024, at https://www.gov.cn/zhengce/zhengceku/2022-01/06/content_5666746.htm

[3] People's Bank of China, ““金融科技发展规划 (2022–2025 年)” (2022–2025年) [Fintech Development Plan (2022–2025)], accessed 25 March 2025, at https://www.gov.cn/xinwen/2022-01/05/content_5666525.htm

[4] Chinese Academy of Information and Communication Technology, “区块链白皮书（2022年）” [Blockchain White Paper (2022) accessed 25 March 2024, at http://www.caict.ac.cn/kxyj/qwfb/bps/202212/P020230105572446062995.pdf

[5] Xinhua, “国家区块链技术创新中心落地中关村”, [National Blockchain Technology Innovation Centre Lands in Zhongguancun], accessed 25 March 2024, at http://www.news.cn/local/2023-05/10/c_1129603623.htm

[6] Tom Zuo, “China's National Blockchain Research Center Aims to Train 500,000 Blockchain Professionals”, Forkast, accessed 25 March 2024, at https://forkast.news/china-national-blockchain-center-launched/

[7] Standardisation Administration of China, “TC590全国区块链和分布式记账技术标准化技术委员会” [National Blockchain and Distributed Ledger Technology Standardization Technical Committee], accessed 25 March 2024, at https://std.samr.gov.cn/search/orgDetailView?tcCode=TC590

[8] Ministry of Industry and Information Technology et al. “算力基础设施高质量发展行动计划” [Computing Infrastructure High-Quality Development Action Plan], accessed 25 March 2024, at https://www.gov.cn/zhengce/zhengceku/202310/P020231009520949915888.pdf

technology and smart contracts, the results for fundamental underlying technologies have not yet been translated into innovation at the level to which the Chinese government aspires. Mainstream blockchain and smart contract platforms still mostly originate from the United States. These are based on technologies that were established previously (such as Ethereum), and that typically are not heavily publicised by their creators in academic venues, which explains why less visibility in research does not necessarily reduce the impact of a product.

The difficulties China faces are not significantly different from those confronting other major players. Both blockchain and smart contracts are maturing as technologies, even though they are still mostly used in emerging applications or relatively niche domains. On the blockchain side, advances have been made in energy efficiency, especially after Ethereum switched to the energy efficient "proof of stake" paradigm in September 2022. Furthermore, work is continuing to make the software platforms for blockchains more resilient by allowing multiple versions of a blockchain implementation or multiple blockchains to interact better using "relays". For smart contracts, tools for verifying larger-scale applications are still improving and need more development before they can be widely used by engineers. In the interim, runtime monitoring of running smart contracts is an efficient alternative that can ensure that attacks on a smart contract with weak security are stopped as soon as possible.

This chapter assesses whether or to what extent China relies or could come to depend on European capabilities. In other words: are reverse dependencies feasible, even if only in soft form?

CHINA'S PILOT USES OF BLOCKCHAIN TECHNOLOGY

China has significant ambitions to develop blockchain capabilities. In 2021, the MIIT identified five categories of blockchain-related tasks as crucial: (a) empowering the real economy through, for instance, better supply chain management, product traceability and data sharing; (b) improving public services, including in areas such as education, employment, healthcare, the judiciary and smart city infrastructure; (c) establishing an industrial foundation for blockchain by ensuring compliance with industry standards, cybersecurity and intellectual property protection; (d) fostering blockchain industry chains with high-level blockchain products and enterprises, and a flourishing open source ecosystem; and (5) promoting the integrated development of blockchain with the industrial Internet, big data, cloud computing and artificial intelligence.[9] Since then, multiple pilots have taken place across China and across various policy areas.[10]

In December 2022, the Central Committee and State Council published "Opinions Concerning Building Basic Data Structures and Giving Greater Rein to the Role of Data".[11] This set an overall blueprint for China's data economy and tasked local government in technologically advanced areas with exploring ways to achieve its objectives. In Shanghai, the result was the establishment of the Shanghai Data Exchange, which envisages a "one chain, three platforms" blockchain tool to coordinate data registration, trading and clearing processes.[12] A similar state-backed blockchain system is part of a pilot zone set up in Beijing to experiment with fostering commercial data markets.[13] Perhaps more ominously, China's national-level blockchain programme Blockchain

---

[9] Ministry of Industry and Information Technology and Cyberspace Administration of China, "关于加快推动区块链技术应用和产业发展的指导意见" [Guiding Opinions concerning Accelerating the Application and Industrial Development of Blockchain Technologies], accessed 25 March 2024, at http://www.cac.gov.cn/2021-06/07/c_1624629407537785.htm

[10] To facilitate fiscal administration, the tax authorities of multiple cities and provinces such as Beijing, Hunan, Shandong, Shanghai, Shenzhen and Ningbo instituted programmes for digitised invoicing, and blockchain supports many of them. The Supreme People's Court has launched a pilot to use blockchain in the judiciary, most notably to preserve evidence materials. Kaiming Quan, "区块链电子发票应用研究" [A Study of Blockchain E-Invoice Applications], Allbright Law Office, accessed 25 March 2024, at https://www.allbrightlaw.com/CN/10475/3e31b67cb669d8e2.aspx; and Supreme People's Court, "最高人民法院关于加强区块链司法应用的意见" [SPC Opinions concerning Strengthening the Judicial Application of Blockchain], accessed 25 March 2024, at http://gongbao.court.gov.cn/Details/6743107386c86617673dcd3503bd3d.html

[11] CCP Central Committee and State Council, "关于构建数据基础制度更好发挥数据要素作用的意见" [Opinions concerning Building Basic Data Structures and Letting Data Bettter Play Its Role as Production Doctor, accessed 25 March 2024, at https://www.gov.cn/zhengce/2022-12/19/content_5732695.htm

[12] Shanghai has also launched policies on the development of blockchain applications in the metaverse. Specifically, it envisages controllable blockchain architectures and blockchain-enabled storage systems as the foundation for immersive virtual environments and the activities that take place there. This is quite a gamble as the economic potential of the metaverse is far from certain and it is worth remembering that large international companies seem to have withdrawn from pursuing it. Moreover, even if that potential is realised, it may be through technical infrastructures other than blockchain-enabled ones. Li Lanqing et al. "上海落实"数据二十条" [Shanghai Implements '20 Data Articles'] 21 Caijing, accessed 25 March 2024, at https://m.21jingji.com/article/20230731/herald/2f63b81a9a107ca1e8e1073e936bb028.html?mc_cid=e7d12e966b&mc_eid=ad7c94e0d8

[13] Xinhua, "北京数据基础制度先行区启动运行" [Beijing Basic Data System Starts Operations], Xinhuanet, accessed 25 March 2024, at http://www.bj.xinhuanet.com/20231111/3d975226a02d4ce4be2513635414b985/c.html?mc_cid=b7deca7c7d&mc_eid=ad7c94e0d8

Service Network has collaborated with the Ministry of Public Security to launch an online decentralised identity verification mechanism.[14]

Despite its rejection of cryptocurrencies, Chinese financial institutions have started experimenting with tokenised financial assets on international blockchain platforms. Most notably, in June 2023 the Hong Kong subsidiary of the Bank of China issued US$28 million in tokenised securities on Ethereum's blockchain platform.[15] Hong Kong is also the hub for mBridge, a blockchain-based platform built to facilitate international financial settlements in central bank digital currencies. As of October 2023, it had grouped four founding central banks and 26 observing members including the central banks of France, Italy and Norway, as well as the European Central Bank.[16] mBridge promises to be far quicker and more efficient than the existing SWIFT system for international settlements.

On smart contracts, the Industrial and Commercial Bank of China (ICBC), China's biggest bank, and the e-commerce platform JD.com have developed a supply chain finance application involving smart contracts and the Digital Yuan, China's Central Bank Digital Currency (CBDC).[17] Another smart contract functionality involving the Digital Yuan was launched by the food delivery platform, Meituan. In the latter case, smart contract functionality is somewhat limited, triggering the user's participation in a daily prize draw.[18] These examples illustrate China's ambitions and practical advances in blockchain technology.

ASSESSMENT OF DEPENDENCIES

The challenges outlined above are not unique to China and do not necessarily translate into Chinese dependencies on Europe. However, it is still worth exploring the degree of mutual or unidirectional dependencies between Europe and China.

The Chinese academic literature is largely silent on the extent to which scholars are hampered as a result of having to depend on access to foreign technologies. With the exception of occasional mentions of access to semiconductors for the underlying infrastructure,[19] the term "choke point" (ka bozi) usually refers to the challenges mentioned above, rather than foreign dependencies.

This is because blockchain and smart contract technologies are different from some other sectors in that their use does not depend on restricted technologies. This applies both to hardware and software. Hardware requirements can often be satisfied using off-the-shelf or previous-generation solutions. While relatively difficult cryptographic problems have to be resolved to create a new block, these problems can be solved efficiently on modern consumer-grade hardware. Unlike in machine learning, it is not necessary to have the most advanced processors that can handle the largest amount of data possible. Instead, platforms have to be cost-effective, and this need is best met by consumer-grade hardware that has been mass-produced, such as consumer-level GPUs or even PlayStation 5 consoles, which were at one point the platform of choice for mining blocks for Ethereum until Ethereum changed its algorithm from proof of work to the much more efficient proof of stake.

The situation is similar on the software side. All the key underlying technologies and software libraries are available as published academic papers or open-source software. While some software development tools are proprietary and provide an edge for those who can afford them (or use services that apply them), these tools are not restricted by export control regulations. Furthermore, while using commercial development tools or services can provide a competitive advantage, the lack of access to them does not constitute a fundamental disabling factor. Therefore, even export restrictions on such technologies would not affect the blockchain sector fundamentally.

---

[14] James Rowland, "China to Verify Citizen Identities with New Blockchain-Based Platform", Blockchain Ireland, accessed 25 March 2024, at https://www.blockchainireland.ie/china-to-verify-citizen-identities-with-new-blockchain-based-platform/

[15] Coco Feng, "Bank of China Unit Issues Digital Securities on Ethereum Blockchain in Hong Kong Amid City's Virtual Asset Push", *South China Morning Post*, accessed 25 March 2024, at https://www.scmp.com/tech/tech-trends/article/3223922/bank-china-unit-issues-digital-securities-ethereum-blockchain-hong-kong-amid-citys-virtual-asset

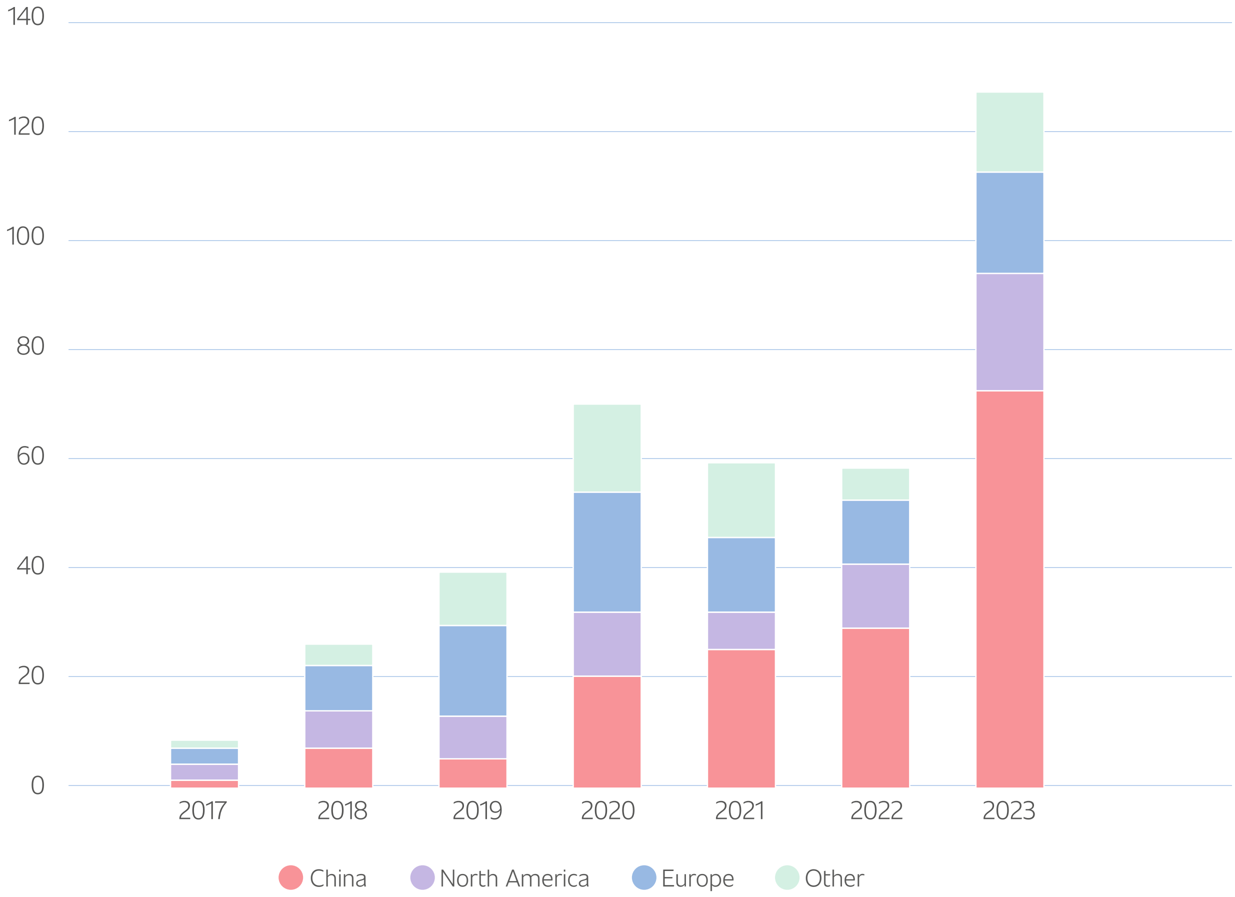
[16] BIS Innovation Hub, "Project mBridge Experimenting with a Multi-CBDC Platform for Cross-border Payments", accessed 25 March 2024, at https://www.bis.org/about/bisih/topics/cbdc/mcbdc_bridge.htm

[17] Ledger Insights, "How do Digital RMB Smart Contracts Work? First Supply Chain Finance Use Cases", accessed 25 March 2024, at https://www.ledgerinsights.com/digital-rmb-smart-contracts-cbdc/

[18] Jesse Coghlan, "China's Digital Yuan Gets Smart Contract Functionality Alongside New Use Cases", Coin Telegraph, accessed 25 March 2024, at https://cointelegraph.com/news/china-s-digital-yuan-gets-smart-contract-functionality-alongside-new-use-cases

[19] China Daily, " "国家区块链算力网络启动建设，打破"区块链孤岛"现象" [The construction of the national blockchain computing power network has started to break the "blockchain island"], accessed 25 March 2024, at https://cn.chinadaily.com.cn/a/202305/10/WS645b01aaa31053798937376f.html

FIGURE 1: Publications in top 20 venues by origin of first author's institution



Publications by origin of lead author's institution, 2017–2023

This is also true because China has access to significant and growing amounts of technical talent operating increasingly at leading levels worldwide. This is demonstrated in the patent statistics: over 90% of the blockchain patents granted in 2023 originated from China,[20] although some care must be taken with these metrics as the number of patents does not necessarily say anything about the quality or economic value of the patented technologies. This is also clearly shown when breaking down scholarly publications on blockchain in leading venues.

To assess trends in the scientific domain, we investigated the past seven years of publications in the top 20 research venues that are relevant to blockchain and smart contracts, more specifically the top ten titles in Software Systems and Computer Security & Cryptography, as measured by Google Scholar.[21] Publications on these topics started to appear in these venues in 2017, and they have seen steady growth since (see Figure 1).

We then counted the number of publications by region, using the institutional affiliation of the first author of each publication. A publication of Chinese origin in

---

[20] Jon Lea, "Blockchain Patent Report 2023", Coincub, accessed 25 March 2024, at https://coincub.com/ranking/blockchain-patent-report-2023/

[21] We counted publications with either "blockchain" or "smart contract" in their title. Our selection comprises the following 20 conferences and journals: ICSE, IEEE Trans. on Softw. Eng., Journal of Systems and Software, Information and Software Technology, ESEC/FSE, Empirical Software Engineering, POPL, IEEE Software, ASE, PLDI, CCS, IEEE Transactions on Information Forensics and Security, IEEE Symposium on Security and Privacy, USENIX Security Symposium, Computers & Security, Network and Distributed System Security Symposium (NDSS), IEEE Transactions on Dependable and Secure Computing, EUROCRYPT, CRYPTO, International Conference on Financial Cryptography and Data Security. The data was last updated on 3 January 2024.

Figure 1 may therefore involve co-authors from outside China, while a publication from outside China may have Chinese co-authors. Overall, the data shows a strong growth in publications on this subject, with a temporary slowdown during the Covid-19 pandemic when research outputs slowed and conference publications were sometimes held back due to a lack of opportunities to present them in person.

We can clearly see that Europe was among the early leaders in the domain, with a large share of publications in the first few years (2017–2019). Conversely, China was initially a relatively small player with fewer than 20% of all publications. Since 2020, China's research output has grown dramatically and now comprises slightly over half of all publications in the field. Conversely, Europe's output stagnated and is still at about the same level as around 2019–2020 in absolute numbers. Europe has therefore not enjoyed the same strong growth in publications that China and, to a lesser extent, North America have.

Overall, the period from 2017 has seen 160 Chinese publications in the top 20 venues. Some of the main topics that were covered are:

- Security (of blockchain and smart contracts) and vulnerability analysis;
- privacy-preserving ways of storing data on a blockchain, which can involve providing anonymity or ways to redact data;
- efficiency of blockchains;
- analysis techniques for smart contracts;
- auditing techniques for bloc-chain and smart contracts.

Figure 2 provides an overview of the numerical distribution between the topics, counting the number of publications for which the title matches the topic. Note that a single publication title may contain more than one keyword. We can see that security is the hottest topic (35 publications), followed by privacy (22 publications). Efficiency, analysis and auditing are about equally important with 14, 12 and 11 publications, respectively.

The key outputs are not the research results per se, but the underlying technologies and number of trained experts. Both fundamental technologies and newly trained PhD graduates constitute force multipliers for future innovation in Chinese enterprises. By already having a shortage of cybersecurity experts, Europe is in this sense not taking sufficient care of its future workforce in new technologies.

However, such technological prowess is a necessary but not a sufficient condition for success, particularly in the international realm. In other words, China's dependencies in the blockchain realm must be sought less in the sphere of technology, and more in "soft" factors, most importantly user trust. As today's popular blockchain platforms are based on open-source software, there is no direct obstacle to adopting or enhancing a platform of choice. However, challenges arise from the increasing complexity of platforms that combine multiple technologies and the complexity of smart contracts that implement business logic on top of these. Strong know-how in creating, assessing and analysing these platforms is therefore crucial.

China's strong research impact today will result in a large number of highly qualified experts in this domain tomorrow. This expertise is needed to prevent logical flaws and expensive vulnerabilities in blockchain-based platforms, which cost industry billions of euros annually. High quality and robust quality assurance practices are therefore essential for trust in a platform. A faulty platform could leak or lose data, or even directly lose tokens or funds. A malicious platform could provide a chosen actor with a certain level of (surreptitious) control that could give it market advantage in similar ways.

On the technical side, verification – or the ability to assess the correctness of software – is a key technical skill. Verification can detect defects in software before it is used and in some cases even ensure the absence of certain critical flaws. While it is impossible to conclusively prove the correctness of software, strong verification techniques (formal verification methods) can give very strong confidence that the key properties of software or systems will hold. Formal verification methods use detailed mathematical descriptions of properties and relate them in a mathematically sound way to the system in question.

Europe's strong tradition in formal verification methods had put it in pole position to establish itself as a leader

FIGURE 2: Publications with common keywords in their title

five years ago.[22] However, Europe's research funding was not adequate to build a strong community in the field. While several research groups from Europe or with European collaborations have published in leading academic venues, their impact is dwarfed by China's output.

In future, establishing a successful blockchain-based platform with a global impact will require not only good engineering, but also trust. This applies both to software interfacing with blockchain platforms, as this external data also needs to be trustworthy, and the correctness of the blockchain platform itself. By strengthening its research, Europe can put itself in a strong position in both respects. This does not just apply to platform flaws or as a defence against malicious actors. It also has a strong political component. Potential clients may be more wary of privacy, surveillance and transparency issues in platforms that originate from China or the United States.

Because it is fundamentally impossible to fully prove the correctness of systems or software in general, we can only gain a high degree of confidence in them at best. Furthermore, deliberately placed flaws in a system can take advantage of this fact by crafting code that is too hard to understand even for experts but introduces hidden flaws that can be exploited by unscrupulous attackers.[23] Therefore, even with best development practices, a user has to have faith not only in the technical capabilities of the platform provider – and the entire software supply chain behind it – but also in their intentions.

Trust is therefore essential for market acceptance of any new platform. Beijing cannot force businesses beyond its border to use Chinese blockchain platforms for their transactions, a point which the Chinese authorities increasingly recognise. The CAICT Blockchain White Paper, for instance, states, that "blockchain platforms are often established by centralised institutions [but] there are

---

[22] Wolfgang Ahrendt, Gordon J. Pace and Gerardo Schneider, "Smart Contracts: A Killer Application for Deductive Source Code Verification", in Peter Müller and Ina Schaefer, *Principled Software Development: Essays Dedicated to Arnd Poetzsch-Heffter on the Occasion of his 60th Birthday*, Champaign, Illinois, Springer, 2018, pp. 1–18.

[23] Wu Qiushi and Lu Kangjie, "On the Feasibility of Stealthily Introducing Vulnerabilities in Open-Source Software Via Hypocrite Commits", University of Minnesota, 2021, accessed 25 March 2023, at http://www.coding-guidelines.com/code-data/OpenSourceInsecurity.pdf

shortcomings in credibility and recognition". Mu Changchun, who directs the Digital Currency Research Institute of the People's Bank of China, felt it necessary to underline that mBridge would not be used to interfere with other countries' monetary policies, and would comply with all national regulation concerning money laundering and foreign currency exchange in the countries in which it is active.[24]

Moreover, the potential market for Chinese blockchain services may be limited by foreign legislative action. The US House Representatives has already proposed a bipartisan bill to prohibit federal agencies from using Chinese blockchain networks. Although it is unlikely that this bill will become law at this time, a further deterioration in Sino-US relations could create more propitious conditions for a future initiative of this kind.

In short, Chinese dependencies are less on the technological side but rely instead on soft factors:

1. a widespread perception that blockchain technology in general is mature enough to be trustworthy for large-scale industrial applications;

2. trust in the software solution providers who create blockchain-based platforms;

3. access to a highly qualified workforce that is capable of creating, rolling out and maintaining a blockchain-based service or platform.

We believe that all three of these factors must be considered together.

When it comes to trust in the technology itself, blockchain is still at an early stage. At present, existing successful blockchain-based platforms are still in relatively small fields compared to the wider sector. Bitcoin (and other digital currencies) as a currency platform is mostly driven by speculation and not yet significant as an actual currency. Blockchain solutions such as data storage and management platforms are using non-fungible tokens (NFTs) successfully to manage the ownership of digital artworks or luxury goods. In the former case, the new technology still constitutes a small part of the art trade sector, while in the latter case the industry is relatively small and fragmented.

QUALITY OF EUROPEAN TECHNOLOGICAL STRENGTH

The prevalence of open-source technologies and the fact that consumer-grade hardware (at scale) is sufficient to build a blockchain environment mean that the underlying technologies for blockchain and smart contracts are widely accessible. Dependencies therefore lie more in other, soft factors.

If dependencies primarily occur in soft factors, the focus needs to be on the extent to which Europe possesses these. We think that Europe's ecosystem around verification technologies could give it a temporary advantage if the stakes are high enough, but China will have enough time to adjust and adapt. After all, as explained above, the challenges in verification are less in the available tools and more in the fundamental limits of underlying technologies, and the need for extensive training and expertise to apply these technologies and tools effectively. Europe's lead from the 2000s and 2010s has therefore been diminished. While European products and services still have a better reputation for quality than Chinese counterparts, if Chinese vendors establish a good track record with digital services, this will eventually gain consumers' trust worldwide, particularly if the Chinese government manages to resolve its political credibility issues.

There are intervening factors. The authorities might mandate the use of certain proprietary platforms, for instance, to gain access to certain service markets, which would slow competitors down. In the long term, however, the open and federated nature of blockchain technologies is unlikely to completely exclude certain regions. Europe does not therefore have particular "chokepoints" but it does have strengths that it can build on and extend. A more favourable environment in terms of laws and regulations means that a service operated in Europe has the potential to gain higher trust and acceptance than services based elsewhere in the world.

This is where Europe's strength lies. Traditionally, Europe has had a strong background in verification technology, as evidenced by many academic tools (e.g., Isabelle/HOL and Coq, UPPAAL, NuSMV) and commercial tools or tools with commercial support (e.g., Rodin for Event-B, NuXmV, Infer, Astrée). These breakthroughs were mostly driven by leading institutions in a few countries that also mirror those countries that are active in analysing blockchain and smart contracts,

---

[24] Liu Ran, "数研所穆长春详解央行数字货币跨境支付原则与实践" [Mu Changchun of the Digital Research Institute Explains the Principles and Practices of Cross-border Payment of Central Bank Digital Currencies], Caixin, accessed 25 March 2024, at https://finance.caixin.com/2023-11-29/102140727.html?mc_cid=a15fabc5a6&mc_eid=ad7c94e0d8

notably the UK, France, Germany, Italy and Switzerland. Successes in cyber-physical systems such as trains and aircraft are to some extent owed to know-how in such technologies, which helps to provide a high level of assurance regarding their software. The underlying skillset for verification translates well into new domains such as smart contracts. Together with high transparency in the legal system, Europe can therefore boast a high degree of trust in its solution providers.

However, Europe has had a dire shortage of qualified software and security engineers in the recent past, which will only get worse as a large percentage of its workforce reaches retirement age soon. University programmes have not kept pace with the need for more highly qualified graduates in these sectors and, unlike China's, Europe's level of research has stayed constant but not grown. China has shown that it can successfully take over market sectors in home appliances, such as robotic vacuum cleaners, or even achieve rapid growth in core industrial sectors, such as electric vehicles, simply by being able to muster a large number of engineers that can innovate faster than small European companies in that sector, and by coordinating the activities of governmental, scientific and commercial organisations.

Driven by the current technical challenges, both the community and the technology behind blockchain are maturing. In the coming few years, better tools and technologies and more highly trained experts will become available. Therefore, once quality and trust pass a certain threshold, we believe that the technology will eventually hit an inflection point where the first successful high-profile platform – for example, shared identity management, visa databases, crime records or similar – will serve as a blueprint for similar solutions that follow. At that point, know-how in software engineering and verification will be crucial to take advantage of this opportunity. Europe is well-positioned in terms of trustworthy software providers and an engineering tradition derived from cyber-physical systems to provide safety- and security-critical solutions. However, its workforce is too small to meet the demands of industry and recent developments have not shown a change in trend.

EUROPE'S LEVEL OF AMBITION

Given the existing, albeit limited, European strengths in blockchain technology in connection with smart contracts, the EU and the UK should consider the different levels of ambition outlined in the introduction.

- **Level 1: Threat prevention.** Threat prevention is all about the control of potential dual-use technology. As indicated above, there is little or nothing Europe can do to prevent the transfer of blockchain technology to China. Most of the software and algorithmic information is already publicly available, as it is either open source or part of academic research. Ordinary consumer-grade hardware will suffice to run blockchain platforms, and China is able to fulfil its own needs to a considerable degree. At the same time, the threats emanating from Chinese capabilities in blockchain are less immediate than those in other realms, be they more economy-oriented or security-oriented, which makes threat prevention a relatively low priority.

- **Level 2: Ability to deny.** The notion of co-dependency with regard to blockchain technology is difficult to ascertain, as such co-dependencies will be dependent more on the specific sphere of application of any blockchain technology than on the blockchain itself. As discussed in a previous report, the embryonic nature of blockchain applications necessarily renders this assessment speculative. Potential areas where Europe could build its strength include supply chain resilience, where European actors might establish platforms for transaction trust and verification that, if European platforms become dominant, would be impossible to avoid for Chinese actors to use.

  At a non-technical level, Europe is in a strong position to deny undesirable platforms being imposed on them and like-minded countries, particularly if it can come up with a better alternative. As described above, trust in blockchain applications is essential for their acceptance. Market forces and government intervention can mitigate security and privacy risks. This is because open markets and open governments favour open, decentralised platforms. A centrally controlled blockchain-based platform intrinsically dilutes blockchain's advantages in terms of transparency, privacy and data immutability, strongly diminishing the business case for using it. Europe can regulate within European markets to forestall these concerns, as well as engage diplomatically with China and affected third countries to mitigate them. Finally, even if a platform is trusted, the interaction with it also has to come from trustworthy sources, so that data on a blockchain, even if securely stored and used digitally, actually corresponds to valid real-world information. Europe can play a leading role in this regard by enhancing scientific funding and creating the conditions necessary for the emergence of such platforms.

- **Level 3: Ability to act.** Given the fact that dependencies in blockchain are primarily to be found in "soft" areas, there are few if any technical advantages that Europe or China could exploit to exert unidirectional influence on the development of the respective other's technological ecosystem. As the majority of Chinese-developed blockchain platforms are developed for domestic use, it is difficult to envisage how European actors could create or strengthen Chinese reliance on European innovation, platforms and applications in a way that would allow Europe to significantly shape the domestic evolution of China's blockchain technology.

Europe could, however, attempt to ensure that its own alternatives retain competitiveness against their Chinese counterparts, to either establish or consolidate their leading role and make it more difficult for Chinese platforms to gain traction. In order to remain an active player in the domain that can not only deny proposed solutions, but also create and assess technology on its own, Europe needs to maintain competence in state-of-the-art technologies and methods. This includes the training of specialists through education and research, and providing sufficient resources for research, development and innovation through government-led innovation programmes and private sector initiatives.

- **Level 4: Curtailment.** Given China's predominance in blockchain research, its high levels of self-sufficiency in producing the hardware necessary to run blockchain platforms and the political will to experiment with applications in a plethora of areas, we assess it as impossible for Europe to prevent China from further development of these technological and economic capabilities.

POLICY RECOMMENDATIONS

In general, in the area of blockchain technology research and application, it is essential that Europe first and foremost sets and implements its own agenda, rather than being overly responsive to what China might or might not do. "Hard" leverage is impossible for the EU or any other actor, as the required hardware consists of easily available, consumer-grade or commodity components. The fundamental software knowledge is publicly available, and so can be adapted to provide specific kinds of blockchain services relatively quickly. Consequently, any ambitions Europe could harbour in this space must be sought in "soft" factors: trust in service providers and governments, a reputation for quality, as well as strong skill sets among specialised engineers in areas such as verification. Depending on which of the two feasible levels of ambition Europe aims for, EU and UK policymakers should consider the policies set outflow.

Ability to deny

As it is unlikely that Europe will be able to significantly influence market conditions within China, among the four categories discussed in this report, Europe's best option is to pursue ambitions based on Chinese dependencies on European blockchain platforms. This would depend on Europe's ability to forestall market opportunities for Chinese operators within the EU, as well as in like-minded countries, by creating the conditions in which trusted blockchain platforms can establish market dominance and network effects, in the following ways:

- **Research and competence promotion:** First and foremost, Europe should have an ambition to regain its strength in high-assurance software; this strength is currently in danger of being eroded, at least in new sectors such as blockchain. For Europe to retain its prominent position, training the next generation of engineers at the scale that its industry demands is of the utmost importance.

  Fortunately, many of the underlying problems in creating secure blockchain systems or secure software in general are quite commonplace. Competence in secure blockchain therefore extends beyond blockchain: Building a strong ecosystem in the blockchain field will also cross-fertilise technically similar sectors such as high-assurance cyber-physical systems, so efforts in blockchain competence will also help Europe maintain its strength in related domains. As of now, Europe is still strong in innovation but risks being eclipsed by China. Europe needs to address this at its root. Its research funding to train PhD students and invent new technologies is not keeping pace with China's. Indeed, the budget for Horizon Europe is lower than that of its predecessor, Horizon 2020, even in nominal terms. This erodes Europe's attractiveness as an academic platform in the long term and makes it harder to attract top talent from outside, and will eventually result in an outflow of talent. Counteracting this is therefore crucial.

  We expect that the recent rapid growth in publications by Chinese institutions will be translated within a few years into visible innovation in this sector. European progress has been stagnant and it needs to invest more. Intellectual property and patents can play a role in ancillary technology, such as verification or certification tools, and can be a technical advantage, but they will not be a delimiting factor because most technologies are open-source. Verification and auditing tools and services are strongest in the USA, but competitive European companies also exist. As these technologies improve and cybersecurity becomes more important, they may provide more competitive leverage in the future.

Research in blockchain should, however, cover not only technological aspects, but also "soft" elements. In contrast to semiconductors or electric vehicles, the market value and political impact of blockchain applications remain to be demonstrated in many fields, particularly once cryptocurrencies are taken out of the equation.[25] It is essential for European policymakers to invest in research that seeks to identify what the social, economic and political relevance of blockchain applications might be, and what kinds of threat or harm they might generate, before spending scarce political capital on policy and regulation.

- **Knowledge security:** The open-source nature of blockchain technology makes knowledge and tech transfer management at the research and development stage very difficult, if not impossible. In addition, given the current highly speculative state of blockchain-originated threat perceptions, export controls in relation to ancillary technology should not be a policy priority. Investment screening in either direction might be a useful tool for ensuring the security of data stored on blockchain platforms, as well as the transparency, reliability and compliance levels of the platform's functioning. However, this should occur in a targeted manner, taking into consideration the importance and impact of these platforms as they develop, to avoid the costs and chilling effects associated with blanket measures.

- **Production and commercialisation:** Turning technological breakthroughs into products and services is highly challenging, especially in emerging domains. Technically superior solutions do not by themselves guarantee market acceptance. In this respect, China has been lagging behind, as evidenced by its own observations in, among other things, the CAICT White Paper mentioned above. US-based platforms and service providers are currently dominant, and we expect this to remain the case for the foreseeable future. Europe can support its own ecosystem by putting in place sensible policies that strike a good balance between privacy, cybersecurity and adequate consideration of (usually non-commercial) open-source technologies. It is important in this regard to think beyond blockchain, which – when considering the benefits it brings to its user – is an incremental technology, not a transformational one. For instance, if the EU wishes to forestall China's use of mBridge as an alternative to the SWIFT system for cross-border payment clearing, it would do well to address the inefficiencies in the current system, and shore up the political trust in its functioning in the Global South, which may have been harmed through SWIFT's inclusion in sanctions on Russia. It would also be useful for European governments to coordinate the development of blockchain-related policies within the Single Market, as well as with close partners such as the UK and the European Economic Area countries, particularly in relation to any blockchain applications governments might use. This would serve to create considerable market opportunities for trusted platforms. Specific measures could take the form of harmonising legal and regulatory requirements, government procurement and usage practices, facilitating cross-border data flows and integrating research.

- **Regulation:** Regulation primarily serves to protect European interests in its home territory. By enshrining expected standards of conduct into law, most importantly in terms of trust-related liability, data protection and cybersecurity, Chinese operators will be forced to either comply with European standards or not enter its market.

Ability to act

To a certain degree, within the realm of blockchain, the "ability to act" is correlated with – and a far more ambitious version of – the ability to deny, as they both rely on Europe successfully generating the conditions in which European platforms become the dominant venues where blockchain-enabled services are used. This is, however, significantly more difficult if not almost impossible to achieve, given the high level of dominance in market share, scientific capabilities and technological know-how that would be required. Nonetheless, if Europe should choose to pursue this level of ambition, the above-mentioned recommendations in the categories of research and competence promotion and knowledge security would apply.

In addition, European stakeholders should consider measures in the following categories:

- **Production and commercialisation:** In the same way that Europe should explore coordination within the Single Market, it should also do so with like-minded partners around the world. This will not only protect European interests at home, but also enable it to gain strength in key strategic regions. Particular attention should be paid to the constructive role that could be played by the Digital Economy Partnership Agreement (DEPA) or other such multilateral and mini-lateral free trade forums.

---

[25] Asif Raza Kazmi et al. "Is Blockchain Overrated?", 2021 IEEE 19th International Conference on Embedded and Ubiquitous Computing (EUC), IEEE Xplore, accessed 25 March 2024, at https://ieeexplore.ieee.org/document/9742227

- **Regulation:** Here, a strong card in Europe's hand is the Brussels effect. In other areas of digital regulation, like-minded countries have often adopted European standards, both to harmonise with the EU's market and because European regulation tends to be of high quality. If appropriate regulation is adopted to deal with blockchain applications within Europe, this could have a similar anchoring effect, embedding European norms and standards into international codes of behaviour.

SCORECARD 2 TECHNOLOGY FIELD: BLOCKCHAIN FOR SMART CONTRACTS

	Threat prevention	Ability to deny	Ability to act	Curtailment
Feasibility of level of ambition	Not feasible	Medium	Low	Not feasible
Core policy recommendations	• None	• Gain strength in high-assurance software • Increase research funding and support for start-ups • Monitor emergence of Chinese blockchain platforms within Europe • Enhance the performance of European blockchain platforms and adjacent applications • Coordinate blockchain roll-out within Single Market, as well as with EEA/UK. • Enshrine European norms in regulation	• All of the measures under the "ability to deny", plus: • Coordinate roll-out of blockchain platforms with like-minded partners worldwide • Leverage Brussels Effect for global regulatory harmonization	• None

AUTHORS

Cyrille Artho is an Associate Professor at KTH Royal Institute of Technology, Stockholm, Sweden. Contact: artho@kth.se

Rogier Creemers is an Assistant Professor in Modern Chinese Studies at Leiden University, the Netherlands. Contact: r.j.e.h.creemers@hum.leidenuniv.nl

Critical Raw Materials: What Chinese Dependencies, what European Strengths?

John Seaman, Florian Vidal and Raphaël Danino-Perraud

ABSTRACT

China has come to dominate the supply chain for many critical raw materials. Despite the premium placed on bolstering self-reliance, however, China is also and will remain dependent on imports of a number of mineral resources that are vital to achieving Beijing's high-tech ambitions. It is on this dependence on third-party producers that Europe might be able to enhance its relevance and exercise a level of influence over the next 10–15 years. This will require more robust, integrated and strategically oriented resource and mining diplomacy, as well as a more concerted effort to develop European competencies. Europe's interest in reducing dependence on China and diversifying mineral supply chains ultimately matches that of mineral producers, which seek to generate economic development opportunities at home. Europe must look to follow through on the promise of responsible, sustainable and supply-chain enhancing partnerships with producing countries, and in parallel ensure a level of convergence with allies and demand-side partners on how to approach the issues facing the minerals sector in the light of the green and digital transitions.

SCORECARD 1 TECHNOLOGY FIELD: CRITICAL RAW MATERIALS

Source of European technology strength	Research and innovation	Intellectual property and patents	Production and commercialisation
	● Low	Not feasible	Not feasible

Type of European technology strength	Technological excellence	Commercialisation advantage	Conditioning of market access	Regulatory, political and normative factors	Sustainability	Research partnerships with third countries
				X	X	X

Degree of European leverage: Low ○ — Medium — High

INTRODUCTION

As part of Europe's ambitious goals to achieve carbon neutrality and press forward with the digital transition, securing supplies of raw materials is now a policy priority. In particular, dependence on China up and down a number of mineral supply chains, whether for production, processing or transformation, has become a significant source of concern and a major driver of the European Commission's push for a "de-risking" strategy. At first glance, Europe's dependence on China is alarming. Of the 34 raw materials that the Commission identified as "critical" in 2023, China accounts for over 50% of the share of global extraction and/or processing in 19 cases. Of these, China's share extends beyond 60% in 13 cases and over 70% in eight of those.[1] From rare earths and the permanent magnet value chain to graphite and the battery supply chain, germanium, gallium and value chains for semiconductors and photovoltaics, the narrative of dependence on China has come to resemble one of absolute Chinese advantage in critical raw materials and a high level of vulnerability for Europe.

---

[1] European Commission, "Study on the Critical Raw Materials for the EU 2023: Final Report", Brussels, March 2023, https://single-market-economy.ec.europa.eu/publications/study-critical-raw-materials-eu-2023-final-report_en

This perspective misses a key dimension, however: that of China's own vulnerabilities. While it is certainly true that, in relation to the theme of this report, Europe can hardly be considered indispensable to China in this field, it is important to add nuance to the understanding of China's position. Indeed, an analysis of the available policy discourse and the debate in Chinese academic circles reveals an increasing sense of concern and urgency with regard to China's raw material import dependencies, as Beijing seeks to set the country on a course for technological and industrial self-reliance and global leadership of the digital and green transitions. Seen in this light, Europe's approach to critical raw material value chains can be assessed and ways can be considered to bolster mining diplomacy as part of a long-term, sustainable resource strategy for improving the European position in a broad sense, and relative to China in particular.

ASSESSING CRITICAL AND STRATEGIC RAW MATERIALS FOR CHINA

China's most recent official and publicly available assessment of strategic minerals is the National Mineral Resources Plan, 2016–2020, published in 2016 by the State Council in the context of the 13th Five-Year Plan. According to assessments by Chinese experts (see Table 1) the plan provides a list of 24 energy-related, metallic and non-metallic minerals considered to be "strategic" for "protecting national economic security, defence security and the development needs of strategic emerging industries".[2] The specific criteria involved in drawing up this list are unclear but as it includes resources for which China has a distinct supply advantage, as well as those for which it does not, the plan puts a premium on economic importance over supply risks.[3] This was the first official assessment of its kind but while it was intended to be repeated every five years, the 2021–2025 plan has not been published. Other policy-driven assessments are also not available in open source, either abroad or in China. These notably include "My Country's Strategic Mineral Resources Demand Forecast 2040" (《我国战略性矿产资源需求预测2040》), a foresight study and policy orientation document drafted by the Ministry of Natural Resources to assess "new characteristics of global resource competition, new trends in global resource cooperation, and the global resource pattern", as well as the geopolitical and other challenges presented by overseas resources, which indicates a shift in policy assessment towards a review of vulnerabilities.[4] That such policy reports are no longer made public is an increasing trend in China, but also fairly common practice among other governments. In France, for instance, the Rapport Varin completed in 2022 to assess the country's strategic mineral supply chain dependencies has not been made publicly available.

The report of the 20th National Party Congress of the Chinese Communist Party is often cited in public discourse and academic articles as providing critical guidance on China's overall raw materials strategy.[5] The report makes "self-reliance" (自立自强) a cardinal principle for guiding Chinese policy and sets the broad goal of boosting domestic capacity to ensure resource security in industrial and raw material supply chains. Such ambitions can be effective where China has sufficient resources to respond to demand, but Chinese officials have explained that the country remains reliant on overseas production for two-thirds of its strategic minerals.[6] As China's Minister of Natural Resources, Wang Guanghua, explained in an article in the *Economic Daily* in November 2023, meeting the challenge of burgeoning demand from strategic emerging industries at a time when the international environment is increasingly contentious presents China with a "very urgent task" (十分紧迫的任务) to pursue a new round of "strategic action"

---

[2] State Council, 全国矿产资源规划 (2016-2020 年) [National Mineral Resources Plan (2016-2020)], accessed 13 November 2023, at https://www.ndrc.gov.cn/fggz/fzzlgh/gjjzxgh/201705/t20170511_1196755.html.

[3] Wang Anjian and Yuan Xiaojing, 大国竞争背景下的中国战略性关键矿产资源安全思考 [Thoughts on the Security of China's Strategic Key Mineral Resources in the Context of Great Power Competition], China Development Portal, 2 December 2022, accessed 27 November 2023, at http://cn.chinagate.cn/news/2022-12/02/content_78542546.htm.

[4] Ministry of Natural Resources, 我国战略性矿产资源需求预测2040 [My Country's Strategic Mineral Resources Demand Forecast 2040], accessed 15 October 2023, at https://jlps.mnr.gov.cn/global/reward!viewDJAchievement.do?djh=20200114 (link no longer active).

[5] State Council, "Report to the 20th National Congress of the Communist Party of China", 25 October, 2022, accessed 27 November 2023, at https://english.www.gov.cn/2022special/20thcpccongress/, original text: https://www.gov.cn/xinwen/2022-10/25/content_5721685.htm.

[6] CCTV, 自然资源部：我国矿产资源国情调查主体工作基本完成 [Ministry of Natural Resources: The Main Body of Investigation on The National Conditions of My Country's Mineral Resources has been Basically Completed], 24 March 2022, accessed 24 November 2023, at https://content-static.cctvnews.cctv.com/snow-book/index.html?item_id=18092849498197699336&toc_style_id=feeds_default.

TABLE 1: Official and Expert Assessments of Critical and Strategic Minerals for China and the European Union

CHINA: CRITICAL AND STRATEGIC MINERALS (OFFICIAL AND UNOFFICIAL)

UNCLASSIFIED MINERALS	ADVANTAGEOUS MINERALS (优势矿种)		SHORTAGE MINERALS (短缺矿种)		EUROPEAN UNION: CRITICAL AND STRATEGIC RAW MATERIALS	
Coalbed methane*	Indium		Cesium	Potassium salt*		
Gold*			Chromium*	Rhenium		
Molybdenum*			Iron*	Uranium*		
Selenium			Natural gas*	Zirconium*		
Shale gas*			Oil*			
Tin*						
Boron	Antimony*	Rare Earths*	Aluminium* (Bauxite)	Manganese	Arsenic	Scandium
Coal*	Bismuth	Tungsten*	Beryllium	Nickel*	Baryte	Silicon metal
Phosphorus*	Fluorite* (Fluorspar)	Vanadium	Cobalt*	Niobium	Feldspar	Strontium
Titanium	Gallium		Copper*	Platinum Group	Helium	
	Germanium		Hafnium	Tantalum	Magnesium	
	Graphite*		Lithium*		Phosphate Rock	

*Listed as critical mineral in China's 2016 National Mineral Resources Plan
Mineral classification for China is defined by Li Jianwu et al. 2023. Unclassified minerals did not appear in Li Jianwu et al. 2023 but were taken from other lists. The list of minerals is compiled from Li Jianwu et al. (note 8), Wang Anjian and Yuan Xiaojing (note 3), Yan Wenyi et al. (note 8), State Council (note 5) and European Commission (note 1).

(略行动).[7] For Wang, strategic action primarily revolves around enhancing the domestic production environment and increasing China's resource autonomy, following the call for self-reliance that has grown more urgent with the deepening of strategic competition, notably with the United States, and is leading China to turn inwards where it can.

An analysis of academic articles written by Chinese experts in the field provides further insight into how the country's critical mineral dependencies are assessed and the types of risk associated with them. While China is a major producer of many strategic minerals, it is also very often the world's largest consumer. Ultimately, despite its efforts to boost domestic production, China's

---

[7] Wang Guanghua, 推动重要能源和矿产资源增储上产, [Promoting the Increase in Reserves and Production of Important Energy and Mineral Resources], 经济日报 [Economic Daily], 8 November 2023, accessed 24 November 2023, at https://www.ydkj.ha.cn/?shizhengyaowen/3855.html.

dependence on foreign production is likely to grow as demand evolves. Among the various categories ascribed to strategic minerals in China, the notion of "advantageous minerals" (优势矿种) appears in both official policy documents and academic debates, highlighting areas where China has a strong position with regard to its own supply security, but also relative to others. The notion of "shortage minerals" (短缺矿种), meanwhile, which is only referred to in more recent, unofficial assessments, highlights areas where China is becoming increasingly vulnerable, despite – or in some cases as a result of – its competitiveness elsewhere along the supply chain.[8]

Chinese experts note the widening gap between the growth in demand from Chinese industry and the ability to ramp up domestic mine production. Wang Jianliang et al., for instance, discusses a pessimistic scenario in which China's production of a number of mineral resources needed to facilitate the manufacture of renewable energy technologies has either already peaked or will peak by 2030.[9] While comprehensive, up-to-date studies detailing mine production, imports, exports and overall Chinese consumption are not made publicly available, some assessments can be gleaned from Chinese sources to assess China's import dependency on strategic and critical raw materials and then cross-referenced with foreign assessments to provide verification.[10]

This consideration of China's import dependence helps to contextualise its dominance of certain mineral and technology supply chains. In battery manufacturing, as in other technologies such as rare earth permanent magnets or photovoltaics, large proportions of the supply chain are concentrated in China following decades of investment. At the same time, however, while China dominates in graphite production for battery anodes, it depends heavily on overseas extraction of cobalt, nickel and lithium, relying respectively on the Democratic Republic of the Congo (DRC), Indonesia and the Philippines, and Latin America and Australia. Platinum group metals (PGMs), meanwhile, will become increasingly important for China's ambitions to develop its hydrogen economy, but the country has no prospect of mining and over 90% of global reserves are concentrated in South Africa.[11] For important base metals such as copper and iron ore, China also relies on imports for 75% to 85% of supply.

CRITICAL MINERALS AND SEMICONDUCTORS

To understand the key issues around critical minerals, it is useful to look more closely at a number of metals that are important for the semiconductor industry. Semiconductors have in many ways become the lifeblood of the digital and energy transition, making the supply of metals for their production all the more crucial. Semiconductor production is highly consuming of metals, less in terms of quantity than the number of substances used and the specificity of the components required. A non-exhaustive list of the metals incorporated into semiconductors includes germanium, gallium, silicon, indium, tantalum, palladium, rare earths, arsenic, beryllium, hafnium, antimony, gold and even barium. Furthermore, many metals are used indirectly in their manufacture, such as tin, silver, bismuth, nickel, chromium, copper, aluminium, iron, manganese or zinc. Each metal has particular geological, industrial and economic characteristics, which makes precise analysis all the more complex. A closer look at gallium, germanium, tantalum, indium and beryllium will help to explain some of the core concepts and challenges.

First, in geological terms, semiconductor metals are often referred to as "companion metals" or co-products, meaning a metal recovered jointly or incidentally with another metal in an industrial extraction process.[12] This makes these metals dependent on other metals for their production and requires specific recovery and refining processes, which can make the market particularly opaque. Gallium, for instance, is primarily produced from the refining of bauxite into

---

[8] Li Jianwu, Li Tianjiao, Jia Hongxiang and Wang Anjian, 中国战略性关键矿产目录厘定 [Determination of China's Strategic and Critical Minerals List], 地球学报 [Acta Geoscientica Sinica], vol. 44, no. 2, pp. 261–270, March 2023; Wang Anjian, op cit. 2022; and Wenyi Yan, Zhaolong Wang, Hongbin Cao, Yi Zhang and Zhi Sun, "Criticality assessment of metal resources in China", in iScience, vol. 24, June 2021, https://doi.org/10.1016/j.isci.2021.102524.

[9] Jianliang Wang, Lifang Yang, Jingli Lin and Yongmei Bentley, "The Availability of Critical Minerals for China's Renewable Energy Development: An Analysis of Physical Supply", in *Natural Resources Research*, vol. 29, no. 4, August 2020, https://doi.org/10.1007/s11053-020-09615-5.

[10] Mingguo Zhai et al., "Mineral Resource Science in China: Review and perspective", in *Geography and Sustainability,* vol. 2, no. 3, pp. 107–114, June 2021, https://doi.org/10.1016/j.geosus.2021.05.002; and Andrew L. Gulley, Nedal T. Nassar and Sean Xun, "China, the United States, and Competition for Resources that Enable Emerging Technologies", in *Proceedings of the National Academy of Sciences*, vol. 115, no. 16, pp. 4111–4115, April 2018, https://doi.org/10.1073/pnas.1717152115.

[11] Can Zhang, Fan Chen, Siyu Huang and Sheng Shen, "Resource Nationalism and Platinum Group Metals: Chinese Strategies in a Hydrogen-Powered Future", in *The Extractive Industries and Society*, vol. 15, September 2023, https://doi.org/10.1016/j.exis.2023.101317.

[12] Michel Jébrak and Eric Marcoux, *Géologie des ressources minérales*, Québec: Ressources Naturelles et Faunes, 2008.

alumina (95%), but also to a lesser extent from zinc (5%). For its part, germanium is a by-product of zinc metallurgy (75%) as well as the exploitation of coal ash (25%).[13] However, not all zinc or bauxite deposits contain or refineries produce gallium or germanium, and producers publish little data on this subject. This makes it difficult to estimate specific production locations and reserves, but also to assess the prospects for new production.

Furthermore, the markets for these metals are often very small. Annual gallium and germanium production is between 300 and 500 tonnes, and Beryllium is 280 tonnes. While production of indium (around 1,000 tonnes) and tantalum (around 2,000 tonnes) is slightly larger, these quantities pale in comparison to base metals such as copper (26 million tonnes) or aluminium (50 million tonnes). Cobalt, a market that could be described as intermediate, is only produced at 200,000 tonnes per

TABLE 2: CHINA'S IMPORT DEPENDENCE AND PEAK PRODUCTION YEARS FOR SELECT MINERALS

MINERAL	IMPORT DEPENDENCE PERCENTAGE*	PEAK YEAR (PESSIMISTIC/ OPTIMISTIC)+
Niobium	100 (100)	
Chromium	98 (100)	2011
Cobalt	95 (95)	2016/2018
Nickel	90 (90)	2014
Manganese	85 (80)	
Lithium	75 (70)	
Platinum group	74 (87)	
Copper	70 (75)	2017/2020
Iron	60 (85)	2016/2019
Tantalum	58 (65)	
Beryllium	57 (69)	
Aluminium	50 (80)	2021/2027
Potassium salt	45	2029/2039
Tin	38	2007
Zirconium	20 (84)	
Molybdenum		2029/2041
Rare earths		2088/2039

*Primary figure drawn from Zhai et al. (note 10), with secondary figures in parentheses draw from Gulley et al. (note 10) +Assessment made by Wang Jianliang et al. (note 9)

---

[13] Government of France, Bureau des Recherches géologiques et Minières (BRGM), "Fiche de synthèse sur la criticité des métaux- Le gallium", August 2016, at https://www.mineralinfo.fr/fr/substance/gallium-ga.

year.[14] Thus, the narrowness of their market and their physio-geological particularity lead to tensions, linked to a lack of transparency regarding the formation of their prices and a lack of knowledge of reserves, processes and production capacities. Finally, their market value is tiny compared to the larger volume metals mentioned above, which is paradoxical given their importance and the difficulty of substituting them. The larger, more experienced mining companies therefore largely ignore minor metal markets.

The uses of these metals are also poorly known, particularly in terms of quantities. Thus, we know that 87% of gallium is used for the production of semiconductors, either in the form of nitride (7%) or in the form of arsenide (80%). The latter (GaAs) serves mainly as a substrate as a physical support is necessary in an integrated circuit to allow the components placed on it to establish connections between them. For its part, germanium is used in many fields such as optical fibres (30%) and infrared optics (25%) in the form of germanium tetrachloride. Finally, 34% of the tantalum produced is used to produce capacitors, compared to only 3% of indium.[15] However, it is unclear exactly what quantities are used to produce electronic chips, but these probably do not exceed a few nanograms in "each" Ku estimates the quantities of tantalum and germanium to be 0.6 and 0.3 t/zettabyte, respectively.[16]

Tantalum is considered a conflict metal, as it is largely derived from coltan mined in Rwanda (23%) and the DRC (43%).[17] It is therefore subject to particularly restrictive regulations that add many constraints to supply flows. This does not exclude the possibility that a certain quantity of this substance comes from illegal routes that have benefited warlords or from the corruption of political elites, which is a widespread phenomenon in this area.[18]

Finally, it is important to emphasise that China produces a majority of these metals in their *refined* form. For instance, China refines over 95% of gallium, 60% of germanium, around 50% of indium and 25% of beryllium.[19] The statistics on tantalum are much less precise, but China is one of the largest exporters of refined tantalum, without the quantity produced being precisely mentioned. The case of gallium demonstrates the complexities. Whereas China accounts for over 95% of global gallium production from aluminium processing, this is primarily in low-purity form. Galley et al. estimates that Beijing's import dependence on high-purity gallium was at 65% in 2014.[20] While these figures have certainly evolved in the past 10 years, China nonetheless continues to largely if not wholly rely on foreign producers of gallium nitride (GaN) composites to supply the latest generation of power semiconductors.[21] Moreover, China still relies on imports from the Republic of Guinea, Australia and Indonesia for up to 70% of its feedstock of bauxite for the aluminium processing that allows for gallium extraction.[22] Beijing has recently established a licensing regime to tighten control of gallium exports but vulnerabilities persist at various points along the supply chain.

CHINA'S DEPENDENCIES AND TWO SOURCES OF VULNERABILITY

China's dependencies on overseas extraction for mineral resources that it considers vital to the country's economic well-being are an increasingly important source of concern and continue to drive China's strategic debate on resource security. Resource diplomacy has long been and continues to be an important component of China's foreign policy. The Chinese literature on critical minerals continues to identify multiple layers of risk

---

[14] "Cobalt", L'Elémentarium, accessed 26 March 2024, at https://lelementarium.fr/element-fiche/cobalt/.

[15] European Commission, Study on the EU's list of Critical Raw Materials, Brussels, 2020

[16] Anthony Y. Ku, "Anticipating Critical Materials Implications from the Internet of Things (IOT): Potential Stress on Future Supply Chains from Emerging Data Storage Technologies", in *Sustainable Materials and Technologies*, 15 April 2018, at https://doi.org/10.1016/j.susmat.2017.10.001. 1 zettabyte is equal to 1^12 gigabyte.

[17] "Tantale", L'Elémentarium, accessed 26 March 2024, at https://lelementarium.fr/element-fiche/tantale/.

[18] Pierre Jacquemot, "Ressources minérales, armes et violences dans les Kivus (RDC)", Hérodote, vol 134, 2009.

[19] L'Elementarium, multiple pages, accessed 26 March 2024, at https://lelementarium.fr/.

[20] Andrew L. Gulley, Nedal T. Nassar and Sean Xun, "China, the United States, and Competition for Resources that Enable Emerging Technologies", in *Proceedings of the National Academy of Sciences*, vol. 115, no. 16, pp. 4111–4115, April 2018, https://doi.org/10.1073/pnas.1717152115

[21] John Seaman, "China's Weaponization of Gallium and Germanium: The Pitfalls of Leveraging Chokepoints", Briefings de l'Ifri, 27 July 2023, accessed 5 April 2024, at https://www.ifri.org/en/publications/briefings-de-lifri/chinas-weaponization-gallium-and-germanium-pitfalls-leveraging.

[22] Matthew P. Funaiole, Brian Hart and Aidan Powers-Riggs, "De-risking Gallium Supply Chains: The National Security Case for Eroding China's Critical Mineral Dominance", Center for Strategic and International Studies, 3 August 2023, at https://www.csis.org/analysis/de-risking-gallium-supply-chains-national-security-case-eroding-chinas-critical-mineral.

stemming from the country's continued reliance on imports. Two issues in particular make a regular appearance in the current debate among mineral resource specialists: the behaviour of resource producing states and the growing geopolitical competition in the critical minerals space from the USA and Europe in particular.

In the first instance, Chinese analysts identify increasing "resource nationalism" among producing countries – a term used by minister Wang Guanghua.[23] In particular, government policies such as a nickel export ban imposed by Indonesia or Chile's nationalisation of its lithium sector increasingly favour the development of in-country processing and value-added growth, and limit the supply of critical raw materials for processing in China.[24] Even Myanmar has acted on occasion to limit supplies of rare earth ores to China for processing. As the digital and energy transitions move forward, leading to rapid growth in demand for critical minerals and putting pressure on mines and adjacent communities, Chinese firms will be increasingly called on to adapt to local political, economic, social and environmental conditions. Even if many of the overseas mines associated with these resources are controlled by Chinese investors, and China has made efforts to respond to local demands and expectations, its overseas mining ventures regularly run into difficulties, particularly related to social, environmental and governance concerns, exacerbated by a lack of political control over what has effectively become a diverse ecosystem of private sector Chinese actors overseas.[25] Beijing's perception of supply chain vulnerability therefore remains acute.

In parallel, growing geopolitical pressures are seen as challenges to ensuring China's access to resources and maintaining its position in downstream processing. Chinese analysts regard the efforts by Europe, the United States and others to diversify supply chains, and in particular multilateral initiatives such as the Mineral Security Partnership or a Critical Raw Materials club, with growing apprehension.[26] While Chinese firms remain highly competitive, analysts worry that Beijing might struggle to compete with increasingly competitive offers from other foreign investors, particularly if such offers prove more attractive than Chinese offers in terms of generating local development, spurring knowledge and technology transfer, and improving local social, economic and environmental conditions in producer countries.[27] These are all dimensions for Europe to consider when striving to develop competitive offers and strengthen its role in global critical raw material supply chains (see below). The importance of western allies such as Australia and Canada in the production of key minerals, and the seemingly rapid advances in production capacity in the USA are seen as presenting further challenges for China to maintaining the dominant position it has been able to establish for itself in downstream processing.[28]

EUROPE'S DIVERSIFICATION STRATEGY: AN EXERCISE IN RISK REDUCTION

Assessing where Europe might find some level of influence, if not indispensability relative to China in the field of critical and strategic minerals first requires an examination of Europe's existing strategy and where it has fallen short. In a broad sense, Europe is first and foremost looking to diversify its sources of supply, and to reduce dependencies on China in particular. Thus, European levels of ambition over the next 10–15 years are realistically within the realm of risk reduction through diversification and bolstering supply chain resilience, rather than developing and exercising strategic leverage over China.

Since 2008, the European Commission has taken a keen interest in the issue of mineral raw materials. It has published a list of critical metals every three years since 2014, and in 2023 outlined a more ambitious strategy for action in its Critical Raw Materials Act. The Raw

---

[23] Wang Guanghua, op cit., 2022.

[24] Yuyan Jiang, 能源转型期中国与拉美锂矿合作的机遇和挑战 [Opportunities and Challenges of Lithium Mineral Cooperation Between China and Latin America During Energy Transition], 中国国土资源经济 [Natural Resource Economics of China], no. 426, pp. 22–31, May 2023, doi:10.19676/j.cnki.1672-6995.000849.

[25] Sun Zijian et al., 我国采矿业"走出去"现状及政策建议 [Current Situation of China's Mining 'Going Global' and its Policy Suggestions], in China Mining Magazine, October 2023, pp. 11–20, doi: 10.12075/j.issn.1004-4051.20220888; Wei Shen, "China's Role in Critical Mineral Mining and its Impacts", Institute for Development Studies, accessed 20 July 2023, at https://www.ids.ac.uk/opinions/chinas-role-in-critical-mineral-mining-and-its-impacts/.

[26] Wang Anjian, op cit. 2022.

[27] Qing Zhu, Wei Tan, Xiehua Zou and Yalin Lei, 矿业企业ESG治理与矿业可持续发展 [The ESG Governance of Mining Enterprises and Sustainable Development of the Mining Industry], 中国国土资源经济 [Natural Resource Economics of China], no. 412, March 2022, doi:10.19676/j.cnki.1672-6995.000710.

[28] Jianjun Song and Guoping Wang, "双碳"背景下保障关键矿产供应链安全的思考 [Thoughts on Securing the Supply Chain for Critical Minerals under Carbon Peaking and Carbon Neutrality], 中国国土资源经济 [Natural Resource Economics of China], no. 417, August 2022, doi:10.19676/j.cnki.1672-6995.000786.

Materials Initiative launched in 2008 set out a three pillared approach: (a) the sustainable and legal production of mineral raw materials; (b) control of European Union (EU) supply routes; and (c) a strategy of resource efficiency through recycling. However, the reshoring of European primary production on European soil was ultimately not a priority and industrial capacities in the field have further decreased since 2008. Instead, the other two pillars – the diversification of supplies from abroad, if they are produced in a sustainable and legal way, and secondary production – have been favoured.

In practice, this approach has done little to reduce dependencies or mitigate supply risk. European manufacturers were encouraged to diversify their supplies from China in the 2010s, but ultimately did not invest in new industrial capacities, either in Europe or abroad. Furthermore, European countries have distanced themselves politically and economically from regions rich in resources but known to be unstable, or marked by weak governance and human rights abuses. European supply chains were partially diverted through Russia, which had the industrial and technological capacities to meet European needs. This move left room for China to invest in Africa (the DRC, Zambia, Uganda and Rwanda, among others). Russia's invasion of Ukraine in February 2022 reshuffled the cards, but not to the benefit of the EU. Indeed, its opportunities for commercial diversification are limited and it is increasingly facing competition or even exclusion from its geographical margins, including in Turkey, the Maghreb and the Balkans, where it faces fierce competition from China and Russia, but also from India and the USA.

The second pillar, of secondary supply through recycling, faces three difficulties. The first is linked to product lifecycles and the notion of stock and flow – the supply of secondary resources is subject to a fluctuating, unpredictable timeline because product lifecycles can vary, causing delays in the availability of secondary resources for processing. The second difficulty is the challenge of economically extracting metals from end-of-life products. While 95% of a battery is technically recyclable, for instance, only 15% is actually recycled in practice for a combination of organisational, economic and technical reasons. The challenge is even greater for semiconductor metals, where the size of chips and the dispersion of the metallic substances within them make recycling technically difficult, as well as economically unviable. Finally, long lead-times, high capital expenditure and market uncertainty mean that the construction of recycling capacities faces the same problems as all industrial investments in the field of raw materials. Ultimately, in the case of semiconductors, as with many other metals, neither recycling nor commercial diversification of supply can be considered the only elements of a comprehensive policy aimed at securing the flow of critical metals. It is also necessary to think about a European mining industry ecosystem and how to make it an instrument of an ambitious international industrial policy.

It is not as if the EU is powerless in the face of such challenges. Indeed, the metallurgical industry still has a number of high-tech competencies, for instance in France (Aubert & Duval, Arcelor Mittal), Belgium (Umicore), Germany (Thyssenkrupp, Aurubis) or Sweden (Boliden), among others. In terms of secondary production, companies such as Eramet, Umicore, BASF and Boliden are investing in heavy battery recycling capacities to reach operational production in 2026 and full capability by 2028. Ferropem in France is able to produce silicon metal, which is essential for the manufacture of semiconductors. There is also production potential for other niche metals, but the capability to scale-up operations remains weak. Ultimately, the Critical Raw Materials Act and the recycling directive set ambitious goals for the use, production and recycling of critical minerals, but they lack sufficient financial incentives, leaving the EU strategy incomplete in comparison with the US Inflation Reduction Act.

CALIBRATING EUROPE'S LEVEL OF AMBITION: TOWARDS A LONG-TERM, SUSTAINABLE CRITICAL RAW MATERIALS STRATEGY FOR EUROPE

As noted above, European levels of ambition over the next decade in the critical raw materials space are realistically within the realm of risk reduction through diversification and bolstering supply chain resilience, rather than developing and exercising strategic leverage over China. Against a backdrop of Chinese control over critical mineral production and value chains, and massive reindustrialisation in the United States, European countries urgently need to mitigate supply risks.[29] In addition to securing primary resources, the EU must seek to reduce the geopolitical risks linked to critical raw material dependencies.

Nonetheless, in the context of the four levels of ambition set out in this study, the pursuit of a more proactive mining diplomacy over the next decade could afford Europe a limited degree of leverage with regard to its

---

[29] Yves Jégourel, "Europe and Securing Supplies of Mineral Resources: From Strategic Urgency to Diplomatic Pragmatism", Schuman Papers, no. 675, Robert Schuman Foundation, 23 June 2023, at https://www.robert-schuman.eu/en/robert-schuman-foundation.

ability to deny, or at least obstruct, China's access to the resources it needs to achieve its policy ambitions; and act to shape the technological and normative features of mineral markets in a way that compels China to adapt to new realities in third markets. Given China's own import dependencies and Europe's efforts to diversify supplies through overseas production, Europe could effectively hope to deepen the entanglement of China's strategic interests with those of Europe while at the same time reducing European dependencies on China and improving resilience. The policy ambitions of threat prevention and curtailment, meanwhile, do not apply in the case of critical raw materials.[30]

- **Ability to deny:** There is a clear need for Europe to diversify supply chains beyond China, on the one hand, and a clear ambition among Europe's partners to capitalise on their resource wealth by moving up the technological value chain and ensuring economic development, on the other. Europe can capitalise on this convergence of interests by proactively responding to the needs and ambitions of mineral producing states. Such an approach would strengthen the economic, technological and political linkages between Europe and its partners while broadening the field of strategic options for the latter, allowing for a greater degree of independence and agency for these states to make political choices. While this is a relatively weak source of leverage over China, not least in that it depends on the interests and political will of partners to make strategic choices in line with European interests, it nonetheless rebalances the degree of leverage and control that China can expect to have over mineral markets and, to a degree, could act as a deterrent to more coercive behaviour by Beijing in the field.

- **Ability to act:** By developing the technical solutions to effectively develop mining and processing activities within Europe's constrained regulatory space, and enhancing coordination with other supply- and demand-side partners in the area of sustainable and responsible mining practices, starting with forums such as the Mineral Security Partnership or the Organisation for Economic Co-operation and Development's Forum for Responsible Mineral Supply Chains, Europe can help to effectively shape the normative dimensions of the extractive industries and mineral markets, compelling China to adapt. Here again, the feasibility of such an approach and the ultimate degree of indispensability it affords to Europe in its relations with China remain limited, particularly in a context where China is also looking to enhance its domestic production while strengthening its environmental regulations, pressing Chinese actors to also develop technologies and methods for mining and refining that can be applied in third markets.

Ultimately, while Europe finds itself in a highly vulnerable situation with regard to critical raw materials, it is not without options and, if it acts strategically, can hope in the medium to long term to find a degree of co-dependence with China in this space. Nonetheless, tangible progress towards achieving either level of ambition will require Europe to double down on a more proactive and strategically oriented minerals and mining diplomacy while investing in building European competencies in the field. In both respects, Europe must look to make good on the promise of responsible, sustainable and supply-chain enhancing partnerships with producing countries, and ensure a parallel level of convergence with allies and demand-side partners on how to approach these issues. Most of the policy recommendations set out below would help Europe to enhance both the "ability to deny" and the "ability to act", while some relate only to the latter.

A STRATEGIC FRAMEWORK FOR MINING DIPLOMACY

Among the long-term responses available to Europe in the face of growing mineral resource challenges, the EU's and the UK's strategies should explore an adaptative and flexible approach with third parties. The forging of a tailor-made, proactive mining diplomacy could facilitate the establishment of a secure and sustainable supply network for critical raw materials essential for the ecological transition and for most advanced technologies.

To implement such a global strategy, Europe must concentrate its approach most effectively by following a long-term and coherent policy that reflects the anticipated reshaping of post-Cold War globalisation. Among the options discussed, regionalisation of the

---

[30] European countries do not possess the necessary market position to allow the curtailment of strategic mineral supplies to China and it is impractical to think that it could develop such a position in the coming years. It is also impractical to act on the dual-use nature of certain mineral supplies that are critical for digital technologies but for which, again, Europe lacks the necessary supply advantage to effectively apply direct leverage.

global economy could provide a suitable solution to the challenges of the ecological transition.[31] This policy must mobilise different instruments to respond to specific local contexts. To achieve this, European actors will need to consider whether the resources at their disposal are sufficiently attractive to third party partners. For good reason, the EU's strategy should look to cooperate closely with its closest economic partners, notably the United Kingdom and Norway.

In 2022, the *UK* published a Critical Minerals Strategy for the next 25 years.[32] Like the EU and many of its member states, the UK is accelerating the development of critical minerals projects and further expanding trading and diplomatic relations to secure the supply of critical raw materials. It should be noted that the presence of the London Metals Exchange (LME) in the nation's capital – the world's largest market in standardised forward contracts, futures contracts and options on base metals – continues to be a significant asset and could leverage the UK's role as the centre of mining finance. The UK is also a key, proactive partner in the Minerals Security Partnership.

In April 2023, the EU established a "Green Alliance" with Norway to work jointly on critical raw materials, among other things.[33] In March 2024 the two parties signed a memorandum of understanding on a strategic partnership to better integrate raw material and battery value chains, cooperate on research and innovation, develop and apply high-level environmental, social and governance (ESG) standards, mobilise financial and investment instruments, and develop skills and human capital.[34] Norway has stated its intention to implement a sustainable mining industry.[35] This includes the development of its seabed extractive resources to make it the world's leading subsea mining power in the coming decades.[36] While cooperation has been limited to land-based resources while the EU presses for environmental impact studies on marine ecosystems, forging synergies with Norway in this field, as in the case of the UK, should be on the radar in Brussels.

The EU must also use its political and historical proximity to strengthen its ties with its near abroad of North Africa, the Western Balkans, Greenland, Ukraine and Turkey, many of which are largely ill-equipped for the development of sustainable mining activities. Cooperation between the EU and Greenland is tightening, for instance,[37] and mining is among the priorities on the agenda,[38] particularly following President of the European Commission Ursula von der Leyen's March 2024 visit to Nuuk.[39] By contrast, China's attempts to develop mining in Greenland have fallen through.

In addition, the EU's closest allies and partners – such as the United States, Japan, Canada and Australia – are associated with implementation of a de-risking strategy with regard to Chinese mineral supply chain dependencies. The EU has already established a strategic partnership with Japan based on the European Green Deal.[40] It also bolstered relations with Canada in 2021 and is negotiating a Critical Minerals Agreement with the USA and Australia.

In the next 10 years, partnering with key critical raw materials producer countries will be a high priority. For this reason, there are ongoing discussions between

---

[31] Svitlana Radziyevska and Ivan Us, "Regionalization of the world as the key to sustainable future", E3S Web of Conferences, 166, 13016, 2020, at https://doi.org/10.1051/e3sconf/202016613016.

[32] UK Department for Business, Energy and Industrial Strategy, Resilience for the Future: The United Kingdom's Critical Minerals Strategy, London, July 2022.

[33] European Commission, "European Green Deal: New EU-Norway Green Alliance to Deepen Cooperation on Climate, Environment, Energy and Clean Industry", 24 April 2023, at https://ec.europa.eu/commission/presscorner/detail/en/ip_23_2391.

[34] European Commission, "EU and Norway Sign Strategic Partnership on Sustainable Land-based Raw Materials and Battery Value Chains", Press release, Brussels, 21 March 2024, accessed 15 April 2024, at https://ec.europa.eu/commission/presscorner/detail/en/ip_24_1654.

[35] Ministry of Trade, Industry and Fisheries, Norwegian Mineral Strategy, Oslo, June 2023.

[36] Trine Jonassen and Birgitte Annie Molid Martinussen, "Norwegian Political Agreement on Deep-sea Mining in the Arctic", High North News, 5 December 2023, at https://www.highnorthnews.com/en/norwegian-political-agreement-deep-sea-mining-arctic.

[37] Denmark's Representation, "Ny chef til EU's kontor i Grønland", European Commission, Brussels, 21 November 2022, at https://denmark.representation.ec.europa.eu/news/ny-chef-til-eus-kontor-i-gronland-2022-11-21_da.

[38] European Commission, "EU and Greenland Sign Strategic Partnership on Sustainable Raw Materials Value Chains", Press release, Brussels, 30 November 2023, at https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6166.

[39] European Commission, "President von der Leyen Inaugurates the EU Office in Nuuk and Signs Cooperation Agreements to Strengthen the EU-Greenland Partnership", Press release, Brussels, 15 March 2024, at https://ec.europa.eu/commission/presscorner/detail/en/ip_24_1425.

[40] Izabela Wróbel, "The 'green' agreement between the European Union and Japan", Stosunki Miedzynarodowe - International Relations, vol, 2, no, 24, accesses 5 April 2024, at https://doi.org/10.12688/stomiedintrelat.17582.1.

the European Commission and some African and Latin American countries. Such efforts must be expanded and systematised in all regions of the world. In Central Asia, for instance, Kazakhstan's exceptional mineral potential makes it an excellent partner in this category.[41]

The EU is already shaping a global mining diplomacy, but this must be enhanced and sustained throughout the next decade. For instance, the Commission has signed key agreements with third parties, such as:

- A partnership on critical and strategic raw materials value chains with the DRC;
- A sustainable raw materials partnership with Zambia;[42] and
- A memorandum of understanding with Chile to establish a partnership on sustainable raw materials value chains as part of the EU's Global Gateway.[43]

Broadly speaking, the EU is gradually introducing initiatives to build a consistent strategy that can lead to the advent of raw materials diplomacy.[44] The latter should be flexible depending on the local context, and based on what the EU can offer, such as specific training programmes, technologies and processes configured to meet the new environmental constraints. To the degree that such cooperation leads to the establishment of new standards, the EU will not only be developing its ability to deny, but also enhancing its ability to act. The emergence of mining diplomacy will be a long path that requires a tailor-made, complex and lasting network of various partners, according to their respective proximity to the core. European industrial stakeholders are also actively deploying a strategy to secure critical metals. In the car making industry, Stellantis, for instance, is strengthening its position in Argentina to secure battery metal minerals by expanding its investments in lithium and copper.[45] Nonetheless, such an integrated approach by European industrial operators will require greater synergy if the EU plans to become a competitive and consistent economic powerhouse in critical mineral markets.

The development of such a strategy should foster the EU's efforts to consolidate strategic locations and secure supplies. In addition, a proactive diplomacy in the mining arena offers a range of opportunities through various EU-funded schemes in science diplomacy, education cooperation, economic investments, and so on.

ADDRESSING FUTURE MINING CHALLENGES THROUGH ENHANCED PARTNERSHIPS AND INCENTIVE INSTRUMENTS

As part of this large-scale strategy, Europe should further invest not only in extractive industries but also in downstream production in support of local economic development in partner countries. Institutional bodies and stakeholders in industry, research and education should be part of this comprehensive effort to secure the critical metals and mineral supply chains that are a prerequisite for the success of the EU's reindustrialisation strategy. The latter will unfold under the premise of the ecological transition and strategic autonomy – two fundamental drivers of the long-term affirmation and resilience of European competitiveness – which must enhance and safeguard the most cutting-edge mining and recycling equipment.[46] To this end, the EU will need to protect intellectual property more sharply against any potential Chinese espionage activities and ensure the economic security of industries that are integrated into critical parts of the supply chain. Furthermore, orienting

---

[41] Craig Guthrie, "Europe to Fund Lithium, Tungsten Projects in Kazakhstan", *Mining Magazine*, 15 November 2023, at https://www.miningmagazine.com/exploration/news/1462040/europe-to-fund-lithium-tungsten-projects-in-kazakhstan.

[42] European Commission, "Global Gateway: EU Signs Strategic Partnerships on Critical Raw Materials Value Chains with DRC and Zambia and Advances Cooperation With US and Other Key Partners yo Develop the 'Lobito Corridor'", Press release, Brussels, accessed 26 October 2023, at https://ec.europa.eu/commission/presscorner/detail/en/IP_23_5303.

[43] European Commission, "Global Gateway: EU and Chile Strengthen Cooperation on Sustainable Critical Raw Materials Supply Chains", Press release, Brussels, 18 July 2023, at https://ec.europa.eu/commission/presscorner/detail/en/ip_23_3897.

[44] European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, "Raw Materials Diplomacy", accessed 5 April 2024, at https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/raw-materials-diplomacy_en.

[45] James Attwood, "Stellantis, Rio Tinto Raise Bets on Argentina Copper Mining", Bloomberg, accessed 11 October 2023, at https://www.bloomberg.com/news/articles/2023-10-11/stellantis-rio-tinto-raise-bets-on-copper-mining-in-argentina; and "Stellantis Invests $90 Million in Argentina Lithium Explorer for 20% Stake", Mining.com, accessed 23 September 2023, at https://www.mining.com/stellantis-invests-90-million-in-argentina-lithium-explorer-for-20-stake/.

[46] Tobias Gehrke and Julian Ringhof, "Indispensable Leverage: How the EU Can Build its Technological Edge", European Council on Foreign Relations, accessed 12 September 2023, at https://ecfr.eu/article/indispensable-leverage-how-the-eu-can-build-its-technological-edge/.

inbound investment screening to cover critical mineral value chains would help to ensure that the gains made in Europe by developing a mining, processing and recycling ecosystem remain anchored in Europe.

Among the ways to strengthen Europe's position in the mining economy, knowledge creation should be seen as a critical asset to be emphasised as a distinctive edge over the global competition. For instance, the Swedish mining group LKAB and Luleå University of Technology are cooperating to establish a new training programme related to the needs and challenges of the ecological transition, which will require related skills and competences.[47] In this respect, expertise and human capital development could be emphasised and implemented with partner countries through training programmes and university partnerships. Europe should look to capitalise on what is left of its know-how in geology, mineralogy and metallurgy – from the mining and minerology institutes scattered across the continent to the leading firms mentioned above that still have high-tech competencies in metallurgy and primary and secondary metals production – and build on this base to service the needs of the ecological transition.

In the meantime, the number and extent of the industrial initiatives in Europe – from mines to refining, recycling, the Chips Act, hydrogen and the Battery Alliance, among others – mean that it is doubtful that there will be either the space or the human resources for all of them. Investments in key partners, starting with Europe's neighbourhood, could be seen as both a soft power strategy and an industrial necessity. Specifically, EU-funded programmes might facilitate the accreditation and certification of a skilled workforce, based on European standards, among partner countries able to meet the demand for high-skilled jobs.[48]

Responsible and sustainable mining is high on the European agenda as negative systemic impacts related to extractive activities are a global concern. For instance, the German company BMW is facing a pollution scandal related to arsenic-contaminated water due to cobalt mining in Morocco.[49] The German group secured part of its cobalt supplies from the North African state while shifting away from cobalt mines in the DRC.[50] In this regard, the EU must be able to offer unique incentives for the governance of mining operations – from exploration to management of the post-mining phase. Among other things, the EU and its member states must ensure that the best practices in mineral extraction and processing developed for the European market are applied to investments overseas, to avoid simply leaving the dirty work of mining and processing to others, and offer a qualitative improvement on what Chinese competitors are currently offering.

Such a set-up would require the reintroduction of mining activities more extensively throughout European territory to strengthen its influence on the ground. On this basis, the EU could eventually be able to lay claim to a singular normative model that seeks to close the loop of systemic socio-environmental issues. In this way, third parties could join similar arrangements, tying them to a standardised system that regulates both the lifecycle of a mine and the flow of critical raw materials through the industrial value chain. Proactively engaging in international standards development, particularly in the field of ESG standards as applied to the mining sector, is one way of ensuring that more responsible practices gain global resonance and continue to be followed by European actors beyond European borders.

On the technological side, European mining companies already implement high-value technologies (e.g., in robotisation, AI and digitalisation) in their operations, developed in part with financing from the EU.[51] Such technologies are instrumental in boosting resource efficiency, promoting sustainable practices and improving labour conditions in partner countries. For example, Finland's Metso Outotec has technologies, such as filtration for dry stack tailings, that could be used to promote more

---

[47] LKAB, "New Training Courses for the Mining Industry", accessed 2 January 2024, at https://lkab.com/nyheter/new-training-courses-for-the-mining-industry/.

[48] Judit Arnal, Emilio García and Raquel Jorge, "Policies and Tools for Strengthening the European Semiconductor Ecosystem", Elcano Policy Paper, Real Instituto Elcano, October 2023.

[49] Sam Metz, "A Moroccan Cobalt Mine Denies Claims of Arsenic-contaminated Local Water: Automakers are Concerned", AP, accessed 15 November 2023, at https://apnews.com/article/bmw-renault-electric-batteries-cobalt-morocco-31d29d6498999a3ec44ee0efd3b008e4.

[50] Jacqueline Holman, "BMW signs €100 Million Sustainable Cobalt Supply Contract with Moroccan Miner", S&P Global, 9 July 2020, accessed 5 April 2024, at https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/070920-bmw-signs-eur100-million-sustainable-cobalt-supply-contract-with-moroccan-miner.

[51] Project Goldeneye, accessed 26 March 2024, at https://www.goldeneye-project.eu/; Autonomous Monitoring and Control System for Mining Plants (AMICOS), accessed 26 March 2024, at https://amicos.fbk.eu/.

environmentally friendly mining activities with third parties.[52] The use of blockchain, for instance, is being explored as a way to ensure traceability and standards compliance along mineral supply chains.[53] At the same time, Chinese tech companies such as Huawei have been adapting their expertise to the mining sector, for instance through "Intelligent Mining" solutions that employ AI.[54] In parallel, the state has been financing academic research, for instance at the State Key Laboratory for Geological Processes and Mineral Resources at the China University of Geosciences, since at least 2020 in pursuit of such aims.[55] Thus, European governments and firms are not necessarily unique in their turn towards high-tech mining solutions. When accompanied by a more comprehensive resource and mining diplomacy, however, the use of such technologies could represent a source of competitive leverage to boost their normative and geopolitical influence.

Ultimately, deepening mutually beneficial resource partnerships with producer countries, particularly in Europe's neighbourhood, and working to bring key demand-side partners in line with good practices would help to construct a model for sustainable mineral markets to which Chinese firms and state actors would eventually have to adapt.

---

[52] Jax Jacobsen, "Eldorado to Use Metso Outotec Filtration Technology", *Mining Magazine*, accessed 2 November 2022, at https://www.miningmagazine.com/environment/news/1442645/eldorado-metso-outotec-filtration-technology.

[53] EIT Raw Materials, "EIT RawMaterials Funded Project to Develop a Blockchain Based Circular System for Assessing Rare Earth Sustainability", accessed 6 April 2022, at https://eitrawmaterials.eu/eit-rawmaterials-funded-project-to-develop-a-blockchain-based-circular-system-for-assessing-rare-earth-sustainability/

[54] Huawei, "Intelligent Mining", accessed 14 January 2024, at https://e.huawei.com/en/industries/mining.

[55] Stephen Chen, "Chinese Scientists Turn to Artificial Intelligence as Potential 1,000km Seam of Rare Metal Minerals Found in Himalayas", *South China Morning Post*, accessed 21 June 2023, at https://en.cug.edu.cn/info/1195/1459.htm

SCORECARD 2 TECHNOLOGY FIELD: CRITICAL RAW MATERIALS

	Threat prevention	Ability to deny	Ability to act	Curtailment
Feasibility of level of ambition	Not feasible	● Low	● Low	Not feasible
Core policy recommendations	• None	Enhance European competencies: • Make Europe a more attractive technical partner for third parties by re-investing in European competencies in geology, mineralogy, mining, processing and recycling. • Maintain commitment to international IP enforcement. • Apply inbound investment screening procedures to ensure that Europe's emerging critical mineral industrial ecosystem remains anchored in Europe. Enhance mining and minerals diplomacy: • Deepen strategic partnership initiatives with key third-party producers and consumers. • Seek supply chain complementarity with key third-party producers, matching partners' needs for downstream industry development with European needs for supply chain diversification. • Develop and enhance training and education programmes in mineral sciences with strategic partners to promote innovation cooperation, skills development and socio-economic synergies. • Couple supply-chain development with broader sustainable development initiatives such decarbonized energy infrastructure to ensure compliance with European regulations and access to the European market.	In addition to actions related to the "ability to deny": • Deepen support for the development of cutting-edge techniques and the highest social and environmental standards in Europe. • Coordinate standards and best practices and deepen supply-chain synergies with key supply and demand side partners. • Work to ensure and enhance European participation in international technical standards development.	• None

AUTHORS

John Seaman is a Research Fellow in the Center for Asian Studies of the French Institute of International Relations (Ifri). Contact: seaman@ifri.org
Florian Vidal is a Research Fellow in International Affairs and Science & Technology at UiT The Arctic University of Norway in Tromsø, Norway. Contact: florian.f.vidal@uit.no
Raphaël Danino-Perraud is an Associate Research Fellow in the Center for Energy & Climate at the French Institute of International Relations (Ifri), an independent consultant and lecturer at Centrale Supélec in France. Contact: daninoperraud.raphael@gmail.com

AI for Medical Imaging: MRI Scanners and the Roles of Philips and Siemens in China

Carlo Fischione, Sanne van der Lugt and Frans-Paul van der Putten

ABSTRACT

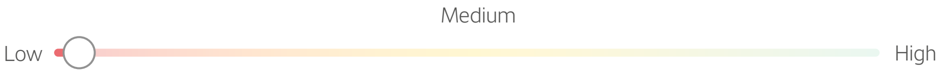
This chapter provides a preliminary exploration of whether Europe's strength in medical artificial intelligence (AI) technology can be a tool for bolstering European strategic autonomy. It focuses in particular on AI for magnetic resonance imaging (MRI). Two European companies, Siemens and Philips, are among the market leaders in the production of MRI scanners, both globally and in China. China's dependence on European AI for MRI is limited and likely to decline. However, as the sizeable market shares of both companies indicate, there is a high demand for their MRI systems. Chinese access to European AI for MRI cannot be seen separately from the MRI scanners themselves, the companies that make them and their comprehensive MRI products, which include support services. Therefore, in practice European strength in AI for MRI in relation to China means that European companies are commercially highly competitive with their Chinese counterparts. It seems likely that Chinese actors will be increasingly able to match or possibly exceed European technological capabilities in key elements of MRI technology, such as imaging AI or magnets. There is, however, at least for now, a high degree of co-dependence. Siemens and Philips need China's large and growing market for MRI devices, and Philips in particular needs Chinese AI technology, while Chinese hospitals need the two companies' integrated MRI systems, and Philips' AI suppliers have a need for that company's MRI scanners. There is some scope for using the dependencies already in place to strengthen China's reliance on European technology. The European authorities could help to slow the decline in European market share in China by protecting European companies from the effects of Chinese state support for their Chinese competitors.

SCORECARD 1 TECHNOLOGY FIELD: AI FOR MEDICAL DEVICES

Source of European technology strength	Research and innovation	Intellectual property and patents	Production and commercialisation
	High	High	High

Type of European technology strength	Technological excellence	Commercialisation advantage	Conditioning of market access	Regulatory, political and normative factors	Sustainability	Research partnerships with third countries
		X	X			

Degree of European leverage



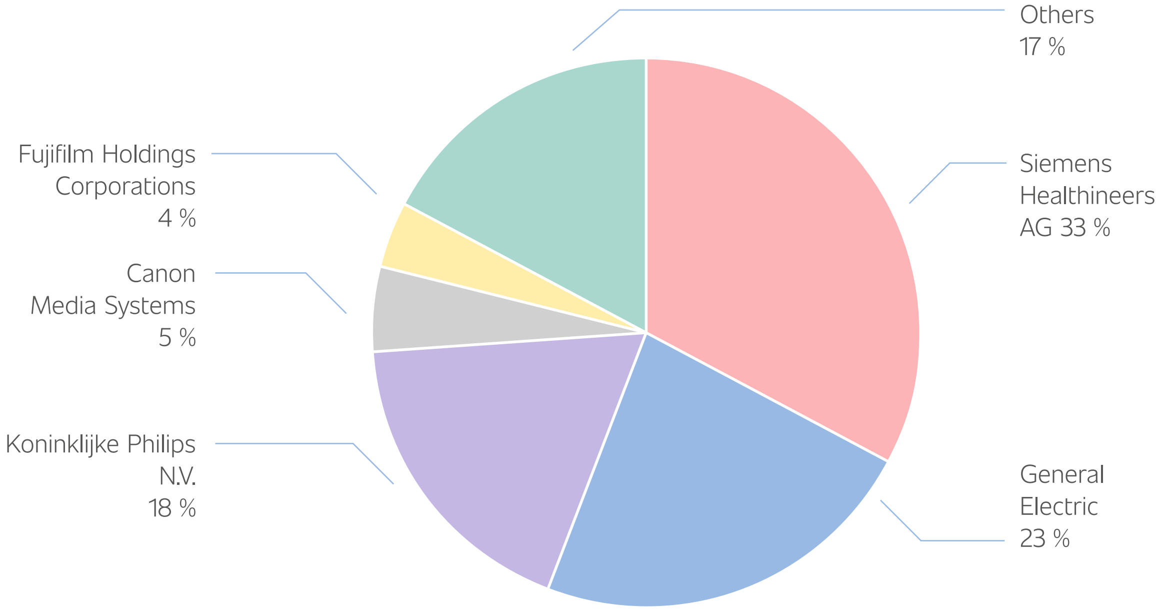
INTRODUCTION

This chapter provides a preliminary exploration of whether Europe's strength in medical artificial intelligence (AI) technology can be a tool for bolstering European strategic autonomy.[1] It focuses in particular on AI for magnetic resonance imaging (MRI). Medical staff in hospitals and clinics make use of MRI by using magnetic fields to view detailed images of the interior of their patients' bodies, with the aim of diagnosing a wide variety of conditions. AI has rapidly become a major enabler of diagnostic imaging in recent years. The question is whether Europe can maintain a degree of superiority so that China continues to rely on European MRI equipment. This could result in a case of European indispensability.

---

[1] The authors are grateful to Dr Xinyu Huan, Anouschka Modak, Christine Binghua Lu and Angelina Molchanova for contributing to the research for this chapter, as well as to Frans Greidanus and the anonymous interviewees for their kind support.

FIGURE 1: GLOBAL MARKET SHARE OF LEADING MRI MANUFACTURERS, 2022



Source: Next Move Strategy Consulting

Artificial intelligence for MRI as an applied technology is an integral part of MRI scanners. These are typically large and expensive machines produced by a small number of companies. Two European companies, Siemens and Philips, are among the market leaders in the production of MRI scanners, both globally and in China. China's access to, and potential dependence on, European AI for MRI cannot be seen separately from MRI scanners and the companies that make them. This chapter therefore discusses not only AI as a technology, but also the position of European MRI devices in China's market, and the roles of the two manufacturing companies.

CHINA AS A MARKET FOR EUROPEAN MRI TECHNOLOGY

Two of the three companies that dominate the global medical device market are European: Philips and Siemens. The third company – GE HealthCare, a spin-off from General Electric – is based in the US. Europe has a strong healthcare system but an aging population and a massive labour shortage in the healthcare industry. To address the labour shortage and the growing number of people in need of care, European companies have been investing heavily to develop AI-powered healthcare solutions. Both Philips and Siemens are major makers of healthcare equipment, and both have extensive R&D, manufacturing and commercial activities in China.

Siemens, a German enterprise, is Europe's largest industrial conglomerate. Its healthcare subsidiary, Siemens Healthineers AG, is 75% owned by Siemens AG. In 2022, Siemens Healthineers was responsible for 30.1% of Siemens' overall sales, making it the largest contributor to sales within the conglomerate.[2] In the same year, China accounted for 10.8% of the sales of Siemens Healthineers,[3] which provides equipment for medical imaging, laboratory diagnostics and hospital information systems, as well as digital health services. Philips, a Dutch company, is a former industrial conglomerate that now focuses almost exclusively on the healthcare sector, in particular diagnostic imaging, image-guided therapy, patient monitoring and health informatics, as well as consumer

---

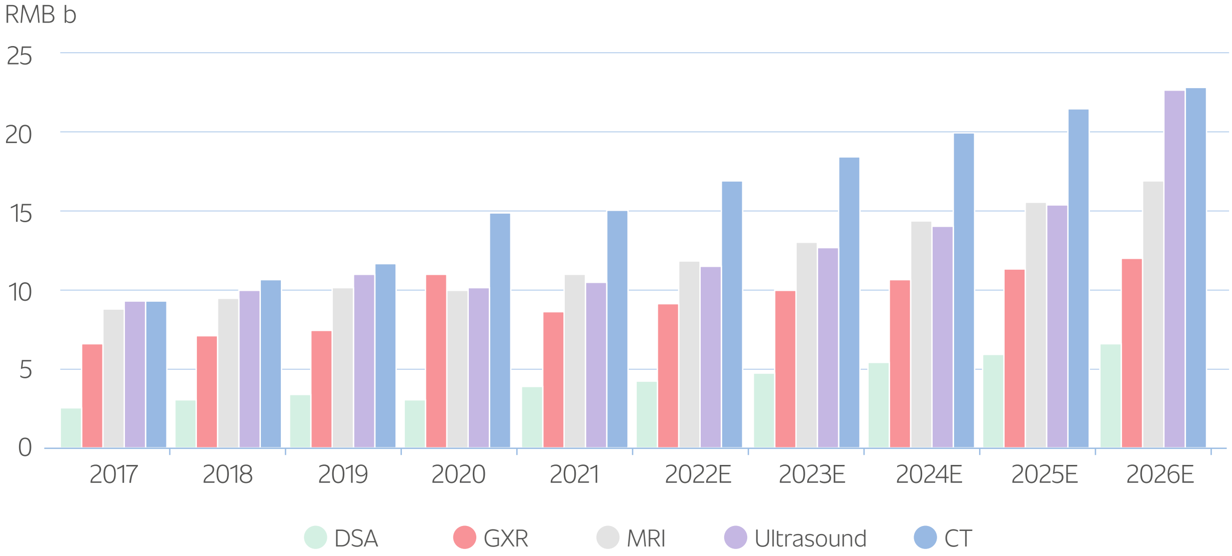
[2] Market Screeners, "Siemens Healthineers AG", accessed 3 April 2024, at https://www.marketscreener.com/quote/stock/SIEMENS-AG-56358595/company/

[3] Market Screeners, "Siemens Healthineers AG", accessed 3 April 2024, at https://www.marketscreener.com/quote/stock/SIEMENS-HEALTHINEERS-AG-42379342/company/

health and home care. In 2022 the company's sales in China accounted for some 12.4% of its total sales. While Siemens is much larger than Philips, Siemens Healthineers is somewhat comparable in scale to Philips. (It has slightly fewer employees but higher sales than its Dutch competitor.) Since 2007–2008, both companies have been manufacturing MRI scanners and developed research centres in China.[4] In recent years, like many foreign manufacturing companies, their China operations have become increasingly localised and integrated into their Chinese context. Figure 1 shows the global market shares of the leading manufacturers in the sector. It is not clear how much of the 17% share of 'others' is accounted for by Chinese companies.

China is the world's second-largest healthcare market, the second-largest market for medical imaging and the largest market for MRI equipment.[5] The medical device market in China is expected to expand by 8.6% between 2021 and 2026 (compound annual growth rate), bringing it to $48.8 billion by 2026.[6] The market for MRI scanners in China is expected to be $2.4 billion (17.070 million RMB) in 2026 (See Figure 2).

FIGURE 2: MARKET FOR MEDICAL IMAGING DEVICES IN CHINA ,GROWTH RATE 2017–2021 AND FORECAST FOR 2022–2026.



	CAGR				
PERIOD	CT	ULTRASOUND	MRI	GXR	DSA
2017–2021	12.8%	3.3%	5.0%	6.5%	10.4%
2021–2026 E	8.6%	9.5%	8.9%	7.1%	11.5%

Source: Neusoft Medical Systems Co., Ltd.; and Frost & Sullivan (Noting that, DSA stands for digital subtraction

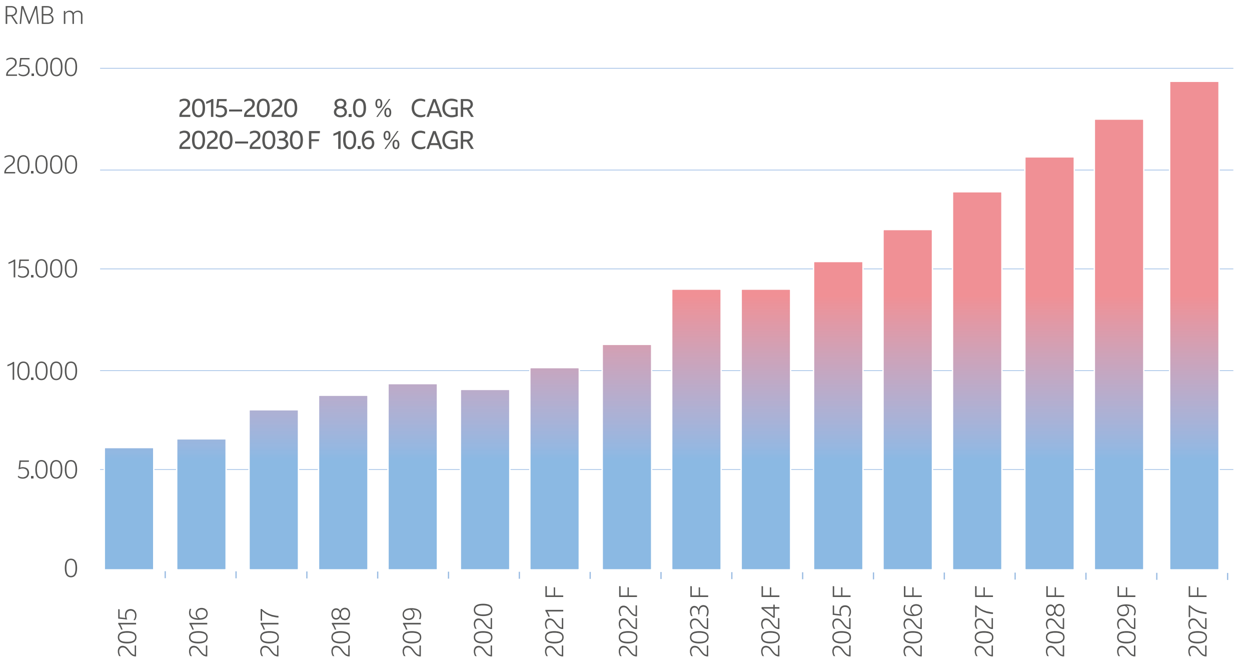
---

4 Bruce Einhorn, "Made in China: MRI Machines", Bloomberg, accessed 3 April 2024, https://www.bloomberg.com/news/articles/2008-04-30/made-in-china-mri-machines

5 Sally Ye, "China's Medical Artificial Intelligence Market Continues to Grow", Omnia Health, accessed 3 April 2024, at https://insights.omnia-health.com/artificial-intelligence/chinas-medical-artificial-intelligence-market-continues-grow

6 International Trade Administration, "Healthcare", Country Commercial Guide, accessed 3 April 2024, at https://www.trade.gov/country-commercial-guides/china-healthcare#:~:text=Imports%20of%20medical%20devices%20comprised,50%25%20of%20the%20market%20value

FIGURE 3: MARKET FOR MRI SCANNERS IN CHINA, 2015-2020 AND FORECAST 2021-2030.



Source: Shanghai United Imaging: and China Insights Consultancy (ex-factory price as estimate)

In 2018, there were still only about 6.7 MRI scanners per 1 million citizens in China,[7] which was much lower than the level in Japan (55.2), the US (40.4) or Germany (34,7) in 2019, and also lower than in the Netherlands (13).[8] The UK has about the same number of MRI scanners per million citizens as China.

The two main types of MRI scanner are 1.5 Tesla (T) and 3T scanners. The latter have a more powerful magnet and are useful for specific purposes, such as brain MRI scans or musculoskeletal scans (related to bones, muscles, joints and connecting tissues). For many other purposes, 1.5T scanners are sufficient or even more suitable. The Chinese market for both types is dominated by four companies.[9] In addition to the three foreign firms (Siemens, Philips and GE Healthcare), the group includes Shanghai United Imaging Healthcare Company (see Figures 4 and 5), a Chinese enterprise founded in 2011 based in Shanghai. Shanghai United Imaging Healthcare Company (United Imaging) achieved profitability for the first time in 2020.[10] Since 2022, the company has been listed on STAR Market, the tech exchange of the Shanghai Stock Exchange. United Imaging has production facilities in Wuhan and Changzhou, and R&D activities in Shanghai and Wuhan. It also has foreign sales offices in Tokyo, Seoul, Kuala Lumpur, Melbourne, Houston, Warsaw, Casablanca and Johannesburg. The company has production and R&D activities in Houston.[11] United Imaging is the market leader for 1.5T scanners in China. Siemens has the largest market share in the 3T scanners segment.

---

[7] According to statistics from the 2020–2026 China Nuclear Magnetic Resonance Industry Market Research and Investment Feasibility Study Report by the China International Capital Corporation (CICC), there were about 9,255 MRI units in China in 2018, https://gtdcbgw.com/index/show/id/1485.html. At the time, the population of China was approximately 1.403 billion.

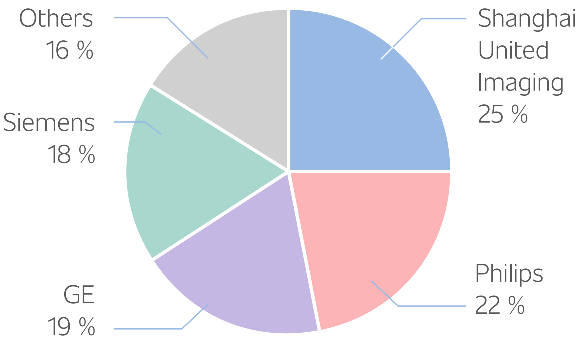
[8] Statista, "Number of magnetic resonance imaging (MRI) units in selected countries as of 2019", accessed 3 April 2024, at https://www.statista.com/statistics/282401/density-of-magnetic-resonance-imaging-units-by-country/

[9] Caitong Securities, "掘金医学影像领域的白马龙头" [Uncovering White Horse Leaders in Medical Imaging], accessed 3 April 2024, at https://pdf.dfcfw.com/pdf/H3_AP202208241577533558_1.pdf

[10] Mingmin Zhang, "China's 'Top Student' Takes on the 'International Exam': United Imaging's Path to Overseas", Equalocean, accessed 3 April 2024, at https://equalocean.com/analysis/2023062319806

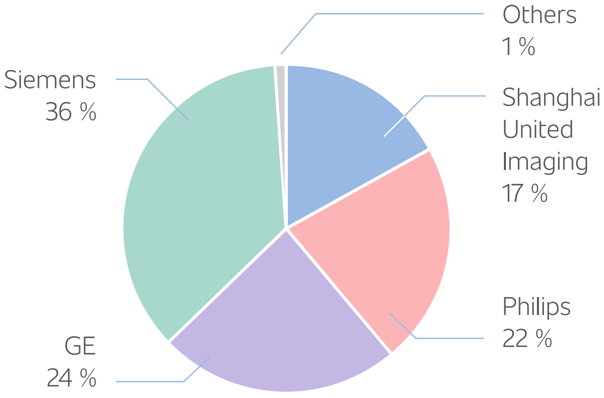
[11] United Imaging, "About United Imaging", accessed 3 April 2024, at https://www.united-imaging.com/en/about-united-imaging

FIGURE 4: MARKET SHARE OF 1.5 TESLA MRI EQUIPMENT MAKERS IN CHINA, 2020



Source: created by the authors based on data from Caitong Securities, accessed 3 April 2024, at https://pdf.dfcfw.com/pdf/H3_AP202208241577533558_1.pdf

FIGURE 5: MARKET SHARE OF 3 TESLA MRI EQUIPMENT MAKERS IN CHINA, 2020



Source: created by the authors based on data from Caitong Securities, accessed 3 April 2024, at https://pdf.dfcfw.com/pdf/H3_AP202208241577533558_1.pdf

HOW DEPENDENT IS CHINA ON EUROPEAN AI FOR MEDICAL IMAGING?

The Chinese government launched its Made in China 2025 strategy (MiC 2025) in 2015, with the aim of building national competence in developing and producing advanced technology. The MiC 2025 strategy identified the medical device industry as one of ten key industries, with a focus on developing imaging equipment and medical robots. The aim was to improve innovation and industrial mass production of these high-end medical devices.[12] The MiC 2025 strategy set a target that half of all the medical devices used in county-level hospitals should be produced in China by 2020. By 2025, this should be 70% and by 2030 95%. Specifically relevant to MRI equipment is China's policy aim to produce MRI magnets domestically. Magnets are key components of MRI scanners. Assessing academic contributions to the efforts to control the Covid-19 outbreak in March 2020, President Xi Jinping declared: "We should accelerate the improvement of the weak links of China's high-end medical equipment; break through the bottleneck of technology to realize the autonomous and controllable development of high-end medical equipment".[13] Public hospitals in China require the approval of the local authorities to procure imported medical equipment.[14] In 2019, China initiated a policy of centralised state procurement of medical devices, which paved the way for Chinese firms to make up a larger share of the market.[15]

According to the New Generation Artificial Intelligence Development Plan, announced by the central government in 2017, China will build a strong AI industry and become the leading AI power by 2030. Smart healthcare is one of five key AI-based applications alongside smart manufacturing, smart city, smart agriculture and smart national defence.[16] This was followed in 2018 by the Internet + Healthcare Initiative;[17] and in 2021 by the government's development plan for the medical

---

12 Zhang, Z. and Rao, W., "Key Risks and Development Strategies for China's High-End Medical Equipment Innovations", National Library of Medicine, accessed 3 April 2024, at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8302230/

13 Zhang and Rao, op. cit.

14 Catherine Longworth, "What China's domestic agenda means for foreign medical device developers", Medical Devices Network, accessed 3 April 2024, at https://www.medicaldevice-network.com/features/what-chinas-domestic-agenda-means-for-foreign-medical-device-developers/

15 Fredrik Erixon et al., "China's Public Procurement Protectionism and Europe's Response: The Case of Medical Technology", Ecipe, accessed 3 April 2024, at https://ecipe.org/publications/chinas-public-procurement-protectionism/

16 Sally Ye, "China's Medical Artificial Intelligence Market Continues to Grow", Omnia Health, accessed 3 April 2024, at https://insights.omnia-health.com/artificial-intelligence/chinas-medical-artificial-intelligence-market-continues-grow

17 National Health Commission National Medical Security Administration, '"关于深入推进"互联网+医疗健康""五个一"服务行动的通知'" [Notice on Further Promoting the 'Five One' Service Action of 'Internet + Medical and Healthcare'], National Health Planning, Issue [2020] no. 22, 2020, accessed 3 April 2024, at https://www.gov.cn/zhengce/zhengceku/2020-12/10/content_5568777.htm

equipment sector as part of the 14th Five-Year Plan (FYP).[18] The latter is not only about a secure supply of medical devices. The 14th FYP envisages six to eight Chinese enterprises ranking among the top 50 in the global medical device industry.[19]

Smart healthcare (zhìhuì yīliáo 智慧医疗) is an approach to improving healthcare by systematically combining new technologies, including AI, into existing medical activities to create new medical services.[20] The concept applies to diagnosis and treatment, health examination, public health management, medical insurance and medical service management, as well as intelligent platform construction and data safety.[21] Other relevant concepts are smart hospitals, or AI and Internet of Things-enabled hospitals;[22] and internet hospitals for online medical treatment.[23] According to Chinese media, however, "AI healthcare in China is still developing and transferring perceptual intelligence to cognitive intelligence. It is not ready for mass distribution and application".[24]

The Chinese government is therefore prioritising the development of AI-powered medical equipment and reducing China's dependence on foreign technologies in that area. Imaging is currently the most common application of medical AI in China. The consulting firm Omdia estimates that there are around 150 Chinese medical AI providers, and more than 40% of them focus on medical imaging.[25] China's aging population and the increasing prevalence of chronic diseases are driving demand for improved and faster diagnosis, and better healthcare services.[26] China's AI market for medical imaging diagnosis applications is estimated to increase from RMB 2.3 billion(b) in 2021 to RMB 28.5b in 2025, and probably reach RMB 76.9b by the end of 2030.[27]

According to Huang Zhenyao of Nikkei Asia, technology for image processing is growing faster in China than in the rest of the world for four reasons. First, the huge size of the Chinese market offers a large parameter for the accumulation of image data, as well as ample volumes and a variety of data sources. Second, compared with Europe or the US, China has more workers trained in data annotation, the process of labelling data to make it usable for machine learning. In addition, many Chinese companies are able to operate quickly and flexibly, and there is policy support from the government, which sees AI development as a national strategy.[28]

---

[18] Xinhua, "China Releases Development Plan for Medical Equipment Industry", accessed 3 April 2024, at https://english.news.cn/20211228/07e7e56402544559936d3fa2c71d938c/c.html

[19] China Association for Medical Devices Industry, "Interpretation of the Development Plan for the Medical Equipment Sector During the 14th Five-Year Plan Period", 28 December, 2021

[20] There are several concepts that relate to AI in healthcare in Chinese policies and official documents. "智慧医疗Zhihui Yiliao" "智慧健康养老Zhihui Jiankang Yanglao" "互联网+医疗健康Hulianwang + Yiliao Jiankang" "三位一体智慧医院Sanwei Yiti Zhihui Yiyuan", the most frequently seen terms, are the very core of the China"s strategy on developing medical-related AI. "智慧医疗" "互联网+医疗健康""大健康产业" are more general concepts, while "智慧健康养老" "三位一体智慧医院" delve into more specific discussion of medical AI applications.

[21] 李敏,劉世明,沈怡等.智慧醫療研究現狀與熱點分析——基于中國知網數據庫的CiteSpace可視化分析[J].現代醫院,2023,23(06):825-829. "智慧健康养老" ['Analysis of Current Status and Hot Spots of Smart Healthcare Research: A CiteSpace Visualization Analysis Based on China Knowledge Network Database', 'Modern Hospital'] Intelligent Health and Elderly Care and "三位一体智慧医院" Three-in-one Smart Hospital are the vital application of "智慧医疗" [smart healthcare]. "互联网+医疗健康" Internet + Medical and Health has overlapping connotations with "智慧医疗", but more focused on the role of the internet in medical-biological information-sharing, and the management of related subjects.

[22] Jielong Tan, "Development and Technology Application of Smart hospitals in China", *Frontiers in Computing and Intelligent Systems,* accessed 3 April 2024, at https://drpress.org/ojs/index.php/fcis/article/view/3167

[23] Deloitte, "Internet Hospitals in China: The New Step into Digital Healthcare", accessed 3 April 2024, at https://www2.deloitte.com/cn/en/pages/life-sciences-and-healthcare/articles/internet-hospitals-in-china-the-new-step-into-digital-healthcare.html

[24] CGTN, "Smart Healthcare: China is Building a New Model of Smart Healthcare", accessed 3 April 2024, at https://news.cgtn.com/news/2022-11-16/VHJhbnNjcmlwdDY5NDg4/index.html.

[25] Sally Ye, "China's Medical Artificial Intelligence Market Continues to Grow", accessed 3 April 2024, at https://insights.omnia-health.com/artificial-intelligence/chinas-medical-artificial-intelligence-market-continues-grow,

[26] CCB International, Healthcare & Medical Devices, 20 April 2023

[27] CCB International, Healthcare & Medical Devices, 20 April 2023. Key players in the Chinese AI health market include Infervision (CHN), Yitu Healthcare (CHN), 12 Sigma Technologies (CHN), Huiying Medical Technology (CHN), Deepwise (CHN), United Imaging (CHN), Airdoc(CHN), IBM Watson Health (USA) and NVIDIA Corporation (USA), https://www.insights10.com/report/china-artificial-intelligence-ai-in-medical-imaging-market-analysis/

[28] Huang Zhenyao, "China takes Lead in AI-based Diagnostic Imaging Equipment", Nikkei Asia, accessed 3 April 2024, at https://asia.nikkei.com/Business/Startups/China-takes-lead-in-AI-based-diagnostic-imaging-equipment

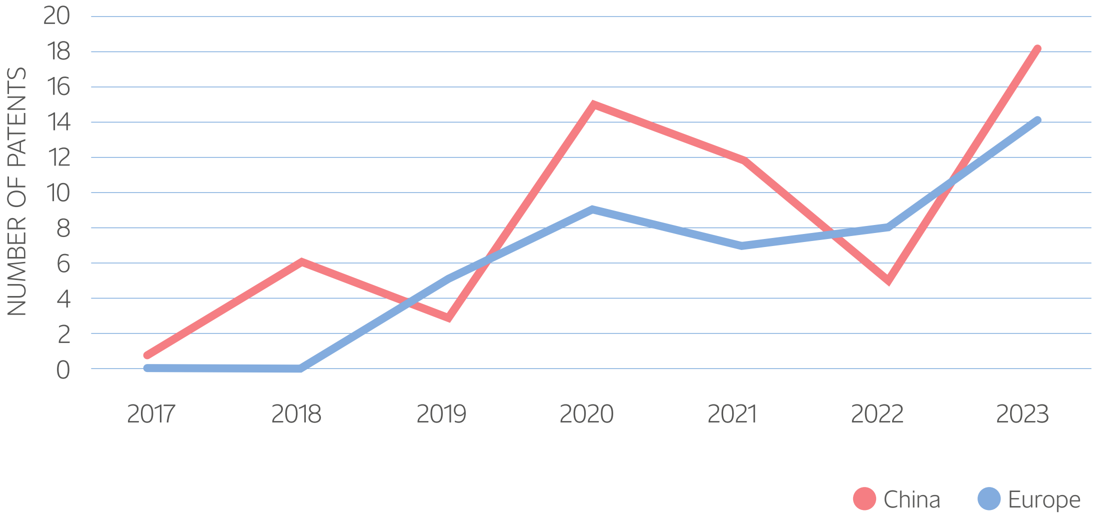
Figure 6 provides a comparative analysis of patents on the topic of AI and healthcare over time, showing trends in China and Europe. The data indicates a consistent upward trajectory in the number of patents in both regions in the period 2017–2023. It is noteworthy that China generally has a higher count of patents compared to Europe, which is particularly evident in 2018, 2020 and 2023.[29]

Figure 7 shows the distribution of AI and healthcare patents applied for by various companies and institutions in China. The concentration of patents in China primarily revolves around Siemens and United Imaging. These entities stand out as the major contributors to patent applications in the sector within China, with an almost similar number of patents.

In terms of patent applications, Siemens has an apparent lead, but when the two separate figures for United Imaging are combined the company is ahead of Siemens. Given the overall trend for patents in AI and healthcare in China, it seems likely that Chinese companies and research institutions might have an even more dominant role in the coming years. United Imaging is still a young company, and ensures that each of its products has inherently AI-capable hardware and software components from the beginning.[30]

Notably, Philips is absent from Figure 7. The company appears to have chosen a different strategy from Siemens. China's AI regulatory requirements are more difficult for foreign companies to follow, especially if they have followed US (Food and Drug Administration) and EU (Medical Device Regulation) requirements during the R&D phase, which means that they are not automatically compliant with China's National Medical Products Administration (NMPA) requirements. In order for AI medical devices to obtain certification from the NMPA, they must comply with requirements on data collection, as well as full lifecycle requirements for AI medical devices covering algorithm development, verification and validation. Data collection is essential for algorithm training. Rather than develop AI software specifically for the Chinese market, which Siemens appears to be doing, Philips sources AI for its MRI scanners from Chinese suppliers.[31] It is clear that China is not dependent on Philips for access to AI for MRI.

FIGURE 6: COMPARISON OF THE NUMBER OF PATENTS IN HEALTHCARE AI BETWEEN CHINA AND EUROPE, 2017–2023



Source: Pantentscope, available at https://patentscope.wipo.int/

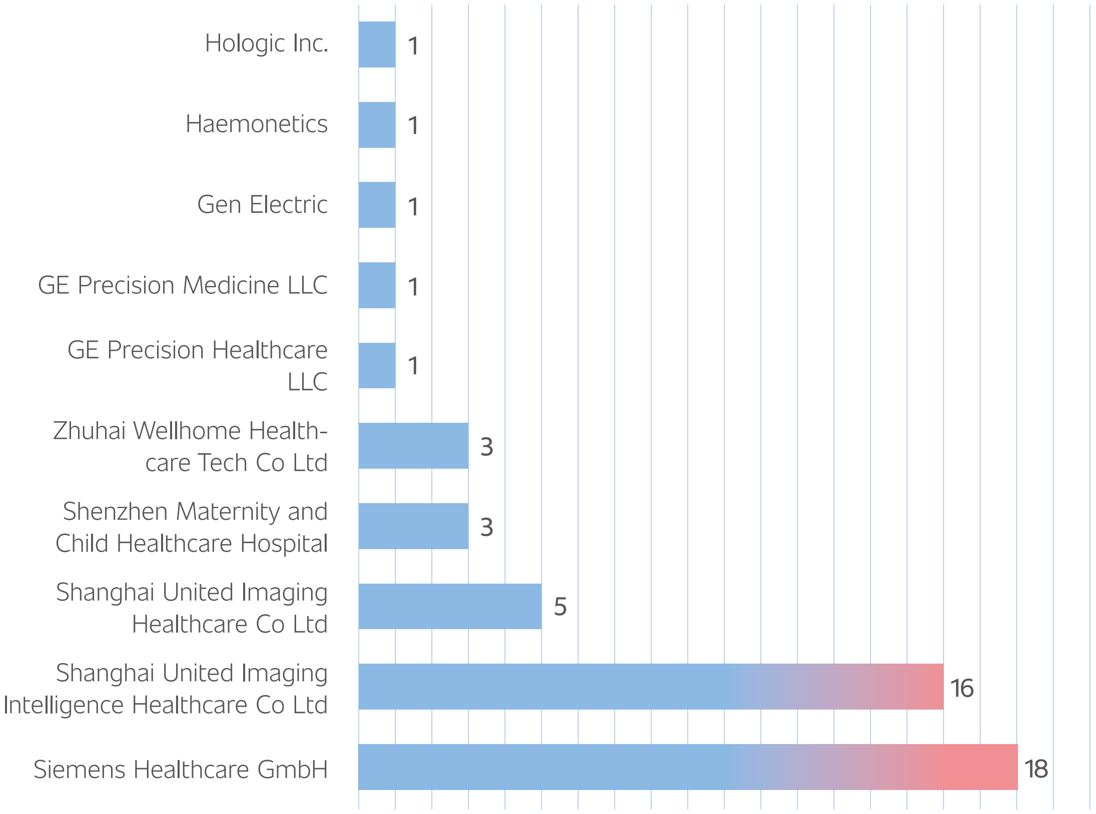
---

[29] The search was conducted using the patent search engine Patentscope, available at https://patentscope.wipo.int/. We extracted the companies or institutions that are contributing most to patents in Europe and China. For patents in Europe, we focused on the patents approved by the patent offices of all the EU member states. For patents in China, we focused on the patents approved by the patent office of the Peoples Republic of China.

[30] Shanghai United Imaging, United Imaging Showcases Pioneering Advances and Reinforces US Growth at RSNA 2023, accessed 3 April 2024, at https://www.prnewswire.com/news-releases/united-imaging-showcases-pioneering-advances-and-reinforces-us-growth-at-rsna-2023-301994454.html

[31] Philips uses its own AI technology inside China for purposes that do not require patient data.

FIGURE 7: THE NUMBER OF PATENTS APPLIED FOR IN AI AND HEALTHCARE BY COMPANIES AND INSTITUTIONS IN CHINA, 2017–2023



Source: Pantentscope, available at https://patentscope.wipo.int/

MAGNETS AND SUPPORT SERVICES

Both Siemens and Philips are well-entrenched as providers of MRI devices to Chinese hospitals. Their brand names have a presence in China that goes back more than a century and that predates the role of the two companies as suppliers of medical equipment. However, while AI is an increasingly important element of MRI equipment, it is not the AI itself that constitutes a technology on which China is highly dependent. Not only is United Imaging developing its own AI, but Philips' suppliers of AI for MRI are Chinese. To understand why the two European companies are major players in China's MRI market, it is necessary to look at the MRI devices themselves, and at the companies' support services.

Magnets

An MRI scanner consists of four major components: a main magnet formed by superconducting coils, gradient coils, radiofrequency coils and computer systems. Advanced magnets, in particular, provide large, established producers of MRI equipment such as Philips and Siemens with a competitive advantage with regard to their Chinese counterparts. However, stimulated by their government, Chinese researchers and companies are working hard to make China self-sufficient in MRI magnets. The country is already a major force in battery production, and produces about 45% of the world's strongest magnets and 94% of all permanent magnets.[32] It is unclear how long the leading global MRI manufacturers can maintain their lead in MRI 1.5T and 3T magnets. China is also focusing on developing even stronger magnets. According to reports in the Chinese media, in May 2022, Chinese researchers at the Chinese Academy of Sciences (CAS) succeeded in developing a

---

[32] Ian Johnston et al., "Can Europe Go Green Without China's Critical Minerals?", accessed 3 April 2024, at https://ig.ft.com/rare-earths/

superconducting 9.4T magnet for MRI.[33] United Imaging launched a 5T MRI scanner in March 2023.[34]

Support services

The competitive strength of Siemens and Philips (and GE) stems not just from their technological capabilities, but also from providing hospitals with comprehensive medical systems.[35] Customers are not just buying the physical MRI devices and the AI algorithms needed for imaging, but all the support services required to integrate such equipment into the hospital environment and manage the complete related workflow. This includes for instance the IT architecture and apps used by the staff. It is this comprehensive package of MRI technology and related services that both Siemens and Philips regard as a strong line of defence against smaller and more recent market entrants, either in China or in other markets.[36] It is unclear whether or to what extent United Imaging as their main Chinese competitor will be able to match this broad range of MRI support systems.

CONCLUSIONS AND POLICY RECOMMENDATIONS

China's dependence on European AI for MRI is limited and likely to decline. This is not a domain in which Europe (or the US) formerly had an established leading position. AI for MRI is a new field that is still very much in development in both Europe and China. However, as the sizeable market shares of both companies indicate, there is a high demand for their MRI systems. It is clear that AI is an inherent part of these systems in the case of Siemens, although for Philips this is less obvious. The fact that, outside China, Philips is also working on its own AI for MRI suggests that the company's experience makes it more capable of integrating Chinese-made AI into its local systems. In any event, it is important to note from this case study that Chinese access to European AI for MRI cannot be seen separately from the MRI scanners themselves, the companies that make them and their comprehensive MRI products, which include support services. European strength in AI for MRI in the relationship with China therefore in practice means that European companies are commercially highly competitive with their Chinese counterparts.

In key elements of MRI technology, such as imaging AI or magnets, it seems likely that Chinese actors will increasingly be able to match or possibly exceed European technological capabilities. Should European companies lose their position as major suppliers of Chinese hospitals, it will be more likely that Chinese producers of MRI equipment will be able to use the advantages of scale that their home market provide to expand their market shares in Europe and globally. A long-term outcome that made European hospitals wholly dependent on Chinese MRI equipment would be detrimental to European strategic autonomy.

The introduction to this volume identifies four levels of ambition for European governments to address Europe's technological strengths in their relations with China.

- **Threat prevention:** AI for MRI is not a technology that the Chinese government could leverage to threaten European national security.

- **Ability to deny:** there is, at least for now, a high degree of co-dependence. Siemens and Philips need China's large and growing market for MRI devices and Philips in particular needs Chinese AI technology. On the other hand, Chinese hospitals need the two companies' integrated MRI systems, and Philips' AI suppliers need the company's MRI scanners.

- **Ability to act:** there is some scope for taking advantage of the cost of dependencies already in place to strengthen China's reliance on European technology. Over time, the market positions of the two European companies in China are likely to diminish. This process might be slowed by their continuing investment in relevant R&D, products and marketing. The European authorities could support this process by protecting the companies against the effects of Chinese state support for their Chinese competitors.

- **Curtailment:** Cutting off China's access to European healthcare technology in order to prevent Chinese actors from developing relevant economic and technological capabilities would not be feasible. Chinese research institutes and companies are likely to develop, or to some degree already have developed, relevant capabilities without European involvement.

---

[33] CGTN, "China Develops Superconducting Magnet for World-leading MRI", accessed 3 April 2024, at https://news.cgtn.com/news/2022-05-19/China-develops-superconducting-magnet-for-world-leading-MRI-system-1a9Qzfdp408/index.html,

[34] Xinhua, "China-made Ultra-high-field MRI System Debuts at European Radiological Meeting", accessed 3 April 2024, at https://english.news.cn/20230302/c3f5e0ff3a8e451e97b9d3f357b798e3/c.html

[35] Discussions with various industry representatives.

[36] Discussions with various industry representatives.

European policymakers should:

- Seek to maintain the current situation of co-dependence between China and Europe in the domain of MRI technology, in which AI is a major but not the only element, by protecting European companies against the effects of state support for Chinese companies. This should apply to competitive relations in China, in Europe and in third regions.

- Support the ability of European companies to operate in China, including by investing in local manufacturing and R&D, and refrain from using policy instruments aimed at limiting direct investment in China or technological cooperation with Chinese counterparts in the field of AI for MRI.

- Create a supportive ecosystem for healthcare technology start-ups in Europe.

- Stimulate financial markets and financial institutions to invest in European healthcare technology.

- Develop standards for AI in medical imaging, in which Europe and China have a common interest.

The Scorecard attributes these policy recommendations to the two levels of ambition that are feasible for Europe: the ability to deny and the ability to act.

SCORECARD 2 TECHNOLOGY FIELD: AI FOR MEDICAL DEVICES

	Threat prevention	Ability to deny	Ability to act	Curtailment
Feasibility of level of ambition	Not feasible	● Medium	● Low	Not feasible
Core policy recommendations	• None	• Support European companies' ability to operate in China • Refrain from using policy instruments aimed at limiting direct investments in China or technological cooperation with Chinese counterparts	• Protect European companies against the effects of state support for Chinese companies • Protection should apply to third regions, in addition to China and Europe	• None

AUTHORS

Carlo Fischione is a full Professor of the Internet of Things at the KTH Royal Institute of Technology in Sweden. Contact: carlofi@kth.se

Sanne van der Lugt is a researcher and policy adviser on China in Africa, Chinese technological developments and the consequences for European strategic autonomy. She is based in the Netherlands. Contact: sannevdlugt@fastmail.com

Frans-Paul van der Putten is an independent researcher on China and geopolitics, and the founder of ChinaGeopolitics. He is based in the Netherlands. Contact: fputten@chinageopolitics.nl

Automotive Chips: a European Chokepoint?

John Lee and Jan-Peter Kleinhans

ABSTRACT

The chapter examines the evolving dynamics of the global automotive chip market, highlighting the strategic competition between European chip manufacturers and the burgeoning Chinese electric vehicle (EV) sector. Automotive chips are semiconductors used in vehicles for various functions such as engine control, infotainment systems and driver assistance technologies. They are pivotal to modernising cars, and making them safer, more efficient and more connected. Chinese companies benefit from the country's large EV market by leveraging the massive domestic demand to scale production, reduce costs and accelerate innovation in automotive technology. This local demand provides a robust foundation for Chinese firms to advance automotive chip technology, potentially shifting global market dynamics and supply chain dependencies. Thus, while Europe maintains a stronghold on automotive chip technology due to its longstanding industry dominance, China's rapid advancement in EVs presents both challenges and opportunities for European companies. The study explores the competitive landscape, market trends and the impact of Chinese industrial policies aimed at self-reliance in semiconductor production. It particularly focuses on China's strategic moves to bolster its domestic automotive chip capabilities to support its leading position in the global EV market.

SCORECARD 1 TECHNOLOGY FIELD: AUTOMOTIVE CHIPS

Source of European technology strength	Research and innovation	Intellectual property and patents	Production and commercialisation
	Medium	High	Medium

Type of European technology strength	Technological excellence	Commercialisation advantage	Conditioning of market access	Regulatory, political and normative factors	Sustainability	Research partnerships with third countries
	X					

Degree of European leverage

Medium

Low ——○—————— High

INTRODUCTION

European companies are still global leaders in the market for automotive chips, which are semiconductors essential to the functioning of cars and other vehicles. The dominant market share and technical leadership of these European firms are based on decades of operation and closely linked to the strong European car making industry, which has provided an end-user for such products. This puts European leaders in this field in a good position to capitalise on the massive expansion in demand and on the technological development pathways for automotive chips being generated by the transition to electric vehicles (EVs) and autonomous driving.

Historically, internal combustion engine vehicles have required only a limited number of chips (semiconductors) – by one estimate, around 160.[1] Today, the growing use

---

[1] Novosense Microelectronics, "Revolutionizing High-Voltage Controller Chips for Electric Vehicles", EETimes, 27 November 2023, accessed 10 April 2024, at https://www.eetimes.com/revolutionizing-high-voltage-controller-chips-for-electric-vehicles/

in new passenger cars of feature-rich infotainment systems, advanced driver-assistance systems (ADAS) and increasingly sophisticated autonomous driving (AD) capabilities is driving a dramatic rise in the chip content of vehicles. Amplifying this trend is the rise of EVs and hybrids, going beyond passenger cars to include vehicles for mass transit and industrial uses such as mining or construction.

Today's highly autonomous EV passenger cars may require 400 or more chips to manage over 100 electronic and electrical components, which are continually evolving subsystems.[2] For example, an EV's powertrain[3] contains ten times more semiconductor content than that of an internal combustion engine car.[4] It is this twin transition of 'intelligentisation' and electrification that is driving chip demand in the automotive industry. While the automotive industry accounted for 8% of the global chip market in 2021, its share could well rise to around 15% by 2030, when the total semiconductor market may be US$ 1 trillion.[5]

China's domestic vehicle industry has emerged as the global leader in EVs and is also at the cutting-edge of intelligentisation. Its rise has been dramatic enough to prompt an EU anti-subsidy investigation into Chinese EV imports, initiated in October 2023.[6] The implications affect not just vehicle original equipment manufacturers (OEMs) such as Volkswagen or Stellantis, but also the supplier ecosystem behind them. Just as a strong automotive industry in the EU has supported European leaders in automotive chips such as Infineon, NXP and STMicroelectronics, the world-leading expansion of China's EV industry is boosting development of Chinese vendors of such chips. This in turn will enhance the competitiveness of Chinese OEMs such as BYD, with potentially major impacts for European firms and national economies.

This paper first provides an overview of the competitive landscape, market dynamics and characteristics of the global automotive chip market. Section 2 elaborates on Chinese policy efforts to strengthen its domestic automotive and semiconductor sector. Section 3 assesses why, how and in which areas China depends on European automotive chip suppliers. The final sections discuss Europe's potential ambitions with regard to China in the area of automotive semiconductors and offers policy recommendations.

THE GLOBAL AUTOMOTIVE CHIP MARKET

As mentioned above, modern cars need many different semiconductors to enable infotainment systems, Advanced Driver Assistance and Autonomous Driving Systems capabilities, electric drivetrains and many other functions. Table 1 provides an overview of the market shares of the largest five chip suppliers by revenue in the total automotive chip market, and in three of its sub-segments by chip type – sensors, automotive microcontrollers and power semiconductors.

Compared to other semiconductor markets, such as memory chips or general-purpose processors, the automotive semiconductor market is not substantially consolidated. The five largest suppliers – Infineon, NXP and STMicroelectronics in Europe, Texas Instruments in the United States and Renesas in Japan – controlled roughly half the global automotive chip market in 2022 (see Table 1). However, several sub-segments of the automotive chip market are substantially more concentrated.

In the *automotive sensors* market, the four largest European chip suppliers controlled more than 50% of sales globally. Sensors (e.g. that measure pressure, temperature, proximity, accelerometers) read the environment and translate this information for use by various systems. The sub-segment of *automotive microcontroller units* (MCUs) is highly concentrated and the leading five suppliers controlled more than 90% of global sales in 2022. MCUs integrate different functions on one chip (processing, memory, input/output peripherals) to control specific operations within a larger functional system. Automotive power *semiconductors* are also a relatively concentrated sub-segment led by Infineon and STMicroelectronics. Power semiconductors in cars manage electrical operations, such as battery

---

[2] Ibid.

[3] The powertrain in an EV refers to the set of components that generate power and deliver it to the road, notably the electric motor, battery, and transmission.

[4] German Association of the Automotive Industry, "Semiconductor Crisis Requirements for future relevance, competence and resilience for Europe", May 2023, , accessed 10 April 2024, at https://www.vda.de/en/news/publications/publication/semiconductor-crisis

[5] McKinsey, "The semiconductor decade: A trillion-dollar industry", 1 April 2022, accessed 10 April 2024, at https://www.mckinsey.com/industries/semiconductors/our-insights/the-semiconductor-decade-a-trillion-dollar-industry

[6] European Commission, "Notice of initiation of an anti-subsidy proceeding concerning imports of new battery electric vehicles designed for the transport of persons originating in the People's Republic of China", C/2023/160, accessed 10 April 2024, at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:C_202300160

TABLE 1: Global market shares in automotive chips as of 2022

AUTO CHIPS MARKET		SENSORS		MICROCONTROLLERS		POWER	
Infineon	12.4%	Bosch	16.3%	Renesas	27.3%	Infineon	31.9%
NXP	11.6%	Infineon	16.1%	Infineon	23.7%	STMicro	20.3%
STMicro	8.8%	NXP	14.1%	NXP	23.1%	Texas Instr.	11.2%
Texas Instr.	8.3%	Allegro	8.0%	STMicro	8.8%	Onsemi	8.4%
Renesas	7.9%	Melexis	7.8%	Microchip	7.5%	Rohm	5.5%
RoW	51.0%	RoW	37.7%	RoW	9.6%	RoW	22.7%

🔴 United States 🔵 Europe 🟢 Japan

Notes: Including 3 sub-segments: sensors, microcontrollers and power. Colors indicate headquarter locations of the companies
Source: TechInsights cited by Infineon

charging and control, voltage conversion and control of the electric motors.

The fourth sub-segment of the automotive chip market (not listed in Table 1) is *high performance ADAS/AD* chips. These chips, from suppliers such as Nvidia, Qualcomm and Mobileye, interpret the data from all the different sensors, cameras and radar systems. Since European automotive chip suppliers have almost no presence in this particular sub-segment, this chapter focuses on the other three sub-segments and the automotive chip market more generally.

To better understand the barriers to successfully competing in the different subsegments of the production of automotive chips, and to assess the extent to which China will continue to depend on foreign suppliers of automotive chips, three aspects must be considered.

1. Apart from ADAS/AD chips, automotive semiconductors *do not depend on cutting-edge front-end manufacturing.* For example, modern automotive microcontrollers are mainly manufactured on 20–40 nanometer (nm) fabrication processes. Power semiconductors and sensors are largely not dependent on node shrinkage and are built on older generation 90–180nm processes. According to a forecast by Gartner and ASML, even by 2030, the automotive chip market will largely depend on manufacturing processes at 20nm and above.[7] This, in turn, means that automotive chips are largely unaffected by US export controls (as of April 2024) and China's manufacturing capacity build out in these mature nodes is generally unconstrained.[8]

2. Extensive *safety and reliability certification* constitutes a barrier to entry to the automotive chip market. As an industry, automotive chip suppliers have historically striven for "zero defects".[9] Chip suppliers, foundries and the chip itself must adhere to various safety and reliability requirements in order to sell to automotive companies.[10]

---

[7] ASML, "European Chips Act: ASML Position Paper", 8 February 2022, accessed 10 April 2024, at https://www.asml.com/en/news/press-releases/2022/asml-position-paper-on-eu-chips-act

[8] Jan-Peter Kleinhans, Reva Goujon, Julia Hess and Lauren Dudley, "Running on Ice: China's Chipmakers in a Post-October 7 World", Rhodium Group and Stiftung Neue Verantwortung, 4 April 2022, accessed 10 April 2024, at https://rhg.com/research/running-on-ice/

[9] Anne Meixner, "The Race to Zero Defects in Auto ICs", in *Semiconductor Engineering*, 7 June 2022, accessed 10 April 2024, at https://semiengineering.com/the-race-to-zero-defects-in-auto-ics/

[10] Richard Oshiro, "Fundamentals of AEC-Q100: What "Automotive Qualified" Really Means", Presentation, November 2018, accessed 10 April 2024, at https://media.monolithicpower.com/mps_cms_document/w/e/Webinar_-_Fundamentals_of_AEC-Q100-6Nov2018.pdf

3. The *automotive chip supply chain is quite complex* since chip suppliers sell to distributors, automotive tier 1 suppliers (which provide complete functional systems) and increasingly also directly to automotive OEMs. Standard parts, such as single transistors or simple microcontrollers, are mainly sold through distributors, such as AVNet and Arrow Electronics.[11] Specific chips might be sold by the automotive chip company directly to an automotive tier 1 supplier, such as Denso, Continental or Bosch.[12] Automotive OEMs, especially EV start-ups, are also increasingly sourcing some chips, such as power semiconductors, directly from automotive chip suppliers.[13] Finally, some automotive OEMs, such as China's BYD and Tesla, are developing some chips of their own.

In summary, automotive semiconductors are highly diversified. The broad sub-segments of sensors, microcontrollers, power semiconductors and high-performance ADAS/AD chips all depend on specialised domain expertise and a range of manufacturing technologies. It is no coincidence that the leading automotive manufacturing economies of the past three decades – Europe, Japan and the United States – are also home to the leading automotive chip suppliers, as well as leading automotive tier 1 suppliers. Domain expertise and close cooperation with tier 1 suppliers are critical elements in the competitiveness of automotive chip suppliers.[14]

CHINESE INDUSTRIAL POLICY FOR THE AUTOMOTIVE SECTOR AND AUTOMOTIVE CHIP DEVELOPMENT

The efforts of the Chinese state to develop its domestic automotive industry go back almost to the start of the era of reform and opening up. Partnerships between Chinese and foreign carmakers began in the 1980s. China became the world's largest national car market in 2009, in terms of both sales and production.[15] Industrial policy for the sector targeted electrification from 2001, when a major special project on EV development was initiated under the 863 high-tech R&D programme, and the intelligentisation and networking of vehicles from the mid-2010s. In 2015 and 2017, "Made in China 2025" and a "Medium to Long Term Development Plan for the Car Industry" set relevant quantitative targets over the period until 2025. New energy [electric] vehicles (NEVs) are among the "strategic emerging industries" prioritised in China's current Five-Year Plan for 2021–2025.[16]

Other elements of Chinese state-led industrial policy have supported the transition to vehicles that are electric powered, wirelessly networked and increasingly intelligent. The development of sensors and wireless communications has been pursued since 2009 under the Internet of Things (IoT) rubric, including various trials and implementation of networked and autonomous driving.[17] The sophistication of Chinese manufacturing and new firms' capacity to build capital and scale-up have been boosted by policies on promoting smart manufacturing, the industrial IoT and small and medium-sized enterprises.[18]

---

[11] AVNet, "Automotive and Transportation", accessed 10 April 2024, at https://www.avnet.com/wps/portal/us/solutions/by-market/automotive-and-transportation/

[12] NXP, "NXP Honored with Prestigious Automotive Awards", 21 September 2023, accessed 10 April 2024, at https://www.nxp.com/company/about-nxp/nxp-honored-with-prestigious-automotive-awards:NW-NXP-HONORED-WITH-AWARDS

[13] Renault, "Renault Group and STMicroelectronics enter strategic cooperation on power electronics", 25 June 2021, accessed 10 April 2024, at https://media.renaultgroup.com/renault-group-and-stmicroelectronics-enter-strategic-cooperation-on-power-electronics/

[14] Jan-Peter Kleinhans and Nurzat Baisakova. "The Global Semiconductor Value Chain: A Technology Primer for Policy Makers", Stiftung Neue Verantwortung, October 2020, accessed 10 April 2024, at https://www.stiftung-nv.de/sites/default/files/the_global_semiconductor_value_chain.pdf

[15] Yuan Chen, C.-Y., Cynthia Lin Lawell and Yunshi Wang, "The Chinese Automobile Industry and Government Policy", May 2020, accessed 10 April 2024, at https://clinlawell.dyson.cornell.edu/China_auto_mkt_JTRF_paper.pdf

[16] Tuyu Zhou, Jorrit Gosens and Frank Jotzo, "China's EV plans: Domestic Market and Policy Developments & Australia-China links in Decarbonisation", Australian National University Policy Brief, 17 April 2023, accessed 10 April 2024, at https://iceds.anu.edu.au/files/Policy%20brief%20-%20EV%202023-04-06_0.pdf

[17] John Lee, "The Connection of Everything: China and the Internet of Things", Mercator Institute for China Studies, June 2021, accessed 10 April 2024, at https://merics.org/en/report/connection-everything-china-and-internet-things

[18] John Lee, "China and the Industrial Internet of Things", Leiden Asia Center, June 2023, accessed 10 April 2024, at https://leidenasiacentre.nl/china-and-the-industrial-internet-of-things/; and Bown, A., Chimits, F. and Sebastian, G., "China's 'Little Giants' turn up the Heat on Europe's Hidden Champions", Mercator Institute for China Studies, January 2024, accessed 10 April 2024, at https://merics.org/en/comment/chinas-little-giants-turn-heat-europes-hidden-champions

Industrial policies specific to semiconductors and integrated circuits (ICs) have increasingly targeted compound/wide-bandgap semiconductors such as silicon carbide (SiC) and gallium nitride (GaN), which have electrical properties that make them the preferred substrate materials for power chips. For example, Shanghai's 2021–2025 IC industry plan gives high priority to intelligent connected NEVs as an application to be served by integrated development across different steps of the chip supply chain, from chip design to electronic design automation (EDA) tools and chip fabrication (manufacturing).[19]

Technical standardisation is also a focus of coordinated industrial policy. China's Ministry for Industry and Information Technology published a new guidance document on the development of a comprehensive system of standards for automotive chips in December 2023.[20] Chinese actors now play a leading role in international standardisation processes for certain semiconductor categories important to the automotive sector, probably as a direct result of the rapid development of NEVs and other relevant end-user sectors in China. The global semiconductor industry association (SEMI) has chapters

TABLE2: CHINESE AUTOMOTIVE SECTOR-RELATED INVESTMENT FUNDS SET UP IN 2023 (SELECTION)

REGION/COMPANIES	CAPITAL (RMB)	TARGETED FIELDS FOR INVESTMENT (SELECTION FROM GENERAL DESCRIPTION)
Henan/SAIC	4.2 bn [1]	Automotive electronics, semiconductors, extension of the industrial chain
Guangzhou/GAC	10 bn (phase 1)[2]	New energy vehicles (NEVs): energy ecology, intelligent networks, automotive chips
Tianjin/Geely	1 bn (phase 1)[3]	Automotive and new energy, integrated circuits, intelligent connected vehicles (ICVs)
Wuhan (Econ. & Tech Dev. Zone)	50 bn [4]	NEVs, intelligent manufacturing, digital economy,
Chongqing (Liangjiang New Area)	20 bn [5]	NEVs, high-end equipment, aerospace, digital economy,
Hunan (Xiangjiang New Area)	500 mn [6] (phase 1)	ICVs, Artificial intelligence, new materials, intelligent manufacturing

Sources:

1. Sina, "上汽集团：关于子公司参与河南尚颀汇融尚成一号产业基金合伙企业(有限合伙)扩募的公告" [SAIC Group: Announcement on subsidiary's participation in the expansion of Henan Shangqi Huirong Shangcheng No. 1 Industrial Fund Partnership (Limited Partnership)], October 2023, accessed 10 April 2024, at https://vip.stock.finance.sina.com.cn/corp/view/vCB_AllBulletinDetail.php?stockid=600104&id=9556237
2. GAC, "广州汽车集团股份有限公司 关于参与发起设立智能网联新能源汽车产业发展基金的公告" [Announcement by Guangzhou Automobile Group Co., Ltd. on participation in establishing the Intelligent Connected New Energy Vehicle Industry Development Fund)], November 2023, https://img.gac.com.cn/topic/file/2023-11-10/1699612521952-广汽集团关于参与发起设立智能网联新能源汽车产业发展基金的公告.pdf
3. Sina, "吉利集团拟发起汽车领域产业基金，首期10亿元" [Geely Group intends to launch an industry fund in the automotive sector with a first phase of 1 billion yuan], March 2023, accessed 10 April 2024, at https://finance.sina.com.cn/tech/roll/2023-03-06/doc-imyixivu3758544.shtmll
4. Hubei, "武汉经开区设立500亿元车谷产业发展基金", March 2023, accessed 10 April 2024, at http://www.hubei.gov.cn/hbfb/xsqxw/202303/t20230324_4599024.shtml
5. Chongqing Provincial Government, "两江新区设立200亿高质量发展产业投资基金" [Liangjiang New Area establishes 20 billion high-quality development industry investment fund], March 2023, accessed 10 April 2024, at https://www.cq.gov.cn/zjcq/yshj/zshd/202303/t20230321_11792856.html
6. People's Daily, "首期规模5亿元！湖南湘江红土智能产业基金成立" [First phase of 500 million yuan! Hunan Xiangjiang Hongtu Intelligent Industry Fund established], February 2023, accessed 10 April 2024, at http://hn.people.com.cn/n2/2023/0210/c336521-40296711.html

---

[19] YICAI, "建设全球影响力"东方芯港"！上海临港新片区发布集成电路产业专项规划" [Build a globally influential "Oriental Chip Port"! Shanghai Lingang New Area releases special plan for integrated circuit industry], 3 March 2021, accessed 10 April 2024, at https://www.yicai.com/news/100966145.html

[20] Chinese Ministry of Industry and Information Technology, "工业和信息化部办公厅关于印发国家汽车芯片标准体系建设指南的通知" [Notice: Issuing of Guidelines for the Construction of National Automotive Chip Standards System], December 2023, accessed 10 April 2024, at https://www.gov.cn/zhengce/zhengceku/202401/content_6924893.htm

of its standards-setting technical committees in China for compound semiconductor materials, high brightness light emitting diodes (HB-LEDs), used for vehicle interiors among other lighting applications, and information and control (see chapter 12 in this volume).[21]

Chinese governments at different levels and leading Chinese automotive OEMs are directing large sums of capital towards achieving these development goals. An impression of the scale of such funding can be gained from the partial list in Table 2 of relevant investment funds and industry projects established in 2023 alone. These are aimed at driving the development of EVs, automotive chips and underlying technologies, such as those related to SiC wafer production. Not listed in Table 2 is the so-called Big Fund, China's main state-linked fund for chip sector investment, which received significant new capital injections in 2023. To provide one example of Chinese companies' fundraising capacity within this sector, GTA Semiconductor, which manufactures power semiconductors among other products, raised around 13.5 billion renminbi (US$ 1.8 billion) in late 2023 in a funding round that involved national and subnational funds and private investors.[22]

These large sums are unlikely to sit idle, given the existing state of development of China's automotive industry and the ambitious targets being set by subnational governments. The Wuhan-based fund listed in Table 2, for example, is directed at Wuhan's Smart Internet and Electric Vehicle Industrial Park "Car Valley", which in 2023 produced 60,000 NEVs and which according to the Wuhan municipal government's plan should expand this tenfold by the end of 2025.[23]

China now also has a network of research institutes funded and operated by subnational governments, universities and companies, focused on R&D of compound semiconductors so-called third-generation-semiconductors and their applications in power chips. Some of these R&D operations are integrated into large scale production facilities, such as Bronze Technologies' Third Generation Semiconductor Industry Base in Shenzhen, which is reportedly engaged in the entire SiC device supply chain and aiming for an annual output of 2 million SiC devices.[24] Bronze Technologies claims to have a relationship with Infineon, among other foreign industry partners. [25]

SITUATION OF CHINESE INDUSTRY RELATIVE TO POLICY AMBITION

Despite all these efforts and the rapid rise of Chinese EV OEMs, the market share of Chinese firms in automotive chips remains low. Chinese industry figures in public statements in late 2023 estimated that China's import substitution rate for chips across the automotive sector was around 10%.[26] As with many semiconductor industry segments, the dominance of several long-established incumbents makes it difficult for Chinese newcomers to get a foothold in the market. The above-mentioned safety and reliability standards, including certification requirements, present another obstacle to rapid catch-up by new players.

Rather than a significant technical challenge, however, this catch-up is only a matter of time. Some data indicates that for NEVs (as distinct from combustion engine vehicles), import substitution levels for certain chips are rising rapidly. For example, one Chinese market research report of January 2024 estimated that comparing 2022 to 2023, BYD's share of China's power chip market for NEV passenger vehicles increased from approximately 21% to 28%, while Infineon's fell from 22.6% to 9.09%. The same report estimates that Chinese vendors' share of

---

[21] SEMI, "Organisational Chart", September 2023, accessed 10 April 2024, at https://www.semi.org/sites/semi.org/files/2023-09/Standards_OrgChart_2023Sept_v1_0.pdf

[22] Reuters, "Chinese auto chipmaker raises over $1.8 billion as Beijing prepares new chip fund", 6 September 2023, accessed 10 April 2024, at https://www.reuters.com/technology/chinese-auto-chipmaker-raises-over-18-billion-beijing-prepares-new-chipfund-2023-09-06/; and Yahoo, "中國力挺半導體產業，積塔半導體完成人民幣135億元融資" [China strongly supports the semiconductor industry, GTA Semiconductor completed RMB 13.5 billion in financing], September 2023, accessed 10 April 2024, at https://ynews.page.link/GDbSM

[23] YICAI, "中国车谷：2025年新能源汽车产量力争达到100万辆", December 2023, accessed 10 April 2024, at https://m.yicai.com/news/101942958.html

[24] Ersetzen durch: Ijiwei, "碳化硅器件年产能将达200万只，青铜剑第三代半导体产业基地预计2023年4月投产" [Annual production capacity of silicon carbide devices will reach 2 million units, Bronze Sword's third-generation semiconductor industry base is expected to be put into production in April 2023], July 2021, accessed 10 April 2024, at https://www.laoyaoba.com/n/785611

[25] Bronze Tech, "About Us", accessed 10 April 2024, at https://www.qtjtec.com/en/company

[26] China Money Network, "Localization Rate of Automotive Chips in China Doubles, But Is Still Less Than 10%", 10 November 2023, accessed 10 April 2024, at https://www.chinamoneynetwork.com/2023/11/10/localization-rate-of-automotive-chips-in-china-doubles-but-is-still-less-than-10

the main drive power module market for NEVs in China was around 61% by the end of 2023.[27]

Furthermore, as noted above, most automotive chips are manufactured at older (“legacy”) fabrication nodes that are generally within the existing capabilities of Chinese industry. Mainland China is currently the location for around 27% of global fabrication capacity at the 20–45 nanometre nodes and some 30% at 50–180 nanometres. In the latter range, mainland China will add more fabrication capacity over the next 3–5 years than the rest of the world combined.[28] Access to these domestic fabs will give Chinese firms designing automotive chips familiarity with the manufacturing process, enabling performance improvements to obtain the certifications needed for their products to be viable for use by automotive OEMs and tier one suppliers.

At present, older chip fabrication nodes are not directly covered by US export controls targeting China, and statements from US officials in February 2024 suggest that US controls will not be extended to these “legacy chips”.[29] Thus, for automotive sensors, microcontrollers and power semiconductors, the design and manufacturing capabilities of Chinese chip suppliers are currently not significantly affected or constrained by US export controls.

However, it may still be the case that policy or regulatory steps by foreign governments will have some impact on access by Chinese automotive chip vendors and automotive OEMs to foreign customers and industry partners, which could affect the development of Chinese industry in this area. In addition to the European Union’s anti-subsidy investigation concerning Chinese EVs, in late February 2024 US President Joe Biden ordered “an investigation into connected vehicles with technology from countries of concern (expressly including China) and to take action to respond to the risks”.[30] In April 2024, a joint statement from a ministerial meeting of the EU-US Trade and Technology Council included a statement that the EU and US ”share concerns about non-market economic policies and practices that may lead to distortionary effects or excessive dependencies for mature node (“legacy”) semiconductors“, and that the two sides ”may develop joint or cooperative measures to address distortionary effects on the global supply chain for legacy semiconductors”.[31]

On high-performance *ADAS/AD* chips, in the medium to long term, Chinese firms *might potentially be* constrained by a lack of access to leading-edge nodes, due to US, Dutch and Japanese export controls that cut Chinese actors off from the necessary equipment.[32] For now, however, continued Chinese progress on ADAS/AD chips can be expected given China’s capacities in artificial intelligence (AI) and software development and that current generation ADAS/AD chips do not necessarily require leading-edge nodes for fabrication. For example, China’s Horizon Robotics has reportedly surpassed US AI leader Nvidia to lead the market for one AD chip subsegment, with a market share of over 49%.[33]

On *microcontrollers*, where the incumbent advantage of foreign industry leaders is greater, Chinese products are also starting to meet global industry standards. In early 2023, for example, one of Suzhou Flagchip’s MCU series received AEC-Q100 Grade-1 and ISO26262 ASIL-B certifications, while one of Yuntu Semiconductor’s MCU series obtained ASIL-B functional safety certification from the

---

[27] Guosen Securities, “能源电子月报” [Energy Electronics Monthly Report], 30 January 2024, accessed 11 April 2024 https://pdf.dfcfw.com/pdf/H3_AP202401311619773549_1.pdf?1706692450000.pdf

[28] Kleinhans, J.-P. et al., “Running on Ice: China’s Chipmakers in a Post-October 7 World”, Rhodium Group and Stiftung Neue Verantwortung, 4 April 2023, accessed 10 April 2024, at https://rhg.com/research/running-on-ice/

[29] Sadayasu Senju, “US export curbs on China won’t extend to legacy chips: official”, Nikkei Asia, 23 February 2024, accessed 10 April 2024, at https://asia.nikkei.com/Politics/International-relations/US-China-tensions/U.S.-export-curbs-on-China-won-t-extend-to-legacy-chips-official

[30] US White House, “Statement from President Biden on Addressing National Security Risks to the US Auto Industry”, 29 February 2024, accessed 10 April 2024, at https://www.whitehouse.gov/briefing-room/statements-releases/2024/02/29/statement-from-president-biden-on-addressing-national-security-risks-to-the-u-s-auto-industry/

[31] European Commission, ”Joint Statement EU-US Trade and Technology Council of 4-5 April 2024 in Leuven, Belgium”, 5 April 2024, accessed 11 April 2024, at https://ec.europa.eu/commission/presscorner/detail/en/statement_24_1828

[32] Goujon, R. and Kleinhans, J.-P., “All In: US Places a Big Bet with October 17 Controls”, Rhodium Group, 6 November 2023, accessed 10 April 2024, at https://rhg.com/research/all-in/

[33] China Money Network, “Localization Rate of Automotive Chips in China Doubles, But Is Still Less Than 10%”, November 2023, accessed 10 April 2024, at https://www.chinamoneynetwork.com/2023/11/10/localization-rate-of-automotive-chips-in-china-doubles-but-is-still-less-than-10 note 32

German Motor Vehicle Inspection Association (Deutsche Kraftfahrzeug-Überwachungs-Verein, DEKRA).[34] While these levels of safety and reliability certification are insufficient for safety-critical ignition or braking systems, they should be perceived as important first steps for new automotive chip suppliers entering the market.

In relation to *automotive power semiconductors,* China is not just heavily investing in the production of SiC wafers and fabs,[35] but also doubling down on filing patents. Chinese patent accumulation has proceeded rapidly since the early 2010s, with a roughly equal distribution between the SiC material and wafer stages, and the power chips that are built on these wafers. This represents a sustained catch-up effort relative to foreign industry leaders. Chinese patent applications overtook those by Japanese companies in 2018 as the latter's technological capabilities matured.[36] These Chinese patent holders represent the breadth of China's R&D ecosystem: appliance manufacturers; the leading companies involved in SiC wafer production, among them BYD, as a vertically integrated automotive OEM; state-owned enterprises; universities; and state-affiliated research institutions.[37]

ASSESSMENT OF DEPENDENCIES

Chinese auto OEMs still appear to be heavily dependent on European automotive chip suppliers for power chips, sensors and MCUs. European vendors, such as Infineon, NXP, STMicroelectronics and Bosch, have leading positions in each of these segments.[38] For example, according to a 2023 article by researchers affiliated with China's Ministry of Industry and Information Technology, Infineon supplied 58.2% of the power semiconductors (specifically IGBTs and MOSFETs) used in China.[39]

China's import substitution challenge is compounded by the rapid growth in its power chip market, which the same researchers estimate will by 2028 have grown by 81% relative to 2020. In May 2023, in response to investor questions, executives from SAIC, one of China's leading state-owned automotive OEMs, said that only around 7 percent of the chips it used were made in China. In June 2023 SAIC announced a semiconductor investment fund of over 6 billion RMB to increase the proportion of its chips made in China to 30% by 2025.[40]

Even the very low proportion of demand in China that is currently met by domestically produced automotive chips – as noted above, still estimated by Chinse industry figures in 2023 to average under 10% – might still include a significant share produced by foreign-invested enterprises, one of which could be the STMicroelectronics-San'an joint venture mentioned below. In 2021 , the president of China's National NEV Technology and Innovation Centre was quoted as saying that apart from chip design, every major step of the automotive chip supply chain was dominated by foreign enterprises. He concluded that China was still at the 'chokepoint' stage in achieving self-reliance in automotive chips, leaving it critically vulnerable to foreign supply chain interdiction.[41]

At the same time, however, European automotive chip vendors (as well as their US and Japanese competitors) depend on Chinese EV OEMs such as BYD, Geely and

---

[34] Ijiwei, "国产重大突破! 云途YTM32B1M系列车规产品获得ISO26262 ASIL–B功能安全产品认证" [A major breakthrough in domestic production! Yuntu YTM32B1M series automotive products have obtained ISO26262 ASIL-B functional safety product certification], 23 April 2023, accessed 10 April 2024, at https://www.laoyaoba.com/n/858190

[35] Huang, N., "More than Half of the World's SiC Weafers Might Come from China in 2024", DigiTimes, 23 October 2023, accessed 10 April 2024, at https://www.digitimes.com/news/a20231023PD210/silicon-carbide-china-compound-semiconductor-ic-manufacturing-sic.html

[36] Antipolis, S., "Silicon Carbide (SiC) Patents Support the Emergence of a Complete Domestic Supply Chain in China", KnowMade, 20 January 2022, accessed 10 April 2024, at https://www.knowmade.com/technology-news/semiconductor-news/power-electronics-devices-news/silicon-carbide-sic-patents-support-the-emergence-of-a-complete-domestic-supply-chain-in-china/

[37] MEMS, "功率碳化硅（SiC）专利全景分析–2022版" [Panoramic analysis of power silicon carbide (SiC) patents-2022 edition], 18 May 2022, accessed 10 April 2024, at https://www.mems.me/mems/patent_investigation_202205/11430.html

[38] Infineon, "Fourth Quarter FY 2022 Quarterly Update", November 2022, accessed 10 April 2024, at https://www.infineon.com/dgdl/2022-11-15+Q4+FY22+Investor+Presentation.pdf?fileId=8ac78c8b842ede67018477917fa40020

[39] Yu Xinyu, Li Huan and Xu Shiqing, "Research on the Safety Development of the Automotive-grade Chip Industry", in *Electronic Product Reliability and Environmental Testing*, 2022

[40] Shihua, T., "SAIC Motor to Set Up USD838 Million Fund for 30% Quota of China-Made Chips", YICAI, 20 June 2023, accessed 10 April 2024, at https://www.yicaiglobal.com/news/20230620-10-saic-motor-to-set-up-usd838-million-fund-for-30-quota-of-china-made-chips

[41] "汽车缺芯之痛:激发国产机遇" [The Pain of Automobile Chip Shortage: Stimulating Opportunities for Domestic Production], in Invention and Innovation, vol no.2, pp.12-15, 2021.

Nio as customers. In 2022, China produced almost 60% of EVs worldwide.[42] China is on the way to surpassing Japan as the leading car exporting nation, and over a quarter of exports from China are EVs. BYD has surpassed Tesla as the world's leading EV vendor by units.[43]

The location of so much production capacity in China is likely to promote development of Chinese vendors in the underlying supply chain, as has been the case in other industries such as consumer electronics. By one estimate, on the current trajectory, the Chinese market will represent over 40% of all new EVs sold globally by 2030.[44] Furthermore, when discussing NEVs as distinct from combustion engine vehicles, the market dominance of BYD accelerates China's import substitution, because BYD increasingly uses chips that are designed and manufactured in-house. Other Chinese automotive chip vendors like Silan and StarPower now have shares of China's NEV power chip market that by some estimates exceed that of the leading US vendor OnSemi and are approaching that held by Infineon. Although this is not yet true for SiC MOSFETS, for which China's power chip market remains dominated by STMicroelectronics, this situation could change quickly due to massive expansion in cumulative Chinese production capacity in the SiC chip supply chain, with BYD again playing a leading role.[45]

As discussed above, the "intelligentisation" and electrification of cars is substantially increasing the semiconductor content in modern vehicles. Thus, as long as China is home to the largest EV market, it will continue to be among the most important markets for automotive chip suppliers. This also explains why European automotive chip suppliers as well as automotive OEMs are investing in joint ventures with Chinese semiconductor suppliers, with the aim of maintaining or improving access to China's automotive market.

1. In mid-2023, for example, STMicroelectronics established a joint venture with San'an Optoelectronics for a SiC fab in Chongqing that will use STMicroelectronics's proprietary SiC manufacturing process technology and mainly serve the Chinese automotive industry.[46]

2. Volkswagen, which in 2023 carried out executive retrenchment and major cost cutting at its newly established software division CARIAD, is proceeding with a joint venture with China's leading ADAS/AD chip start-up, Horizon Robotics. It will provide ADAS and AD solutions for Volkswagen's EV models in the China market.[47]

Thus, for European automotive chip vendors, China is more than just a sales market. Like their international competitors, Infineon, NXP and STMicroelectronics all operate joint ventures with Chinese companies and back-end fabs (for assembly, testing and packaging of chips) in China. All three European companies also conduct R&D in China at multiple locations, although NXP closed its advanced power systems R&D operation in China in 2022.

Thus, while China's EV sector heavily depends on chips from European automotive chip vendors, these European companies are also deeply invested in China. This was highlighted by the "Joint declaration of intent on dialogue and cooperation in the area of automated and connected driving" signed between Germany and China during the German Chancellor's visit to China in April 2024, emphasising standards and cross-border data transfers.[48]

---

[42] Hufbauer, G., "China's Electric Vehicle Surge Will Shock Global Markets", East Asia Forum, 21 November 2023, accessed 10 April 2024, at https://eastasiaforum.org/2023/11/21/chinas-electric-vehicle-surge-will-shock-global-markets/

[43] Lu, M. and Parker, S., "Global EV Production: BYD Surpasses Tesla", Visual Capitalist, 20 April 2023, accessed 10 April 2024, at https://www.visualcapitalist.com/global-ev-production-byd-surpasses-tesla/ ; and Laura He, "China is 'certain' to have overtaken Japan as the World's Top Auto Exporter in 2023, Industry Group Says", CNN, 10 January 2024, accessed 10 April 2024, at https://edition.cnn.com/2024/01/10/cars/china-cars-overtake-japan-largest-exporter-intl-hnk/index.html

[44] Farmer, R. et al., "Capturing Growth in Asia's Emerging EV Ecosystem", McKinsey, June 2022, accessed 10 April 2024, at https://www.mckinsey.com/featured-insights/future-of-asia/capturing-growth-in-asias-emerging-ev-ecosystem

[45] Guosen Securities, op. cit.

[46] STMicroelectronics. "STMicroelectronics and Sanan Optoelectronics to advance Silicon Carbide ecosystem in China", 7 June 2023, accessed 10 April 2024, at https://newsroom.st.com/media-center/press-item.html/c3186.html

[47] Automotive News Europe, "VW's Cariad Software Unit to Cut Costs by 20%, Avoid Forced Layoffs", 14 December 2023, accessed 10 April 2024, at https://europe.autonews.com/automakers/vws-cariad-software-restructuring-avoids-forced-layoffs; and Pandaily, "Horizon Robotics and Volkswagen Group's Software Company CARIAD Announce Establishment of Joint Venture", 8 December 2023, accessed 10 April 2024, at https://pandaily.com/horizon-robotics-and-volkswagen-groups-software-company-cariad-announce-establishment-of-joint-venture/

[48] Federal Ministry for Economics and Climate Change and Federal Ministry for Digital and Transport, "Germany and China sign a joint declaration of intent on dialogue and cooperation in the area of automated and connected driving", 16 April 2024, accessed 16 April 2024, at https://www.bmwk.de/Redaktion/DE/Pressemitteilungen/2024/04/20240416-deutschland-und-china-automatisiertes-und-vernetztes-fahren.html

Counterbalancing the lack of Chinese access to the US market and potentially to the EU, a significant number of large developing economies are rapidly increasing their use of Chinese EVs. Several Southeast Asian economies in this group are also taking major steps towards integration with the Chinese EV supply chain, including joint R&D and in-country production by Chinese automotive OEMs.[49] Because European automotive chip vendors have significant operations in these countries, increased Chinese involvement in the local supply chain raises potential EU-China interdependencies in this sector.

One example is Infineon's expansion of its manufacturing operation in Malaysia, which will be key to its target to supply 30% of the global SiC device market by 2030.[50] The revenue potential of this expansion is related to around €3 billion in customer purchase commitments and prepayments, around half of which is accounted for by the EV sector. These customers include (alongside non-Chinese companies like Ford) the Chinese automotive OEMs Chery and SAIC, the latter reportedly being investigated under the EU's anti-subsidy investigation into Chinese EVs.[51] The Kulim fab will source SiC wafers and ingots from several international suppliers that include two Chinese companies certified by Infineon as vendors in 2023.[52]

EUROPEAN ASPIRATIONS AND LEVEL OF AMBITION

In this context, *a realistic level of ambition* for European policymakers over the next 10–15 years vis-à-vis China and automotive chips would be mutual dependence at best or self-reliance at worst. The aim should be to *maintain European technological strength* in the face of an unavoidable trend towards Chinese import substitution. This trend is driven by industry and market conditions that are robust over a 10–15-year forward timeframe: the dramatic rise of Chinese automotive OEMs and Chinese industrial strength in the larger automotive/EV supply chain – including inputs and technologies relevant to automotive chips such as those for SiC wafer production. While policymakers are increasingly scrutinising the national security implications of connected vehicles, Europe's automotive industry, including automotive chips, will most likely remain entangled with that of China. Since Chinese EV OEMs seem increasingly to be aiming for a greater degree of autonomy from foreign suppliers, it might be difficult for European automotive chip suppliers to stay indispensable in the medium to long term.

European automotive chip leaders will be hard pressed to maintain market share in China and with Chinese automotive OEMs in their operations abroad (mutual dependence). However, their current technological strengths mean that given the right conditions, they have strong prospects for remaining the preferred vendors for European and other non-Chinese automotive OEMs and component suppliers (self-reliance). These strengths can be highlighted with reference to Infineon, Europe's largest automotive chip supplier by revenue.[53]

- **Research and innovation:** Infineon's R&D spending has averaged above 12% of revenue over the past three years, and in 2023 amounted to around €2 billion.[54] The company is engaged in cutting-edge research on various fronts oriented to commercial applications, such as leading research into GaN chips and AI industrial applications funded through Horizon-Europe in connection with implementation

---

[49] Reuters, "China to set up auto research institute in Thailand as EVs gain traction", 8 December 2023, accessed 10 April 2024, at https://www.reuters.com/business/autos-transportation/china-set-up-auto-research-institute-thailand-evs-gain-traction-2023-12-08/

[50] Infineon, "Infineon to build the world's largest 200-millimeter SiC Power Fab in Kulim, Malaysia, leading to total revenue potential of about seven billion euros by the end of the decade", 3 August 2023, accessed 10 April 2024, at https://www.infineon.com/cms/en/about-infineon/press/press-releases/2023/INFXX202308-140.html

[51] Ibid.; and Reuters, "Exclusive: EU Investigators to Inspect China's BYD, Geely and SAIC in EV probe, Source", 12 January 2024, accessed 10 April 2024, at https://www.reuters.com/business/autos-transportation/eu-investigators-inspect-chinas-byd-geely-saic-ev-probe-source-2024-01-12/

[52] Semiconductor Today, "China's SICC and TanKeBlue to supply silicon carbide wafers and boules to Infineon", 3 May 2023, accessed 10 April 2024, at https://www.semiconductor-today.com/news_items/2023/may/infineon-030523.shtml

[53] SemiMedia, "Infineon replaces NXP as the world's number one automotive semiconductor supplier", 9 June 2021, accessed 10 April 2024, at https://www.semimedia.cc/10000.html

[54] Infineon, "Company Presentation" November 2023, accessed 10 April 2024, at https://www.infineon.com/dgdl/IFX_FY2023_Q3_web_CN.pdf?fileId=5546d46169067e7f01692847c58d0020 ; and Infineon, "Fourth Quarter FY 2022 Quarterly Update", November 2022, accessed 10 April 2024, at https://www.infineon.com/dgdl/2022-11-15+Q4+FY22+Investor+Presentation.pdf?fileId=8ac78c8b842ede67018477917fa40020

of the European Chips Act.[55] In late 2023, Infineon opened a laboratory to develop and test microelectronic circuits for quantum computers. One of its activities will be to use AI to simulate and predict the aging and failure characteristics of power chips, thereby improving estimation of service life and anomaly detection.[56]

- **Intellectual property and patents:** As of November 2023, Infineon's patent portfolio included 29,700 patents and patent applications. Around 1850 new patent applications were registered in 2023.[57] It has strengthened this portfolio through strategic acquisitions. For example, following Infineon's acquisition of the Canadian company GaN Systems in 2023, it now holds 350 GaN patent families, strengthening what Infineon in 2022 already claimed was the leading GaN patent portfolio.[58] Other European automotive chip leaders have also accumulated extensive patent portfolios: NXP's in 2023 included 9500 patent families.[59]

- **Production & commercialisation:** the example of Infineon's Malaysian operations described above shows that if allowed latitude regarding the geographic location of its operations, financing and customers, notwithstanding perceived political risk vis-à-vis China, it can continue to expand production. As with its patent portfolios, strategic acquisitions have reinforced Infineon's competitiveness. Infineon's acquisition of Siltectra and thereby its SiC cutting technology has reportedly allowed Infineon to retain a relatively large amount of useable material during SiC ingot processing, and so reduce input costs for its SiC devices. The acquisition of GaN systems significantly increased Infineon's GaN customer base.[60]

QUALITY OF EUROPEAN TECHNOLOGICAL STRENGTH

In view of the above, some broad judgments can be made about Europe's position vis-à-vis China when it comes to automotive chips, in the context of the wider automotive market and global supply chains.

Ease of circumvention/replication: Among the chips in use in the automotive sector, only the most advanced logic processors are currently beyond the capacity of Chinese industry to produce, due to US export controls and continuing critical gaps in import substitution efforts, notably for photolithography. For most automotive chips, however, Chinese industry not only has the necessary capabilities to develop and manufacture these products, but will increasingly have local advantages vis-à-vis foreign competitors in terms of economies of scale and synergies with Chinese customers and industry partners. China also appears to have achieved a significant level of import substitution upstream in the associated supply chains, for instance in the furnaces and cutting equipment required to make and process SiC ingots for SiC wafer production.[61]

That said, at present China's automotive sector still appears to be extensively dependent on foreign vendors, including the European firms Infineon, NXP, STMicroelecronics and Bosch, at least in three of the four automotive chip categories discussed in this chapter. Substituting these foreign products with domestic alternatives will take many years, and an acceleration of this process forced on China by denial of access to European vendors might require compromises on industry standards that would undermine the competitiveness of Chinese automotive OEMs.

---

[55] Fraunhofer IZM, 'Green, Digital Transformation: Infineon Launches EU Projects for Power Electronics and Artificial Intelligence', 1 June 2023, accessed 10 April 2024, at https://www.izm.fraunhofer.de/en/news_events/tech_news/infineon-launches-eu-projects-for-power-electronics-and-ai.html

[56] Swayne, M., "Infineon Opens Laboratory to 'Reinvent the Core Element of the Quantum Computer'", The Quantum Insider, 26 October 2023, accessed 10 April 2024, at https://thequantuminsider.com/2023/10/26/infineon-opens-laboratory-to-reinvent-the-core-element-of-the-quantum-computer/

[57] Infineon, "Company Presentation", op. cit.

[58] Infineon, 'Infineon completes acquisition of GaN Systems, becoming a leading GaN power house', 24 October 2023, accessed 10 April 2024, at. https://www.infineon.com/cms/en/about-infineon/press/press-releases/2023/INFXX202310-014.html ; and Infineon, 'Fourth Quarter FY 2022 Quarterly Update' accessed 10 April 2024, at https://www.infineon.com/dgdl/2022-11-15+Q4+FY22+Investor+Presentation.pdf?fileId=8ac78c8b842ede67018477917fa40020

[59] NXP, 'NXP Recognized as 2023 Top 100 Global Innovator', 17 February 2023, accessed 10 April 2024, at https://www.nxp.com/company/about-nxp/nxp-recognized-as-2023-top-100-global-innovator:NW-NXP-RECOGNIZED-2023-TOP-100-GLOBAL-INNOVATOR

[60] Ting-Fang, C., 2023. 'Infineon Upbeat on Next-Gen Power Chips as Broader Market Struggles', Nikkei Asia, 16 March 2023, accessed 10 April 2024, at https://asia.nikkei.com/Business/Tech/Semiconductors/Infineon-upbeat-on-next-gen-power-chips-as-broader-market-struggles

[61] Soochow Securities, "碳化硅设备行业深度报告" [Silicon Carbide Equipment Industry In-depth Report], 14 September 2023, accessed 10 April 2024, at https://pdf.dfcfw.com/pdf/H3_AP202310201602189432_1.pdf?1697832796000.pdf

Spillover damage if used as a chokepoint: The dominant position of Chinese firms in many segments of the EV supply chain is well-known. It means that there are many potential avenues for retaliation against European attempts to use automotive chips as a chokepoint. Loss of access to European automotive chip technologies would accelerate the loss of market share in these products by the relevant European firms in China and potentially in other foreign markets too. This would undermine their technological and commercial competitiveness against both Chinese rivals and those from the US, Japan and South Korea, and hence their capacity to support R&D in the wider context of advancing European technological and industrial strength.

DISCUSSING EUROPE'S LEVEL OF AMBITION

All the above implies a *modest level of ambition* for European policies targeting China over automotive chips. European firms throughout this supply chain will suffer from Chinese import substitution, but they will suffer more if forced to cut Chinese ties – whether in China or in the Southeast Asian economies increasingly linked to China – that support their competitiveness in a global market.

Automotive chips are among the few high-tech sectors in which Europe still has firms that lead the market in both technology and scale. This leadership should not be risked by attempts to leverage it against China, given the potential for Chinese retaliation and the bright prospects for Chinese automotive OEMs and automotive chip vendors to continue their advance without access to European products in this field.

European chip vendors are likely to struggle to maintain their current market shares in China in the face of Chinese import substitution and the Chinese government's potential use of its own export controls to exert leverage over supply chain dependencies. One way forward would be to strengthen the competitiveness of European firms throughout the EV supply chain, not only of automotive chip vendors, but also the OEMs that are the end-users of these products, as well as makers of chip and wafer manufacturing equipment.

The following are potential options for policymakers in Europe across four levels of ambition.

- **Level 1: threat prevention.** The ambition for European policymakers would be to ensure that European automotive chips do not contribute to the technological upgrading of the Chinese military. Automotive chips have somewhat indirect military utility since they can also be used to control military vehicles. Beyond that, regarding the potential application of export controls, it would be challenging to objectively characterise the automotive chips in the product categories discussed in this chapter as "dual-use items", although this might be easier with some of the technologies involved in their production. In a wider context, Chinese R&D collaborations and corporate acquisitions that involve relevant fields such as GaN and SiC development should be scrutinised, but with a view to avoiding harming European actors through excessive constraints on participation in beneficial arrangements.

- **Level 2: ability to deny.** If the goal is to utilise China's dependence on European automotive chips to discourage China from going against European security interests, Europe would need to ensure it continues to be easier for China to depend on automotive chips from Europe than to successfully develop domestic alternatives. Loss of access to European automotive chip production would probably harm the competitiveness of Chinese automotive OEMs in the short term, especially in non-Chinese markets, but these effects would be outweighed by damage to European automotive chip vendors and by the boost given to Chinese import substitution in this field. It would also be unlikely to shift the long-term development trajectory of the Chinese automotive sector.

- **Level 3: ability to act.** European options for leveraging automotive chips are constrained by the fact that momentum and leverage across the wider automotive sector and EV supply chain are so heavily in China's favour. Most of the demand for Chinese EVs over the next 10–15 years is likely to be generated within China, while Chinese exports to the developing world are growing strongly. As one reference point, BYD is reportedly confident that even without access to the EU or US markets, it can increase its 2023 exports of 250,000 cars more than tenfold in the coming years. It is hard to see any prospects for making China dependent on Europe for automotive chip technologies when conditions for Chinese advancement in these products can be generated without access to EU markets or supply chains.

- **Level 4: curtailment.** Chinese industry already has the capabilities to develop and produce automotive chips, and Chinese firms have demonstrated the ability to produce competitive products. The complexity of semiconductor fabrication, however, means that a total embargo on China across this field might significantly reduce Chinese industry's ability to manufacture automotive chips. Nonetheless, China seemingly has everything it needs to become self-reliant in automotive chips so curtailment does not seem feasible at this stage.

POLICY RECOMMENDATIONS

The following recommendations depend on the level of ambition policymakers choose to pursue. The current status quo could be described as threat prevention (level 1). If continued, this would mean minimal intervention in terms of controls on technology, research and investment, focused mainly on prevention of technology transfers with dual-use potential. While this level of ambition entails minimal control aspects, it would still require promotion of Europe's automotive chip ecosystem to support future competitiveness with the aim of achieving indispensability.

If the level of ambition of European policymakers is to ensure a certain ability to deny (level 2) China the ability to act against European security interests, Europe would need to encourage continued entanglement. Thus, following a two-pronged strategy, European automotive chip suppliers would continue to establish technology partnerships with Chinese companies and try to stay ahead of competing Chinese automotive chip suppliers. Such a strategy would encounter difficult challenges since Chinese automotive OEMs are already looking to achieve import substitution.

Even more challenging would be an ambition to ensure Europe a certain ability to act (level 3) vis-à-vis China. It would be unrealistic to think that European automotive chips will continue to be indispensable to Chinese automotive OEMs even in the medium-term. However, technological indispensability would be essential if Europe wanted to protect its ability to act while remaining entangled in China's automotive ecosystem. Europe would need to double down on R&D across the automotive ecosystem, focused on autonomous driving and electrification. Such a strategy would only be possible if European automotive OEMs, tier 1 and chip suppliers all shared the same ambition, which is not necessarily the case. Importantly, this would not just depend on the technological competitiveness of European automotive chip suppliers or whether they continue to play an indispensable role in Chinese EV OEMs. It is very much about the purchasing decisions of Chinese OEMs: if they are willing to sacrifice performance or features for reduced geopolitical risk, there is simply very little Europe could do to keep China from becoming less dependent and more autonomous in automotive chips.

Curtailment (level 4), or essentially forcing China to develop its own automotive chip ecosystem without relying on European technology and research, is neither feasible nor in Europe's best (security) interest. If Europe was ready to cooperate in a total embargo on China's access to foreign inputs for semiconductor fabrication, a short term reduction in China's capacity to manufacture automotive chips might be conceivable. But the political challenges involved with implementing this, which would include attaining not just European consensus but also necessary cooperation from non-European actors, make it an unrealistic objective. Furthermore, the longer term outcome would likely be complete Chinese self-reliance in automotive chips and European companies' loss of access to this market in China.

SCORECARD 2 TECHNOLOGY FIELD: AUTOMOTIVE CHIPS

	Threat prevention	Ability to deny	Ability to act	Curtailment
Feasibility of level of ambition	Medium	Medium	Low	Not feasible
Core policy recommendations	• Prevent technology transfers to China that have dual-use potential • Promote Europe's automotive chip ecosystem to support its future competitiveness	• Encourage China's continued entanglement • European automotive chip suppliers continue to pursue technology partnerships with Chinese companies • At the same time, European automotive chip suppliers take actions to stay ahead of Chinese competitors	• Double down on R&D across the European automotive chip ecosystem, focused on autonomous driving and electrification • Seek to make the European automotive chip ecosystem indispensable to China • Make this the shared goal of actors within the European automotive chip ecosystem (OEMs, tier 1 suppliers and chip vendors)	• None

AUTHORS

John Lee is Director of East West Futures in Berlin, Germany. Contact: johnlee@eastwestfutures.com
Jan-Peter Kleinhans is the Lead of Global Chip Dynamics at Stiftung Neue Verantwortung e.V. in Berlin, Germany. Contact: jkleinhans@stiftung-nv.de

Space Exploration 2040: Regaining European Technological Leadership?

Marco Aliberti, Angela Stanzel, Lars Pezold

ABSTRACT

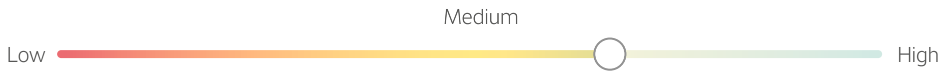
The past decade has seen China resolutely assert itself as one of the top-tier space powers. Particularly in an internationally visible area such as exploration, China has succeeded in catching up – and even surpassing – the leading position traditionally held by Europe. Against this backdrop, this paper discusses how Europe can remain a leading, transformative actor in the glaring light of China's surging ambition in the field of lunar exploration. The current debate in Europe on how to de-risk itself from China while at the same time maintaining an edge as a technological power can be also applied to the current dynamics of space exploration. This chapter examines which technologies have the most potential to provide Europe with some leverage vis-à-vis China's space exploration goals. In the process, it disentangles the key tenets and underlying objectives of Beijing's space exploration strategy and discusses the implications of the opening up of the International Lunar Research Station to international partners.

SCORECARD 1 **TECHNOLOGY FIELD: SPACE EXPLORATION**

Source of European technology strength	Research and innovation	Intellectual property and patents	Production and commercialisation
	● Medium	● Medium	● Medium

Type of European technology strength	Technological excellence	Commercialisation advantage	Conditioning of market access	Regulatory, political and normative factors	Sustainability	Research partnerships with third countries
		X		X		X

Degree of European leverage



INTRODUCTION: WHY SPACE, WHY SPACE EXPLORATION?

In March 2023, the High-Level Advisory Group (HLAG) on Human Space Exploration set up by the European Space Agency (ESA) published a report, Revolution Space 2023, which highlights that "space is undergoing a revolution comparable to the growth of the Internet 20 years ago. Like the Internet, the space revolution will affect all domains of life".[1] From climate change to national security, passing through mobility, energy and connectivity, the already important contribution offered by space assets and services, such as in telecommunications, Earth observation or navigation, will become even more fundamental and all-pervasive.

The space industry is currently witnessing an extraordinary surge in activity. The sector has seen remarkable

---

[1] High-Level Advisory Group (HLAG) on Human Space Exploration for Europe, Revolution Space, 2023, accessed 20 July 2023, at https://esamultimedia.esa.int/docs/corporate/h-lag_brochure.pdf.

growth in the past decade, as the number of active space companies rose from approximately 600 in 2012 to over 1,000 in 2022. The annual satellite launch rate has also soared, moving from an average of around 300 between 2010 and 2019 to over 2,800 in 2023, largely fuelled by private sector companies such as SpaceX. This expansion in space activity has heightened competition. The North Atlantic Treaty Organisation (NATO) has identified space as the fifth domain of warfare, while the United States has established a dedicated Space Force. Governments around the globe are boosting their investment. Expenditures in 2022 exceeded $100 billion and the estimated value of space for the world economy in 2022 amounted to ~$3.1 trillion.[2] Major players are intensifying their space efforts, and new countries are joining this increasingly lucrative and highly strategic sector.

Mainly thanks to the manyfold cross-fertilisation effects across the space economy and beyond, space exploration has become a core engine of this unfolding revolution. Indeed, together with its immediate economic benefits in terms of gross domestic product (GDP) and job creation, space exploration provides cross-fertilisation effects across the different elements of the broader space sector, supporting the overall development of the space industry, bolstering industrial competitiveness and promoting synergies with other space domains, such as industrial capability as part of security policy. In the European context alone, it has been estimated that implementation of a major space exploration programme would generate a GDP multiplier effect of >5x the overall budget, with estimated benefits that stem from the investment amounting to a cumulative GDP impact of at least €260 billion and an average of 90,000 jobs created between 2025 and 2040.[3]

In the light of these premises, it comes as no surprise that the international space exploration landscape is currently witnessing a significant wave of investment and development not experienced since the Space Race in the second half of the 20th century. Beyond the increasingly ambitious plans for the development of new institutional and commercial space stations in Low Earth Orbit (LEO), the Moon has re-emerged as a key target for human space exploration activities for the world's major spacefaring nations. On this front, the leading space powers all have plans to land and sustain their respective astronauts on the lunar surface within the next decade. China has embarked on an ambitious plan aimed at landing a taikonaut by 2030 and constructing an International Lunar Research Station (ILRS), a complex and multi-purpose experimental research facility to be built on the surface and in orbit around the Moon, capable of sustaining a semi-permanent human presence on the lunar surface.

For its part, Europe has not yet decided what role it wants to play in this upcoming exploration wave: whether it wants to be a leader, a junior partner or even a mere spectator in these major developments.[4] Admittedly, thanks to decades-long efforts led by ESA, the continent is now one of the most established actors in space exploration, boasting a state-of-the-art technological base and a solid set of critical capabilities that make it the "partner of choice" for international cooperation. Nonetheless, uncertainties remain regarding the why, the what and the how of a major European space exploration effort. There is a risk that the implications of current inaction and the absence of any position by European countries could be far-reaching, as they will condemn the continent to be a junior partner or even a customer of non-European companies in ensuring its astronauts access to space.[5]

Against this backdrop, this chapter identifies the requirements for Europe to retain a leading role in the context of future space exploration and assesses the various policy options available to European decision makers. It demonstrates that while Europe may not be indispensable to China's lunar and space exploration plans, it retains its appeal for China to explore cooperation as a means of improving performance, ensuring optimisation, increasing mission scope and supporting commercialisation. If the right policies are put in place, this could provide leverage for Europe.

---

[2] ESPI/BCG, More than a Space Programme: The Value of Space Exploration to Empower the Future of Europe, accessed 16 November 2023: at https://www.bcg.com/publications/2023/italy-more-than-a-space-programme.

[3] Ibid.

[4] In this chapter, Europe is defined as the European Union, the European Space Agency and the member states of the two organisations. The ESA is an international organisation independent of the EU. Although there is a significant overlap between the memberships of the two organisations, ESA membership also includes Switzerland, Norway and the United Kingdom (UK). The UK is one of the most capable space actors in Europe.

[5] To echo the recent admonition of the High-Level Advisory Group (HLAG) on Human Space Exploration for Europe, "Without its own capabilities, Europe's exploration timelines will forever be dictated by others, our space technology will fall behind, and our brightest talents will pursue their dreams elsewhere. Thus, the adage "'if you are not sitting at the table, you are on the menu'" risks becoming a harsh reality". HLAG on Human Space Exploration for Europe, Revolution Space, 2023, accessed 20 July 2023, at https://esamultimedia.esa.int/docs/corporate/h-lag_brochure.pdf.

CHINESE PLANS FOR THE MOON: WHAT DEPENDENCIES WITH EUROPE?

China's ambitions for space exploration are laid out in a number of policy documents, most notably the fifth white paper on space published by the State Council Information Office of China in early 2022.[6] All are part of China's overarching vision, as articulated by President of China Xi Jinping, to establish itself as the foremost "space power" by 2045.

Named after the legendary goddess of the Moon, Chang'e, China's lunar exploration programme began in the late 1990s. Three main stages of development were envisaged:

- Orbiting the Moon:
  Chang'e-1 (2007) and Chang'e-2 (2009)
- Landing on the Moon:
  Chang'e-3 (2013) and Chang'e-4 (2018)
- Returning samples from the Moon:
  Chang'e-5 (2020) and Chang'e-6 (2024).

Following its successful demonstration of sample return capabilities in 2020, China has opened a new phase of its lunar exploration programme. The Chang'e-6, 7 and 8 robotic missions will scout the lunar south pole for water reserves. Its almost constant exposure to sunlight, which can be used as an energy source, makes the south pole region an ideal location for a human presence on the Moon.

In fact, these planned robotic missions are an integral part of China's goal to construct a lunar base, the ILRS,[7] at the Moon's south pole. The ILRS will be deployed in three phases. The above-mentioned Chang'e-6, 7 and 8 constitute Phase 1. Phase 2 will be the main deployment phase, which will take place between 2030 and 2035 and comprise five missions to establish power supply, communications and research facilities, and other infrastructure. As part of Phase 2, China plans to build the Queqiao communications and navigation constellation, which is to be capable of supporting crewed lunar landings.

TABLE 1: Key capabilities and technologies for lunar exploration

KEY CAPABILITY	UNDERPINNING TECHNOLOGIES	
Super heavy launch vehicle	• Propulsion • Avionics • Stage separation	• Thermal protection • Guidance
Lunar cargo/Crew transport vehicle	• Propulsion • Crew compartment/ life support	• Abort system • Power system
Lunar human lander and re-entry	• Lunar module • Crew compartment	• Propulsion • Power system
Lunar surface infrastructure	• Crew compartment	• Power system
Lunar communications and navigation	• Deep space network • Relevant frequency bands • High-gain directional antennas • Communications and Navigation Satellite technology • Navigation systems (Celestial, Inertial, Optical, Terrain relative)	

Source: The overview is based on ISECG, Global Exploration Roadmap Critical Technology Needs, 2019.

---

[6] State Council Information Office of China, "国务院新闻办公室" [China's space programme in 2021], accessed 21 February 2024, at https://www.gov.cn/zhengce/2022-01/28/content_5670920.htm.

[7] CNSA, "International Lunar Research Station", accessed 21 February 2024, at https://www.unoosa.org/documents/pdf/copuos/2023/TPs/ILRS_presentation20230529_.pdf.

TABLE 2: Comparison of Chinese and European planned key capabilities for lunar exploration

KEY CAPABILITY	CHINA'S PLANNED CAPABILITIES (2040)	EUROPE'S PLANNED CAPABILITIES (2040)
Super heavy launch vehicle	Planned inaugural launches of Long March (LM) 10 and LM 9 in 2027 and 2033. LM 10 will be able to deliver 27 tonnes to Lunar Transfer orbit, while LM 9's capability for the same destination is 54 tonnes.	None
Lunar Cargo/Crew transport vehicle	Next-generation crewed spacecraft around 2027 as successor to the Shenzhou vehicle currently in use. This will double the crew capacity from 3 to 6.	No autonomous capability planned; Europe delivers its European Service Module (ESM) as a critical component of the US Orion spacecraft
Lunar human lander and re-entry	A Chinese Lunar lander has been announced, but no precise flight date has been given. It will be capable of transporting two astronauts and a 200 kg rover to the lunar surface.	None
Lunar surface infrastructure	Yuegong and Lunar surface support facility as part of the ILRS.	Argonaut Large Logistics Lander with a transport capacity of up to 2100 kg (first launch targeted for 2031).
Lunar orbital infrastructure	Not foreseen.	No autonomous capability planned; the ESA is developing two modules (built in the UK), infrastructure and telecommunications, and the NASA-led Lunar Gateway for international habitation
Lunar communications and navigation	Queqiao constellation announced in October 2023. • Queqiao-2 is set to launch in 2024 to provide initial capabilities and support the Chang'e-7 (2026) and Chang'e-8 (2028) missions • The wider constellation aims to provide services from 2030 and would provide communications, navigation and remote sensing support for the ILRS.	Lunar Pathfinder and Moonlight. • Lunar Pathfinder is a communications relay satellite that aims to offer initial lunar communications capabilities; scheduled to launch in Q4 2025 • Moonlight is a constellation of satellites intended to provide lunar connectivity and navigation services building on Lunar Pathfinder

Phase 3 of the ILRS project is scheduled to begin in or around 2040. It will see the ILRS transition from a station focused on research to a multifunctional lunar base. The station will help collect experience of the effects of long-term human spaceflight and validate the technology and capabilities for a potential human mission to Mars.

In order for China to reach its stated ambition to sustain a long-term robotic and human presence on the Moon, a number of core capabilities in several dimensions will have to be mastered. Table 1 provides an overview of the key capabilities and underpinning technological systems required for sustainable lunar exploration.

While China has been advancing the development of autonomous capabilities in all these areas, it still considers international cooperation key to advancing the ILRS, providing partners to participate in research and the construction of the station at each stage of the mission.[8] It has signed various agreements with third countries consistently since 2021, and announced the creation of the International Lunar Research Station Cooperation Organization (ILRSCO) based in Hefei in

---

[8] The importance of international cooperation was highlighted in the 2022 white paper, among other sources.

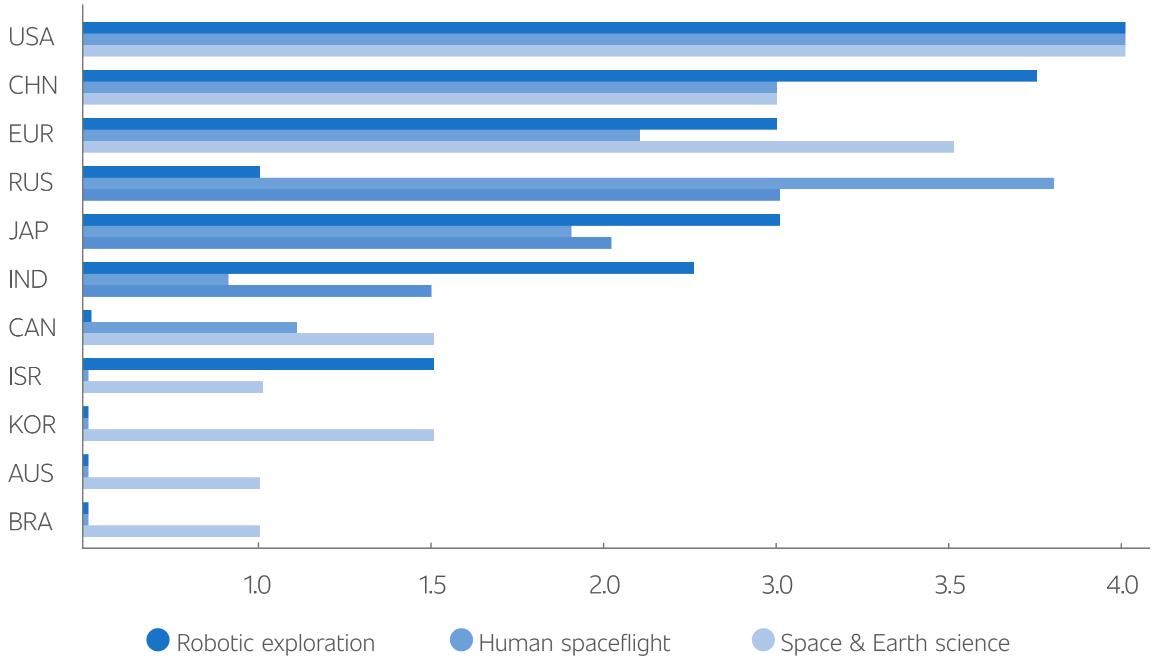
October 2023. Although not publicly depicted as such, the ILRS initiative can be understood as an alternative to the US-led Artemis programme.[9] In fact, the current exploration landscape appears polarised around two main pathways with no major interactions, let alone dependencies, envisaged between Chinese-led plans and the US-led plans to which Europe contributes. As a result, there is no path dependency currently embedded in Europe-China's space exploration activities.

Admittedly, Europe and China have a longstanding history of space cooperation, and a number of important initiatives have been undertaken in recent decades. Among these, the ESA provided spacecraft and ground operations support services through its European Space Tracking (ESTRACK) network for China's space laboratory, Tiangong-1, and the first three Chang'e lunar missions discussed above.[10] In 2014, the ESA and the China Manned Space Agency (CMSA) set up joint working groups on astronaut operations to study human behaviour and enhance performance training. A Human Spaceflight Consultation Committee co-chaired by the ESA and the CMSA was also established to assess new cooperative activities, including future European participation in Tiangong.

Any further deepening of Europe-China cooperation in the field of space exploration, however, was eventually vetoed by the USA, which was greatly concerned about the inadvertent transfer of dual-use technologies.[11] In addition, the emergence of strains in wider political relations created a reluctance on the part of ESA member states to explore more substantive avenues of cooperation. The current situation can therefore be characterised as centred on a paradigm of self-reliance, with no visible trend towards creating paths of mutual dependence.

Table 2, which compares China's and Europe's planned capabilities up to 2040, shows that realisation of China's lunar plans will not necessarily require European cooperation. China is already planning autonomous capabilities across the full spectrum of technologies required for lunar exploration. For Europe, the lack of core capabilities

FIGURE 1: Assessment of Space Exploration Capabilities[12]



---

[9] The Artemis Accords signatories and the ILRS members are currently exclusive sets of states with no overlap, except for the United Arab Emirates, which is part of both initiatives.

[10] European Space Agency, "Helping China to the Moon", accessed 21 February 2023, at https://www.esa.int/Enabling_Support/Operations/Helping_China_to_the_Moon#:~:text=Shortly%20after%20China's%20Chang'e,vessel's%20five%2Dday%20lunar%20cruise.

[11] Marco Aliberti, When China Goes to the Moon...., Vienna, Springer, 2015.

will be compensated for by close cooperation with the USA. A situation of European dependency is therefore anticipated, but on the USA, not on China.

China's relative strength vis-à-vis Europe was brought to the fore in research published in 2023 that measures the "space power" of the major spacefaring nations through a series of quantitative indicators.[12] The data confirm China's edge over Europe in the areas of robotic exploration and human spaceflight, but not in space science.

Similarly, patent data on cosmonautics from the European Patent Office (EPO) confirms China's extant position in space. The China Aerospace Science and Technology Corporation (CASC) is the undisputed leading player worldwide in terms of patent data while European players are trailing a considerable distance behind.[13] The Chinese Academy of Science, the Beijing Institute of Technology and the Nanjing University of Aeronautics and Astronautics also feature among the top players ahead of the ESA. Even by restricting the analysis to the patents filed in EPO38+, CASC continues to rank among the top players in terms of number of patent filings, ahead of the US government.[14]

Unsurprisingly, there is also great emphasis within the Chinese scholarly debate on China having mastered technological self-reliance in the field of robotic and human space exploration. Although the desire to pursue international cooperation is frequently mentioned in official statements and academic articles, the respective officials and authors rarely go into detail about what international partners could offer China. From our analysis, it appears that China is well prepared to develop the technologies required for lunar exploration (and more specifically for a lunar navigation and communications system), and to overcome any bottleneck issues independently.[15]

While not in a majority, however, some authors provide more detail on the technological issues China faces and allude to the advantages of international cooperation. Notably, in 2021 the director of the National Space Science Centre at the Chinese Academy of Science highlighted several gaps and shortcomings in achieving self-reliance in space technologies.[16] In his view, the key core technologies were not strong enough, and there was too much caution in choosing mature technologies over innovative technologies. The accuracy and sensitivity, and the types of detection instruments in China's payloads are far behind those at the advanced international level. In addition, the number of China's space science satellites (including dedicated Earth-orbiting science satellites and deep space detectors) has only just exceeded double digits after more than 50 years of development, resulting in a less advanced exploration programme.[17]

The author acknowledges the lack of international cooperation projects on space science and deep space exploration led by China.[18] Correspondingly, he accepts that China has little influence on international cooperation; has failed to effectively publish on or organise around major scientific issues, plans or tasks of global influence; and has failed to effectively leverage China's strengths and advantages in the field of space science.

From such statements it can be deduced that international cooperation would be desirable for China. As a consortium of Chinese engineering experts stated in a 2023 paper: "Because of the difficulty, high risk, and high cost of lunar exploration technology, international

---

[12] Marco Aliberti, Ottorino Cappelli and Rodrigo Praino, *Power, State and Space*, Vienna, Springer, 2023.

[13] European Patent Office, Cosmonautics, 2021.

[14] The EP038+ are the contracting states to the European Patent Convention plus the extension states and the validation states. It is important to note that the presence, absence or volume of patents within a specific domain or by an entity does not necessarily correlate with the level of innovation or technological advancement.

[15] E.g. Wu Yansheng (Party Secretary and Chairman of China Aerospace Science and Technology Corporation): "Key core technologies cannot be obtained, bought, or begged for". See Wu Yansheng, "创新突破 为高质量发展贡献航天力" [Innovative breakthroughs contribute aerospace power to high-quality development], Qiushi, 2022, accessed 24 February 2024, at http://www.qstheory.cn/dukan/qs/2022-10/17/c_1129068029.htm.

[16] Wang Chi, "王赤. 打造空间科学"梦之队"努力实现高水平科技自立自强" [To Realise High-level Scientific and Technological Self-reliance by Constructing "Dream Team" of Space Science], Chinese Academy of Sciences Bulletin, 2021, accessed 24 February 2024, at http://old2022.bulletin.cas.cn/publish_article/2021/Z2/2021Z206.htm.

[17] The challenges of establishing a lunar communications and navigation system are also mentioned in various articles, e.g. Feng Lifei, Wang Min and Meng Lingxiao, "中国深空探测迈向更深更远处" [China's deep space exploration moves deeper and further], China Science News, 2023, accessed 24 February 2024, at https://www.cas.cn/cm/202304/t20230425_4885163.shtml. See also: "月球也要上卫星导航了" [The moon will also have satellite navigation], Sina Cooperation, 2023, accessed 24 February 2024, at https://finance.sina.cn/2023-05-10/detail-imytfqyk8421609.d.html?from=wap.

[18] Ibid.

cooperation can share the costs and risks and share the achievements and developments; thus, it is the general trend of future lunar exploration missions."[19]

Overall, although the realisation of China's lunar plans will not necessarily require European cooperation, China (as confirmed by confidential sources) appears eager to explore European contributions as a means of sharing costs, increasing scientific outputs, and gaining access to key technologies and assets that will improve performance, ensure robustness, increase mission scope and flexibility, and support the commercialisation of China's lunar activities.

WHAT CAN EUROPE LEVERAGE OVER CHINA?

While Europe currently lacks most of the critical technologies and technical capabilities required for autonomous lunar exploration, or even the ambition to develop these, it plans to establish some niche technological strengths that could help it remain an indispensable player in future lunar exploration scenarios. This is particularly the case for technologies that offer communications and navigation services on the Moon, the most notable of which are:

- data transfer, data streaming and teleoperation of lunar assets (e.g., rover operations, deployment of structures, experiments)

- positioning, navigation and timing services for lunar operations and surface augmentation services.

A readily accessible communications and navigation service is a precondition for sustaining a long-term robotic and/or human presence on the Moon. Its ability to simplify mission design also has the potential to open up new opportunities for space missions. This allows missions to focus on their primary objectives, reducing or repurposing their overall payload and expanding their scope and flexibility. The availability of such a service would reduce the cost of lunar exploration, making it more accessible to a broader range of public and private sector entities interested in launching their own lunar missions or offering commercial services.[20]

In the light of these inherent advantages, Europe aims to develop a dedicated system through its planned Lunar Pathfinder mission and the Moonlight programme.[21] In addition, the ESA is working jointly with NASA on the LunaNet Interoperability Specification (LNIS), a system of systems for ensuring interoperability between Moonlight and the lunar communications and navigation systems developed by Europe's traditional partners in space exploration, such as NASA and JAXA.[22]

According to Chinese assessments, China lags behind the USA and Europe in this specific area. The importance of lunar relay communications satellite systems as a prerequisite for successful robotic and human exploration of the Moon has long been recognised by Chinese experts.[23] However, it was only in April 2022 that China announced it would take the lead in demonstrating a small lunar relay communications and navigation system.[24] Zhu Ke et al.[25] proposes a general technical architecture suitable for China's future lunar communications network. This resembles NASA's current cislunar space communications plans in being network-based. The authors argue that one of the general requirements for lunar exploration is that all available resources must be used to reduce the cost of lunar development. Accordingly, the Moon communications network must be open to cooperation with any countries and institutions that are themselves carrying out lunar exploration. The authors point out, however, that "research of the Moon

---

[19] Peng Zang et al, "Overview of the Lunar In Situ Resource Utilization Techniques for Future Lunar Missions", Space: Science & Technology, 2023, accessed 24 February 2024, at https://spj.science.org/doi/10.34133/space.0037

[20] Christian Walter et al, Commercial Applications enabled by Lunar Communication and Navigation, 74th International Astronautical Congress (IAC), 2023.

[21] European Space Agency, "The Moon: where no satnav has gone before", accessed 21 February 2024, at https://www.esa.int/Applications/Navigation/The_Moon_where_no_satnav_has_gone_before.

[22] International Committee on Global Navigation Satellite Systems, "Lunar PNT Overview" accessed 21 February 2024, at https://www.unoosa.org/documents/pdf/icg/2023/ICG-17/icg17.02.07.pdf.

[23] Zhang Lihua, Wu Weiren, "月球中继通信卫星系统发展综述与展望" [Overview and prospects for the development of lunar relay communications satellite systems], *Journal of Deep Space Exploration,* 2018, accessed 24 February 2024, at http://jdse.bit.edu.cn/fileSKTCXB/journal/article/sktcxb/2018/6/PDF/20180601.pdf.

[24] CNSA, "正在论证构建环月球通信导航卫星星座" [Demonstrating the construction of a constellation of communications and navigation satellites around the Moon], China National Radio, accessed 21 February 2023, at https://china.cnr.cn/news/20220424/t20220424_525804822.shtml.

[25] Zhu Ke et al, "载人月球探测月面通信网总体架构及关键技术研究" [Research on System Architecture and Key Technologies of Lunar Communication Network for Manned Lunar Exploration], *Journal of Astronautics*, 2023.

communications system is still in its infancy" and that China still needs "to grasp the development trend of the international mainstream technology system and its technical standards" so it can "build a China-led international Moon communication standard system" in the future.

Overall, even though it seems unrealistic to make China completely reliant on Europe's communications and navigation services, some leverage can be envisaged in principle. This potential for leverage stems specifically from the continent's proven ability to foster the commercialisation of its space products and services, and ensure the required level of international cooperation.

With regard to the former, it is worth highlighting that projections of the size of the lunar market have grown significantly. It is anticipated that approximately 400 missions will be sent to the Moon between 2023 and 2032, encompassing scientific, robotic and crewed human missions.[26] Global government allocations for space exploration are projected to rise to $13 billion and for human spaceflight to reach $15 billion by 2031.[27] Overall revenue prospects for the next decade are estimated at $137 billion.[28] This figure is expected to increase, leading to a cumulative market worth of $170 billion by 2040.[29] This emerging lunar economy on the horizon makes communications and navigation services one of the applications with the strongest economic enabling potential.[30]

Conversely, China mostly relies on state-owned enterprises to develop its space programmes, with private sector actors given only minor roles. China's commercial space industry has grown since the opening up of the sector to private investment in 2014,[31] and has made some important breakthroughs, such as in satellite launch.[32] However, the sensitivity of China's space programme means that the private sector remains under state control and a mere appendix to the state-owned space industry. This has been recently exemplified by the competition for contracts for low-cost cargo supply to the Chinese LEO space station, where all four of the groups selected for the second stage of the process are linked to state-owned entities.[33]

It should therefore be expected that Europe will have an edge over China in unleashing the potential of commercial creativity and adaptability to develop innovative commercial applications enabled by lunar communications and navigation technologies. These services could provide Europe with a degree of leverage over China, which might need some time to catch up in this specific area of capability.

The second main dimension where Europe has an edge over China rests in the value of its international partnerships. Especially in deep space exploration, Europe has a rich and longstanding history of cooperation with all the major spacefaring nations on ambitious undertakings such as the International Space Station or the planned Lunar Gateway. Similarly, the ESA's Moonlight Initiative will not be an isolated initiative, but part of a broader system of systems named LunaNet. Within LunaNet, Europe's lunar communications and navigation systems will be made interoperable with those of the United States and other geopolitically aligned countries thanks to the LunaNet Interoperability Specification (LNIS). Interoperability will in turn improve the performance of the lunar communications and navigation services, in terms of coverage and latency, and ensure operational continuity through redundancy. Interoperability would work in a similar way to Global Navigation Satellite Systems (GNSS), where the European Galileo

---

[26] Northern Sky Research, "Lunar Markets, 3RD edition", accessed 21 February 2023, at https://www.nsr.com/?research=lunar-markets-3rd-edition.

[27] Euroconsult, *Government Space Programs: Benchmarks, Profiles and Forecasts to 2031*, 2022

[28] Northern Sky Research, "Lunar Markets, 3RD edition", accessed 21 February 2023, at https://www.nsr.com/?research=lunar-markets-3rd-edition.

[29] PwC, "Lunar Market Assessment: Market Trends and Challenges in the Development of a Lunar Economy", accessed 21 February 2023, at https://www.pwc.com.au/industry/space-industry/lunar-market-assessment-2021.pdf.

[30] See e.g. Walter et al., op. cit.

[31] National Development and Reform Commission, "国家民用空间基础设施中长期发展规划（2015–2025 年)." [National mid- and long-term development plan for civil space infrastructure (2015-2025)], 2014, accessed 24 February 2024, at https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/201510/W020190905497791202653.pdf.

[32] Since 2014–2015, more than 200 commercial space corporate entities have been established. See Han, Y., Chen, Z., Hu, Y. et al., "A PIE Analysis of China's Commercial Space Development", *Humanities and Social Sciences Communications*, vol. 10, October 2023, https://doi.org/10.1057/s41599-023-02274-w.

[33] CMSA, "中国空间站低成本货物运输系统总体方案征集初选结果公告" [Announcement of the preliminary results of the solicitation for the overall plan of the low-cost cargo transportation system for the China Space Station], accessed 21 February 2023, at https://www.cmse.gov.cn/gfgg/202309/t20230925_54351.html.

system is covered by the US GPS in case of potential system failure.[34]

China on the other hand does not have a strong record of cooperation.[35] This is often highlighted as a limiting factor in the development of its space programme.[36] It is unlikely that the Chinese lunar communications and navigation network will be part of a broader system. As a result, it will inevitably miss out on the two distinct advantages provided by an interoperable system: performance and redundancy.

More specifically, China might be unable to ensure improvements in coverage and latency,[37] as well as the continuity of its lunar operations should its national system become unavailable. Without international cooperation, China would have no back-up and therefore remain vulnerable should its system fail. Considering these two dimensions, it becomes even more obvious why China is eager to pursue and develop technological cooperation with Europe on the implementation of its extensive lunar plans.

FIGURE 2: Continuum of strategic entanglement and autonomy in the field of space exploration technology

Source: Author's graphic

DISCUSSING EUROPE'S LEVEL OF AMBITION

When considering the Chinese and European roadmaps for space exploration and their relative strengths and weaknesses, the questions that arise for Europe are: What level of ambition could it aim for in a timeframe of 10–15 years? What would it take to achieve this? Importantly, these questions also need to take account of the fact that space exploration, and space more generally, is a field where Europe has over the past decade decided to address the China challenge through autonomy – or more precisely through dependency on the USA – rather than entanglement (or indispensability).

Threat prevention

Threat prevention is a policy stance aimed at preventing the transfer of any sensitive technology to China while also avoiding dependence on Chinese technology to achieve Europe's own objectives. In the case of space exploration, this means Europe limiting the export of any space (exploration) technologies to China. It will also heavily scrutinise scientific exchanges and limit Chinese investment and acquisition of talent and assets in the European space ecosystem.

Opting for threat prevention is a practicable option for Europe. In fact, a policy of threat prevention has long been a de facto foreign policy objective. With the exception of space science, cooperation on space exploration has been halted for the past eight years. There have essentially been no exchanges at the technical or programmatic level. While Europe does not possess full autonomy in its lunar exploration, dependency on China has been carefully avoided, and Europe has opted for reliance on the USA instead.

In addition, given the dual-use nature of any space technology, any transfer to China remains subject not only to the European export control regime,[38] but also to that of the USA. In any typical ESA satellite programme, more than half the electrical, electronic and

---

[34] JAXA, "Lunar Navigation Satellite System (LNSS) and its Demonstration Mission", accessed 21 February 2023, at https://www.unoosa.org/documents/pdf/icg/2022/ICG16/WG-B/ICG16_WG-B_03.pdf.

[35] In 2011, the US Congress passed the Wolf Amendment, which prohibits NASA from working with actors affiliated with the Chinese government. This effectively excludes China from participating in the ISS and most other international space missions.

[36] Wang Chi, "王赤. 打造空间科学"梦之队"努力实现高水平科技自立自强" [To Realize High-level Scientific and Technological Self-reliance by Constructing "Dream Team" of Space Science], *Chinese Academy of Sciences Bulletin,* 2021, accessed 24 February 2024, at http://old2022.bulletin.cas.cn/publish_article/2021/Z2/2021Z206.htm.

[37] Even though the second phase of the Chinese system will ensure coverage of the entire Moon, interoperability will remain important to enhance the performance of Chinese systems.

[38] European Union, Regulation (EU) 2021/821 of the European Parliament and of the Council of 20 May 2021 setting up a Union regime for the control of exports, brokering, technical assistance, transit and transfer of dual-use items, accessed 21 February 2023, at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R0821.

electromechanics (EEE) components are procured from outside Europe, in particular from the USA.[39] This gives the USA the de facto power to place conditions on Europe-China space cooperation.

At the same time, maintaining a policy of threat prevention would not provide European decision makers with any tools to shape the direction or behaviour of China's spaceflight activities. As the governance of lunar activities is largely unsettled, a policy of threat prevention could hamper the necessary coordination/cooperation to ensure the safety, security and sustainability of future lunar activities.

Ability to deny

This policy stance is more ambitious than threat prevention. It aims to develop a sufficient degree of Chinese dependency to make it irrational for China to turn against Europe. For lunar communications and navigation services, this would mean that China is dependent on Europe's role as broker for the interoperability of the Chinese system.

Acting against European interests would be costly for China because the loss of cooperative gains would hinder optimal implementation of the Chinese lunar programme, at least in the short term. Although China is fully autonomous in space capabilities, lunar communications and navigation represents a special issue-area where services profit tremendously from interoperability with other systems, in terms of both redundancy and performance. Cooperation with Europe could be seen as an invaluable tool for reaping those benefits.

A policy premised on the ability to deny may therefore prove a feasible option for Europe, provided that the necessary green light is secured from the USA. The advantage would be to disincentivise China from positioning against European interests; for instance, by upholding the safety and security of lunar operations and more broadly preventing the emergence of confrontational stances in space. Another potential payback would be greater European insight into China's technical capabilities and intentions. While there is currently uncertainty and a lack of transparency over China's space goals, resulting in the need for worst-case planning, exchanges of information could help Europe to understand China's intentions more clearly and reduce mistrust and ambiguity.

At the same time, this strategy would run the risk of allowing China to extract considerable practical benefits from Europe, while only marginally deterring China from turning against it. In terms of relative gains, cooperation could benefit Chinese stakeholders more than European. China could use the partnership to gain direct or indirect access to sensitive information on lunar operations by western countries, and to their technologies, while offering Europe little more than rhetorical concessions about Chinese willingness to amicably resolve outstanding issues. It is in fact possible that cooperation in space will not translate into closer political relations, reduce mistrust and prevent China from turning against European security interests.

Ability to Act

There is currently no path dependency embedded in Europe-China relations in space exploration. This level of ambition would therefore first require Europe to proactively engage in space cooperation to develop a critical Chinese dependency that could be then leveraged to influence Chinese programmatic directions or gain concessions from it in the space or other arenas. The above-mentioned case of lunar communications and navigation services would make China reliant on Europe's role as a broker for the interoperability of the Chinese system. Using this broker role, Europe would seek to gain major concessions from China.

However, this specific strategy has several limitations. While it might prove useful in deterring China, it will probably not be useful to put major pressure on China or influence the direction of its lunar programme. As a matter of fact, possible cooperation on lunar communications and navigation would not put Europe on a "critical path". Providing lunar communications and navigation services or offering China membership of the LunaNet initiative would only provide auxiliary benefits in terms of performance and redundancy, which would not generate critical spillover should the stronghold be used as a chokepoint by Europe. In fact, China would in any event be able to implement its stated ambition, albeit in a suboptimal manner.

In addition, it should be recalled that most space exploration activities in Europe are under the programmatic-driven steam of ESA, and it would therefore be challenging to make China reliant on Europe just for the sake of actively utilising the cost of such dependency from a political or economic perspective. Pursuing this level of ambition should therefore be taken to imply the development of an all-round, critical European edge across the full spectrum of capabilities required for exploration,

---

[39] European Space Agency, European Space Technology Master Plan, 2022.

rather than some niche technologies, the added value of which could be circumvented or replicated by China.

Building such an edge is a necessary pathway if Europe aims to become an indispensable, transformative actor for both China and the rest of the global space community. Importantly, it is also a feasible pathway, provided that sufficient investment is secured from ESA member states. According to a 2023 assessment, an investment of €50 billion over the 15-year period 2025–2040 would allow Europe to secure a prominent role in the context of future exploration. This funding level is within reach, given that in Europe space is currently underinvested in compared to other space powers. (For example, the European budget as a share of GDP invested in space is around 0.07%, compared to about 0.25% in the USA.)[40] Such a stance would provide Europe with the necessary technical and political autonomy to decide when and under what conditions to cooperate with China.

Curtailment

The most ambitious of the policy options, curtailment, would mean not only that Europe maintains a technological edge over China, but also that it uses this to slow or even prevent China's development of certain economic and technological capabilities. In the context of space exploration, curtailment would see Europe actively use its position to slow down or even curb implementation of China's Moon exploration programme.

However, this scenario is no longer practical as past exclusion policies put in place by western countries, most notably the USA, have already pushed China to invest significant resources in development of all the hardware capacities and techniques required to implement its lunar ambition fully and autonomously. China would therefore be able to circumvent any restrictions Europe might wish to put in place.[41]

POLICY RECOMMENDATIONS FOR EUROPE

Based on the assessed feasibility of the four levels of ambition laid out in the previous section, some concrete policy recommendations are provided below on what European policymakers need to do either to prevent risks or to politically leverage possible engagement with China.

The first element to note is that a policy premised on knowledge security and threat prevention is de facto already in place. Therefore, should European policymakers opt to maintain this level of ambition, they would as a baseline need to be careful not to create new dependencies vis-à-vis China. This would require guaranteeing that European industry has unrestricted access to required technologies, products, services or information and is not dependent on imports of products and services from China. This would in particular apply to basic electrical and electronic components, advanced materials, equipment, processes and modelling tools. A specific recommendation would be to identify critical resources for space exploration systems, map them against Europe's availabilities and devise roadmaps to either develop them in-house or procure them from aligned countries. All this inevitably means continuing to bandwagon on US exploration activities and striving to position Europe on a "critical path" to the provision of the core capabilities required for sustaining a long-term presence on the Moon.

Be this as it may, it should be stressed that maintaining a policy of threat prevention would not provide European decision makers with any tools to shape the direction and behaviour of China's spaceflight activities. Although Europe can certainly continue to opt for a low-risk approach, it is also clear that if it wants to achieve broader objectives in the medium term – and be able to ensure that Chinese lunar plans occur in a predictable, non-threatening manner – Europe needs to be ready to take some risks through engagement.

A higher level of ambition whereby Europe actively exploits some political leverage therefore seems advisable. More specifically, should Europe opt for a policy premised on the "ability to deny" over the next 10–15 years, it would need to use its planned niche technology strengths to make implementation of the Chinese lunar exploration programme somehow dependent on

---

[40] European Space Policy Institute, *ESPI 2040: Space for Prosperity, Peace and Future Generations*, 2023.

[41] Where curtailment might have more of a chance of being successful is limiting Chinese participation in the provision of services as part of the future lunar economy, as well as preventing China from developing closer partnerships with third countries in lunar exploration by launching a proactive space diplomacy initiative aimed at luring partners away from China. A policy of curtailment would prevent China from achieving a dominant position in lunar activities and posing non-negligible threats to European interests in space. It would also ensure that conditions in the lunar environment remain more attuned to European activities, from a safety, security and sustainability perspective. At the same time, an explicit policy of curtailment would only strengthen China's resolve to develop its lunar infrastructure and reach out to other partners. It would also reinforce competition dynamics and make lunar governance more challenging. Furthermore, curtailment would be likely to impact other fields where Europe and China engage in mutually beneficial cooperation and could be detrimental for Europe.

Europe; that is, make China dependent on Europe's role as a broker for the interoperability and commercialisation of Chinese communications and navigation systems. As discussed above, China would be eager to explore cooperation as a means of improving performance, ensuring robustness, increasing mission scope and flexibility, and supporting commercialisation of its lunar activities.

These inherent strengths of Europe, however, should not be overestimated. For one thing, they have a low degree of leverage, and possible chokepoints only in the medium to long term. More importantly, there are limited margins for European institutions to leverage these key strengths and make it costly for China to threaten Europe, let alone strive to influence or contain China. Most of the key technologies under consideration will be developed by the ESA, and its international activities are programmatically driven and do not necessarily serve foreign policy objectives. In addition, the lunar exploration landscape is already polarised around two contending – and mutually exclusive – pathways. There are no substantial interactions, let alone dependencies, between Chinese efforts and the US-led plans to which Europe contributes. Therefore, should Europe decide to move towards an engagement policy that uses path dependencies to deter or influence China, close coordination with (and a green light from) the USA would be required.

More broadly, should Europe opt for a higher level of ambition whereby it actively aims to exploit its strengths politically, it would first need to identify and develop capabilities with higher degrees of leverage over China. For instance, the development of large sample re-entry capabilities offers a specific example, as China has no existing or planned capabilities capable of returning sizable quantities of lunar samples to Earth. A similar logic applies to cislunar space infrastructures, as China is not currently planning the deployment of any orbital infrastructure similar to NASA's Lunar Gateway.

Specific examples apart, the possibility of Europe leveraging any key strengths vis-à-vis China in the field of exploration will ultimately depend on Europe's ability (and determination) to regain technology strength across the board and craft a more ambitious space exploration programme. Such an endeavour would require a significant departure from the current Europe- or ESA-led exploration strategy towards a new, bolder framework that encompasses the entire range of exploration activities.

Specifically, should Europe seek to take this course of action and develop a "real ability to act", it would need to build up extensive capabilities in all the critical technologies required for space exploration and put its ambition on the same level of full-fledged space powers like the USA or China. This would require a significant step up in investments devoted to the development of a more ambitious exploration architecture with critical building blocks, such as cargo vehicle capability, a crew lunar landing system, and the development of lunar surface infrastructures for energy, life support, resource utilisation and refuelling. Ultimately, the whole architecture should be put in place autonomously and conditioned on the availability of a European heavy launcher and end-to-end coverage of the Moon.[42]

More European autonomy will of course not be to the detriment of international cooperation with the USA. On the contrary, being a more capable partner will improve the quantity and quality of cooperation opportunities through enhanced international standing. Greater autonomy would therefore also prove the best way to balance China's ambition and bring forth concrete tools for pursuing a degree of curtailment, specifically by reducing China's international outreach. The development of autonomous capabilities would allow Europe to position itself as a "dispenser" of international cooperation and engage in a proactive diplomatic initiative, offering potential ILSR partners alternative and more attractive pathways.

The actionable policy instruments for European policymakers can be summarised as follows:

- In preparation for the ESA Council at the ministerial level in 2025, propose a major overhaul of the ESA's space exploration strategy as laid out in the Terrae Novae 2030+ roadmap, with a clear emphasis on the development of autonomous capabilities for human lunar exploration.

- Identify and develop specific technologies that provide Europe with a unique set of capabilities and hence higher degrees of leverage over foreign space powers.

---

[42] Achieving this would require substantial public investment. According to ESPI and the BCG, a dedicated investment of roughly €3 billion per year over the next 15 years (2025–2040) would be needed to ensure Europe a leading role on a par with that of China and the USA in the future exploration context. Similarly, Europe should attract significant private investment and devise public-private partnerships to fully unleash the development of innovative commercial applications in the future lunar economy. These developments would provide Europe with key leverage over China, which would need more time to catch up.

- Increase institutional funding for space exploration by the ESA and its member states and define (direct or indirect) contributions to space exploration by the EU in the next Multi-Annual Financial Framework, 2028–2035.

- Stimulate private investment in lunar exploration activities geared towards the development of a commercially oriented lunar economy.

- Deepen cooperation on standards, norms and rules-setting for future governance of cislunar and lunar surface activities among like-minded countries.

- Tighten both inbound and outbound investment screening to prevent technology transfer and innovation export respectively.

SCORECARD 2 TECHNOLOGY FIELD: SPACE EXPLORATION

Feasibility of level of ambition	Threat prevention	Ability to deny	Ability to act	Curtailment
	● High	● Medium	● Low	○ Not feasible
Core policy recommendation	Identify critical resources for space exploration systems, map them against Europe's strengths and devise roadmaps to either develop them in-house or procure them from aligned countries Tighten both inbound and outbound investment screening to prevent technology transfer and innovation export, respectively	Make China dependent on Europe's role as a broker for the interoperability and commercialisation of Chinese communication and navigation systems Identify and develop capabilities with higher degrees of leverage with regard to China Deepen cooperation on standards, norms- and rules-setting for future governance of cislunar and lunar surface activities among like-minded countries	Revamp the ESA's space exploration strategy putting a clear emphasis on the development of autonomous capabilities for human lunar exploration Increase institutional funding for space exploration by the ESA and its member states Stimulate private sector investment in lunar space exploration activities geared to the development of a commercially oriented lunar economy Build up extensive capabilities in all the critical technologies required for space exploration	None

AUTHORS

Marco Aliberti is an Associate Manager and Lead on International Engagement at the European Space Policy Institute (ESPI) in Austria. Contact: marco.aliberti@espi.or.at
Angela Stanzel is a Senior Associate at the German Institute for International and Security Affairs in Germany. Contact: angela.stanzel@swp-berlin.org
Lars Petzold is a Research Fellow at the European Space Policy Institute (ESPI) in Austria. Contact: lars.petzold@espi.or.at

The Role of European Providers in China's Facial Recognition Apparatus

Greg Walton and Valentin Weber

ABSTRACT

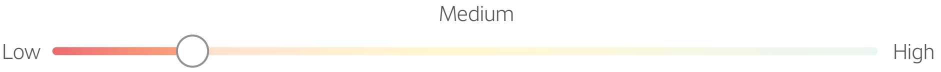
Imports of European video surveillance and facial recognition equipment to China have dwindled in recent years. China, however, remains reliant on European machines that are used to produce the most advanced semiconductor chips in facial recognition systems. In addition, China might become reliant on emerging European general purpose technology capabilities, such as quantum annealing, which are used to make processes across industries more efficient and could be used by China to make facial recognition more powerful. In order to prevent Chinese actors from misusing existing European semiconductor capabilities, as well as emerging quantum annealing ones, we suggest that European policymakers pursue a two-part strategy. On the one hand, European actors should tighten their export controls on these critical technologies and closely monitor enforcement of those restrictions. At the same time, Europe needs to intensify its focus on developing quantum annealing capabilities and diffuse those to third markets. This would be economically beneficial across European industries and could build leverage over China trying to acquire the same capabilities. As with semiconductors, however, Europe must ensure that these technologies do not diffuse to China, where they could be misused to infringe human rights.

SCORECARD 1 TECHNOLOGY FIELD: FACIAL RECOGNITION TECHNOLOGY

Source of European technology strength	Research and innovation	Intellectual property and patents	Production and commercialisation
	● Low	● Medium	● Low

Type of European technology strength	Technological excellence	Commercialisation advantage	Conditioning of market access	Regulatory, political and normative factors	Sustainability	Research partnerships with third countries
	X		X			

Degree of European leverage



INTRODUCTION: CHINA'S FACIAL RECOGNITION AMBITIONS[1]

Global patent filings for facial recognition have increased considerably in the past two decades (see Figure 1). China's facial recognition technology in particular has sparked grave concerns in Europe.[2] The EU has noted that the People's Republic of China (PRC) has expressed a strong desire to be a global leader in artificial intelligence (AI) technology,[3] of which computer vision

---

[1] The authors would like to thank Maria Pericàs Riera for her editorial and research assistance.

[2] China has taken steps to regulate the use of facial recognition technology, highlighting the complex interplay between technological advancement, privacy and state surveillance.

[3] Ulrich Jochheim, "China's Ambitions in Artificial Intelligence", European Parliamentary Research Service, PE 696.206, Brussels, 2021, https://www.europarl.europa.eu/thinktank/en/document/EPRS_ATA(2021)696206

research and development is a key dimension.[4] This is also evident from the substantial state support provided for research and development in AI and related frontier technologies.[5] China's aspirations have implications for its surveillance capabilities.

China's ambitions in developing facial recognition technology are underscored by a range of articles and reports in the public domain that highlight China's growing interest and investment in this area.[6] These ambitions can be inferred from a combination of party media,[7] the sheer scale of deployment,[8] and the strategic integration of facial recognition into various industries, such as smart cities.

China has made significant investment in smart city projects.[9] This often includes the integration of advanced surveillance systems with facial recognition capabilities.[10] This reflects an ambition to enhance urban management and public safety, but also raises concerns about privacy and mass surveillance. The widespread use of facial recognition technology in law enforcement and security in China, reflected for example in Ministry of Public Security technical standards for video (VIID) surveillance systems,[11] highlights the state's ambition to use technology to maintain public order and national security. Beyond the domestic market for mass surveillance systems, Chinese companies are major suppliers of facial recognition technology globally.[12] The export of technology, particularly in areas such as facial recognition surveillance systems,[13] supports China's broader strategic goal of establishing itself as a leading global technological superpower.

The promotion of facial recognition technology is also part of China's strategy for economic growth through innovation.[14] The technology sector, particularly AI, is seen as a key driver of future economic development. In summary, China's ambitions in facial recognition technology are multifaceted, aiming for technological leadership, economic development, public security and global influence. However, these ambitions are balanced by a growing awareness of the need for regulatory oversight of cybersecurity and the protection of individual privacy rights.

The importance China attributes to facial recognition technology explains why the country is striving for technological self-reliance in this field. As discussed in detail below, China's dependency on European input to its facial recognition technology has decreased, but it remains reliant on enabling technology for the most advanced semiconductors. Its appetite for facial recognition technologies is still growing, as reflected in central government procurement documents (see Figure 2). There is also potential to make China more dependent on European dual-use technologies. Emerging European strengths in quantum technology could create Chinese reverse dependencies on Europe. Quantum technology could revolutionise facial recognition in the coming 10–15 years, making it far more efficient. China's surveillance state will need more efficient systems as more cameras

---

[4] Ashwin Acharya, Max Langenkamp and James Dunham, "Trends in AI Research for the Visual Surveillance of Populations", Center for Security and Emerging Technology, Washington, DC, 2022, https://cset.georgetown.edu/publication/trends-in-ai-research-for-the-visual-surveillance-of-populations/

[5] Jeffrey Ding, *Deciphering China's AI Dream: The Context, Components, Capabilities and Consequences of China's Strategy to Lead the World* in AI, Oxford, 2018.

[6] Jeffrey Ding, op. cit.; Tom Simonite, "Behind the Rise of China's Facial-Recognition Giants," Wired, accessed 10 April 2024, at https://www.wired.com/story/behind-rise-chinas-facial-recognition-giants/; Elsa Kania, "China's Ambitions in Artificial Intelligence: A Challenge to the Future of Democracy?," Power 3.0: Understanding Modern Authoritarian Influence, accessed 10 April 2024, at https://www.power3point0.org/2018/08/08/chinas-ambitions-in-artificial-intelligence-a-challenge-to-the-future-of-democracy/.

[7] Zhang Xiangyang, "人民时评：让人工智能更好造福社会", [People's commentary: let artificial intelligence better benefit society], CPC News, accessed 10 April 2024, at http://theory.people.com.cn/GB/n1/2020/1201/c40531-31950335.html

[8] Will Knight, "China is the World's Biggest Face Recognition Dealer", Wired, accessed 10 April 2024, at https://www.wired.com/story/china-is-the-worlds-biggest-face-recognition-dealer/

[9] Alice Ekman, "China's Smart Cities: The New Geopolitical Battleground", French Institute of International Relations, Paris, 2019, https://www.ifri.org/sites/default/files/atoms/files/ekman_smart_cities_battleground.pdf

[10] Robert Muggah, "'Smart' Cities Are Surveilled Cities", *Foreign Policy*, accessed 10 April 2024, at https://foreignpolicy.com/2021/04/17/smart-cities-surveillance-privacy-digital-threats-internet-of-things-5g/

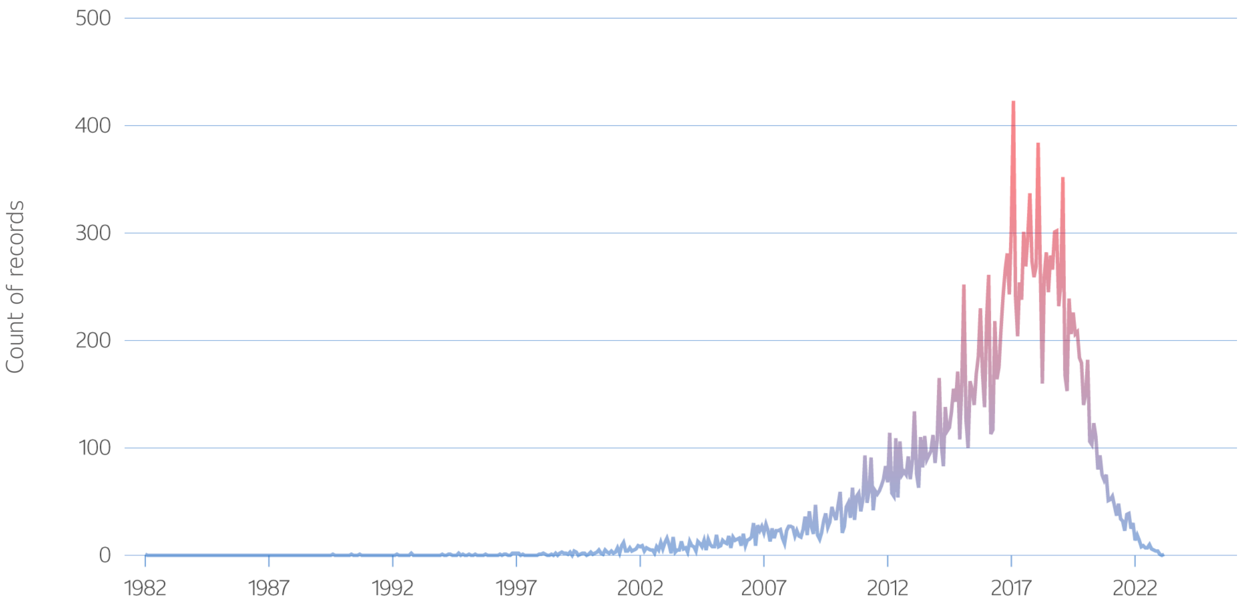
[11] Chinese Standard, GA/T 1400.3-2017 (GAT1400.3-2017), accessed 10 April 2024, at https://www.chinesestandard.net/PDF/English.aspx/GAT1400.3-2017

[12] Martin Beraja et al., "Exporting the Surveillance State via Trade in AI", Brookings Center on Regulation and Markets, Washington, DC, 2023, https://www.brookings.edu/wp-content/uploads/2023/01/Exporting-the-surveillance-state-via-trade-in-AI_FINAL-1.pdf

[13] Ibid.

[14] Saemoon Yoon and Michelle Mormont, "What Makes China's Innovation Ecosystem Unique?", World Economic Forum, accessed 10 April 2024, at https://www.weforum.org/agenda/2023/06/why-china-innovation-ecosystem-is-unique-amnc-23/

FIGURE 1: The rate at which facial recognition (人脸识别) patents have been filed globally, 2001–23



Source: Google Patents/DGAP

go online and as the data they collect grows rapidly.[15] At the same time, China's facial recognition systems are being integrated and fused with ever more data from other sources, which requires rapid processing.[16]

What China needs to deploy facial recognition technologies

In the simplest terms, China needs the hardware and software capable of producing advanced facial recognition cameras. It will be more difficult for the PRC to become self-sufficient on the hardware side, especially regarding chips. Compared to other actors, however, it is closer to achieving self-reliance. Russia, for instance, acquires Chinese facial recognition physical equipment but deploys software from local Russian companies. China is host to two giants in CCTV equipment making, Hikvision and Dahua. One of the few hardware restrictions on Chinese deployment is the availability of cutting-edge graphics processing units (GPU), which are largely provided by US companies such as Nvidia.[17] China has some of the most advanced tech players in software.[18] Inside China, four companies – Megvii, Cloudwalk, Sensetime and Yitu – have a market share of 60% in the computer vision industry.[19] Chinese companies are leading the world in the export of facial recognition technologies.[20] As of the end of 2022, 201 Chinese export deals had been recorded. The US lags behind with 128. China is still aiming to improve by reducing the cost of the surveillance apparatus, including through AI which helps to make things more efficient and increasingly takes on tasks for which people were needed.

---

[15] Yanan Wang and Dake Kang, "Exposed Chinese Database Shows Depth of Surveillance State", Associated Press News, accessed 10 April 2024, at https://apnews.com/article/6753f428edfd439ba4b29c71941f52bb

[16] Dahlia Peterson, "How China Harnesses Data Fusion to Make Sense of Surveillance Data", Brookings, Washington, DC, 2024, https://www.brookings.edu/articles/how-china-harnesses-data-fusion-to-make-sense-of-surveillance-data/

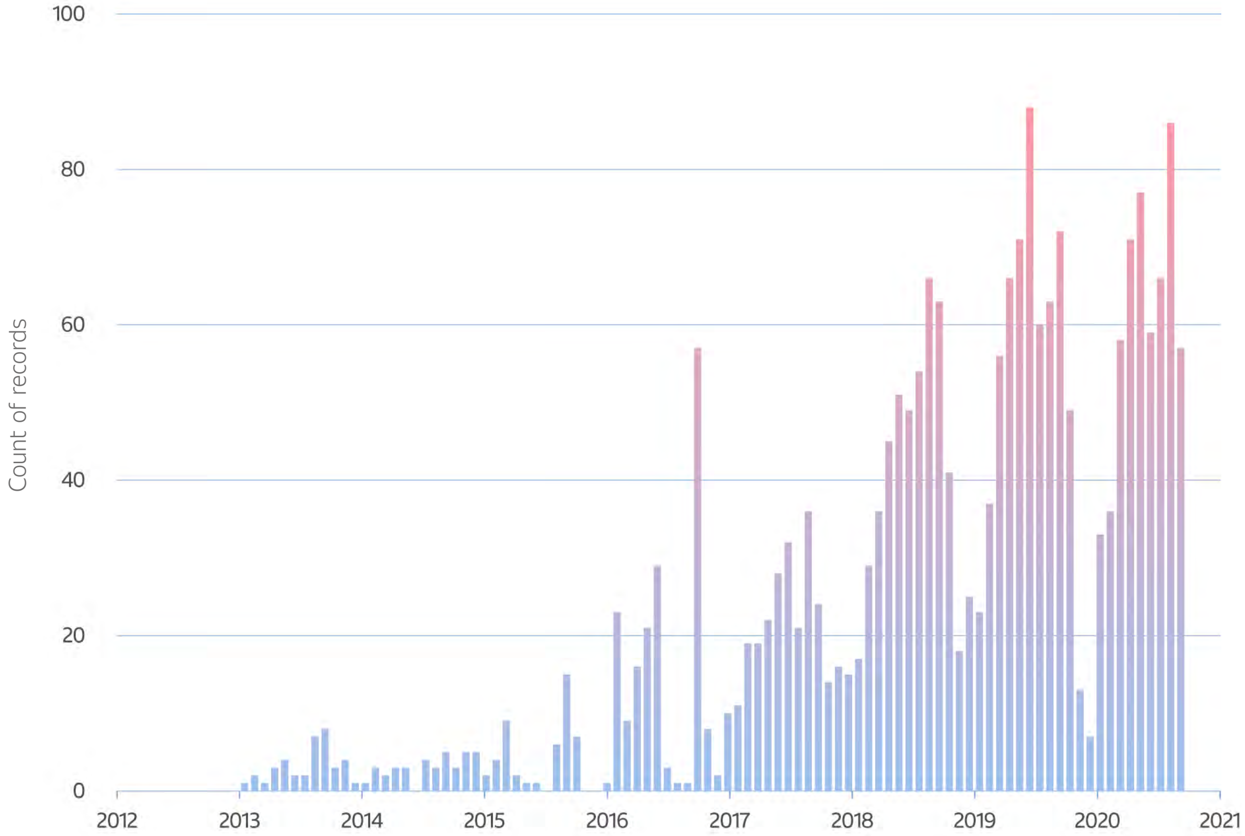
[17] Chris Szewczyk, "The US Wants to Restrict China's Access to AI Chips Even More, and Nvidia Could Lose Out as a Result", PC Gamer, accessed 10 April 2024, at https://www.pcgamer.com/the-us-wants-to-restrict-chinas-access-to-ai-chips-even-more-and-nvidia-could-lose-out-as-a-result/

[18] Eduardo Baptista, "Insight: China Uses AI Software to Improve its Surveillance Capabilities", Reuters, accessed 10 April 2024, at https://www.reuters.com/world/china/china-uses-ai-software-improve-its-surveillance-capabilities-2022-04-08/

[19] He Shujing, Zhai Shaohui, Wei Yiyang and Han Wei, "China's Quartet of AI Giants Walk Through the 'Valley of Death'", Nikkei Asia, accessed 10 April 2024, at https://asia.nikkei.com/Spotlight/Caixin/China-s-quartet-of-AI-giants-walk-through-the-valley-of-death

[20] Will Knight, "China is the World's Biggest Face Recognition Dealer", op. cit.

FIGURE 2: The rate at which central government procurement notices mentioning facial recognition (人脸识别) were posted, 2013-20 Source: CCGP.GOV.CN/DGAP



Source: CCGP.GOV.CN/DGAP

While Europe is not world-leading in producing GPUs, ASML, a Dutch company focused on building photolithography machines, could have leverage over the ability of Chinese chip manufacturers to produce advanced chips for facial recognition purposes. As discussed in more detail in the chapter 2, ASML is a strategic chokepoint in the global semiconductor manufacturing supply chain.[21] It specialises in producing photolithography machines that are essential for etching circuits on to silicon wafers. These machines, particularly those capable of extreme ultraviolet (EUV) lithography,[22] are crucial for creating the most advanced semiconductor chips used in a variety of technologies, including AI biometric surveillance systems such as facial recognition.[23] ASML is the only company capable of producing EUV lithography machines and has a quasi-monopoly on the most advanced deep-ultraviolet (DUV) lithography. China's ability to manufacture state-of-the-art chips, chip design software and chip making equipment,[24] for applications such as facial recognition, is to a significant extent dependent

---

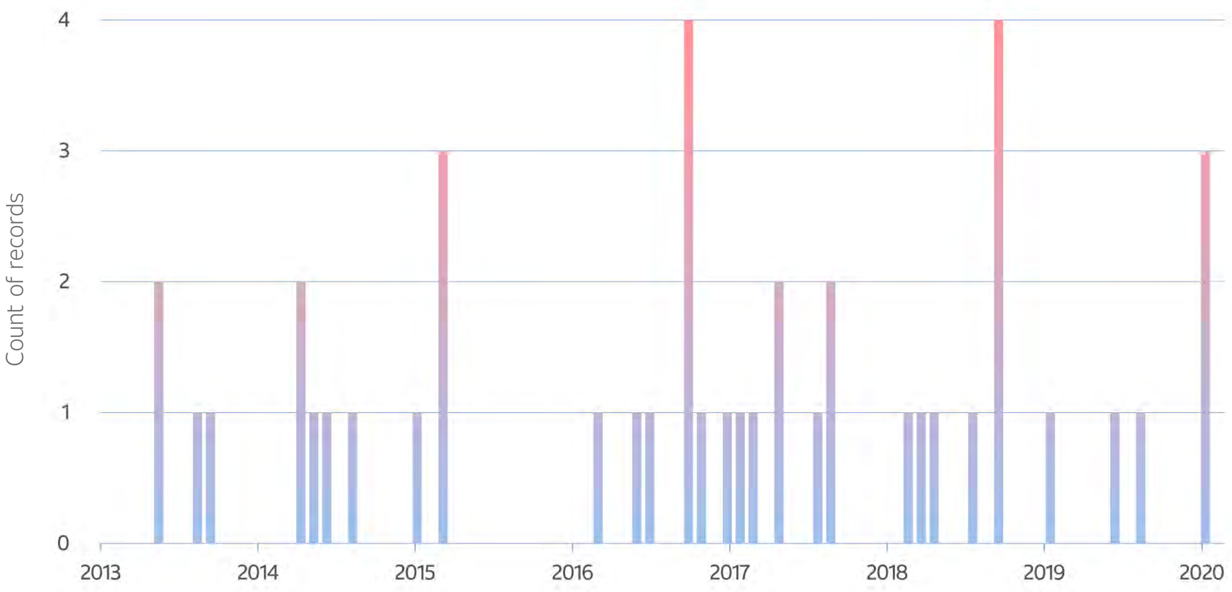
[21] Tim De Chant, "The Chip Choke Point", The Wire China, accessed 10 April 2024, at https://www.euvlitho.com/Blogs/The%20Chip%20Choke%20Point%20-%20The%20Wire%20China.pdf

[22] Will Knight, "The $150 Million Machine Keeping Moore's Law Alive" Wired, accessed 10 April 2024, at https://www.wired.com/story/asml-extreme-ultraviolet-lithography-chips-moores-law/

[23] Jim Davis, "Chip Suppliers, Startups Team up to Advance Edge AI for Biometric Applications", BiometricUpdate.com, accessed 10 April 2024, at https://www.biometricupdate.com/202108/chip-suppliers-startups-team-up-to-advance-edge-ai-for-biometric-applications

[24] Gregory Allen, "In Chip Race, China Gives Huawei the Steering Wheel: Huawei's New Smartphone and the Future of Semiconductor Export Controls", Center for Strategic and International Studies, Washington, DC, 2024, https://www.csis.org/analysis/chip-race-china-gives-huawei-steering-wheel-huaweis-new-smartphone-and-future

FIGURE 3: 42 procurement notices from ccgp.gov.cn that mention known EU manufacturers of face recognition equipment



Source: CCGP.GOV.CN/DGAP

on access to such technologies. In other words, the chokepoint discussed in the lithography chapter has ripple effects for a variety of technological applications, including facial recognition.

Apart from ASML, China currently no longer needs Europe to achieve its ambitions

To analyse whether China requires additional European technologies, we scraped Central Government Procurement notices from the website.[25] We identified 42 procurement notices that mentioned EU manufacturers of facial recognition equipment in the period 2013–20 (see Figure 3).

These 42 notices, from a total of 2,202 that mention "人脸识别", suggest that just 1.9% of the facial recognition procurement notices in the period 2013–20 involved EU manufacturers. The small fraction of total contracts awarded to EU manufacturers in this period demonstrates that Europe does not have an additional chokepoint apart from its role in the advanced semiconductor supply chain. Europe is of minor importance to the overall procurement of facial recognition technology in China. However, this data needs to be understood in the light of a number of factors related to domestic procurement dynamics in the PRC and the quality of EU technologies in this sector – as opposed to the quantity of sales, discussed below with regard to patents. It is our contention that the quantity of EU exports to the PRC of equipment in this sector has dwindled to almost zero over the past two decades.

For example, Cognitec Systems, a company based in Dresden, Germany, which focuses on software but also sells facial recognition cameras, announced in 2013 that it had offices in Hong Kong.[26] In the same year, it publicly stated that its products could identify ethnicity.[27] In 2016, its facial recognition products were used in a casino in Macao.[28] Using LinkedIn, however, the authors could only find one company employee based in Hong Kong.

---

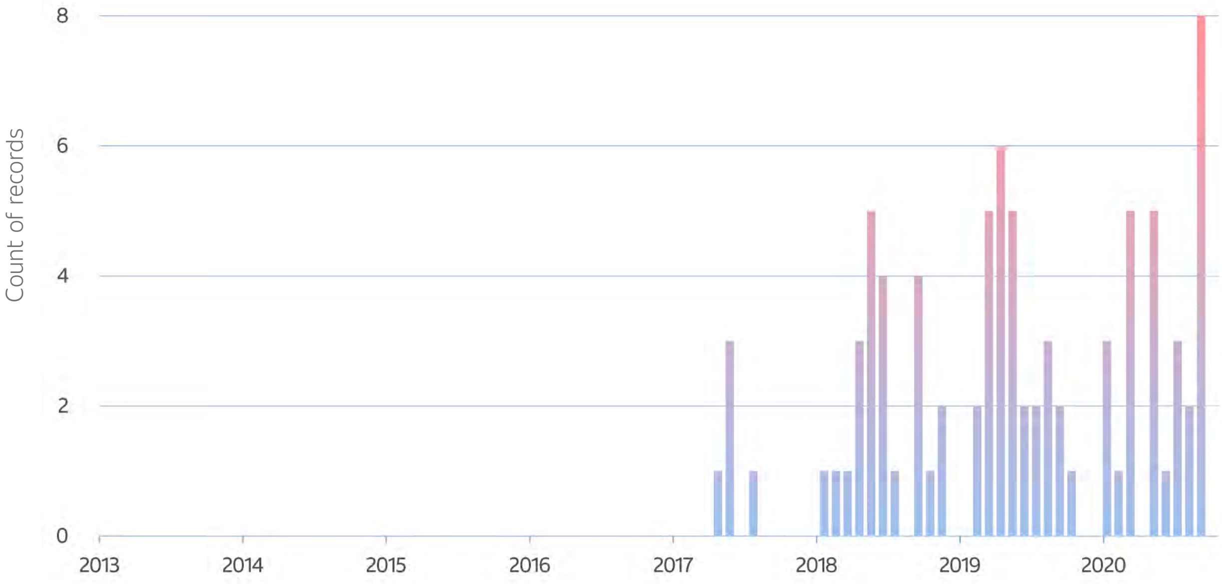
[25] The notices were ingested into Elasticsearch and we performed manual searches and searches guided by machine learning to surface anomalies in the rate of publication of notices for specific themes related to identifying European exports of concern.

[26] Business Wire, "Cognitec Releases Video Analytics Product with Advanced Anonymous Face Recognition Technology", accessed 10 April 2024, at https://www.businesswire.com/news/home/20130212006158/en/Cognitec-Releases-Video-Analytics-Product-with-Advanced-Anonymous-Face-Recognition-Technology

[27] Silicon Trust, "Video: Cognitec Brings Face Recognition to Digital Signage Market", accessed 10 April 2024, at https://silicontrust.org/2013/03/05/video-cognitec-brings-face-recognition-to-digital-signage-market/

[28] Canal Macau, "A German Company has Installed Face Recognition Technology at Melco Crown's Major Casinos in Macau", TDM News, accessed 10 April 2024, at https://www.facebook.com/watch/?v=932629176853239

FIGURE 4: “本项目不接受进口产品” AND “人脸识别” ("This project does not accept imported products” and “Facial Recognition”) 2013–2020



Source: CCGP.GOV.CN/DGAP

In addition, Noldus, a Dutch emotion recognition provider that boasts that its products can identify when people are sad, happy or angry by analysing images, has its Asia headquarters in Beijing and offices in Shanghai, Chengdu, Wuhan and Tianjin. It appears to have last exported to the Chinese Ministry of Public Security and the Xinjiang Normal University (in 2018). The latter deal included its product Face Reader,[29] which is a system for identifying the emotional state of passers-by.

Idemia,[30] a France-based entity, appears to be active in China through two subsidiaries: 莫弗安全系统（上海）有限公司 [Morpho Security Systems,[31] Shanghai Co., Ltd.]; and 爱德觅尔（深圳）科技有限公司 [Admire (Shenzhen) Technology Co., Ltd.].[32] The former is engaged in the import and export of electronic equipment and accessories. In the mid-2010s, Idemia sold facial recognition technology to the Shanghai Public Security Bureau that could identify individuals on pre-recorded footage.[33]

Axis had also been very active in China. It supplied the cameras used in larger facial recognition deployment projects in China. In a series of surveillance deliveries, Axis sold cameras[34] to Guilin city, Lingchuan County and the Shanghai and Jingjiang Public Security Bureaus.

---

[29] Amnesty International, “Out of Control: Failing EU Laws for Digital Surveillance Export”, London, 2020, https://www.amnesty.org/en/documents/eur01/2556/2020/en/#:~:text=This%20report%20gives%20evidence%20of,upcoming%20Recast%20Dual%20Use%20Regulation.

[30] Piper Lounsbury, “Risky Business: Growing Peril for American Companies in China”, Congressional Testimony, House Select Committee on the Strategic Competition Between the United States and the Chinese Communist Party, Washington, DC, 2023, https://selectcommitteeontheccp.house.gov/committee-activity/hearings/hearing-notice-risky-business-growing-peril-american-companies-china

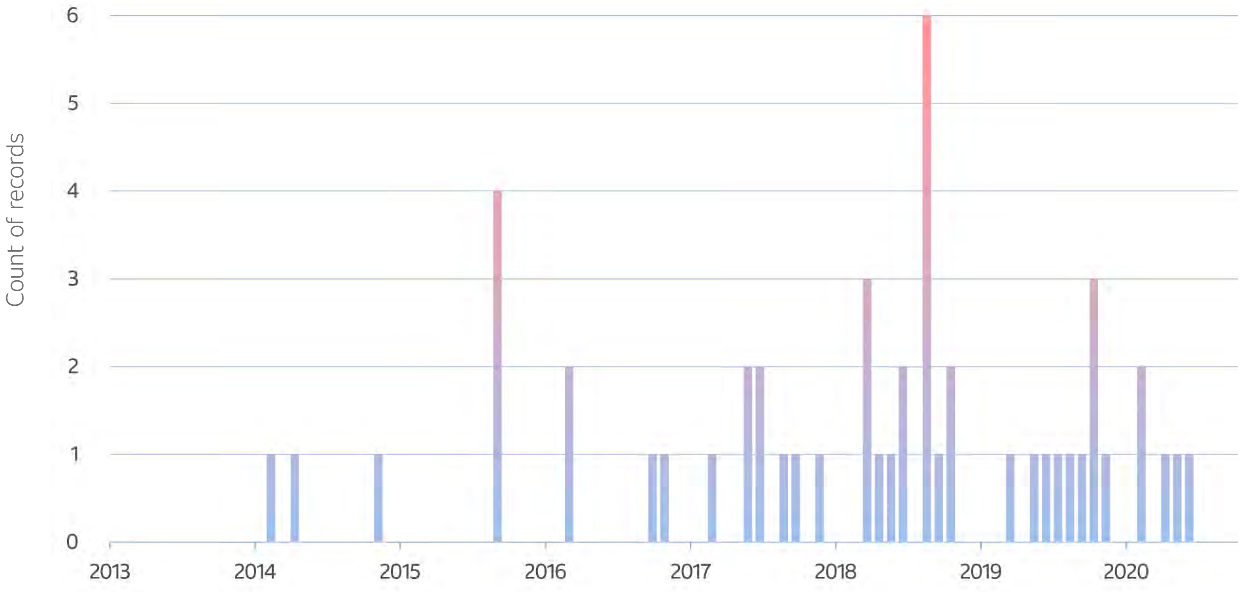
[31] Ibid.

[32] Admire Technology Website, accessed 10 April 2024, at https://www.zhipin.com/gongsi/f019122e24f7dd721nV43N-8F1E~.html

[33] Amnesty International, op. cit.

[34] Ibid.

FIGURE 5: “本地化” AND “人脸识别” (“Localisation” AND “Face Recognition”) 2013-20



Source: CCGP.GOV.CN/DGAP

However, Axis seems to have decreased its footprint in China in recent years. Its Chinese-language[35] website appears not to have been updated since 2021, as the news articles on the website date from August 2021.

This sharp decline in European exports to China is at least partly the result of article 10 of the Government Procurement Law of the People's Republic of China (2002),[36] which states that governments (central and provincial) “shall procure domestic goods”, permitting exceptions only if such goods “are not available” domestically or “cannot be acquired on reasonable commercial terms”. At the same time, the law allows domestic contractors [some exceptions that they have used to source facial recognition], products manufactured overseas. The PRC government itself noted in 2021 that “government procurement law does not clearly formulate relevant rules of origin standards, resulting in a large number of foreign companies' products using relevant policies to reasonably evade the law and participate in [PRC government] procurement”.[37]

In 2010, the *Financial Times* reported that “over the past decade, the government [has] launched several initiatives aimed at strengthening local companies and bolstering government control, but watered them down after an outcry from the foreign business community”.[38] As early as 2012, China's state media was warning that importing foreign video surveillance equipment was a “risk to national security”.[39] This was at a time when

---

[35] Axis Communications, “不断创新，打造更聪明更安全的世界” [Continuous innovation for a smarter and safer world], Axis Website, accessed 10 April 2024, at https://www.axis.com/zh-cn

[36] China.org.cn, “The Government Procurement Law of the People's Republic of China”, accessed 10 April 2024, at http://www.china.org.cn/china/LegislationsForm2001-2010/2011-02/14/content_21917023.htm

[37] National Government Offices Administration, “原产地规则在政府采购中的应用” [Application of rules of origin in government procurement], accessed 10 April 2024, at https://web.archive.org/web/20211013100352/https:/www.ggj.gov.cn/gzdt/ggjgzdt/hqzzs/zgjghq/2021/202107/202108/t20210805_33021.htm

[38] Kathrin Hille, “Beijing Softens Procurement Policy”, *Financial Times*, accessed 10 April 2024, at https://www.ft.com/content/bf5ee78a-4698-11df-9713-00144feab49a

[39] John Honovich, “China: Foreign Video Surveillance is Security Risk”, IPVM, accessed 10 April 2024, at https://ipvm.com/reports/china-foreign-risk

overseas manufacturers accounted for an 80% share of the domestic video surveillance market.[40] During the period 2009–2013, EU-based manufacturers such as Axis Communications won significant video surveillance contracts,[41] including large deals with the Ministry of Public Security, and even deployed a CCTV network in Tiananmen Square.[42] Axis called China the "market with the greatest potential". As a result, the number of public procurement notices that require local products for a contract to be awarded has increased and fewer European products have been deployed in China (see Figures 4 and 5).

However, the law does not generally forbid the procurement of foreign facial recognition technology. We contend that European, including British, R&D in facial recognition-adjacent technologies in the coming 10–15 years has the potential to be of significance in niche areas. These are areas that are of long-term interest to the PRC's security apparatus, and in which indigenous Chinese R&D lags behind European research.

ASSESSMENT OF DEPENDENCIES ON EUROPE

Chinese weaknesses and potential European strengths in the coming 10 to 15 years

As noted above, China used to be more dependent on Europe for CCTV surveillance cameras. While it should not be the goal of Europe to become the prime facial recognition camera exporter in the world, it could nonetheless develop European technological strengths in the non-surveillance AI and quantum technologies that China will probably need to further improve its surveillance apparatus. In short, Europe could focus on key niches in the AI and quantum markets relevant to facial recognition and emphasise its key strengths, which are innovation and research as well as intellectual property (IP) and patents. In the semiconductors industry, certain European companies have also been very strong when it comes to production and commercialisation.

Facial recognition systems typically require specialised hardware components,[43] such as image sensors, advanced processors (often GPUs or dedicated AI chips) and memory to store and process facial data efficiently. Algorithms for facial detection and recognition are also essential components, but these are typically implemented in software rather than hardware.[44] Facial recognition systems rely on a combination of hardware and software components, in a co-design approach,[45] to accurately identify and authenticate individuals based on their facial features. The hardware components play a crucial role in capturing, processing and analysing facial data, while the software components are responsible for interpreting and making decisions based on that data.

The technology trends in facial recognition will most likely be to make systems more efficient, and capable of processing more data at higher quality, both faster and cheaper. To achieve this, companies will have to make advances in quantum annealing, as well as in artificial intelligence (deep learning),[46] semiconductors (Contact Image Sensors, CIS), AI chips, GPUs and lenses. The following section focuses on two of these technologies that have the greatest potential for Chinese reverse dependencies on Europe: semiconductor fabrication (CIS and AI chips) and quantum annealing technologies.

---

[40] Tuo Yannan, "New Standard for Security", *China Daily,* accessed 10 April 2024, at https://europe.chinadaily.com.cn/business/2012-03/28/content_14930394.htm

[41] Charles Rollet, "Axis Rise and Fall Inside PRC China", IPVM, accessed 10 April 2024, at https://ipvm.com/reports/axis-prc-fall

[42] Charles Rollet, "Axis CEO Touted Tiananmen Square Cameras Sale in 2010, Says Likely Make Different Decision Today", IPVM, accessed 10 April 2024, at https://ipvm.com/reports/axis-tiananmen

[43] Yassin Kortli et al., "Face Recognition Systems: A Survey", in *Sensors*, vol. 20, no. 2, p. 342, https://doi.org/10.3390/s20020342

[44] Michal Kawulok, M. Emre Celebi and Bogdan Smolka, *Advances in Face Detection and Facial Image Analysis*, Springer, 2016.

[45] Laurentiu Acasandrei and Angel Barriga, "Design Methodology for Face Detection Acceleration," IECON 2013, 39th Annual Conference of the IEEE Industrial Electronics Society, 2013, pp. 2238-2243, doi: 10.1109/IECON.2013.6699479.

[46] While hardware components provide the computational power necessary for facial recognition, algorithms for facial detection, feature extraction and matching are also important. These algorithms analyse facial data to detect key landmarks (such as eyes, nose and mouth), extract unique features (such as the shape of the face or arrangement of facial landmarks), and compare these features against a database of known individuals to make a match. While some basic algorithms may run directly on the hardware, more complex algorithms, particularly those based on deep learning techniques, are typically implemented in software running on CPUs or specialised GPU processors. Synergy between specialised hardware components and sophisticated software algorithms is essential for the accurate and efficient operation of facial recognition systems. Advances in both hardware technology and algorithm development continue to drive improvements in the performance and capabilities of these systems.

Semiconductors: fabrication of CIS and AI chips for use in facial recognition systems

CIS are the first step in the facial recognition process.[47] They capture high-quality images or video frames of faces. These sensors can vary in resolution and sensitivity to light, which affects the quality of the captured facial data. High-resolution sensors are essential for capturing detailed facial features, especially in challenging lighting conditions.

ASML, one of Europe's largest companies, has a dominant global market position in latest generation photolithographic semiconductor fabrication equipment.[48] These machines are an essential system in manufacturing CIS for facial recognition cameras and GPUs for servers and AI platforms.[49]

Processors are the "brain" of facial recognition systems, responsible for executing the complex algorithms required for facial detection, feature extraction and matching. General-purpose processors (CPUs) are often used for initial data processing, while specialised processors such as GPUs or dedicated AI chips accelerate the performance of the deep learning algorithms commonly used in facial recognition tasks.[50] These specialised processors are optimised for parallel computation,[51] making them well-suited for handling the large volumes of data involved in facial recognition. Memory also plays a crucial role in storing and accessing facial data efficiently during the recognition process. Both volatile memory (RAM) and non-volatile memory (e.g., flash memory) are used in facial recognition systems. RAM is used for the temporary storage of data and intermediate results during processing, while non-volatile memory is used for storing reference facial images or databases of known individuals for comparison during recognition.

The leading manufacturers of GPUs and AI chips use lithography machines manufactured by ASML in their semiconductor fabrication processes. ASML's photolithography machines are essential for the production of advanced semiconductor chips, including the GPUs developed by NVIDIA and AMD.[52] These machines play a crucial role in patterning the intricate circuitry on to silicon wafers during the semiconductor manufacturing process. ASML's technology is an integral part of NVIDIA's chip fabrication operations, enabling production of the high-performance GPUs used in various applications, including facial recognition systems. NVIDIA does not manufacture its own chips but relies on Taiwan's TSMC, while TSMC is reliant on ASML for the lithography machines essential for its fabrication processes.[53]

Despite ASML's critical role in production of the GPUs used for facial recognition, there are no major European companies anywhere near as prominent in the GPU market as NVIDIA and AMD. However, like the emergence of novel applications of quantum annealing in the facial recognition R&D space, there are European companies involved in the development and manufacturing of specialised processors or AI chips that could be used to accelerate deep learning algorithms for tasks such as facial recognition.[54]

Graphcore, headquartered in the United Kingdom, is a prominent company specialising in AI accelerators. Its Intelligence Processing Units (IPUs)[55] are designed to accelerate various machine learning tasks, including facial recognition. Although based in the United States,

---

[47] Luiz Carlos Paiva Gouveia and Bhaskar Choubey, "Advances on CMOS Image Sensors", in *Sensor Review*, vol. 36, no. 3, pp. 231–239, 2016, https://doi.org/10.1108/SR-11-2015-0189

[48] Reuters, "Chinese Ambassador Warns Dutch Government Against Restricting ASML Supplies", *South China Morning Post*, accessed 10 April 2024, at https://www.scmp.com/tech/policy/article/3046302/chinese-ambassador-warns-dutch-government-against-restricting-asml?module=inline&pgtype=article

[49] Charles Rollet, "Hikvision AI Products Powered By NVIDIA, Despite Sanctions", IPVM, accessed 10 April 2024, at https://ipvm.com/reports/hikvision-nvidia-use

[50] Purushothama Reddy Bandla, "The Roadmap to Crafting an Efficient Face Detection System in the Digital Age", CYIENT, accessed 10 April 2024, at https://www.cyient.com/blog/the-roadmap-to-crafting-an-efficient-face-detection-system-in-the-digital-age

[51] Marwa Chouchene et al., "Optimized Parallel Implementation of Face Detection Based on GPU Component", in *Microprocessors and Microsystems*, vol. 39, no. 6, pp. 393–404, 2015, https://doi.org/10.1016/j.micpro.2015.04.009

[52] NVIDIA Corporation, "NVIDIA, ASML, TSMC and Synopsys Set Foundation for Next-Generation Chip Manufacturing", NVIDIA Newsroom, accessed 10 April 2024, at https://nvidianews.nvidia.com/news/nvidia-asml-tsmc-and-synopsys-set-foundation-for-next-generation-chip-manufacturing

[53] Arjun Kharpal, "Two of The World's Most Critical Chip Firms Rally After Nvidia's 26% Share Price Surge", CNBC, accessed 10 April 2024, at https://www.cnbc.com/2023/05/25/tsmc-asml-two-critical-chip-firms-rally-after-nvidias-earnings.html

[54] Turing, "Using Deep Learning to Design Real-time Face Detection and Recognition Systems", accessed 10 April 2024, at https://www.turing.com/kb/using-deep-learning-to-design-face-detection-and-recognition-systems

[55] Graphcore Ltd, "IPU Programmer's Guide", accessed 10 April 2024, at https://docs.graphcore.ai/projects/ipu-programmers-guide/en/latest/ipu_introduction.html

Cerebras Systems has a significant presence in Europe. It produces the Cerebras Wafer Scale Engine (WSE),[56] a chip specifically designed to accelerate deep learning tasks. Its European presence could contribute to the European AI ecosystem. Kalray, headquartered in France, develops and sells many-core processors for use in data centres and embedded systems.[57] While not strictly focused on AI chips, its processors can be used for AI workloads, including facial recognition tasks. SiPearl, also based in France, is focused on developing high-performance, low-power microprocessors for various applications, including AI.[58] While it might not currently be producing dedicated AI chips, future developments could contribute to the European AI hardware landscape. While these companies may not manufacture GPUs in the traditional sense, they are developing specialised processors or AI accelerators that could be used to accelerate deep learning algorithms, including those used in facial recognition tasks.

Quantum annealing

One way to optimise facial recognition capabilities is by building special conventional or quantum hardware. This process is called quantum annealing. Patent data demonstrates a European share of around 10% at the intersection of quantum and facial recognition technologies, compared to a 40% share for PRC companies (see Figure 6), but numbers can be misleading. Experts estimate that 90% of Chinese patents are of low quality and only 10% have market value.[59] Keeping this in mind, European patents might be leading China in the amount of market value patents contribute at the intersection of quantum and facial recognition technologies.

Quantum annealing is a type of quantum computing algorithm that can be used to resolve optimisation problems. In the context of facial recognition, quantum annealing could be used to find the optimal match between a new face image and a database of known face images.[60] One way that quantum annealing could help facial recognition is through its ability to search a large database of face images much more quickly than classical computers. Quantum annealing can explore a much larger number of possible solutions in parallel. Quantum annealing also has the ability to find more accurate matches between face images because it can take account of more subtle features.

QUALITY OF EUROPEAN TECHNOLOGICAL STRENGTH

Technological strength does not provide political leverage. Such leverage is dependent on several factors, not least how easily China could replicate European strengths in semiconductors and (quantum) annealing, but also consideration of spillover damage. On the spillover effects of quantum technologies, if Europe were to ever achieve a situation where China relied on it for quantum annealing technologies, withholding those technologies would be politically acceptable in Europe, as further transfer of technologies at the intersection of quantum and image recognition could be used to infringe on human rights.

Semiconductors

One of the risks resulting from Europe's strength in semiconductor manufacturing equipment is technology leakage due to IP theft.[61] In 2023, for instance, ASML reported a significant security incident involving IP misappropriation by a former employee based in China.[62] However, the company indicated that the incident was not believed to have materially affected its business.

Cases of IP theft could nonetheless have implications for the development of facial recognition technology in China. For example, stolen IP could support the acceleration of indigenous technology development. If the IP includes advanced lithography techniques, it could accelerate China's ability to develop and produce advanced semiconductors domestically. This would include chips that are essential for sophisticated

---

[56] Cerebras, "Cerebras Systems Unveils World's Fastest AI Chip with Whopping 4 trillion Transistors", accessed 10 April 2024, at https://www.cerebras.net/press-release/cerebras-announces-third-generation-wafer-scale-engine

[57] Kalray, "Kalray MPPA DPU Processors for Intelligent Data Processing", accessed 10 April 2024, at https://www.kalrayinc.com/products/dpu-processors

[58] SiPearl Website, accessed 10 April 2024, at https://sipearl.com/en

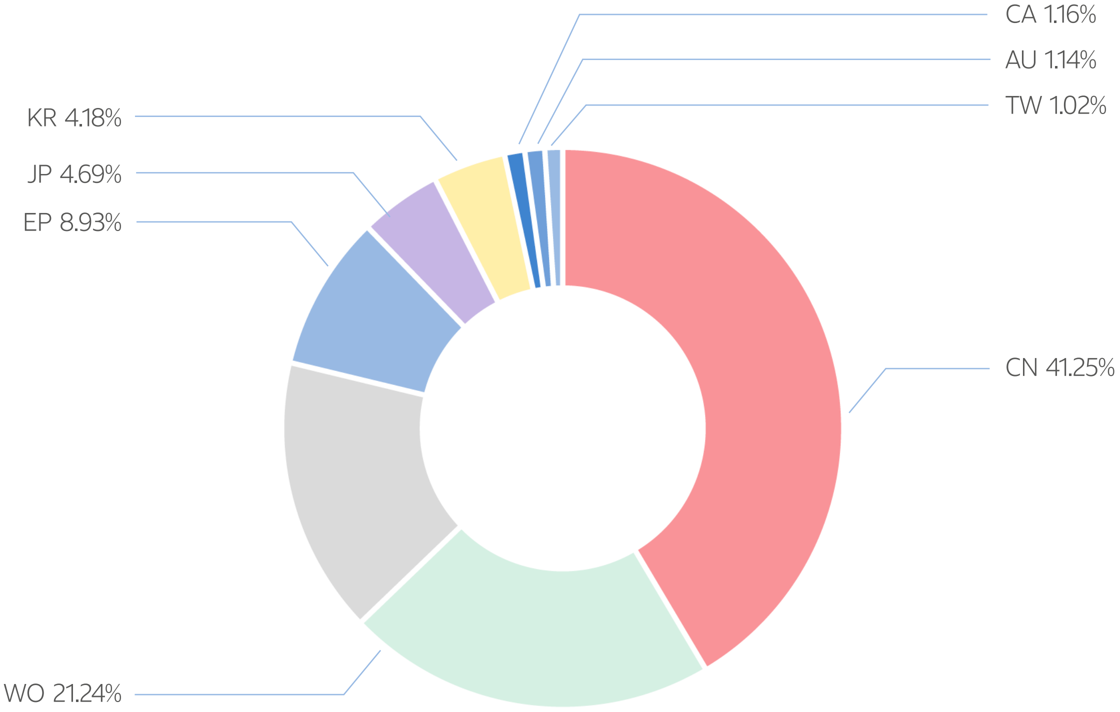
[59] Alex He, "What do China's High Patent Numbers Really Mean?", Centre for International Governance Innovation, accessed 10 April 2024, at https://www.cigionline.org/articles/what-do-chinas-high-patent-numbers-really-mean/

[60] Jeremy Liu et al., "Adiabatic Quantum Computation Applied to Deep Learning Networks", in *Entropy*, vol. 20, no 5, p. 380, May 2018, https://doi.org/10.3390/e20050380

[61] Anna Gross and Tim Bradshaw, "ASML Chief Warns of IP Theft Risks Amid Chip Sanctions", *Financial Times*, accessed 10 April 2024, at https://www.ft.com/content/dfef74a7-bcc0-441b-95a5-380e212d9854

[62] Anna Gross, "ASML Reveals Intellectual Property Theft by China Employee", *Financial Times*, accessed 10 April 2024, at https://www.ft.com/content/b686c84a-8d5f-46dc-af67-90cbf635170a

FIGURE 6: Global share of facial recognition patents that mention quantum computing, by country



Note: WO are World Intellectual Property Organisation registered patents; EO are European Patent Office registered patents.
Source: European Patent Office/DGAP

facial recognition systems, enhancing their capabilities and deployment.

ASML's experience is not an isolated case of IP infringement in China. In its 2021 annual report,[63] ASML mentioned monitoring a situation where another business in China was potentially infringing on its intellectual property rights, and it was ready to take legal action if necessary.[64]

In response to these concerns, the US had previously implemented measures requiring special licences for companies exporting chips to China using US tools,[65] regardless of the chips' manufacturing location. Influenced by strategic considerations and international alliances, particularly with the US, and in the context of EU policy, the Dutch government has restricted the sale of critical machines to China.[66] This move has significantly impacted China's ability to develop indigenous advanced semiconductor manufacturing capabilities to support the development of advanced GPUs for facial recognition servers.[67]

IP theft alone, however, is unlikely to play a decisive role in China's efforts to become more independent. It will be difficult for China to replicate an entire ecosystem that is focused on creating machines for chip making, including ASML's suppliers. Therefore, IP theft

---

[63] ASML, *Annual Report 2021*, Veldhoven, The Netherlands, 2021, https://www.asml.com/en/investors/annual-report

[64] Simon Sharwood, "World's Top Chipmaking Equipment Maker Claims Chinese Rival May Infringe IP", *The Register*, accessed 10 April 2024, at https://www.theregister.com/2022/02/11/asml_chinese_rival_ip_abuse/

[65] Annabelle Liang and Natalie Sherman, "China Curbs Exports of Key Computer Chip Materials", BBC, accessed 10 April 2024, at https://www.bbc.com/news/business-66093114

[66] Mattew Townsend et al., "The Netherlands, European Union and China all Make their Next Moves in the Game to Control Semiconductor Supply Chains", Allen & Overy, London, 2023.

[67] 3DiVi, "Benefits of Using Face Recognition with GPU Acceleration", accessed 10 April 2024, at https://3divi.ai/news/tpost/ylg1i21151-benefits-of-using-face-recognition-with

could only partly support China's effort to develop a domestic chip industry and is insufficient to replicate European strengths in this area. A bigger issue could be the forced transfer of technology innovations enabled by weak export controls. As Chris Miller put it succinctly in his book Chip War, insufficient export controls have enabled technology transfer from many US chip making companies and harmed US competitiveness.[68]

Quantum annealing

Economic competitiveness in the production and commercialisation of quantum annealing seems to be emerging from countries outside Europe. For instance, D-Wave Systems (Canada),[69] which provides hardware and software for quantum annealing, has computers that are especially good at tackling optimisation problems and have already been demonstrated by academics to outperform standard deep neural network architecture in classifying images under certain conditions.[70] D-Wave Systems is also advanced in the sense that it is already listed on the New York Stock Exchange and is therefore expected to demonstrate commercialisation and generate revenue for investors. European quantum annealing projects, such as AvaQus, funded by Horizon 2020, are still at the experimental stage of building a 5-qubit quantum computer. AvaQus aims to do so by September 2024, when its funding runs out. The research project is a good example of European research institutes and start-ups joining forces to consolidate their respective expertise in quantum annealing hardware in Europe.[71] Its members include the University of Glasgow (UK), Karlsruher Institut für Technologie (Germany) and Delft Circuits (Netherlands). As mentioned above, Europe has a qualitative lead when it comes to patents in this area.

Increasing efficiency is not all about quantum annealing. Specialised non-quantum hardware is well suited to resolving similar hard problems to those at which quantum annealers excel. Several European institutions, such as the TU Dortmund[72] and Fraunhofer,[73] are especially good at increasing the efficiency of machine learning algorithms by building specialised conventional hardware. Researchers at TU Dortmund do this, for instance, using highly customised chip hardware architecture, which is especially good at resolving certain optimisation problems. Fraunhofer for its part has developed the IAIS Evo Annealer, which is non-quantum hardware that can resolve similar problems to quantum annealing. The IAIS Evo Annealer, for instance, has been used to optimise the process of extracting information from satellite images and removing clouds from this type of image.

It is difficult to gauge how difficult it will be for China to replicate or circumvent this technology strength as it is still in development. It will also depend on the extent of collaborations between European and Chinese researchers in this area. Very little is currently known about the extent of this collaboration. The chokepoint in the short to medium term is probably not severe, as China already has advanced capabilities in facial recognition even without quantum annealing. It can also probably maintain control over its population without quantum annealing. However, if it is shown that quantum annealing technologies increase efficiency, China will want and need to acquire this technology rather than fall back internationally in the sale of facial recognition systems. Quantum annealing is very likely to have impacts beyond facial recognition.[74] It speeds up the resolution of difficult problems, such as assigning shifts to medical personnel, or any similar problem that has an extensive number of possible solutions and variables. Since quantum annealing is likely to increase levels of efficiency beyond facial recognition, banning the use of it in facial recognition products could have negative spillover effects on other technological fields.

---

[68] Chris Miller, *Chip War: The Fight for the World's Most Critical Technology*, Scribner, New York, 2022.

[69] Business Wire, "D-Wave, a Global Leader in Quantum Computing Systems, Software and Services Announces Plans to Bring Commercial Quantum Computing to Public Markets Via Transaction with DPCM Capital, Inc.", accessed 10 April 2024, at https://www.businesswire.com/news/home/20220208005520/en/D-Wave-a-Global-Leader-in-Quantum-Computing-Systems-Software-and-Services-Announces-Plans-to-Bring-Commercial-Quantum-Computing-to-Public-Markets-Via-Transaction-with-DPCM-Capital-Inc

[70] Nga Nguyen and Garrett Kenyon, "Image Classification Using Quantum Inference on the D-Wave 2X", IEEE Proceedings of the 3rd International Conference on Rebooting Computing (ICRC), November 2018, https://doi.org/10.1109/icrc.2018.8638596

[71] Avaqus Website, accessed 10 April 2024, at https://www.avaqus.eu/about

[72] Sascha Mücke, Nico Piatkowski and Katharina Morik, "Learning Bit by Bit: Extracting the Essence of Machine Learning", Workshop Proceedings, vol. 2454, pp. 144–155, September 2019, http://ceur-ws.org/Vol-2454/paper_51.pdf

[73] Fraunhofer Website, "Fit for the Future: Quantum Readiness for Companies", accessed 10 April 2024, at https://www.iais.fraunhofer.de/en/business-areas/cognitive-business-optimization/quantum-readiness.html

[74] Kazuki Ikeda et al., "Application of Quantum Annealing to Nurse Scheduling Problem", Sci Rep no. 9, 12837, May 2019, https://doi.org/10.1038/s41598-019-49172-

What is more, as the quantum annealing technology involves hardware, this provides a certain degree of leverage compared to software-only products, which are more easily reproduced. As it currently stands, the quantum technology supply chain is still very much located in European and allied countries.[75] China can only supply mass-fabricated electronics and optics, but all of these components could also be produced in allied countries, as they are not as advanced. For instance, a project like AvaQus would need cryogenic cables,[76] or transmission lines that keep superconductivity at freezing temperatures; attenuators,[77] which reduce noise, and are needed for quantum computers to operate; and infrared filters to prevent quantum devices from overheating.

DISCUSSING EUROPE'S LEVEL OF AMBITION

European ambitions regarding China in this area, as defined in the introductory chapter, could range from threat prevention to the ability to deny or the ability to act. Curtailment is not a feasible option.

Threat prevention

In the context of facial recognition technologies, the main avenue for the EU to exert threat prevention would be through the use of export controls on dual-use technologies, either through an EU framework,[78] or in line with the Wassenaar Arrangement. On the EU front, the most pertinent regulation would be 2021/821, which updates EU Dual Use Regulation 428/2009.[79] Notably, EU member states are now required to refuse an export if the member state assesses that the risk is high that the equipment will be used for serious human rights violations.

In order to limit the transfer of technologies, Europe would need good knowledge of which capabilities individual countries have in facial recognition adjacent technologies. Only in this way will it be able to prevent leaks of technology that could be used to further infringe on human rights in China.

Ability to deny

The ability to deny rests on an idea that there is a co-dependence between China and Europe. The quantum supply chain is an interesting subject to examine here as, surprisingly, Chinese and European suppliers are largely disentangled. This might change however if Europe takes on leadership in quantum annealing and if China started to rely on European expertise in this niche area. China appears to be focusing its efforts on general quantum computing,[80] where the rewards are greater but implementation is more challenging, rather than on quantum annealing, which is closer to commercialisation as it focuses on resolving narrow problems such as those prevalent in image recognition. This particular focus by China on general quantum computing might incentivise it to rely on foreign technologies and push for a level of co-dependence and entanglement.

Ability to act

It is unlikely that Europe will achieve such a dominant position in chipmaking and annealing technologies that it could shape standards and policies in China. It is also improbable that Europe would ever develop such a dominant market share. European leadership is more likely, however, in third markets, which could in turn lead China to have to conform with European technologies if it wants to compete in those markets. European actors have not yet started to develop these markets, however, due to the novelty of the technologies.

Curtailment

Another level of ambition for Europe could be to threaten to cut China off from the technologies needed for facial recognition capabilities. One of Europe's few cards for exerting leverage over China has already

---

[75] Valentin Weber, "The New Quantum Technology Race", in *Internationale Politik Quarterly,* Berlin, 2024, https://ip-quarterly.com/en/new-quantum-technology-race

[76] Everything RF, "What Are Cryogenic Cables?", accessed 10 April 2024, at https://www.everythingrf.com/community/what-are-cryogenic-cables

[77] Jeff Shepard, "Why Use Attenuators in Quantum Computers?", Analog IC Tips, accessed 10 April 2024, at https://www.analogictips.com/why-use-attenuators-in-quantum-computers-faq/

[78] European Parliament and Council of the European Union. "Regulation (EU) 2021/821 of the European Parliament and of the Council of 20 May 2021 Setting Up a Union Regime for the Control of Exports, Brokering, Technical Assistance, Transit and Transfer of Dual-Use Items." *Official Journal of the European Union*, 2021, https://eur-lex.europa.eu/eli/reg/2021/821

[79] Council of the European Union. "Council Regulation (EC) No 428/2009 of 5 May 2009 Setting Up a Community Regime for the Control of Exports, Transfer, Brokering and Transit of Dual-Use Items.", *Official Journal of the European Union*, L134/1, 2009, https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:134:0001:0269:en:PDF

[80] John Costello, "Chinese Efforts in Quantum Information Science: Drivers, Milestones, and Strategic Implications", Testimony for the US-China Economic and Security Review Commission, accessed 10 April 2024, at https://www.uscc.gov/sites/default/files/John%20Costello_Written%20Testimony_Final2.pdf

been played – not by the EU, but by the US. Washington has imposed export limits on equipment,[81] including ASML products. Beyond Europe's strength in chips equipment, however, there are currently few cards to play. Any further ambition to curtail Chinese technology advances in facial recognition is not feasible. As noted above, there are almost no current dependencies on Europe among China's facial recognition equipment makers. A dependence on quantum annealing technologies, which would have a severe economic impact and could limit or even freeze Chinese economic development more broadly, is also unlikely.

POLICY RECOMMENDATIONS

Depending on the concrete level of ambition, European policymakers have a number of policy options to consider. Due to the major human rights implications that arise from the diffusion of facial recognition adjacent technologies to China, the authors argue for a highly restrictive export policy. While it would be useful to have some leverage over a dependent China and to exert pressure on it when needed, the ethical concerns are just too great. Europe needs to situate its policies in line with the goal of autonomy rather than entanglement. If it were to export technology that enabled more efficient facial recognition in China, this would only strengthen the regime security of the Chinese Communist Party, which would in turn weaken European security.

Threat prevention

As mentioned above, Europe has dual-use regulations in place that could limit the export of facial recognition adjacent technologies. At present, the EU's restrictions on the export of facial recognition systems to China does not extend to controls on the export of the AI chips or GPUs used to power those systems. The EU appears to be moving in that direction with its initiatives on economic security.[82] However, as with other key technologies where export is restricted due to their potential military usefulness to adversaries, enforcement is lacking when it comes to surveillance-related dual-use goods.[83] In line with this observation, our first policy recommendation is to tighten export controls and double down on enforcement. In order to facilitate this, Europe should establish risk trackers that identify European capabilities in facial recognition adjacent technologies, and in a second step track attempts to transfer such technologies to China. This policy bundle could also involve inbound and outbound investment screening to preclude "innovation export". To give an example of why outbound investment screening is necessary, despite heavy US restrictions on investment in Chinese firms,[84] a Congressional investigation has revealed that investments by US venture capital funds in Chinese chip vendors, such as SMIC, significantly contributed to the advancement of China's domestic semiconductor manufacturing capability and thereby directly facilitated the development of facial recognition systems that targeted Uyghurs in Xinjiang.[85]

It should also be acknowledged that sometimes companies might engage in voluntary technology transfer to gain access to the Chinese market, which ultimately leads to considerable damage to the competitiveness of western companies. Chinese pressure for technology transfer has long been a prevalent tendency in the semiconductor industry.[86] It should be inhibited by European states in facial recognition adjacent technologies.

Ability to deny

If Europe wanted to create a level of co-dependence with China, it would have to follow a two-pronged strategy. On the one hand, it could continue to buy

---

[81] Toby Sterling, "Dutch Lawmakers Question New US Export Restrictions on ASML Chip Machine", Reuters, accessed 10 April 2024, at https://www.reuters.com/technology/dutch-lawmakers-question-new-us-export-restrictions-asml-chip-machine-2023-10-24/

[82] European Commission, "Commission Proposes New Initiatives to Strengthen Economic Security", Brussels, 2024, https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ip_24_363/IP_24_363_EN.pdf

[83] Amnesty International, "New EU Dual Use Regulation Agreement 'a Missed Opportunity' to Stop Exports of Surveillance Tools to Repressive Regimes", 2021, https://www.amnesty.org/en/latest/news/2021/03/new-eu-dual-use-regulation-agreement-a-missed-opportunity-to-stop-exports-of-surveillance-tools-to-repressive-regimes/

[84] The White House, "Executive Order on Addressing United States Investments in Certain National Security Technologies and Products in Countries of Concern", Washington, DC, 2023, https://www.whitehouse.gov/briefing-room/presidential-actions/2023/08/09/executive-order-on-addressing-united-states-investments-in-certain-national-security-technologies-and-products-in-countries-of-concern/

[85] The Select Committee on the Strategic Competition between the United States and the Chinese Communist Party, "The CCP's Investors: How American Venture Capital Fuels the PRC Military and Human Rights Abuses", https://selectcommitteeontheccp.house.gov/sites/evo-subsites/selectcommitteeontheccp.house.gov/files/evo-media-document/2024-02-08%20FINAL%20VC%20Report.pdf

[86] Chris Miller op. cit.

off-the-shelf and non-advanced quantum technologies from China (e.g. in electronics and optics), but would have to ensure that these remain substitutable with equipment from manufacturers based in like-minded countries. This would mean hand-picked dependence on China, but only for less advanced technologies and with no major costs when a switch needs to be made.

On the flipside, European policymakers should proactively build up niche capabilities that will allow Europe to have limited leverage over China. Europe needs to hone its capabilities in quantum annealing and chip manufacturing. It might be too late for Europe to try to build China's reliance on Europe regarding facial recognition adjacent capabilities, since China is already attempting to wean itself off foreign equipment. However, Chinese entities across regions have in certain cases wanted access to the most advanced technologies, and eagerly bought these despite Chinese laws that bar foreign equipment makers. It is unlikely that European companies will be able to build up a market share in facial recognition capabilities in China, due to the stigma of selling such equipment there, given the human rights violations that facial recognition cameras have enabled. So it is unlikely that Chinese actors will be able to import much European quantum annealing equipment legally, even if Europe were producing cutting edge research on it. Europe is likely to remain competitive in chip manufacturing, but exports are already restricted and shipments to China therefore unlikely to grow. All in all, it might be the case that Europe will export only a very limited amount of these technologies to China. These dual-use exports would be highly scrutinised due to their sensitive nature, and only allowed to be used for specific optimisation problems in chemistry sciences, such as drug discovery, where human rights implications are less likely to arise. Despite their limited amounts, however, these may be valuable for China and create a moderate level of co-dependence.

At the same time, European governments will have to encourage the growth of these niche areas, which are the most promising in Europe's competition with China in this technology field. In this vein, Europe should deepen innovation cooperation with countries such as Canada, which has been leading the development of quantum annealing technologies. Inter-European cooperation should also be deepened. AVaQus is one example where Horizon 2020 funding enabled a European consortium of start-ups and research institutions to work on quantum annealing hardware. The digital Single Market more broadly needs to be strengthened by creating common data pools and fostering harmonisation of regulations and standards.

All this is not to say that Europe ought to become a world leader in facial recognition camera technology, but it should become a cutting-edge research hub in technologies that can be used not only in facial recognition, but also in many other industrial fields that require process optimisation. In this way, Europe can focus on becoming a leader in fields that are not prone to human rights abuses while at the same time have leverage in the dual-use technologies that are used in China to perpetuate its surveillance apparatus.

Ability to act

All the above policy recommendations will be useless if Europe does not manage to commercialise its products in these frontier fields. The focus of European efforts should therefore not only be the domestic market, which is today the primary focus of European policymakers, but the international market. This international promotion can be fostered by organising trade fairs in markets of interest and bringing European products in contact with customers in Europe's neighbourhood and further abroad. Current use cases for quantum annealing are mostly developed with domestic optimisation problems in mind and largely omit challenges to be resolved on other continents. Designing and marketing quantum annealing products with a broader audience in mind might help with the targeting of third markets. As mentioned in other chapters in this volume, we believe that instead of building R&D hubs in China, European companies and universities should focus on building up niche capabilities in third markets and aim to gain a larger market share there. In this way, European actors could indirectly shape how the technology develops in China through third markets.

The EU should also further encourage public-private partnerships in the AI chip space.[87] National governments should collaborate with private sector companies and increase public high-risk R&D investment in European and like-minded companies to maintain a leading edge in these strategic technologies. In a similar vein, European states should reinvigorate like-minded digital industrial policy coordination to prevent the duplication of efforts and resource spending. These partnerships can drive innovation in the chipsets that are also the foundation for advanced facial recognition software. In parallel, the EU should focus long-term resources on educational and workforce development

---

[87] Martin Greenacre, "EU Launches Chips Partnership with €1.7B for Pilot Lines", *Science Business*, accessed 10 April 2024, at https://sciencebusiness.net/news/semiconductors/eu-launches-chips-partnership-eu17b-pilot-lines

across the member states by investing in education and skill development specific to AI, semiconductor manufacturing and related technologies, to tackle the skills shortage.[88] This will provide a sustainable and skilled workforce to support this strategic industry.

Europe should engage diplomatically to navigate the complex global supply chain dynamics that are defining de-risking and resilience in the early 21st century.[89] This should include dialogue with both major players, the US and China, and key strategic partners, such as Taiwan and Japan, to manage export controls while maintaining good trade relationships. Alternative AI chip foundries should be developed in the most advanced industrial bases in the EU (e.g. in Germany),[90] and in Japan. Reducing dependency on a single supplier or country by diversifying the supply chain could mitigate the risks associated with geopolitical tensions or trade disputes.[91]

SCORECARD 2 FACIAL RECOGNITION TECHNOLOGY

	Threat prevention	Ability to deny	Ability to act	Curtailment
Feasibility of level of ambition	High	Medium	Low	Not feasible
Core policy recommendations	• More stringent enforcement of dual-use export controls • Establish a risk tracker for AI chip equipment and quantum annealing technologies	• Deepen innovation cooperation with like-minded countries such as Canada • Increase public funding for promising niche capabilities such as quantum annealing	• Reinvigorate like-minded digital industrial policy coordination • Support commercialisation of quantum technologies in markets beyond the EU	• None

AUTHORS

Greg Walton is Senior Research Associate for Cyber Security, Smart Cities, & Data Analytics at the SecDev Group, based in the United Kingdom. Contact: g.walton@secdev.com

Valentin Weber is a Senior Research Fellow at the German Council on Foreign Relations and a China Foresight Associate at LSE IDEAS. He is based in Germany. Contact: weber@dgap.org

---

[88] Semi, "Semi Europe and European Commission Representatives Develop Key Actions to Tackle Chip Industry Skills Shortage", accessed 10 April 2024, at https://www.semi.org/en/news-media-press-releases/semi-press-releases/semi-europe-and-european-commission-representatives-develop-key-actions-to-tackle-chip-industry-skills-shortage

[89] Groupe D'Études Géopolitiques, "De-risking and Tech Supply Chains: Europe in the World of National Security", 2023, https://geopolitique.eu/en/2023/07/05/de-risking-and-tech-supply-chains-europe-in-the-world-of-national-security/

[90] Mathieu Duchâtel, "TSMC in Germany: The Successes and Limits of the EU Chips Act", Euractiv, accessed 10 April 2024, at https://www.euractiv.com/section/industrial-strategy/opinion/tsmc-in-germany-the-successes-and-limits-of-the-eu-chips-act/

[91] Conor Savoy and Sundar Ramanujam, "Diversifying Supply Chains: The Role of Development Assistance and Other Official Finance", Center for Strategic and International Studies, 2022, https://www.csis.org/analysis/diversifying-supply-chains-role-development-assistance-and-other-official-finance

Regaining and Maintaining the Advantage in Biotechnologies by Protecting Against Genomic Data Flows to China

Una Bērziņa-Čerenkova, Elena Ferrari Karina Palkova and Julia Voo

ABSTRACT

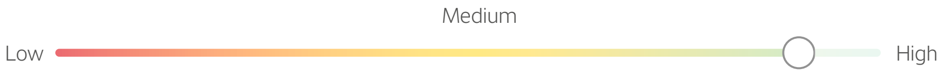
European genomic data is indispensable to China's biotech and med-tech research and exports. International collaboration on scientific advancement has been a key contributor to innovation and collective progress. In recent years, the European Union and China have conducted joint research partnerships bilaterally and with other countries. These have included the sharing of sensitive genomic data. However, growing geopolitical competition and concerns about the application of discoveries have had a chilling effect in a broad range of technological areas, including genomic data-sharing. Research partnerships are already subject to access and ethics controls but increasing geopolitical tensions have prompted calls for a review of the transfer of sensitive data to China due to concerns about its use. Data can provide insights that contribute to societal benefits but transfers have competition and national security implications. This chapter outlines China's stated ambitions in genomics, analyses China's dependencies vis-à-vis Europe, and assesses Europe's strengths in genomic data. The example of Latvia MGI Tech provides a case study of EU-China genomic data collaboration that could be exploited by China for competitive advantage at significant risk to European industry, and potentially the citizens of EU member states.

SCORECARD 1 TECHNOLOGY FIELD: GENOMIC DATA

Source of European technology strength	Research and innovation	Intellectual property and patents	Production and commercialisation
	Medium	Not feasible	Not feasible

Type of European technology strength	Technological excellence	Commercialisation advantage	Conditioning of market access	Regulatory, political and normative factors	Sustainability	Research partnerships with third countries
	X		X	X		X

Degree of European leverage



INTRODUCTION

Europe is a global scientific leader. Nearly a quarter of the more than 250,000 biotech patents granted in Europe, the United States and the People's Republic of China (PRC) between 2012 and 2021 came from Europe.[1] In genomics, Europe's strength is research and innovation excellence, which also crucially translates into intellectual property (IP). It is well known that diversity in genomic data plays a key role.[2] Without diversity, researchers might miss key genetic factors that play a role in disease susceptibility and drug response among different

---

[1] Matthias Evers, Antonia Stein-Asmussen, Nicole Szlezak and Alexandra Zemp, "Europe's Bio Revolution: Biological innovations for complex problems", McKinsey & Company, accessed 10 January 2023, at https://www.mckinsey.com/industries/life-sciences/our-insights/europes-bio-revolution-biological-innovations-for-complex-problems#

[2] Genomic data is a generic term for the entire genetic sequence, DNA. The rise of genomics and related technologies offers considerable opportunities when it comes to a variety of medical treatments from precision medicine to disease prediction, the development of safe medications (pharmacogenomics) and genetic engineering.

population groups. This is true not only for rare diseases, but also for almost any kind of disease related to a genetic modification. The highly diverse European population makes genomic data from Europe particularly valuable. Hence, datasets on citizens of the European Union (EU) member states are strategic for any genomic research, including for widening China-based research to include a broader range of people. The Covid-19 pandemic provides a striking demonstration of the value of research collaboration across borders, where the sharing of SARS-CoV-2 genome sequences to piece together how the virus behaves resulted in research that benefited all.[3]

The Chinese government has long regarded biotech as a national priority. There have been impressive levels of investment and numbers of initial public offerings since 2015.[4] The 13th Five-Year Plan (FYP, 2016–2020) prioritised the wide application of genomics and other biotechnologies.[5] As part of this commitment, the FYP underscored the need to invest in high-throughput genomic sequencers; that is, machines that enable rapid reading and analysis of genomic sequences found in DNA, which help to explain what each component of DNA does and helps scientists to understand humans and the environment. The Chinese government recognises the key role of Chinese industry in making advances in genomics and has committed to support its companies, seeking to expand their footprint globally in all areas identified as strategic emerging industries.[6]

The Outline of the 14th FYP (2021–2025) increases the profile of biotech still further, describing it as an element of an integrated bioeconomy.[7] In 2021, the National Development and Reform Commission (NDRC) produced a dedicated Bioeconomy Development Plan with the approval of the State Council, which was passed on to local governments for "conscientious implementation".[8] The plan stresses the need to "accelerate the development of high-throughput gene sequencing technology, promote the innovation of next-generation sequencing technology marked by single-molecule sequencing, continuously improve gene sequencing efficiency and reduce sequencing costs".[9] In addition, the document calls for an increase in China's overseas presence to: "Promote innovative drugs, high-end medical devices, genetic testing ... to go global, and encourage biological companies to accelerate their integration into the international market by establishing overseas R&D centres, production bases, sales networks and service systems". Based on the growing presence of Chinese biotech companies abroad, including in Europe, it is clear that this plan is being implemented.

This prioritisation of gene technology by the FYPs is reflected in Chinese government action. For example, the PRC General Office of the National Health Commission has called for more professionals to "master cutting-edge technologies such as biomedical information, genetic testing".[10] The Peking Union Medical College Hospital of the Chinese Academy of Medical Sciences has taken the lead in designing a "Large-scale sample registration, management and decision-making data support platform and prediction and decision-making

---

[3] Nature, "Protect precious scientific collaboration from geopolitics", editorial, accessed 18 March 2024, at https://www.nature.com/articles/d41586-021-01386-0.

[4] Bloomberg Businessweek, "China 220$ Billion Biotech Initiative is Struggling to Take off", accessed 18 March 2024, at https://www.bloomberg.com/news/articles/2023-05-15/china-biotech-stumbles-despite-220-billion-investment.

[5] NDRC, "The 13th Five-Year Plan for Economic and Social Development of The People's Republic of China (2016–2020), Box 8 – Development of Strategic Emerging Industries", accessed 18 March 2024, at https://en.ndrc.gov.cn/policies/202105/P020210527785800103339.pdf.

[6] NDRC, "The 13th Five-Year Plan for Economic and Social Development of The People's Republic of China (2016–2020), Section 3", accessed 18 March 2024, at https://en.ndrc.gov.cn/policies/202105/P020210527785800103339.pdf.

[7] Central People's Government of China, "中华人民共和国国民经济和社会发展第十四个五年规划和2035年远景目标纲要" [The 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and the Outline of Long-Range Goals for 2035], accessed 18 March 2024, at https://www.gov.cn/xinwen/2021-03/13/content_5592681.htm.

[8] NDRC, "国家发展改革委关于印发《"十四五"生物经济发展规划》的通知" [Notice of the National Development and Reform Commission on Issuing the "14th Five-Year Plan for Bioeconomy Development Plan"], accessed 19 April 2024, at https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202205/t20220510_1324436.html.

[9] NDRC, ""十四五"生物经济发展规划" [The 14th Five-Year Plan for Bioeconomy Development], accessed 18 March 2024, at https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202205/P020220510324220702505.pdf.

[10] National Health Commission of China, "国家卫生健康委办公厅关于印发出生缺陷防治能力提升计划（2023-2027年）的通知" [Notice from the General Office of the National Health Commission on Issuing the Birth Defects Prevention and Treatment Ability Improvement Plan (2023-2027)], accessed 18 March 2024, at http://www.nhc.gov.cn/fys/s3589/202308/10245921f51d40ea954e96f6199e3e0a.shtml.

data support platform for rare diseases".[11] This has been powered by the establishment of the national big data centres outlined in the 14th FYP. It should be noted that the push for genomic data collection and centralisation falls into a wider trend outlined in the planning documents: that of the strategic utility of collecting more data overall while also protecting the data collected for reasons of national sovereignty.

Developing technology for genomic data analysis is not only crucial for healthcare, but also contributes to China's industrial policy goals, as an element of a "strong manufacturing nation"[12] with a leading export capability in medical technology. To achieve its ambition, China cannot simply rely on the domestically available gene pool and corresponding datasets. Pharmaceuticals developed based on the genomes found in China may not be as effective on populations elsewhere, as genetic variations in drug metabolising enzymes and transporters influence the efficacy of numerous drugs,[13] disadvantaging China's export capabilities.

Alongside all the benefits of transnational cooperation, genomic information can also be used for malicious purposes. It is concern over misuse that prompted the US National Counterintelligence and Security Center to publish a report stating that China "has collected large healthcare data sets from the US and nations around the globe, through both legal and illegal means, for purposes only it can control".[14] Ultimately, the intention behind the collection of such genetic data is obscure.

In recognition of the centrality of data to scientific advancement, commercial benefit and national security, China has increased its access to foreign genomics while at the same time tightening control over access to its own data. According to the 2020 Biosecurity Law, "overseas organisations, individuals, and institutions established or actually controlled by them are not allowed to collect or preserve China's human genetic resources within the territory of China, nor are they allowed to provide China's human genetic resources abroad".[15] China's National Intelligence Law allows intelligence agencies to force businesses and individuals to hand over data and assets on request.[16] This limits the control that non-Chinese researchers could have over information shared with Chinese research partners. It is likely that any scientific advancement derived from access to a larger, more diverse set of data would be to the benefit of whoever has access to this data.

Against this backdrop, some warn of a "chill" in research collaboration with China. The United Kingdom, and the EU and its member states have traditionally followed liberal economic policies that limit government intervention to a minimum. For example, the screening of investments or control of mergers and acquisitions are limited to national security and anti-monopoly concerns. In addition to the difficult balance between openness for the sake of improving global health and protecting European core interests, the EU and the UK should also consider the leverage that stems from access to European genomic data. It is this delicate balance that is the subject of this chapter.

ASSESSMENT OF DEPENDENCIES

Chinese scientists have been emphasising the need to onshore genomics data storage and analysis facilities for the past decade. Its limited access to global genomics data resources is putting China at a disadvantage, as the bulk of the data is stored by the US, the EU and Japan. Researchers at the Chinese Academy of Sciences at the Beijing Institute of Genomics noted in 2016 that: "There are three existing international bioinformatics centres that contain almost all the histological big data produced for scientific research purposes, i.e., the National

---

[11] National Health Commission of China, "对十四届全国人大一次会议第1102号建议的答复" [Reply to Recommendation No. 1102 of the First Session of the 14th National People's Congress], accessed 18 March 2024, at http://www.nhc.gov.cn/wjw/jiany/202307/df157de0454143569ea0678bb8fa5388.shtml.

[12] Xinhua, "第三篇　加快发展现代产业体系　巩固壮大实体经济根基，第八章　深入实施制造强国战略" [Part 3: Accelerate the development of the modern industrial system and consolidate and strengthen the foundation of the real economy, Chapter 8: In-depth implementation of the strategy of manufacturing a strong country], accessed 18 March 2024, at http://www.xinhuanet.com/fortune/2021-03/13/c_1127205564_4.htm.

[13] US National Counterintelligence and Security Center, "China's Collection of Genomic and Other Healthcare Data from America: Risks to Privacy and US Economic and National Security", accessed 18 March 2024, at https://www.dni.gov/files/NCSC/documents/SafeguardingOurFuture/NCSC_China_Genomics_Fact_Sheet_2021revision20210203.pdf?itid=lk_inline_enhanced-template.

[14] US National Counterintelligence and Security Center, op. cit.

[15] FAO, "Biosecurity Law of the People's Republic of China", accessed 18 March 2024, at https://www.fao.org/faolex/results/details/en/c/LEX-FAOC198696/#:~:text=This%20Law%20is%20enacted%20for,boosting%20the%20construction%20of%20a.

[16] NPC, "中华人民共和国国家情报法" [National Intelligence Law of the People's Republic of China], accessed 23 March 2024, at http://www.npc.gov.cn/zgrdw/npc/xinwen/2017-06/27/content_2024529.htm.

Center for Biotechnology Information (NCBI) in the United States, the European Bioinformatics Institute (EMBL-EBI), and the DNA Data Bank of Japan (DDBJ). These three centres focus on storing, managing, and sharing genome sequence information produced by scientists, and have formed the International Nucleotide Sequence Database Collaboration (INSDC). To date, these three centres have established a global monopoly on genomics data resources and are in the vanguard".[17] While Chinese scientists are able to access the INSDC, the process is slow. The researchers therefore favour China developing its own centralised repository: "genomic big data is an important national strategic biological resource, and the histological data produced by scientists is not only for publication, but also more important as a strategic resource to be protected and reused".[18] Another paper directly connects the construction of this autonomous and controllable genomics big data research platform with geopolitics and national security: "China's demand for the development of independent core technology is increasingly urgent, and complex international relations have also pushed China to elevate information security and independent innovation of key technologies to the height of national strategy. The construction of a medical and healthcare big data research platform based on autonomous and controllable technology is in line with the needs of industry, people's livelihood and the national security strategy".[19]

China has streamlined and adapted its approach to genomic data management over the years. In 2019, the role of China's Vice Minister for Science and Technology focused purely on the health dimension of genomic data.[20] In May 2023, the Ministry of Science and Technology's restrictions on foreign collection, storage or access of Chinese genomic data not only put European researchers at a disadvantage, but demonstrated the geopolitical dimension of the subject. Research collaborations continue to be permitted, but are now subject to more rigorous examination, including mandates for compulsory security assessments in specific circumstances.[21]

A similar trend for data decoupling in sensitive areas, including genomic data, is visible in the US.[22] As the debate on the risks of open scientific cooperation with Chinese entities progresses in the West, China anticipates that its access to genomic data repositories could be limited. However, China is walking a fine line. The PRC risks setting a precedent by limiting foreign access to Chinese data that only hurts itself. Currently, most genomic data is stored in the EU, the UK, the US and Japan, and any sudden restriction triggered by the West could leave China unprepared. This hints at the indispensability of such data stored in Europe and the leverage access to such data carries. Should the relationship between China and the West deteriorate to the point where Chinese companies are denied access to European and US genomic databases, not only would Chinese pharmaceutical companies take an economic hit, but the ability of clinicians to conduct prenatal, neonatal and diagnostic testing would be severely impeded.

As genetic mutations differ across populations, access to different pools is crucial for a clinician to determine whether a variant found in a patient is pathogenic. If a mutation is found in a patient that is not typical for their geographic pool, clinicians routinely search other pools to establish whether such mutations are compatible with healthy populations elsewhere in the world.

---

[17] China InfoCom, "赵文明，张思思，唐碧霞，陈婷婷，郝丽丽，桑健，李茹姣，肖景发，章张，"面向国际的生命组学大数据管理体系建设"", [Zhao Wenming, Zhang Sisi, Tang Bixia, Chen Tingting, Hao Lili, Sang Jian, Li Rujiao, Xiao Jingfa, Zhang Zhang, "Construction of an internationally oriented big data management system for life-omics"], accessed 18 March 2024, at doi: 10.11959/j.issn.2096-0271.2016065.

[18] China InfoCom, op. cit.

[19] Kuang Yalan et al., "医疗机构自主可控大数据科研平台建设方案" [Construction Plan for Independent and Controllable Big Data Research Platform for Medical Institutions], in *Journal of Medical Informatics* no. 3,2022, accessed 23 March 2024, at https://www.sinomed.ac.cn/article.do?ui=2022239977.

[20] "Human genetic resources, as an important strategic resource, are of great significance to our understanding of the nature of life, exploration of the principles and mechanisms of disease occurrence and development, research and development of disease prevention and intervention strategies, and promotion of population health", see MOST, "《中华人民共和国人类遗传资源管理条例》吹风会" [Briefing on "Regulations of the People's Republic of China on the Management of Human Genetic Resources"], accessed 19 April 2024, at https://www.most.gov.cn/xwzx/twzb/fbh19061201/twbbwzsl/201906/t20190614_147075.html.

[21] Jessie Yeung, "China's Sitting on a Goldmine of Genetic Data: and It Doesn't Want to Share", accessed 18 March 2024, at https://edition.cnn.com/2023/08/11/china/china-human-genetic-resources-regulations-intl-hnk-dst/index.html.

[22] Executive Office of the US President, "Preventing Access to Americans' Bulk Sensitive Personal Data and United States Government-Related Data by Countries of Concerns", Executive Order 14117 of 28 February 2024, accessed 18 March 2024, at https://www.federalregister.gov/documents/2024/03/01/2024-04573/preventing-access-to-americans-bulk-sensitive-personal-data-and-united-states-government-related; see also Yuka Hayashi and John D. McKinnon, "US Looks to Restrict China's Access to Cloud Computing to Protect Advanced Technology", accessed 8 March 2024, at https://www.wsj.com/articles/u-s-looks-to-restrict-chinas-access-to-cloud-computing-to-protect-advanced-technology-f771613.

This illustrates that the benefits of access to genomic databases are not unidirectional: a European database that includes vast data from China is superior to a database that does not.[23] There is currently a visible underrepresentation of East Asian genetic samples in free access databases.[24]

Onshoring a global gene database is in line with China's state-driven industrial policy goals. A strong biotechnology industry is an integral part of strengthening China's export capacity in high-value added sectors such as pharmaceuticals and medical technology. China's course is likely to exacerbate non-reciprocal market openness and the uneven playing field for EU companies. If China accumulates a broad global database while limiting access to its domestic data, it will be able to outcompete other databases that are currently market leaders, including EU champions such as the German company Centogene, which offers affordable genetic tests but charges significant database access fees.[25]

Ultimately, international pharmaceutical companies and genetic testing labs from around the world might end up with no viable alternative to China's service, which would give China a monopoly on access to this data and the capacity to implement its own preferred controls on who can access it. This could result in suboptimal sharing arrangements of Chinese data with European partners in terms of speed and scope, but also cost.

In short, genomic data decoupling would be suboptimal for all actors while mutual China-EU dependency would be the best outcome. At worst, however, the PRC would gain a monopoly over genomic data due to an uneven playing field that it could use as a tool of economic coercion against Europe. However, China will not be able to achieve such dominance without steady access to foreign genomic data. Europe is a key market for Chinese pharmaceuticals and European genomic data is key to China's bio-tech ambitions, as is securing access to genetic data from other regions of the world. European strength lies in the accessibility of its data and its data diversity, which is then developed through innovation and research in cooperation with like-minded global partners.

With the indispensability of European genomic data in mind, a realistic level of ambition for Europe in the coming 10–15 years would be to maintain Chinese dependency on Europe. Given the current level of data mobility and the unlevel playing field in China's favour, Europe should strengthen controls over the data originated in Europe by loophole proofing existing data transfer legislation, ensuring its implementation and introducing implementable penalties that provide sufficient deterrence. The case study of Latvia MGI Tech, a subsidiary of the leading Chinese genomics company, BGI Group, illustrates these dynamics.

CASE STUDY: LATVIA MGI TECH

BGI Group, a Shenzhen-based Chinese genomics company that provides "academic institutions, pharmaceutical companies, healthcare providers and other organisations with integrated genomic sequencing and proteomic services" is one of the world's leading genomics companies.[26] Ye Yin, the Chief Executive of BGI group, is a high-profile scientist and the 2016 recipient of the honorary title 'Excellent Communist Party Member of Yantian District, Shenzhen'.[27] In public statements, he links the work of BGI to President Xi Jinping's concept of a "community of common destiny of mankind" in the sphere of biological advancements.[28]

There have been widespread concerns about BGI Group's protection of and access to data. A 2021 Reuters investigation found that: "DNA data collected from [BGI-produced] prenatal tests on women outside China have also been stored in China's government-funded

---

[23] Ieva Mičule, clinical geneticist and doctoral researcher, Children's Clinical University Hospital, Interview with the author, 8 January 2024.

[24] For example, the "gnomAD" genome aggregation database, which releases data from large-scale sequencing projects for the benefit of the biomedical community, demonstrates a huge disparity, with 622,057 European samples versus only 22,448 East Asian samples available for search – a set critically low in both absolute and comparable numbers. Meanwhile, the information on worldwide unique gnomAD users in the past 12 months shows that access from Asia (107,123) is close to that from Europe (137,351), illustrating significant demand from Asia, see gnomAD, "What's in gnomAD?", accessed 19 April 2024, at https://gnomad.broadinstitute.org/stats.

[25] Centogene, "The Centogene Biodatabank", accessed 18 March 2024, at https://www.centogene.com/about-us/biodatabank.

[26] BGI, "About BGI", accessed 18 March 2024, at https://www.bgi.com/global/company/about-bgi.

[27] Baidu Encyclopaedia, "尹烨" [Yin Ye], accessed 23 March 2024, at https://baike.baidu.com/item/%E5%B0%B9%E7%83%A8/8331588.

[28] Yin Ye, "所有人类竟然是一家人? " [Are all humans one family?], accessed 23 March 2024, at https://www.youtube.com/watch?app=desktop&v=TqMznSlu80s&feature=youtu.be, 4:28.

gene database".[29] A company spokesperson is on record as stating that: "BGI is interested in large national projects, such as the creation of a [Chinese] national biobank".[30] In March 2023, the US government placed BGI Group on its entity list over concerns about the security of US citizens' genetic data under BGI's control.[31] BGI has a self-reported business presence in more than 100 countries worldwide. In 2016, BGI created a subsidiary, MGI, which has a core focus on "R&D, production and sales of DNA sequencing instruments, reagents, and related products".[32] In 2019, Latvia announced the launch of "Latvia MGI Tech" (Latvia MGI). Despite the above-mentioned US concerns, four years and €20 million in investment later,[33] Latvia now houses the second largest BGI-affiliated facility outside China. (The largest is in the US.) Its activities are extensive. According to the Head of Latvia MGI, Andis Šlaitas, the facility carries out commercial functions, such as production of genome sequencing equipment and reagents,[34] and the development of new equipment, as well as non-commercial functions that include research activities in relation to "a privately financed research institute, the China national gene bank, as well as others".[35] Latvia MGI has been involved in a number of joint scientific projects with researchers in Latvia and the EU, including the EU's key research and innovation funding instrument, Horizon. Most of these projects involve human samples, for example in metagenome analysis.[36] In 2022, Latvia MGI founded a training centre with 20 study programmes designed to familiarise researchers and partners from Europe and Africa with MGI technologies.[37]

Latvia MGI's ties with its blacklisted parent BGI Group are not transparent. During a visit to Latvia in 2023, in a public relations exercise, Ye Yin donated €2.8 million to a Latvian children's hospital on behalf of Latvia MGI.[38] It appears that BGI Group has strong links with the activities of Latvia MGI and there is no definitive way to ensure that due process is followed in isolating the data of the daughter company from the parent company. Nor is there due process to ensure the data is not accessed by Chinese government or Chinese Communist Party (CCP) structures. Genomic data falling into the hands of the CCP is a real concern:

Entities in the United States healthcare market can access bulk sensitive personal data, including personal health data and human genomic data, through partnerships and agreements with US healthcare providers and research institutions. Even if such data is anonymised, pseudonymised, or de-identified, advances in technology, combined with access by countries of concern to large data sets, increasingly enable countries of concern that access this data to re-identify or de-anonymize data, which may reveal exploitable health information.[39]

---

29 Kirsty Needham and Clare Baldwin, "China's Gene Giant Harvests Data from Millions of Women", accessed 8 March 2024, at https://www.reuters.com/investigates/special-report/health-china-bgi-dna/.

30 Latvijas Avīze, "FOTO: Latvija kļūst par gēnu izpētes centru" [PHOTO: Latvia is becoming a gene research centre], accessed 23 March 2024, at https://www.la.lv/latvija-klust-par-genu-izpetes-centru.

31 Jamie Smyth and Demetri Sevastopulo, "Chinese genetics company targets US despite political tensions", accessed 23 March 2024, at https://www.ft.com/content/cc905012-f264-4e87-8171-8e7e243c5d51.

32 MGI, "About", accessed 23 March 2024, at https://en.mgi-tech.com/about/.

33 Dienas Bizness, "MGI Latvia uzsāk sekvencēšanas iekārtu ražošanu eksportam" [MGI Latvia starts production of sequencing equipment for export], accessed 23 March 2024, at https://www.db.lv/zinas/mgi-latvia-uzsak-sekvencesanas-iekartu-razosanu-eksportam-511835.

34 Reagent production is a substance used in genome sequencing.

35 LIAA, "Labs of Latvia, Intervija ar MGI Tech Latvija vadītāju Andi Šlaitas" [Labs of Latvia, Interview with MGI Tech Latvija manager Andis Šlaitas], accessed 23 March 2024, at https://www.youtube.com/watch?v=ARYWBLY19Po.

36 Dr Andis Šlaitas, Interview with the author, 20 October 2023.

37 MGI, "MGI Opens the Doors of Customer Experience Center in Europe", accessed 18 March 2024, at https://en.mgi-tech.com/news/347/.

38 The press release on the donation envisages that the funds will be used to facilitate implementation of several crucial projects aimed at enhancing the health of Latvian children. This allocation of resources will enable the provision of essential medical treatments and the advancement of methods for timely and accurate diagnosis. Furthermore, the donation seeks to foster progress with hospital infrastructure development, specifically the development of next-generation genome sequencing technologies for disease management. The donation will also contribute to the advancement of wider research projects. See Latvijas Sabiedriskie Mediji, "Bērnu slimnīcas fonds no biotehnoloģiju uzņēmuma «MGI Latvia» saņēmis 2,8 miljonu eiro ziedojumu" [The Children's Hospital Foundation received a donation of € 2.8 million from the biotechnology company MGI Latvia], accessed 19 April 2024, at https://www.lsm.lv/raksts/zinas/latvija/19.04.2023-bernu-slimnicas-fonds-no-biotehnologiju-uznemuma-mgi-latvia-sanemis-28-miljonu-eiro-ziedojumu.a505480/.

39 Executive Office of the US President, op. cit.

In fact, genetic data differs from traditional health information since it remains primarily unaltered over a lifetime and often has implications for the privacy of an individual's family members and relatives. Many recent re-identification studies have shown that it is becoming increasingly challenging to ensure that genetic data, even without accompanying personal data such as weight, height and medical history, is not readily identifiable, and that de-identification of that data alone is not sufficient to ensure that genetic data will not be re-identified in the future as new datasets and re-identification techniques become available.

Latvia MGI presents itself as an internationalised and open business entity.[40] However, given the continuing links between BGI Group and Latvia MGI's activities, and the potential link to China's genomic ambitions, the collection, analysis and storage of genomic data on European citizens by Latvia MGI raises concerns. The Latvian State Security Service has been monitoring Latvia MGI's activities since its founding, noting that "the acquisition of and research on genetic data, both domestically and internationally, are essential for China to strengthen its position as a global leader in biotechnology".[41] In addition, the diversification that European samples brings provides important research data points. Apart from the industrial policy lens, the Security Service has also outlined the national security aspect: "Chinese private sector companies are largely under the control of the Chinese government and are required to cooperate with Chinese authorities, including special services, when necessary. The activities of Chinese companies in Latvia are therefore associated with intelligence risks".[42]

In fact, access to the Latvian data is both sensitive and critical for the Chinese firm. European data adds diversity and thereby enhances the potential scope for a broad field of research conducted by China: genome and personalised medicine. The monitoring of data flows by the Scientific Council at the Latvian Biomedical Research and Study Centre for compliance with the law and strict data protection are therefore critical.[43] The General Data Protection Regulation (GDPR) gives the supervisory authorities the right to impose administrative fines, depending on the nature, gravity, duration and intention of the infringement, and to impose a temporary or indefinite limitation, including a ban on processing; withdraw a certification and "order the suspension of data flows to a recipient in a third country or to an international organisation".[44] While monitoring the flow of data might mitigate the risk of leakage, however, it does not prevent misuse once the data has been acquired. MGI Latvia argues that it uses the data exclusively to demonstrate the capability of the instruments it produces: "We do not collect the actual sequencing data – only anonymised sample codes. All other information (specimen's country, weight, height, medical history) stays with the partner who collects the primary data and runs the research. We at MGI do not develop bioinformatic platforms".[45]

Existing Europe-China cooperation mechanisms rely largely on trust, but this trust is eroding. For example, Chinese researchers' access to the genetic data of half a million British citizens has raised concerns about potential misuse, such as linking the data with other datasets.[46] This carries enormous risks. In 2013, participants in the Personal Genome Project were re-identified by linking participants' data records to publicly available voter registration lists using demographic attributes.[47] Linking de-identified genetic data to genealogy databases such as Ancestry.com, which are growing in popularity and contain identifiable information such as surnames, is another source of concern. More recently, it has been shown that images of an individual's face found in publicly available datasets can be used for re-identification purposes. Although such activity is currently rare,[48] it is

---

[40] MGI, "MGI Technology's X profile", accessed 18 March 2024, at https://twitter.com/MGI_Technology.

[41] Latvijas Sabiedriskie Mediji, "Bērnu slimnīcas fondam ziedojušais Ķīnas uzņēmums «MGI» nonācis Drošības dienesta redzeslokā" [The Chinese company MGI, which donated to the Children's Hospital Foundation, has come under the attention of the Security Service], accessed 23 March 2024, at https://www.lsm.lv/raksts/zinas/latvija/07.05.2023-bernu-slimnicas-fondam-ziedojusais-kinas-uznemums-mgi-nonacis-drosibas-dienesta-redzesloka.a507650/.

[42] Latvijas Sabiedriskie Mediji, op. cit.

[43] Latvijas Sabiedriskie Mediji, op. cit.

[44] EU, "General Data Protection Regulation", accessed 18 March 2024, at https://eur-lex.europa.eu/eli/reg/2016/679/oj.

[45] Dr Andis Šlaitas, Interview with the author, 20 October 2023.

[46] Shanti Das and Vincent Ni, "Fears over China's Access to Genetic Data of UK Citizens", accessed 8 March 2024, at https://www.theguardian.com/science/2022/aug/20/fears-over-chinas-access-to-genetic-data-of-uk-citizens.

[47] Zhiyu Wan, et al.," Sociotechnical safeguards for genomic data privacy", in *Nature Review Genetics*, vol. 23, pp. 429–445, 2022, doi: 10.1038/s41576-022-00455-y.

[48] Rajagopal Venkatesaramani et al., "Re-identification of Individuals in Genomic Datasets Using Public Face Images", in *Science Advances*, vol. 7, no. 47, 2021, doi: 10.1126/sciadv.abg32.

likely that rapid developments in the fields of 3D photography and artificial intelligence (e.g., highly effective approaches for inferring eye colour from images) might make such activity easy and cheap in the future.

There is scepticism in the case of Latvia MGI Tech too. Current regulatory provisions do not guarantee protections for EU genomics data that has already been collected. This could lead to the misuse of genomic data that would give Chinese genomics and pharmaceutical companies a global competitive edge over European counterparts, as EU entities have restricted access to Chinese genomic data and China is developing a more diverse genomic dataset.

The China-Latvia collaboration is not unique in genomics. BGI subsidiaries have been cooperating with the Karolinska Institute in Sweden and have other partners in Slovakia and France. However, Latvia MGI is the largest production facility outside China, covering all of Europe as well as Africa. While Latvia's genomic partnership with China is continuing, some partnerships elsewhere in Europe have ended due to ethical concerns. In 2021, the Polish Academy of Sciences withdrew from scientific cooperation with BGI on an EU-funded project to build a genomic map of Poland, citing lack of compliance with the ethical principles of genetic testing in their gene sequencing technology and the transfer of data to "far-Eastern laboratories".[49] No information on the incidents that triggered these concerns is publicly available.

EUROPEAN CONTROLS ON GENOMIC DATA FLOWS

The General Data Protection Regulation is the primary regulatory source within the EU that impacts EU-China genomic collaboration. It establishes stringent standards on safeguarding personal data, including genetic data. The primary objective of the GDPR is to ensure the unrestricted movement of data within the EU while safeguarding the right to personal data protection both within and beyond its borders. It applies when the data of individual citizens or data collected within the EU is being processed.

The GDPR specifies the lawful grounds for processing data, establishes restrictions on the processing of sensitive categories of data, such as health and genetic data, sets the conditions for obtaining consent (article 7), defines the rights of individuals regarding their data and provides mechanisms for data subjects to exercise their rights. Article 9 addresses the processing of special categories of personal data, such as genetic data, and imposes specific conditions and safeguards. When participating in research collaborations between the EU and China involving the processing of genetic data, strict compliance with GDPR requirements is essential. This entails obtaining explicit consent from the individuals participating in the research, implementing robust security measures, acquiring ethical approvals and limiting the data collection to what is strictly necessary for the purposes of the research.

When it comes to genomic data flows, such as those in the MGI case, it is vital to prioritise GDPR compliance on genetic data. This means obtaining explicit consent (related to one or more concrete research topics), implementing transparent and robust security measures, obtaining ethical approvals and collecting only essential data, as well as strengthening data protection protocols and conducting regular risk assessments of the scientific research. In addition, from the member state perspective, in cases such as that of MGI, it is crucial to establish a clear and safe legal basis for derogations, such as for scientific research purposes. This right of a member state is provided by article 9(2)(j)). In general, the choice of measures is left to member states, leading to significant differences. The synchronisation of rules on genomic data protection in scientific research between member states is crucial.

Cross-border collaborations must consider the legal mechanisms for transferring personal data outside the EU. The GDPR imposes restrictions on transferring personal data to countries that lack an adequate level of data protection. China is considered a third country under the GDPR, where appropriate safeguards such as Standard Contractual Clauses or Binding Corporate Rules (BCRs) may be needed to ensure lawful data transfers.[50] It is important to note that the GDPR allows some flexibility in the application of its provisions, and exceptions or derogations might be applicable in certain circumstances, such as to pursue Freedom of Expression and Information for academic purposes, which can be applied to genomic data. However, it is vital to interpret and implement these exceptions with caution, to ensure compliance with the overarching principles of data protection. While recognising the significance of research and innovation collaboration between the EU

---

[49] Joanna Plucinska, "Exclusive Polish Gene Project Moves to Drop Chinese Tech on Data Concerns", accessed 18 March 2024, at https://www.reuters.com/article/health-china-bgi-poland-idCNL4N2QN2M9.

[50] There are special cases in pharmacy and genomics where data is more protected and additional regulation is added at the national level.

and China, and the value it can bring to both sides, it is imperative to navigate the legal requirements and strictly adhere to data protection regulations, including GDPR article 9, when engaging in genomic collaborations or any research involving personal data.

The case of Latvia MGI Tech demonstrates a loophole in the current frameworks for safeguarding EU-China collaboration in genomics where GDPR does not effectively deter the potential misuse of data. The provisions of the GDPR underplay the risks of processing and sharing genetic data. To close this loophole, a more robust GDPR compliance strategy is required that encompasses explicit consent procedures, stringent security measures, ethical approvals, limits on data collection and enhanced data protection protocols. Another significant legal gap concerns the use of scientific research exceptions as an alternative to explicit consent for processing sensitive data under the GDPR, particularly in scientific research such as computational genetics (article 9(2)(j)). While this provision seeks to address challenges with consent in large datasets or with deceased or minor subjects, it imposes conditions that require compliance with national laws and proportionality. Despite offering flexibility, it restricts certain data subject rights, highlighting the tension between scientific progress and data protection. Clear guidance and harmonisation across jurisdictions are needed to ensure research advances while maintaining data protection standards. If this problem remains unresolved, the future of the EU's biotech advantage, which rests on genomic data, could be at risk.

DISCUSSING EUROPE'S LEVEL OF AMBITION

In the light of the four levels of policy ambition outlined in the introductory chapter to this volume, in the area of genomic data excellence, the EU should aim for either threat prevention or the ability to deny. In the context of genomic data, threat prevention means introducing mechanisms to ensure that Chinese entities are accessing data for purposes that have been agreed and are in line with GDPR. From a technical point of view, many approaches are currently used to limit the risk of privacy breaches for genetic data, such as access control, data aggregation and obfuscation, and cryptographic- and blockchain-based solutions. However, some of these still have significant costs, in both decreased data utility and added resource burdens, that limit their applicability. Therefore, legal and technical protections should be blended into a holistic ecosystem of genomic data, where privacy protection tools depend on the environment, the costs, the stakeholders involved and their underlying assumptions.

The ability to deny in the context of genomic data underscores the value of European genomic datasets, due to their diversity, the traceability of populations and their resource value for commercial use. China will probably need to maintain access to European genomic datasets for the foreseeable future if it aims to become a global leader in biotechnology that can be sold on the European market. In the context of the existence of the European genomic dataset, the ability to cut-off access, and to extract a heavy cost to China's research institutes and industry, in the event of misuse should be the ambition. European data decoupling from the PRC is not desirable, however, although potential disentanglement in case of a major crisis remains a risk. To mitigate this risk, the EU should seek ways to maintain China's reliance on EU genomic data, increasing the cost of potential infringements of European core interests. However, the EU should also remain mindful of the strategic and security value the PRC attaches to genomic data and be aware that circumstances may arise under which defence and security logic in the PRC might overshadow the potential economic loss sudden disentanglement would bring.

The other two levels of ambition – ability to act and curtailment – are not feasible in the field of genomic datasets. The ability to act would mean limiting China's access to other similar datasets elsewhere in the world so that Europe's became more valuable, which is not practically achievable. Curtailment would require stalling China's development through denial of access to European genomic data. This is not feasible either because China has extensive research partnerships in other parts of the world.

POLICY RECOMMENDATIONS

To achieve "threat prevention" or the "ability to deny", the EU should consider the following policy instruments:

Threat Prevention

To prevent China from using EU genomic data sets in ways that have not been agreed to by European business and citizens, the EU needs enforcement to strengthen the regulatory controls on preventing illicit use.

To address regulatory loopholes in the use of EU genomic data by China, the EU should design more stringent controls, synchronise national legal regulations and legal responsibilities, and ensure effective cross-border implementation and enforcement in the field of scientific research. Member states need the resources and capabilities to monitor and enforce compliance in relation to safety of the genomic data – for instance, regular audits – and to synchronise and strengthen the role of the research ethics committees. In addition, fostering international collaboration, promoting public awareness, and maintaining adaptive and synchronised regulatory frameworks are vital components of ensuring responsible, ethical and legal use of genomic data. In instances where the partnership involves the acquisition of specific technologies from the donor, careful consideration must be given to data storage and security aspects. Consequently, if research activities involve the use of genome sequencing technologies obtained from a particular organisation, adherence to the "open door" principle and compliance with the GDPR would allow for greater flexibility in research operations.

It is crucial to prioritise the safeguarding of personal or medical data. At the very least, national legislation must incorporate provisions that establish the legal framework for processing personal data for research purposes. Moreover, these laws should mandate local, impartial authorisation and oversight procedures before data can be used for research purposes.

Europe should consider maintaining the competitiveness of European pharmaceuticals and medical companies so they can compete with China from R&D through to the market in the long term. This means that approval timelines for medicines should be streamlined and marketing exclusivity periods should be reconsidered.[51] Moreover, research blind spots should be strengthened and compliance mechanisms to follow up on tech collaborations introduced. The role of EU member states' ethical research committees should also be enhanced, and a US Chips Act or a joined-up thinking approach to biotech considered.[52] Policy documents on digital infrastructure will need to be developed. In the context of the AI Act, Europe must invest in robust and secure digital infrastructure.

Ability to deny

China will need to maintain access to European datasets to make future medical advancements that are suitable for the European market. However, access to such data must be attuned to consent, privacy risks, trust in the data recipient and reciprocity of data sharing, as well as intended use. Europe should strike a balance in its partnership with China in this field that protects the long-term competitiveness of European industry. To grow Europe's leadership in biotech, it should introduce policies that promote the development of biotech clusters. In cases of genomic data flows, a tightening of inbound investment screening would be advisable.

Europe's venture capital investment landscape is smaller and less mature than in the US and China. It lags the US when it comes to translating promising academic research into start-ups. As most R&D occurs in the private sector, particularly when it comes to largely dual-use technologies such as biotechnology, the biotechnology industry should be targeted to identify promising research and translate it into to start-ups. Europe should increase its public high risk/high gain R&D investment or provide tax incentives for investments that are too risky for private sector actors to make. These should be made available only to EU and like-minded actors to develop and maintain technological leadership in genomic data niches.

To extract the value from genomic data sets, be they European, Chinese or other, the EU needs to address fragmentation and lack of scale in data analysis in European tech companies. A related aspect of advances in biotechnology is parallel establishment of the broader computer and technology ecosystems at the EU level. This would mean maintaining a commitment to and incentivising European contributions.

---

[51] New plans to reduce the market exclusivity period would make the problem worse. To improve access to medicines across the bloc, the European Commission has proposed shaving two years off the amount of time medicines have the market to themselves. A shorter exclusivity period means earlier competition from unbranded competitors, leading to lower drug prices and lower profit.

[52] Pieter Haeck, "EU Legislators Strike Deal on 43B Euro Chips Plan", accessed 18 March 2024, at https://www.politico.eu/article/eu-legislator-strike-deal-e43-billion-plan-boost-chips-production/.

SCORECARD 2 TECHNOLOGY FIELD: GENOMIC DATA

	Threat prevention	Ability to deny	Ability to act	Curtailment
Feasibility of level of ambition	● Medium	● Medium	○ Not feasible	○ Not feasible
Core policy recommendations	• Enforcement: prevent illicit use; introduce compliance mechanisms to follow up on tech collaborations; enhance the role of EU member states' ethical research committees • Close loopholes: stringent controls and synchronised national legal regulations • Take US Chips Act approach (joined-up thinking) to biotech	• Access must be attuned to consent, privacy risks, trust in the data recipient and reciprocity of data sharing, as well as intended use • Introduce policies that would promote the development of biotech clusters • Tighten inbound investment screening to cover cases applicable to genomic data • Increase public high risk/high gain R&D investment or introduce tax incentives for such investment available only to EU and like-minded actors	• None	• None

AUTHORS

Elena Ferrari is a full Professor of Cybersecurity and Privacy at the University of Insubria, Italy. She is a fellow of the Association for Computing Machinery (ACM) and the Institute of Electrical and Electronics Engineering (IEEE) for her contributions to data security and privacy.
Contact: elena.ferrari@uninsubria.it
Una Aleksandra Bērziņa-Čerenkova is Head of the China Studies Centre and director of the PhD Programme in Social Sciences at Riga Stradins University, Head of the Asia Programme at the Latvian Institute of International Affairs and an affiliated researcher at King's College London and MERICS.
Contact: una.berzina-cerenkova@rsu.lv
Karina Palkova is Dean of the Faculty of Social Sciences at Riga Stradins University, a practicing lawyer in Medical law, a member of European Union Artificial Intelligence Alliance, the European Association of Health Law and the World Association for Medical Law. Contact: karina.palkova@rsu.lv
Julia Voo leads the Cyber Power and Future Conflict Programme at the International Institute for Strategic Studies. Prior to joining the IISS, Julia was the Director for Cybersecurity and Technology Policy at HP Inc. She held a concurrent position as a Cyber Fellow at Harvard's Belfer Center for Science and International Affairs in 2020–23. Contact: julia.voo@iiss.org

European Tech Standardisation Power: Durable Indispensability of Another Kind?

Martin Catarata, and Tim Rühlig

ABSTRACT

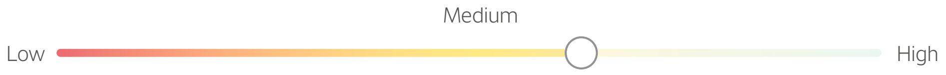
Domestic and international standardisation are increasingly being used as tools in the geopolitical contestation over technology. While standards cannot create unidirectional dependencies, due to their voluntary and cooperation-driven nature, they are very effective at establishing strong co-dependencies. Standards produce network effects, which make deviation from certain technologies or technical standards costly, secure broad market acceptance from a variety of downstream and upstream market players, and generate revenue through the incorporation of standard-essential patents. China has long pursued a strategic approach to domestic and international standard-setting, which has significantly increased its influence in international organisations over time. The European Union, on the other hand, has left standard-setting mostly to private sector companies. Taking 5G energy-saving technologies, automotive chips and facial recognition as case studies, this chapter takes a closer look at the potential for the EU to create or uphold co-dependencies through an active standardisation strategy. It shows that European ambitions should adapt to the concrete technological ecosystem.

SCORECARD 1 TECHNOLOGY FIELD: TECHNICAL STANDARDISATION

Source of European technology strength	Research and innovation	Intellectual property and patents	Production and commercialisation
	● Medium	● Medium	Not feasible

Type of European technology strength	Technological excellence	Commercialisation advantage	Conditioning of market access	Regulatory, political and normative factors	Sustainability	Research partnerships with third countries
	X	X	X	X		X

Degree of European leverage



INTRODUCTION

In recent years, technical standards have become part of the geopolitical contestation over high technology. At first glance, this is a peculiar development. Technical standards are highly technical specifications and their political implications are not eye-catching. The purpose of standards is not to outcompete or outmanoeuvre a state competitor, but to make technology compatible with other technologies. The basic levels of safety and interoperability that result from standards create and demarcate markets, and have positive impacts on economic growth and innovation.[1] Nor can technical standards be imposed on others. Technical

---

[1] Menon Economics et al., "The Influence of Standards on the Nordic Economies", Swedish Standards Institute, accessed 29 May 2023, at https://www.sis.se/globalassets/nyheterochpress/rapport-nordic-market-study---influenceof-standards-final.pdf; Knut Blind et al., "The Influence of Standards and Patents on Long-term Economic Growth," in *Journal of Technology Transfer*, vol 47, no. 5, pp. 979–999, 2022, https://doi.org/10.1007/s10961-021-09864-3; Gregory Tassey, "The Impacts of Technical Standards on Global Trade and Economic Efficiency," East-West Center, accessed 29 May 2023, at https://www.eastwestcenter.org/sites/default/files/filemanager/pubs/pdfs/5-2Tassey.pdf; and Knut Blind, "The Impact of Standardization and Standards on innovation", *Nesta Working paper* no. 13/15. London, Nesta, November 2013.

standards are voluntary by definition;[2] and most standard-developing organisations (SDOs) make inclusivity, transparency and consensus their defining principles.[3] In sharp contrast to patents, a good standard is available and accepted globally.[4] Where technical standards comprise patented technologies, patent holders are obliged to license their patents under fair, reasonable and non-discriminatory (FRAND) terms. Courts around the globe enforce FRAND terms, ensuring that denial of access to standardised technology is impossible. In contrast to other means of global technology competition, such as export controls or punitive tariffs, technical standards are not intended to exclude competitors. In short, technical standards do not lend themselves to exploiting technological indispensability by means of denial of access.

It is true that technical standards can create barriers to market access if they deviate from international norms.[5] Standards can also further cement monopolisation, opt for and lock-in premature technology choices.[6] By their very nature, however, standards are designed to be inclusive. They are also mostly developed by private actors rather than states.[7] All this stands in sharp contrast to the logic of geopolitical competition, which is all about controlling access to technological bottlenecks, and the threat of or actual denial of access to crucial technologies for the purpose of furthering the relative influence of states.[8]

All this might be an idealised characterisation of standard-setting but standardised technology is not a classical hard chokepoint resulting from technological indispensability. Why then discuss it in the context of a report that considers how Europe can remain technologically indispensable to China?[9]

While technical standards cannot create unidirectional dependencies among technology powerhouses, they are very effective at establishing strong co-dependencies. Three factors are decisive in understanding this effect of technical standards:

- **Network effects:** Technical standards often serve as a basis for a variety of use cases for other technologies. For example, telecommunications are all about the connectivity of networked devices such as phones. Accordingly, companies from around the globe have agreed to a new unitary global mobile standard, known as 5G. Technologies that deviate from widely accepted technical standards often remain niche products. Establishing an alternative standard that requires the adaptation of previously existing technology can be costly. Such network effects[10] show that using technical standards with international scope is cost-efficient, and therefore that technical standards are a basis for technology development that often goes unquestioned.

- **Broad market acceptance:** Since technical standards are voluntary, they are only effective if the market applies them. An agreed standard that is not used is irrelevant. The required broad acceptance – often not only across suppliers, but also across countries – is typically generated by standards that comprise contributions from divergent actors from across the globe. Participants in standardisation processes submit competing proposals, and without a certain

---

[2] WTO, "TBT Agreement: Annex 1," accessed 30 May 2023, at https://www.wto.org/english/res_e/publications_e/ai17_e/tbt_ann1_jur.pdf.

[3] See, e.g., CEN-CENELEC, "European standards", accessed 30 May 2023, at https://www.cencenelec.eu/europeanstandardization/european-standards/.

[4] Laure Deron, "Chinese Standards and the New Industrial Markets", Research Paper no. 98, 2020, Institut Recherche Stratégique de l'École Militaire, accessed 30 May 2023, at https://www.irsem.fr/en/institut/news/research-paper-no-98-2020.html.

[5] Digby Gascoine, "Standards as Barriers to Trade and how Technical Assistance can Help." Sida, accessed 29 May 2023, at https://cdn.sida.se/publications/files/sida3407en-standards-as-barriers-to-trade.pdf.

[6] Brian Arthur, "Competing Technologies, Increasing Returns, and Lock-in by Historical Events" in Economic Journal , vol. 99, no. 394, pp. 116–131, March 1989, https://doi.org/10.2307/2234208; Jorge Padilla et al., "Economic Impact of Technology Standards," Compass Lexecon, accessed 29 May 2023, at https://www.compasslexecon.com/wp-content/uploads/2018/04/CL_Economic_Impact_of_Technology_Standards_Report_FINAL.pdf.

[7] Global industry consortia developing technical standards for information and communication technologies, for example, predominantly consist of vendors and other commercial entities. These make up 93.6% of participants, followed by consumer groups (3.8%) and university and research institutions (2.5%). Government agencies comprise just 0.2% of participants. Tim Pohlmann, Back to Basics: Summer webinar, Part 2: SSOs, Patent pools and licensing, Berlin, IPlytics, 2020.

[8] Henry Farrell and Abraham Newman, "Weaponized Interdependence: How Global Economic Networks Shape Coercion", in *International Security*, vol. 44, no. 1, pp. 42–79, 2019, https://doi.org/10.1162/isec_a_00351

[9] In this chapter, Europe, refers to the European Union and the United Kingdom.

[10] Jean-Philippe Bonardi and Rodolphe Durand, "Managing Network Effects in High-tech Markets," in *The Academy of Management Journal,* vol. 17, no. 4, pp. 40–52, 2003.

degree of cooperation and willingness to accept technologically good contributions from all sides, technical standards are unlikely to achieve broad international market acceptance.

- **Standard essential patents:** An increasing proportion of technical standards contains patented technology. That Information and Communication Technologies (ICT) are used more widely across sectors to increase the connectedness of more and more products has been a decisive factor in this development. ICT standards contain a disproportionately high share of standard essential patents (SEPs) compared to other standards: an estimated 55 per cent.[11] SEPs manifest the dependencies that result from technical standards and create significant revenue streams.[12]

These three factors explain how technical standards create and manifest not unidirectional, but mutual dependencies, and thereby a "soft form" of technological indispensability. Network effects and their growing importance to the digital transformation underscore the value of technical standards to all parties. That all parties are inclined to cooperate and accept contributions from others illustrates the need for broad market acceptance. The role of SEPs further demonstrates these co-dependencies. Hence, thinking of technical standards in the context of technological indispensability means considering the co-dependence that stems from the need to develop common, widely accepted technical standards and their underlying SEPs.

However, where technical standards fail to be global in scope they can also divide and demarcate different technological spheres. Deviating standards therefore have the potential to further cement technological decoupling as technologies are developed in distinct ecosystems. Conversely, if foreign companies develop a significant degree of influence over domestic standard-setting in a particular market, leverage through standardisation goes beyond the creation of co-dependence. For example, when European firms shape domestic Chinese technical standards, they help to steer the technological development of a given technology in China.

The integrative and technology-shaping potential of technical standards is the prism through which this chapter explores whether standardisation is an opportunity for Europe to maintain technological indispensability vis-à-vis the People's Republic of China (PRC). To this end, it first delves deeper into the question of how standards can and cannot support European technological indispensability to China by differentiating between the four levels of policy ambition. We then examine standardisation in three concrete cases that are also the subject of other chapters in this volume: energy consumption in future wireless networks, automotive chips and facial recognition. From the general conclusions and examination of the cases, we make policy recommendations for Europe that seek to contribute to maintaining the technological indispensability of Europe.

LEVEL OF AMBITION

The role of standards in maintaining European technological indispensability has so far been largely ignored. This might appear surprising because the dependencies that standards create are obvious. When China commits to any given (international) standard that includes SEPs held by European entities, the PRC becomes dependent on European technology unless it is prepared to lose interoperability. When European firms affect standardisation in China, they directly shape the technological basis for technology development in the PRC. Since technology is not value neutral, this has political and normative implications.

Dependencies arising from standards cannot be used as a hard chokepoint by which Europe could threaten the PRC through export restrictions. However, this does not mean that they are of no use to Europe. Instead, depending on the level of ambition that Europe strives to achieve in any given technology, technical standards can be either a suitable or an insufficient instrument. Using the classification of four levels of ambition outlined in the introduction, we reflect on the usefulness of standards for Europe below.

Threat prevention is the lowest level of ambition as it only seeks to prevent technology transfer to China that could be used against Europe. The focus is primarily on dual-use items. Technical standardisation can serve only an indirect function in achieving this level of ambition, if any. Technical standards do not lend themselves to export restrictions and are therefore of no direct benefit to threat prevention. If anything, technical standardisation

---

[11] Tim Pohlmann, op. cit.

[12] Dan Strumpf, "Where China dominates in 5G technology," *Wall Street Journal*, accessed 13 April 2019, at https://outline.com/dVsKLJ. In 2014, Qualcomm received US$ 8 billion in licensing fees from China. Andrew Polk, "China is Quietly Setting Global Standards," Bloomberg, accessed 22 September 2018, at https://www.bloomberg.com/view/articles/2018-05-06/china-is-quietly-setting-global-standards.

processes in SDOs provide transparency for all participants. Hence, technologies that are standardised tend to have greater trustworthiness and thereby indirectly address security concerns.

The *ability to deny* seeks to develop a sufficient degree of Chinese dependency to make it costly for China to threaten Europe. It follows a defensive logic whereby Europe simply wants to prevent China from acting against European core interests. However, it is not just about dual-use goods but also takes economic dependencies into consideration, aiming to utilise the costs of interdependencies to make it irrational for China to turn against Europe.

Technical standards could be a suitable tool for achieving this goal if China has a strong interest in and commits to a global market with global interoperability. In such a case, China – like Europe – would have an active interest in a global consensus and international standards. This provides an opportunity for Europe to maintain co-dependency through international technical standards.

The *ability to act* goes a step further. It is about utilising the cost of dependencies and striving to make China reliant on Europe. However, it comes with a proactive agenda in that it strives to maintain an edge over the respective other that cannot be explained from a purely defensive viewpoint.

Technical standards can serve this level of ambition to the degree that European actors can not only shape the international standards adopted and applied by China, but also influence domestic standardisation within the PRC or the incorporation of those international standards into a domestic system that is heavily shaped by European actors. Shaping domestic standards is relevant when they gravely deviate from international standards.

This report defines *curtailment* as prevention of the attainment of economic and technological capabilities. This is achieved through export restrictions. By definition, standards guarantee access and therefore are an inappropriate tool for achieving this level of ambition.

CASE STUDIES

This section presents the findings from three concrete case studies that are discussed in more detail in other chapters in this volume. The purpose is not to identify an authoritative list of technical standards that Europe should prioritise. Nor does it discuss China's general emergence as a standardisation power and the characteristics of China's overall state-steered approach to standard-setting, which is outlined in previous publications.[13] Instead, we explore whether, the degree to which and under what conditions standardisation can promote European indispensability.

Case Study I: 5G energy saving technology

Wireless networks are one of the most standardised of all technologies. Consumers of mobile communications expect a high degree of reliability and interoperability. They want to call anyone around the world with the same mobile phones from anywhere in the world and expect fail-safe connectivity at any time. The development of wireless networks has also been highly transnational. Chinese technology companies run labs around the globe and have a strong interest in R&D that can be used across geographic regions. Hence, the network effects of wireless network technology are extraordinarily high.

The strong incentive for China to adopt international standards and avoid deviation in national standards means that the PRC must cooperate with international partners in international SDOs, the most important of which for wireless networks is the Third Generation Partnership Project (3GPP). Confirming China's interest in international wireless standards, the China Communications Standards Association (CCSA) is one of only seven Organisational Partners with responsibilities and influence in the 3GPP. The CCSA operates under the Ministry of Industry and Information Technology (MIIT) and is thus a de facto party-state organisation. China's commitment to the 3GPP reflects its interest in global market acceptance of 3GPP standards.

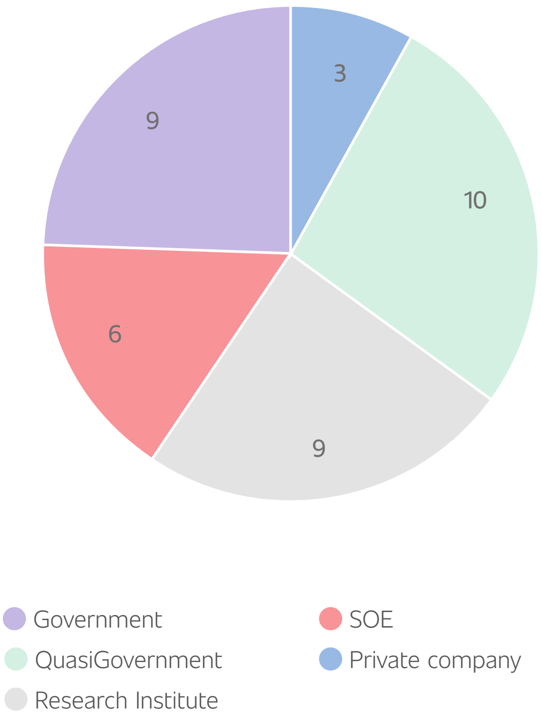
Actors from China, Europe and around the world submit standard contributions to 3GPP, and these contributions involve SEPs. In 2022, China accounted for 39,224 of the 217,749 5G SEP portfolios (18%), ranked second only to the United States, which made up 21.2% of applications (or 46,123 SEPs). Europe ranks third with a 14.1% share

---

[13] See e.g., Tim Rühlig, "The Shape of Things to Come: The Race to Control Technical Standardization", European Union Chamber of Commerce in China, accessed 31 March 2024, at https://static.europeanchamber.com.cn/upload/documents/documents/The_Shape_of_Things_to_Come_English_Final%5b966%5d.pdf ; and Maja Björk and Tim Rühlig, "Power competition and China's technical standardization", in Tim Rühlig (ed.), *China's Digital Power: Assessing the Implications for the EU*, Digital Power China, pp. 77–91, accessed 31 March 2024, at https://dgap.org/sites/default/files/article_pdfs/dpc-full_report-final.pdf.

(30,704 SEPs).[14] Huawei is the single-largest company contributing to SEPs in the 3GPP, responsible for 14% of declared 5G SEP families.[15] While these numbers almost certainly include some over-declaration by companies,[16] and estimates vary, they highlight the importance the Chinese government and industry attach to, and the influence that Chinese companies have today in, international standard-setting for 5G. By all the estimates we are aware of, China has a significant share of 5G SEPs.

FIGURE 1: Publications with common keywords in their title



Source: MIIT, footnote 19

As discussed in more depth in chapter 3, energy saving is a major issue in the development and future operation of wireless infrastructure. Energy-saving is not one of the functionalities that requires high interoperability within wireless technology. Hence, while the strong role of network effects and the resulting interest in broad market acceptance and international standards, including in its underlying SEPs, indicates an important role for international standards, the specifics of energy-saving hint at the mutual relevance of domestic Chinese standards. Reducing the energy consumption of 5G and future 6G networks is a key policy priority for the Chinese government, especially in the context of its decarbonisation goals. This will involve significant Chinese standardisation efforts, both domestically and internationally.

Chinese policy and industry documents identify standardisation as a key element of achieving greener 5G networks. In 2021, the National Development and Reform Committee (NDRC), the Ministry for Industry and Information Technology, the Cybersecurity Administration of China (CAC) and the National Energy Administration (NEA) published an “Implementation Plan to promote the green and high-quality development of new infrastructure such as data centres and 5G”. This identifies the need to “accelerate the formulation of advanced energy efficiency standards for 5G networks”.[17] This was followed up by a 2022 Action Plan that mandates the creation of more than 30 green and low-carbon standards in the information communication industry and calls for the export of Chinese energy-saving and low-carbon technologies.[18]

Unlike in other countries, the Chinese government takes an outsized role in the development of standards. Chinese party-state officials are strongly represented on official standardisation bodies. For example, government or quasi-government institutions (e.g., CCSA) provide 13 of the 37 committee members in TC485, the official TC tasked with researching and setting domestic standards.

---

[14] China IP News, “China Paces the World in SEP Filing for 5G,” China National Intellectual Property Administration, accessed 11 December 2023, at https://english.cnipa.gov.cn/art/2022/6/15/art_2829_176034.html.

[15] Jatin Singla, “5G Standard Essential Patents (SEPs),” Copperpod Intellectual Property, accessed 11 December 2023, at https://www.copperpodip.com/post/5g-standard-essential-patents-seps-all-you-need-to-know.

[16] Lorenzo Casaccia, “How Companies Game the ETSI Standard-essential Patent Database to Manipulate Perceptions of Leadership in 5G,” Qualcomm, accessed 11 December 2023, at https://www.qualcomm.com/news/onq/2023/08/how-companies-game-the-etsi-sep-database-to-manipulate-perceptions-of-leadership-in-5g.

[17] National Development and Reform Commission, “关于印发《贯彻落实碳达峰碳中和目标要求 推动数据中心和5G等新型基础设施绿色高质量发展实施方案》的通知“ [Notice on Issuing the “Implementation Plan for Implementing the Carbon Peak and Carbon Neutral Target Requirements and Promoting the Green and High-Quality Development of New Infrastructure such as Data Centers and 5G], accessed 10 October 2023, at https://www.ndrc.gov.cn/xwdt/tzgg/202112/t20211208_1307105.html.

[18] Ministry of Industry and Information Technology, “工业和信息化部等七部门关于印发信息通信行业绿色低碳发展行动计划（2022–2025年）的通知” [Notice from seven departments including the Ministry of Industry and Information Technology on the issuance of the Green and Low-Carbon Development Action Plan for the Information and Communications Industry (2022-2025)], accessed 10 October 2023, at https://www.gov.cn/zhengce/zhengceku/2022-08/26/content_5706914.htm.

Another 15 seats are taken by state-owned enterprises and public research institutes.[19] Key responsibility for establishing a complete standards system lies with the MIIT, which published draft "Guidelines for the Construction of Green and Low-carbon Standard Systems in the Communications Industry" in 2023, updating the previous standards system established in 2014.[20] The updated draft guidelines put stronger emphasis on reducing the overall level of carbon emissions by the 5G network than the previous version and structure the standardisation system into seven pillars, one of which is about energy saving.[21] Standards for energysaving make up the biggest share of standards within this framework, at almost half of national and sector standards, further indicating the importance the Chinese government attaches to the problem of energy consumption and efficiency in 5G networks.

As is outlined in more detail in chapter 3, an important distinction relevant to energy-saving wireless networks is whether to adopt energy efficiency or total energy consumption as a key metric.[22] Following the analysis in chapter 3, we assume that the shift to total energy consumption has potential technological advantages for Europe.

Creating a standard for the assessment of energy efficiency is highlighted as a priority in policy documents. A 2021 CAICT White Paper emphasises the need to develop a measurement standard for the ICT industry to make different energy-saving solutions comparable.[23] The MIIT guidelines also mention testing and evaluation standards. Huawei is a key driver of the Chinese debate, advocating measurement of energysaving based on the concept of "energy efficiency".[24] Gan Bin, Vice President of Huawei's Wireless Product Line, also specifically emphasises the goal of formulating a globally unified standard.[25]

Importantly, the national standard for the measurement and evaluation of energy efficiency for the base station, which is key to reducing energy consumption, is currently under review, having been updated last only in 2020.[26] This demonstrates that the concept of energy efficiency continues to play the predominant role in China's domestic standardisation.

As the only two foreign companies working in China, Ericsson and Nokia participate as drafting units of the standard that will set the parameters of and test the methodology for 5G base stations and beyond. This gives these European companies an important but limited avenue to shape how energysaving will be defined in the future. Having a say in how these parameters will

---

[19] See Figure 12.1, Ministry of Industry and Information Technology, "全国通信标准化技术委员会第三届委员名单" [List of members of the third session of the National Communications Standardization Technical Committee], accessed 10 October 2023, at https://www.sohu.com/a/664105385_121117464. The classification of actors into categories is rather conservative as many of the research institutions could be attributed to quasi-governmental entities. Hence, state influence is likely to be even higher than the table suggests.

[20] Hence, state influence is likely to be even higher than the table suggests. Shanghai Securities News, "工业和信息化部就《通信行业绿色低碳标准体系建设指南（2023版）》公开征求意见" [The Ministry of Industry and Information Technology publicly solicits opinions on the "Guidelines for the Construction of Green and Low-Carbon Standard Systems in the Communications Industry (2023 Edition)"], accessed 17 October 2023, at https://news.cnstock.com/news,bwkx-202307-5092547.htm.

[21] In addition to energy saving, six pillars are identified as priorities: comprehensive use of resources, carbon peak and carbon neutrality, green manufacturing, joint construction and shared use, infrastructure construction, operation and maintenance, and ICT technology empowerment.

[22] Traditionally, energy efficiency was the key measure of energy consumption in relation to the maximal throughput of data. This means that when the performance of equipment increases while the energy consumption of a device remains the same, energy efficiency improves. Total energy consumption, by contrast, considers the actual energy consumption over a representative period and space. This means that technologies are at the centre of considerations that help networks independently reduce energy consumption when not used to their maximum capacity.

[23] China Academy of Information and Communication Technology, "数字碳中和白皮书" [Digital Carbon Neutrality White Paper], accessed 10 December 2023, at http://www.caict.ac.cn/kxyj/qwfb/bps/202112/P020211220632111694171.pdf.

[24] China Industry and Information Technology Network, "双碳形势下5G应向性能和节能双优发展" [5G should develop towards both performance and energy saving under the dual-carbon situation], accessed 10 December 2023, at https://www.cnii.com.cn/rmydb/202206/t20220629_392568.html; Huawei, "中国移动联合华为发布5G无线网络能效评估白皮书" [China Mobile and Huawei jointly release a white paper on energy efficiency assessment of 5G wireless networks], accessed 10 December 2023, at https://www.huawei.com/cn/news/2022/6/5g-green-power-efficiency.

[25] Huawei, "中国移动联合华为发布5G无线网络能效评估白皮书" [China Mobile and Huawei jointly release a white paper on energy efficiency assessment of 5G wireless networks], accessed 11 December 2023, at https://www.huawei.com/cn/news/2022/6/5g-green-power-efficiency.

[26] SAMR, "移动通信设备节能参数和测试方法 基站" [Mobile communication equipment energy saving parameters and test methods for base stations], accessed 11 December 2023, at https://std.samr.gov.cn/gb/search/gbDetailed?id=E116673ED739A3B7E05397BE0A0AC6BF.

look is important to avoid facing competitive disadvantages or even complete exclusion from public tender processes. In 2021, for example, the Chinese government published a list of officially promoted and government favoured energy-saving 5G technologies to guide public procurement processes. [27] This list should be updated based on the outcome of the standard revisions mentioned above. If the Chinese government and industry widely adopt measurement standards that favour Huawei's products, the competitiveness of European suppliers could be harmed in the short term despite their technological edge in terms of total energy consumption. This would also mean that deviating standards would decrease co-dependence and that European actors would appear not to be shaping Chinese domestic energy-saving standards for wireless networks. However, the presence of Ericsson and Nokia indicates at least limited potential for Europe to shape domestic energy-saving standards for wireless networks.

Internationally, Chinese companies are also strongly involved in standardisation for 5G networks generally and for energy-saving 5G technology in particular. In the 3GPP, Chinese companies actively participate in the discussion on green 5G networks. Considering all energy-saving contributions to Release-18, China's share of contributions is well ahead of that of Europe.[28] Chinese participants almost exclusively focus on energy efficiency as a concept while some European actors, such as Deutsche Telekom or Vodafone, make explicit reference to total energy consumption. Strikingly, original analysis of relevant contributions within 3GPP carried out for this chapter demonstrates that there is little co-authorship across regions.

As in the domestic debate, Chinese companies are also advocating the use of energy efficiency as the key metric for evaluating energy-saving. For example, Huawei argues that research on energy saving should focus on efficiencies gained during low traffic loads, rather than energy efficiencies during high traffic loads. Furthermore, Huawei contends that reduction in absolute power consumption depends on many implementation issues "and hence is not suitable for study in 3GPP".[29] Other Chinese companies agree. China Telecom argues that "the justification is always about lowering the energy consumption while at the same time keeping the same performance".[30]

This demonstrates China's strong stance on international energy-saving standard-setting for wireless networks. Quantitatively, Europe lags well behind and the UK is not a factor at all. However, the focus on Chinese contributions on energy efficiency opens up potential for European leadership on standards, providing the ground for a shift to total energy consumption.

In sum, on domestic and international energy-saving standardisation for wireless networks, it appears that Europe has a good chance of establishing co-dependence and thereby achieving the ambition level ability to deny. While China tends to advocate divergent concepts focused on energy efficiency, both Europe and China continue to have significant influence in the 3GPP and share an interest in globally accepted wireless network standards. To achieve the higher level of ambition that we call the ability to act, European actors, mostly Ericsson and Nokia, would need to develop more influence over domestic standardisation. While both companies are involved in relevant standard-setting, it appears that this has not yet led to a shift in focus from energy efficiency to total energy consumption.

Case Study II: Automotive chips

Standards are an essential aspect of the development of automotive chips. More than any other chip application (with the exception of military applications), automotive chips face harsh environmental conditions and are expected to last for a long time (the useful life of a car ranges from 10 to 15 years). Some chips need to have a malfunction rate of near-zero in order to avoid traffic accidents. Given these requirements, automotive chips have extremely high technical standards for safety, reliability, process control and quality management.[31]

---

[27] Industrial and Technological Innovation Committee, "国家通信业节能技术产品推荐目录（2021）" [National Communications Industry Energy-Saving Technology Product Recommended Catalog (2021)], accessed 11 December 2023, at https://gkw.jiyuan.gov.cn/xxgk/zcfg/t837124.html.

[28] Analysis of contributions of Chinese companies within Release-18 (3GPP TSG RAN meetings 91-102). The eight concepts are energy efficiency, power efficiency, transmit power reduction and low-power transmission, as well as deep sleep, sleep mode, energy saving in network and green communication. The first four concepts are proxies for contributions that adhere to the concept of energy efficiency; the latter four concepts hint at contributions to total energy consumption.

[29] Included in RP-212156, which can be found at https://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_93e/Docs

[30] Included in RP-211958, which can be found at https://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_93e/Docs

[31] For example, the most recognised international standard for functional safety is ISO 26262, which provides a risk classification system (Automotive Safety Integrity Levels A-D). International Organization for Standardization, "ISO 26262-1:2018(en) Road vehicles — Functional safety — Part 1: Vocabulary", International Organization for Standardization, accessed 7 January 2024, at https://www.iso.org/standard/68383.html.

Automotive original equipment manufacturers (OEMs) require high standards of proof that these requirements have been met, typically delivered through certification by accredited laboratories.

Setting unified standards for certain chips across OEMs enables chip suppliers to scale-up their product designs and make use of economies of scale. As Chinese automotive OEMs seek increasingly to internationalise their operations,[32] complying with international certification schemes is indispensable to gaining market acceptance overseas. In other words, Chinese OEMs profit from network effects and Chinese chip vendors and tier-one suppliers, in turn, strive to be accepted by Chinese OEMs. Adopting international standards on safety and reliability is crucial to creating such trust and the network effects that Chinese OEMs require. In terms of testing, however, China currently lacks its own domestic standards and participation in authoritative bodies for international standards. The incorporation of domestic standardisation into testing and certification processes will therefore be crucial in this context. We consider both domestic and international processes in this section.

The high safety and reliability requirements of automotive chips and the long track record of foreign vendors, including on testing and their certification based on globally accepted standards, mean that China is currently still highly dependent on foreign vendors. Foreign chipmakers still dominate more than 90 per cent of China's automotive chip market.[33] This high dependence on foreign imports has been identified as a major issue for the Chinese automotive industry, given the wider geopolitical rivalry with the US and industry shortages triggered by the pandemic in 2022. Chinese officials and industry representatives repeatedly refer to the need to develop an autonomous and reliable automotive chip value chain.[34]

Domestic standardisation is viewed among Chinese stakeholders as an important measure to achieve greater independence along the automotive chip value chain. As mentioned above, the reliability and safety of automotive chips is essential for market acceptance. In addition, the long design and development cycles of products lead to a certain stickiness of tier 1 and tier 2 suppliers, which requires a lot of trust between OEMs and their suppliers. To remedy the trust issue, Gao Xiang, director of the China EV100 Supply Chain Research and Cooperation Centre, suggests that standardisation is needed to provide collaborative development along the value chain.[35] Former head of the MIIT, Miao Wei, has urged OEMs to take responsibility as "chain leaders" ("链长") to develop an independent ecosystem for chips.[36] Many Chinese OEMs have heeded that call.[37]

The key document outlining Chinese ambitions for automotive chip standardisation is the "National Automotive Chip Standard System Construction Guidelines", which was officially published as the authoritative document in January 2024[38]. These guidelines outline an ambition to formulate 30 key standards by 2025 and more than 70 standards by 2030 in order to "cultivate an independent innovation environment" and "enhance China's overall

---

[32] Ilaria Mazzocco, "China's Electric Vehicle Industry's Internationalization", Center for Strategic and International Studies, accessed 10 January 2024, at https://www.csis.org/analysis/chinas-electric-vehicle-industrys-internationalization

[33] New Energy Vehicle Network, "车企与芯片厂, 联手抢夺万亿市场" [Car companies and chip manufacturers join forces to seize the trillion-dollar market], accessed 10 January 2024, at https://nev.ofweek.com/2023-11/ART-77013-8420-30615358.html.

[34] For example, Li Shaohua, Vice-President of China's Association of Automotive Manufacturers (CAAM), argues that promoting localization of the supply chain is an important measure to ensure the healthy development of the automotive and chips industries. CCTV, "融合发展 打造自主可控的汽车芯片供应链体系" [Integrated development to create an independent and controllable automotive chip supply chain system], accessed 10 January 2024, at https://auto.cctv.com/2022/07/04/ARTIVRJga9a2WTFjKVMgaXm3220704.shtml.

[35] New Energy Vehicle Network, "车规级芯片距完全自主还有多远？" [How far is it from car-grade chips to be fully autonomous?], accessed 7 February 2024, at https://nev.ofweek.com/2023-03/ART-77013-8420-30590688_2.html.

[36] CA168, "工信部原部长苗圩演讲全文《当前汽车供应链面临的关键问题思考》" [The full text of the speech by Miao Wei, former Minister of the Ministry of Industry and Information Technology, "Thoughts on Key Issues Facing the Current Automobile Supply Chain"], accessed 7 February 2024, at https://news.ca168.com/202209/120181.html.

[37] For example, Geely in 2023 signed a strategic cooperation agreement with domestic power chip foundry GTA Semiconductor. Gasgoo, "Geely Technology Group, GTA Semiconductor Team up on Auto-grade Chip Businesses", Gasgoo, accessed 8 February 2024, at https://autonews.gasgoo.com/china_news/70022071.html

[38] Ministry of Industry and Information Technology, "工业和信息化部办公厅关于印发国家汽车芯片标准体系建设指南的通知" [Notice from the General Office of the Ministry of Industry and Information Technology on the issuance of guidelines for the construction of the national automotive chip standard system], accessed 7 February 2024, at https://www.gov.cn/zhengce/zhengceku/202401/content_6924893.htm.

technological capabilities and competitiveness".[39] Most of the standards aim to define technical requirements and testing methods for various chip applications within the car. This indicates that the major goal of these standards is to find commonly acceptable measurements and build trust among industry participants. The goal of trust-building is further underscored by the "Reliability Classification Catalogue of Domestic Automotive Chips", which has been jointly issued by relevant industry associations with the explicit goal of promoting the connection between the supply of and demand for automotive chips.[40] It is possible that the standard-setting process coupled with something like the Reliability Classification Catalogue might be used to instruct Chinese OEMs to use domestic automotive chips.[41] This is all the more likely as the Chinese government has formulated specific targets for the localisation rate of different in-vehicle chips, such as that 50% of computing chips should be domestically produced by 2025.[42]

Interestingly, Chinese stakeholders consistently refer to international standards when building the domestic standardisation system. The MIIT guidelines specifically mention ISO 26262.11 as a reference model for the domestic functional safety standard. Similarly, the Reliability Classification Catalogue makes AEC-Q test certification a cornerstone of the assessment. All of this suggests that China is unlikely to deviate far from international standards, especially on functionality, safety and reliability.

Nonetheless, there is a chance that Chinese information security standards could become an increasingly prominent issue. For example, Huada Semiconductor self-reported that one of its automotive security chip series that has received AEC-Q100 Grade-1 certification supports cryptographic algorithms for "national secrets".[43] This hints at close regulatory involvement by the Chinese authorities. Similarly, as early as 2017, NXP advertised being the only foreign-based semiconductor company to pass certification by the China Office of State Commercial Cryptography Administration to develop cryptography products in China.[44] As vehicles become more and more interconnected, China's information security standards could increasingly diverge from international standards as the party-state puts stronger emphasis on the topic than other governments might.

There is little room for participation in the standardisation process by non-Chinese companies. In Sub-Committee 29 (SC29), which is chiefly responsible for automotive chip standardisation under the guidance of the MIIT, with the exception of Toyota, foreign companies only participate as part of Joint Ventures, for example the SAIC Volkswagen JV or the BMW Brilliance JV.[45] The same is true of TC485, where government and government-linked institutions are heavily involved in the committee and likely to bring a strategic dimension to standardisation.

Another key institution tasked with shaping automotive chip standardisation in China is the China Automotive Chip Industry Innovation Strategic Alliance (CACA). CACA issued three reports on the automotive chip standardisation system in 2022, which apparently laid the groundwork for the standardisation guidelines published by the

---

[39] The standards that are identified as most important fall into four pillars: basic standards (involving general terms), general requirements (setting standards for environment and reliability, functional safety and information security, and electromagnetic compatibility), product applications (referencing a wide range of specific chips), and vehicle and key system matching tests. Global Times, "China steps up efforts to set standards for auto chips amid fierce competition", accessed 20 February 2024, at https://www.globaltimes.cn/page/202401/1305028.shtml.

[40] Winniewei, "推动汽车芯片供需对接，《国产车规芯片可靠性分级目录》即将在第十届汽车电子创新大会上重磅发布!" [To promote the connection between supply and demand of automotive chips, the "Reliability Classification Catalog of Domestic Automotive Chips" will be released at the 10th Automotive Electronics Innovation Conference!], accessed 20 February 2024, at https://www.eetrend.com/content/2023/100572501.html.

[41] Shunsuke Tabeta, "EV powerhouse China to set own standards for automotive semiconductors," Nikkei Asia, accessed 22 February 2024, at https://asia.nikkei.com/Business/Tech/Semiconductors/EV-powerhouse-China-to-set-own-standards-for-automotive-semiconductors.

[42] Information obtained from the Seconded European Standardization Expert in China (SESEC).

[43] Huada Semiconductor, "华大半导体旗下华大电子荣获首批汽车安全芯片信息安全认证证书" [Huada Electronics, a subsidiary of Huada Semiconductor, won the first batch of automotive security chip information security certifications], accessed 23 February 2024, at https://www.hdsc.com.cn/News-209.

[44] NXP Semiconductor, "NXP World's First Foreign-Based Semiconductor Company Awarded OSCCA Certificate from China Authority," NXP, accessed 23 February 2024, at https://www.nxp.com/company/about-nxp/nxp-worlds-first-foreign-based-semiconductor-company-awarded-oscca-certificate-from-china-authority:NW-OSCCA-CERTIFICATE-CHINA.

[45] SAC, "TC114/SC29 全国汽车标准化技术委员会电子与电磁兼容分技术委员会", [TC114/SC29 National Automotive Standardization Technical Committee Electronics and Electromagnetic Compatibility Sub-Technical Committee], accessed 23 February 2024, at https://std.samr.gov.cn/search/orgDetailView?tcCode=TC114SC29.

MIIT.[46] Backed by government ministries, the alliance's objective is to unite various players in the automotive chip value chain and facilitate cooperation between upstream and downstream companies. More worryingly, however, another declared goal is to achieve independence for China's automotive industry and promote domestic substitutions.[47] Membership of the alliance is made up of Chinese OEMs (e.g. SAIC, BYD, FAW), automotive electronics and software vendors (e.g. CETC, CATL, Weichai), chip companies (e.g. SMIC, Black Sesame, Horizon), universities and industry groups. While the alliance claims to be open to all industry participants, the technical committee is made up purely of Chinese entities.[48] Since the publication of the standardisation guidelines, more standardisation bodies have been formed to work on associated standards.

As for the international dimension, in contrast to the 5G example, Chinese companies are not yet very active in international SDOs for automotive chips. For example, no Chinese company is a Sustaining Member of the American Electronic Council, which is made up of tier 1 suppliers, chip suppliers and contract chip manufacturers.[49] Geely is the only Chinese OEM that is a member of the International Automotive Task Force, which harmonises quality management in the automotive supply chain and is based on ISO 9001 (quality management systems), and the Chinese Association of Automobile Manufacturers is not included.[50] Only one of the 39 Chinese testing institutions is officially authorised by the IATF to conduct IATF 16949:2016 certification activity.[51]

In sum, a key goal of Chinese standardisation appears to be to build trust among key industry players and break the current monopoly of foreign vendors in the Chinese market. Of course, this goal in and of itself makes it difficult for Europe to actively participate in and shape China's domestic standardisation system. This is reflected in the low level of participation by European actors in the two key SDOs responsible for automotive chips, making it difficult to achieve the ambition level ability to act. Nonetheless, Chinese companies do have an incentive to integrate as closely as possible with existing international standards in order to ship end products to third markets. This makes it unlikely that Chinese standards will deviate significantly. Furthermore, it is clear that China has little experience of testing and the verification of automotive chips, providing an opportunity for European actors to persuade China to cooperate internationally. Given the newness of China's standardisation system, European actors could leverage their experience more actively to ensure that Chinese standards do not develop in a direction that diverges from international standards. Thus, achieving the ambition level of ability to deny would be feasible.

Case Study III: Facial Recognition

Chinese companies are strongly invested in setting international standards for Artificial Intelligence generally and facial recognition technology (FRT) more specifically. These standards pave the way for market access, and the interoperability and connectivity of products and services of companies in both the private and the public sector. They are therefore highly important to companies for capturing market share not only within China, but also abroad.

FRT has been widely adopted in China's domestic market, especially in the public sector.[52] In reaction to the proliferation of the technology, as well as public concern over the abuse of private data, there has been considerable regulatory activity by the Chinese government to

---

[46] Ijiwei, "汽车芯片标准体系建设研究成果发布，黑芝麻、兆易创新、豪威、芯驰等共同参与" [research results on the construction of automotive chip standard system released, with the participation of Black Sesame, GigaDevice, Haowei, Xinchi, etc.], accessed 25 February 2024, at https://ijiwei.com/n/826300. The research produced by CACA included the same four pillars as the MIIT guidelines.

[47] CACA, "联盟简介" [About the alliance], accessed 25 February 2024, at https://caca-chips.com/gaikuang/lianmengjianjie/

[48] CACA, "中国汽车芯片产业创新战略联盟 技术专家委员会" [China Automotive Chip Industry Innovation Strategic Alliance Technical Expert Committee], accessed 25 February 2024, at https://caca-chips.com/zhengwugongkai/zhengcejiedu/143.html.

[49] Automotive Electronics Council, "Home page", accessed 25 February 2024, at http://aecouncil.com/ Chinese chip suppliers such as Horizon Robotics and GigaDevice are now also included as Technical, Associate or Guest Members, but do not have the same influence within the SDO as Sustaining Members.

[50] International Automotive Task Force, "About IATF", accessed 1 March 2024, at https://www.iatfglobaloversight.org/about-iatf/.

[51] International Automotive task Force, "Under Contract", accessed 1 March 2024, at https://www.iatfglobaloversight.org/certification-bodies/under-contract/.

[52] Many government services now use facial recognition for user identification. For example, Guangdong has used facial recognition to access government services such as birth certificates and residence permits since 2018. China Communist Party News Network, "广东：小程序撬动大改革" [Guangdong: Small programmes drive major reforms], accessed 1 March 2024, at http://cpc.people.com.cn/n1/2019/1212/c415067-31503048.html. Nationally, FRT has been used at Custom's registration desks since 2019. General Administration of Customs, "海关监管作业场所（场地）监控摄像头设置规范" [Specifications for the installation of surveillance cameras in customs supervision workplaces (sites)], accessed 1 March 2024, at https://www.gov.cn/zhengce/zhengceku/2021-01/11/content_5578994.htm.

protect private information.[53] Technical standards have been developed to promote stronger consumer protection. For example, GB/T 41772-2022, “Technical requirements for facial recognition systems”, sets out requirements for sample quality, false acceptance or rejection rates and data storage, as well as more technical details. Another key domestic standard is GB/T 41819-2022, “Security requirements of facial recognition data”,[54] which imposes certain requirements on companies using facial recognition to verify or identify individuals:

- Facial recognition should only be used when it significantly improves security and convenience.
- There must be restrictions on using facial recognition for children under 14.
- Alternative identification methods must be provided.
- There must be informed consent from individuals. Use of facial recognition data must be limited to specific purposes, such as security, and prohibited for other purposes, such as evaluating or predicting individual characteristics or behaviour.

While progress has been made on privacy standards concerning the commercial use of FRT by companies, however, the government is less restricted in its use of facial recognition. National security concerns continue to trump all other considerations. The White Paper on GB/T 35273-2020, the standard that lays out the requirements for the handling of private information, specifically upholds the right of the state to access personal information.[55] Similarly, privacy protection is not extended to populations deemed a social threat, such as the Uyghurs. Facial recognition for public surveillance has its own specific national standard, GA/T 1756-2020, which contains technical specifications for “skin colour analysis”, leaving open the potential for racial bias and racial profiling.[56]

It is also worrying that it is mostly Chinese companies that are involved in the drafting of domestic facial recognition standards. The technical committee on cybersecurity, TC260, is a key standard-setting body for facial recognition standards. TC260 is led by a representative of the CAC, China’s top agency for digital governance. While a few foreign companies participate in the technical committee, such as Siemens, Intel, Schneider Electric and Visa,[57] no foreign company participated in the drafting of the standards named above.

Furthermore, China has established an “Overall Group for Artificial Intelligence Standardisation” under TC28, which is responsible for information technology. In March 2020, a new AI Sub-Technical Committee (SAC/TC 28/SC42) was made responsible for Artificial Intelligence (AI), foundation technology, risk management, trustworthiness, governance, products and applications, as well as national standard formulation and revision work in the field of AI.

China is also increasingly active on the international stage. For International Telecommunication Union (ITU) Study Period 2022–2024, representatives from China Telecom and Beijing University of Post and Telecommunication have been made rapporteurs for Question 12, related to intelligent visual systems and services. All the editors responsible for individual work items under Study Question 12 are from Chinese institutions or companies. Many of these companies, such as China Telecom, China Unicom or State Grid, are state-owned. Some of the participating companies, such as Dahua, have been sanctioned by the US for supporting the

---

[53] Since the introduction of the Personal Information Protection Law in 2021, more and more regulation has concerning the collection of private information through FRT has been introduced. In 2022, CAC fined ride-hailing company Didi RMB 8 billion for the excessive collection of facial recognition data. In 2023, CAC issued draft rules on tighter FRT oversight. Most recently, the China People’s Political Consultative Conference (albeit not that significant in China’s legislative process) submitted a proposal to restrict the excessive use of FRT by the security agencies. See NPC, “Personal Information Protection Law of the People’s Republic of China”, accessed 15 March 2024, at http://www.npc.gov.cn/npc/index.html; Julie Zhu, Yingzhi Yang and Kane Wu, “China Fines Didi $1.2 bln but Outlook Clouded by App Relaunch Uncertainty”, Reuters, 21 July 2022, accessed 15 March 2024, at https://www.reuters.com/technology/china-fines-didi-global-12-bln-violating-data-security-laws-2022-07-21/; and Jiemian News, “限制酒店过度使用“人脸识别”, [Restrict hotels from excessive use of “facial recognition”], accessed 15 March 2024, at https://m.jiemian.com/article/10889480.html.

[54] SAC, “信息安全技术 人脸识别数据安全要求” [Information Security Technology Face Recognition Data Security Requirements], accessed 15 March 2024, at https://std.samr.gov.cn/gb/search/gbDetailed?id=EB58F4DA926CB2A2E05397BE0A0A7D33.

[55] TC260, “信息安全技术 个人信息安全规范” [Information Security Technology, Personal Information Security Specifications], accessed 15 March 2024, at https://www.tc260.org.cn/upload/2020-09-18/1600432872689070371.pdf.

[56] IPVM, “Dahua and Hikvision Co-Author Racial And Ethnic PRC Police Standards”, accessed 15 March 2024, at https://ipvm.com/reports/racial-ethnic-standards.

[57] TC260, “全国网络安全标准化技术委员会 (SAC/TC260Ɵ [National Cybersecurity Standardization Technical Committee (SAC/TC260)], accessed 15 March 2024, at https://www.tc260.org.cn/front/tiaozhuan.html?page=/front/gywm/wymd_Detail.

Chinese government with its surveillance of the Uyghur population.[58] While the ITU is less influential on standard-setting in developed countries, it remains an important source for countries with limited policymaking capacities.[59]

China is also active in other international SDOs. ISO/IEC JTC1 has established subcommittee SC42 on AI, focused on the development of data quality and governance, credibility and security. It has been used as a regulatory reference by many countries and regions for AI security and governance. Within SC42, China is leading work on data quality process frameworks.[60] However, China does not dominate SC42, as most working groups are not led by Chinese companies.

In conclusion, China has made significant strides in standardising facial recognition technology. FRT has been widely adopted domestically, particularly in the public sector, raising concerns about privacy and data protection. While the Chinese government has introduced regulations to address these concerns, national security imperatives often take precedence, leaving room for potential abuse. As long as the national security rationale for FRT is predominant, it seems unlikely that European companies will be able to participate significantly in domestic standardisation. Compared to the other two case studies, network effects are weaker and China's strong market power provides less incentive to cooperate for the sake of market acceptance. However, China's ambitions to export FRT and its active participation in international SDOs signal its willingness to stay within the international framework. This provides European companies, which continue to have a good footing in international SDOs on AI, with an opportunity to shape Chinese technical standards through the international stage. In the light of the relatively weak European FRT industry (see chapter 10 in this volume), gaining the ability to act appears hardly feasible. The ability to deny will require Europe to remain active in international SDOs and a leader in technological niches.

POLICY RECOMMENDATIONS

Technical standards have a specific, albeit limited, function in maintaining, building or consolidating China's technological dependencies on Europe. Denial of access to standardised technology is impossible. Technical standards do not constitute unidirectional dependencies and are not a hard chokepoint. The more relevant network effects are for a technology, however, the stronger the interest in global market acceptance of the development of standards that can lock-in all market participants, including those in China, to inherent SEPs. When European actors hold these SEPs a "soft dependence" is the result.

In the cases discussed in this chapter, Europe has the potential to achieve the level of *ability to deny* in all three because the PRC has an active interest in network effects, and thus the application of international standards. Europe's position is the weakest in FRT. In the case of energy-saving wireless network technology, the inclusion of Nokia and Ericsson in relevant domestic standard-setting forums carries at least the general possibility of achieving the ambition level *ability to act*.

Threat prevention

For European actors to use technical standards to contribute to threat prevention would require a four-step process: First, the UK, the EU and its member states would need to understand and identify the specific security relevance of technologies. General findings on the dual-use nature of broad technology categories such as wireless networks are not enough. Instead, a more detailed overview of the dual-use potential of technologies will be necessary. For this, Europe could set up a joint monitoring and research programme – possibly in alliance with like-minded partners, for example within the framework of the North Atlantic Treaty Organisation. Second, where a given technology or technological functionality is found to be of dual use, the same institution could develop mitigation strategies. Where the assessment hints at the value of transparency and trust as means of mitigating risks, technical standards should be considered. Third, since most technical standardisation is private sector-driven, coordination with relevant industry and standardisation organisations would be beneficial,

---

[58] Eduardo Jaramillo, "US, UK, and Australia hit Hikvision, Dahua, and other Chinese Tech Firms with New Restrictions", The China Project, accessed 15 March 2024, at https://thechinaproject.com/2022/12/07/u-s-u-k-and-australia-hit-hikvision-dahua-and-other-chinese-tech-firms-with-new-restrictions/.

[59] Anna Gross, Madhumita Murgia and Yuan Yang, "Chinese Tech Groups Shaping UN Facial Recognition Standards", *Financial Times*, 1 December 2019, accessed 15 March 2024, at https://www.ft.com/content/c3555a3c-0d3e-11ea-b2d6-9bf4d1957a67.

[60] Hongru Zhu, Juntao Peng and Yong Sun, "人工智能治理国内外政策与标准分析" [Analysis of Domestic and Foreign Policies and Standards for Artificial Intelligence Governance], accessed 20 March 2024, at https://mp.weixin.qq.com/s/u-TtDPx93IVPSfz7M-0WdZQ.

which could be carried out within the High-level Forum of European Standardisation. Fourth and finally, where standard-setting is found to have risk mitigation potential following the first three steps, public actors – particularly from European security agencies – will need to participate in relevant standardisation processes. National security concerns are not a priority among companies and must be addressed by public actors. It is likely that the number of such cases will be very limited and therefore the additional funding required to finance the inclusion of public actors in relevant standardisation organisations should be relatively small. Any instruments that increase the transparency and inclusivity of standardisation processes, such as the certification of international SDOs according to best practices, could also be helpful.

Ability to deny

Policies that help European technology companies to continue to be featured in international standard-setting organisations ensure the “soft dependency” of China on European technology and thereby increase the “ability to deny”. These include keeping global markets open for European companies, for example by incentivising the adoption of international standards through the EU’s and the G7’s global connectivity initiatives, which could be tied to the implementation of international standards. European policymakers should also provide conditions conducive to the development of technical standards by European actors. Sustaining if not improving investment in research, development and innovation, for example by means of Horizon projects or national research funding schemes, coupled with the introduction of technical standard contributions as one among several evaluation metrics of such projects, could prove useful. Policymakers should also create incentives for and reduce the costs of companies participating in international standardisation processes, for example, by experimenting with tax credits for payment fees or R&D costs for established standards. Supporting conditions for early mover advantage by means of temporal exemptions from regulations in priority areas, under conditions of constant monitoring, could also be considered. A further example is the continuation of efforts to secure revenue streams from SEPs. In this context, defending existing international practices against China’s anti-suit injunction will be critical.

Ability to act

To untap the potential for technical standards to shape China’s technological development, Europe needs to understand the feasibility and political value of dependencies on technical standards in each technological sector. Europe could consider sponsoring research that brings together technical and strategic expertise to investigate such potential on a technology-by-technology basis. This study could serve as a first example of how such commissioned research might look, although deeper and non-public analysis will be necessary.

Where such potential is identified, Europe must insist on receiving reciprocal access to domestic standard-setting in China or advocate for the identical incorporation of international standards – where shaped by European proposals – into domestic Chinese standards.

All this will require close cooperation between public and private sector actors. The EU, including its member states, the UK and their like-minded partners should continue to insist on reciprocal access to domestic standardisation in China – including to association standard-setting.[61] This will require an indication from European industry and SDOs that they will bring discriminatory practices to the attention of public actors. If these practices cannot be addressed by bilateral means, the UK and the EU should consider bringing them to the World Trade Organisation’s Committee on Technical Barriers to Trade (TBT). In return, public actors should support private sector actors with navigating the specificities of China’s standardisation system, not least by providing information through the Seconded European Standardisation Expert in China (SESEC). In the case of automotive chip standardisation, policymakers could encourage coordination mechanisms among industry players – especially tier 2 suppliers, which are currently completely absent from SC29 – to participate in defining the direction of Chinese auto chip standardisation.

European public actors should continue to encourage China to identically incorporate international standards into their domestic system. In this context, Europe should not give up on the idea of a Beijing and Shanghai Agreement of the Standardisation Administration of China (SAC) with the International Standardisation Organisation (ISO) and the International Electrotechnical Commission (IEC) that resembles Europe’s Frankfurt and Vienna Agreements. These agreements

---

[61] Association standards are technical standards in China that are developed outside of formal party-state institutions within Chinese industry alliances. De facto, the party-state often exercises significant influence over these standard-setting processes as well. Tim Rühlig, “The Shape of Things to Come: The Race to Control Technical Standardization”, European Union Chamber of Commerce in China, accessed 31 March 2024, at https://static.europeanchamber.com.cn/upload/documents/documents/The_Shape_of_Things_to_Come_English_Final%5b966%5d.pdf

synchronise European and international standards, albeit to different degrees. China has promised a similar development in its Standardisation Outline. Europe should advocate for Beijing and Shanghai Agreements as the best way to implement the stated goal of international alignment. *Curtailment* is not achievable by means of technical standards.

Finally, this chapter also demonstrates that what is achievable by means of technical standards varies across technologies. Hence, a careful consideration of the role of technical standards in achieving technological indispensability would be useful, and requires a nuanced agenda as well as cooperation between public and private sector actors.

SCORECARD 2 TECHNOLOGY FIELD: TECHNICAL STANDARDISATION

	Threat prevention	Ability to deny	Ability to act	Curtailment
Feasibility of level of ambition	Low	High	Medium	Not feasible
Core policy recommendations	Four-step process consisting of: • Like-minded security monitor • Like-minded security mitigation strategy • Public-private security dialogue • Targeted inclusion of public security actors	• International standards promotion through procurement and investment • Linkage of public R&D and standard contributions • Early mover enabling • Pushback against anti-suit injunction	All of the ability to deny actions plus: • Insistence on reciprocal access to domestic standard-setting in China • Insistence on access to association standardisation in China • Support for Beijing and Shanghai Agreements with ISO/IEC	• None

AUTHORS

Martin Catarata is a Senior Consultant at Sinolytics and a PhD Candidate at the University of Trier. He is based in Germany. Contact: martin.catarata@sinolytics.de

Tim Rühlig is a China Fellow at the European Commission, DG I.D.E.A., seconded from the German Council on Foreign Relations (DGAP) and the chair of the Digital Power China research consortium (DPC). He is based in Germany and Belgium. he author is writing in his personal capacity and his views should not be considered as representing his employer or any EU institution.
Contact: contact@timruhlig.eu

With contributions by **Oscar Shao**, German Council on Foreign Relations

APPENDIX

APPENDIX A: Members of TC485 National Technical Committee for Communication

AFFILIATION	NAME	CHINESE	ORGANISTION	CHINESE
Quasi-Government	Wen Ku	闻 库	CCSA	中国通信标准化协会
Government	Liu Yulin	刘郁林	MIIT	工业和信息化部信息通信发展司
Government	Yao Jia	姚 佳	MIIT	工业和信息化部科技司
Government	Lei Nan	雷 楠	MIIT	工业和信息化部网络安全管理局
Quasi-Government	Dai Xiaohui	代晓慧	CCSA	中国通信标准化协会
Quasi-Government	Zhao Ying	赵 莹	CAICT	中国信息通信研究院
Quasi-Government	Nan Xinsheng	南新生	CCSA	中国通信标准化协会
Quasi-Government	Cao Jiguang	曹蓟光	CAICT	中国信息通信研究院
Private company	Shi Youtang	石友康	Potin-Tech	博鼎实华（北京）技术有限公司
Private company	Ji Heyuan	续合元	Potin-Tech	博鼎实华（北京）技术有限公司
Quasi-Government	Xie Wei	谢 玮	CAICT	中国信息通信研究院
Research institute	Xiao Li	肖 雱	Shenzhen Institute of Information and Communications Technology	深圳信息通信研究院
SOE	Zhang Yuan	张 园	China Teleco	中国电信集团有限公司
SOE	Xie Lingyun	解灵运	China Mobile	中国移动通信集团有限公司
SOE	Wang Minghui	王明会	China Unicom	中国联合网络通信集团有限公司
Research institute	Liu Xiaoyong	刘晓勇	Testing Center of the National Radio Monitoring Center	国家无线电监测中心检测中心
Research institute	Li Hongtao	李洪涛	China Internet Network Information Center	中国互联网络信息中心
Private company	Liu Hongjun	刘红军	ZTE	中兴通讯股份有限公司
Private company	Zhang Jian	张 健	Huawei	华为技术有限公司
SOE	Yang Zhuang	杨 壮	China Information and Communications Technology Group	中国信息通信科技集团有限公司
Private company	Gu Fangfang	顾方方	Nokia Bell	上海诺基亚贝尔股份有限公司
Research institute	Li Wenjing	李文璟	Beijing University of Posts and Telecommunications	北京邮电大学
Research institute	Song Zhituo	宋志佗	Chengdu Tederic Communication Equipment Testing	成都泰瑞通信设备检测有限公司
Private company	Li Yan	李 俨	Qualcomm	高通无线通信技术（中国）有限公司
Quasi-Government	Sun hang	孙 航	CATARC	中国汽车技术研究中心有限公司
Research institute	Zhu Hao	朱 浩	China Academy of Industrial Internet	中国工业互联网研究院
Research institute	Li Jun	李 俊	National Industrial Information Security Development Research Center	国家工业信息安全发展研究中心

Private company	Xiong Zhuang	熊 壮	YOFC Optical Fiber & Cable	长飞光纤光缆股份有限公司
Quasi-Government	Xie Yi	谢 毅	Telecommunications Terminal Industry Association	电信终端产业协会
Private company	Li Wei	李 伟	Tencent	腾讯云计算（北京）有限责任公司
SOE	Jin Ming	金 鸣	Datang Telecom Group	电信科学技术研究院有限公司
SOE	Zhang Chi	张 弛	Datang Telecom Group	电信科学技术研究院有限公司
Research institute	Qi Wei	戚 巍	CAS Quantum Network Co.	国科量子通信网络有限公司
Quasi-Government	Shu Min	舒 敏	CNCERT	国家计算机网络应急技术处理协调中心
Research institute	Yu Zhong	禹 忠	Xi'an University of Posts and Telecommunications	西安邮电大学
Private company	Hu Qianggao	胡强高	Accelink Technologies	武汉光迅科技股份有限公司
Quasi-Government	Meng Deliang	孟德良	State Radio Monitor Center	国家无线电监测中心

APPENDIX B: Members of TC114/SC29 National Automotive Standardisation Technical Committee Electronics and Electromagnetic Compatibility Sub-Technical Committee

NAME	CHINESE	ORGANISTION	CHINESE
Gong Jinfeng	龚进峰	CATARC	中国汽车技术研究中心有限公司
Zhang Yong	张涌	Nanjing Forestry University	南京林业大学
Li Yan	李燕	Dongfeng Motor Group	东风汽车集团股份有限公司
Wang Hongbo	王洪博	China Academy of Information and Communications Technology	中国信息通信研究院
Zhu Tong	朱彤	CATARC	中国汽车技术研究中心有限公司
Yang Xiaosong	杨晓松	Xiangyang Da'an Automobile Testing Center	襄阳达安汽车检测中心有限公司
Lü Gang	吕刚	Changchun Automobile Testing Center	长春汽车检测中心有限责任公司
Ma Yue	马玥	MIIT	工业和信息化部装备工业发展中心
Hua Jiafeng	华佳峰	Ministry of Public Security	公安部交通管理科学研究所
Wang Jiangdong	王江东	China Quality Certification Center	中国质量认证中心
Li Bo	李波	CATARC	中国汽车技术研究中心有限公司
Ding Yifu	丁一夫	China Automotive Research Institute Automobile Inspection Center (Tianjin)	中汽研汽车检验中心（天津）有限公司
Gu Hailei	顾海雷	Shanghai Motor Vehicle Testing and Certification Technology Research Center	上海机动车检测认证技术研究中心有限公司
Qin Yanming	覃延明	Chongqing Vehicle Inspection and Research Institute	重庆车辆检测研究院有限公司
Huang Xuemei	黄雪梅	China Automotive Engineering Research Institute	中国汽车工程研究院股份有限公司
Xu Mingze	徐铭泽	Tianjin Institute of Internal Combustion Engines (Tianjin Motorcycle Technology Center)	天津内燃机研究所（天津摩托车技术中心）

Chen Lingling	陈玲玲	Changsha Automotive Electrical Testing Center	长沙汽车电器检测中心有限责任公司
Rong Hui	戎辉	China Automotive Research Institute (Tianjin) Automotive Engineering Research Institute	中汽研（天津）汽车工程研究院有限公司
Cui Qiang	崔强	China Electronics Standardisation Institute	中国电子技术标准化研究院
Yang Zhifeng	杨支峰	Suzhou Electrical Apparatus Research Institute	苏州电器科学研究院股份有限公司
Gong Baoquan	龚宝泉	FAW Group	中国第一汽车集团有限公司
Ma Xilai	马喜来	FAW Jiefeng Automobile	一汽解放汽车有限公司
Wu Dingchao	吴定超	FAW-VW Automotive	一汽-大众汽车有限公司
Gao Yuan	高远	FAW Toyota Technology Development	一汽丰田技术开发有限公司
Liu Shuangping	刘双平	Dongfeng Commercial Vehicle Co., Ltd. Dongfeng Commercial Vehicle Technology Center	东风商用车有限公司东风商用车技术中心
Wang Wei	汪巍	Dongfeng Motor Group	东风汽车有限公司
Wang Yan	王焱	DPCA Automobile	神龙汽车有限公司
Zhang Haitao	张海涛	SAIC Group	上海汽车集团股份有限公司技术中心
Shen Xiaobin	沈晓斌	SAIC Maxus Automobile	上汽大通汽车有限公司
Dan Zhangwei	单长伟	Nanjing Automobile Group	南京汽车集团有限公司汽车工程研究院
Sun Jing	孙竞	Pan Asia Automotive Technical Center	泛亚汽车技术中心有限公司
Yu Zhaofeng	余召锋	SAIC Volkswagen	上汽大众汽车有限公司
Deng Fuqi	邓福启	SAIC-GM-Wuling Automobile	上汽通用五菱汽车股份有限公司
Zhu Ye	朱晔	BAIC Motor	北京汽车股份有限公司
Zhang Lifeng	张立峰	Beiqi Foton Motor	北汽福田汽车股份有限公司
Gao Xinjie	高新杰	Beijing Electric Vehicle	北京新能源汽车股份有限公司
Cao Shanggui	曹尚贵	Chery Automobile	奇瑞汽车股份有限公司
Zheng Fangfang	郑芳芳	Anhui Jianghui Automobile Group	安徽江淮汽车集团股份有限公司
Ma Qian	马谦	Geely	吉利汽车研究院（宁波）有限公司
Wu Shaohua	吴少华	Great Wall Motor	长城汽车股份有限公司
He Wen	何文	Chongqing Changan Automobile	重庆长安汽车股份有限公司
Zhong Yilin	钟益林	BYD	比亚迪汽车工业有限公司
Xuwei	徐伟	GAC Group	广州汽车集团股份有限公司
Cheng Bin	程斌	Brilliance	华晨汽车集团控股有限公司
Chen Hongjuan	陈鸿娟	BMW Brilliance	华晨宝马汽车有限公司
Bai Bin	白冰	Haima Automobile	海马汽车有限公司
Lu Changjun	卢长军	Zhengzhou Yutong Bus	郑州宇通客车股份有限公司
Li Zhiqiang	李志强	Xiamen King Long United Automobile Industry	厦门金龙联合汽车工业有限公司
Guo Qingbo	郭庆波	China National Heavy Duty Truck Group	中国重型汽车集团有限公司
Jia Yi	贾谊	Toyota Motor (China)	丰田汽车（中国）投资有限公司
Zhang Xiaodong	张笑冬	United Automotive Electronic Systems	联合汽车电子有限公司
Liao Jianxiong	廖剑雄	Huizhou Desay SV Automotive Electronics Co	惠州市德赛西威汽车电子股份有限公司

Shi Lihui	师立辉	Neusoft Group	东软集团（大连）有限公司
Shi Xiaomi	史晓密	Beijing Xingkedi Technology	北京兴科迪科技有限公司
Luo Xiaoping	罗小平	Shenzhen Longhorn Automotive Electronic Equipment	深圳市豪恩汽车电子装备股份有限公司
Huang Tian	黄田	Hangzhou Haikang Automotive Technology Co	杭州海康汽车技术有限公司
Liu Yunxia	刘云霞	Changzhou Xingyu Auto Lamp Co	常州星宇车灯股份有限公司
Zhang Wei	张伟	CATL	宁德时代新能源科技股份有限公司
Gao Yongqiang	高永强	Huawei	华为技术有限公司
Zhang Peng	张鹏	Weikai Testing Technology	威凯检测技术有限公司

APPENDIX C: Technical requirements for facial recognition sample data (GB/T 41772-2022)

SAMPLE QUALITY

ITEM		REQUIREMENT		
		SAMPLE FOR FACE REGISTRATION	SAMPLE FOR MATCHING IDENTIFICATION	SAMPLE FOR NON-MATCHING IDENTIFICATION
Face size	Interpupillary distance	>60 pixel	>50 pixel	>40 pixel
Clarity	Gaussian blur	<0.24	<0.25	<0.30
	Motion blur	>0.15	>0.20	>0.26
	Laplacian variance	>500	>350	>200
Posture	Horizontal rotation angle	-10°~10°	-20°~20°	-45°~45°
	Pitch angle	-10°~10°	-15°~15°	-20°~25°
	Tilt angle	-10°~10°	-15°~15°	-20°~25°
Completeness	Geometric distortion	<5%	<10%	<15%
	Eyebrow visibility	100%	>90%	>75%
	Eye visibility	100%	100%	100%
	Nose visibility	100%	>95%	>85%
	Mouth visibility	100%	100%	100%
	Cheek skin visiblity	100%	>85%	>75%
Fidelity	Makeup and retouching	None	None	None
Illumination	Uniformity	No light spots	No light spots and shadow/light face	No light spots and shadow/light face
	Overall luminosity	No overexposure or underexposure	No overexposure or underexposure	No overexposure or underexposure
	Grayscale	Level 256	Level 256	Level 256
	Grayscale dynamic range (85-200 grayscale value ratio)	>95%	>90%	>80%
Expression	Expression category	Neutral	Neutral or smiling	Neutral or smiling
	Eyes open or close	Naturally open	Naturally open	Naturally open
	Mouth open or close	Naturally close	Naturally closed or slightly open	Naturally closed or slightly open

Digital and Green Transitions: Opportunities and Challenges for Europe and China

Davide Bonaglia, Rasmus Lema, María de las Mercedes Menéndez and Roberta Rabellotti

ABSTRACT

The digital and green transitions are crucial to the competitiveness of Europe and China. To strengthen their innovation efforts in this direction, it is essential to develop a technology ecosystem that promotes transdisciplinary research and combines digital and green knowledge. This chapter explores how the knowledge base in 'twin' digital and green technologies is developing in the European Union, the United Kingdom and China in comparison with other major players on the global technology scene such as the United States, Japan and South Korea. It investigates the Chinese policy programmes adopted to strengthen the knowledge base in this key area and analyses green digital patents. We conclude that Europe has an advantage over China in most of the twin transition technological areas investigated, but Europe has a few leading edges in the wider global landscape. The chapter emphasises the need for both competition and collaboration between the EU and China in driving the global sustainability goals with these technologies, which calls for ambitious public policies and collaborative efforts to address the challenges in greening digital technologies.

SCORECARD 1 TECHNOLOGY FIELD: DIGITAL AND GREEN TRANSITIONS

Source of European technology strength	Research and innovation	Intellectual property and patents	Production and commercialisation
	Not feasible	● Medium	Not feasible

Type of European technology strength	Technological excellence	Commercialisation advantage	Conditioning of market access	Regulatory, political and normative factors	Sustainability	Research partnerships with third countries
	X	X	X	X	X	

Degree of European leverage	Low	Medium	High

INTRODUCTION

The combined digital and green transition will enhance resilience and sustainability, and create business opportunities. Each has the potential to make countries more environmentally responsible, while at the same time opening up new business opportunities for companies. Both transformations are widely considered crucial for the future competitiveness of national economies. Nonetheless, there is still relatively little overlap in the global policy arena in relation to environmental digitalisation and sustainability.

The urgent need to better understand the interactions between the digital and green transitions is clearly recognised in the European Commission's 2022 Strategic Foresight Report.[1] The report states that digital technologies can provide functions that catalyse the green transition, such as monitoring and tracking to propel the circular economy. In the United Kingdom, the British government has launched a Knowledge Asset Grant Fund that prioritises projects aimed at achieving sustainability in the digital economy.[2] China's 14th Five-Year Plan for Energy Technology Innovation highlights high-quality green development and emphasises that innovation is

---

[1] European Commission, "2022 Strategic Foresight Report: Twinning the Green and digital transitions in the new geopolitical context", 29 June 2022, accessed 15 April 2024, at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0289.

[2] See https://gott.blog.gov.uk/2023/06/16/highlighting-digital-and-green-projects-in-gotts-autumn-knowledge-asset-grant-fund-round/.

at the core of modern development, stressing that the country is entering a new phase of accelerated digitised development.[3]

Developing the full potential of the digital and green transitions globally will depend on the ability to develop new knowledge and technologies that combine both elements. To foster innovation efforts in this direction, it is essential to develop a technological ecosystem that promotes transdisciplinary research and combines digital and green knowledge to enable transformational change.

At the same time, digital and green technologies are increasingly seen through the lens of competition and technological sovereignty, and the aim of mitigating potential strategic dependencies on geopolitical rivals.[4] Many of the most relevant technological ecosystems are deeply transnational, however, and technological relationships are shaped by the relative strength of technological capabilities in different countries and regions.

Against this backdrop, the paper investigates how the knowledge base for digital and green technologies is developing in the European Union, the United Kingdom and China, compared with the other main protagonists on the global technological scene: the USA, Japan and South Korea. We use patents as a proxy for knowledge in digital and green technologies.

While such a broad analysis cannot clearly identify the technological niches in which Europe is technologically superior, the paper does provide pointers for a further exploration of general strengths and weaknesses in Europe and China that can pinpoint future areas of technological priority and assess the relevance of policy ambitions such as those described in the introduction to this report.

CHINA'S CURRENT POLICY FRAMEWORK FOR A GREEN AND DIGITAL TRANSFORMATION

The overlapping green and digital transitions constitute a policy priority for China. Both the academic Chinese-language literature and core Chinese policy documents underline the strategic importance of what in Europe is referred to as the "twin transition". At the same time, however, exploring the interlinkages between both transformations is still in its infancy, opening a window of opportunity for Europe to explore where the room for developing technological strengths or even indispensability could be.

China's policies on the digital and green transitions have gathered pace in recent years, especially since 2021 when decarbonising the economy was first made a central objective by Xi Jinping at the Asia-Pacific Economic Cooperation (APEC) Chief Executive Officer Summit. Several sectoral development plans now target the issue and digital technologies feature prominently.

Given its national scope, the Plan for the Overall Layout of Building a Digital China (2023) by the Central Committee of the Chinese Communist Party (CCP) and the State Council is especially important. The plan calls for the development of a "green and intelligent digital ecological civilisation" and emphasises acceleration of the coordinated transformation of digitalisation and greening.[5] Ministerial documents, such as the White Paper on the Synergistic Development of Digitalisation and Greening (2023) published by the Ministry of Information and Communication Technology, and the cross-ministerial Implementation Plan for Green and Low-Carbon Advanced Technology Demonstration Projects (2023), have also begun to use the term.[6] Several earlier national, sectoral and local development plans, not least 14th Five-year Plan, as well as regulations and industrial plans also span the intersection of digital development and innovation, and green transformation and decarbonisation. A few representative examples below explain the thrust of these national and sectoral policies regarding the digital green transformation.

---

[3] Government of China, "十四五"能源领域科技创新规划" [14th Five-Year Plan for Energy Technology Innovation], accessed 15 April 2024, at https://www.gov.cn/zhengce/zhengceku/2022-04/03/5683361/files/489a4522c1da4a7d88c4194c6b4a0933.pdf

[4] Edler, J. et al., "Technology sovereignty as an emerging frame for innovation policy: Defining rationales, ends and means", *Research Policy*, vol, 52, no, 6, 104765, 2023, https://doi.org/10.1016/j.respol.2023.104765

[5] Government of China, Plan for the Overall Layout of Building a Digital China, 27 February 2023, accessed 15 April 2024, at https://www.gov.cn/zhengce/2023-02/27/content_5743484.htm

[6] Government of China, White Paper on the Synergistic Development of Digitalisation and Greening, accessed 15 April 2024, at http://www.caict.ac.cn/kxyj/qwfb/bps/202301/P020230107860562732799.pdf; and Government of China, Implementation Plan for Green and Low-Carbon Advanced Technology Demonstration Projects, accessed 15 April 2024, at https://www.ndrc.gov.cn/xwdt/tzgg/202308/P020230822522890144093.pdf

It was recognised early on that digital solutions can make energy systems and industry more efficient, flexible and integrated, and these qualities are identified in China's policies on related issues. The efficiency gains of data-driven governance of resources and energy, as well as industrial operations were targeted in the National Informatisation Development Strategy of 2006.[7] China's national framework policy on decarbonisation, the so-called 1+N policy, only mentions digitalisation once, however, aiming to drive integrated development of digital, smart, and green technology in the industrial domain.[8]

The Outline of the National Digitisation Strategy is one of the few strategic policy documents in which green development is integrated with digitalisation. It addresses two main issues: establishment of a data registry on resources (management); and information disclosure for better governance, such as regulating pollution and driving a circular economy.[9] In addition, the 2018 Circular Economy Promotion Law (revised from 2008) connects digitalisation with green development. Again, the focus is on the benefits of efficiency and savings, including recycling, that digitalisation and data-driven management can offer.

Better resource management and more efficient use are seen as important areas to which digital technology is a stepping stone. While national/sectoral policy is not yet as specific, a data infrastructure capable of delivering a reliable monitoring, reporting and verification (MRV) system for environmental and resource data is seen by industry insiders as the target of these policies. MRV systems are also a central requirement of China's key systems for industry regulation and carbon pricing, such as the emission trade system. The importance of such data systems is again mentioned in the authoritative 2021 Notice of the Comprehensive Work Plan for Energy Conservation and Emission Reduction in the 14th National Five-year Plan.[10]

The 14th National Five-year Plan makes clean energy one of the main areas supported, and a strategic emerging industry. While not directly connected with digitalisation, data and digital infrastructures are recognised as a requirement for the development and use of new green tech in the energy sector, and for a systemic shift to sustainability.[11]

The sectoral five-year plans are slightly more specific on this issue. The 14th Five-year Plan for Energy Technology Innovation, for example, outlines that digitalisation to advance so-called clean coal technology is an important factor. Smart solutions are seen as improving hydropower and urban power system usage. Digital energy technologies – especially the power grid – are targeted as one of the five main areas of innovation. While dependence on foreign suppliers is a major concern here, the green dimension of energy technology innovation plays an important role in these strategic development plans, as decarbonisation and future market opportunities are sought.[12]

In addition, the 14th Five-year Plan for National Informatisation discusses synergies between digital and green development, listing the "building of a green, smart, ecological civilisation, and promoting digitised and greened coordinated development … broadening smart green manufacturing, green efficient energies, and the greening of information carriers; develop smart logistics; advocate for low-carbon transportation".[13] More recently, driving the development of data centres as the backbone of digital and data-driven governance and resource management was targeted in the Recommendations on the Work of the National Green Data Centre.[14]

---

[7] Government of China, National Informatisation Development Strategy of 2006, accessed 15 April 2024, at https://www.gov.cn/gongbao/content/2006/content_315999.htm

[8] State Council of China, Action Plan for Carbon Dioxide Peaking Before 2030, 24 October 2021, accesses 10 April 2024, at https://www.lawinfochina.com/display.aspx?id=36700&lib=law

[9] Zhenghzhou Foreign Investment Service Center, "中共中央办公厅国务院办公厅印发《国家信息化发展战略纲要》（全文）" [The General Office of the CPC Central Committee and the General Office of the State Council issued the "National Informatization Development Strategy Outline" (full text)], accessed 15 April 2024, at https://www.waizi.org.cn/law/12015.html.

[10] Government of China, "国务院关于印发"十四五"节能减排综合工作方案的通知" [Notice of the Comprehensive Work Plan for Energy Conservation and Emission Reduction in the 14th National Five-year Plan], accessed 15 April 2024, at https://www.gov.cn/zhengce/content/2022-01/24/content_5670202.htm

[11] 14th Five-Year Plan for National Informatisation, December 2021, Translation by stanford.edu,

[12] Government of China, "十四五"能源领域科技创新规划" [14th Five-Year Plan for Energy Technology Innovation], accessed 15 April 2024, at https://www.gov.cn/zhengce/zhengceku/2022-04/03/5683361/files/489a4522c1da4a7d88c4194c6b4a0933.pdf

[13] 14th Five-Year Plan for National Informatisation, op cit.

[14] National Energy Administration, "国家能源局关于加快推进能源数字化智能化发展的若干意见国能发科技〔2023〕27号–国家能源局网站" [Several Opinions of the National Energy Administration on Accelerating the Development of Energy Digitalization and Intelligent Development Guonengfa Technology [2023] No. 27], accessed 15 April 2024, at http://www.nea.gov.cn/2023-04/07/c_1310709025.htm.

To conclude, China's policy framework for integrating the digital and green transitions is yet to be formulated in an integrated or strategic way. China acknowledges its importance but is yet to tap into the potential. While national development plans are less specific, they target the benefits of increased efficiency, the resource savings that come with digitalisation and data-driven governance. At the sectoral, local and industrial levels, policies are becoming more targeted and effective at achieving these ends. Based on the existing policy and initiatives, there will be a marked increase in more specific policies and technical solutions in the coming months and years, and institutional and industrial developments that deepen China's green and digital transformation should be expected. The policy focus on decarbonisation and the concerted push to make China's green tech industry a world leader are indirectly driving these developments.

The topic of the twin transition is still in its infancy. The tiny body of existing literature focuses on the importance of digitalisation and green innovation if Chinese manufacturing companies are to achieve the country's carbon emissions goals, mainly focused on A-Listed firms and the extent to which digital adoption reduces emissions. This situation opens a general opportunity for Europe. China may have identified the crucial importance of the twin transition, but it is yet to formulate detailed policies that reflect its strategic relevance. This makes it particularly worthwhile for the EU and the UK to explore strengths that could ultimately pave the way to technological indispensability. The patent analysis below provides early pointers on the most promising areas from which such strengths or even indispensability could arise.

DIGITAL AND GREEN INNOVATIONS

Digital and green technologies: conceptualisation and identification

The Paris Agreement has brought the interaction between digital and green technologies to the fore as a key issue in the scientific community and among international organisations, to keep global warming below 2 degrees Celsius above preindustrial levels by 2050. Digital technologies play a significant role in enabling more efficient production and consumption, through efficiency gains, dematerialisation, virtualisation and optimisation. This, in turn, reduces end-use demand and promotes material efficiency and circularity.

Digital general-purpose technologies (GPTs) were recently defined by the World International Patent Office (WIPO) as ubiquitous, spurring innovation in complementary fields and able to be applied across many sectors and industries.[15] GPTs emerged because of the general digitalisation of three interrelated but separate scientific fields: robotics, neural networks and symbolic systems. The WIPO identifies five types of digital GPTs: artificial intelligence (AI) and machine Learning (ML), autonomous systems, big data, cloud computing, and the Internet-of-Things (IoT) and Robotics.[16] Digital GPTs can help to develop more energy efficient products and systems, and have the potential to accelerate clean energy innovation, which is critical for reducing carbon emissions.

Green technologies, or more broadly speaking *sustainable innovations*, are not linked to specific sectors or industries. Various terms are used to identify them, given that no international agreement exists on their conceptualisation.[17] The lack of a standardised classification represents a challenge to understanding their potential transfer;[18] and to investigating how they are interlinked.[19] One possible way to measure green innovations is through patents. This study uses the Y02 and Y04S patent classes proposed by the European Patent Office (EPO) to identify climate change mitigation technologies.[20]

---

[15] General Purpoe Technologies (GPTs) are characterised by their ubiquity, inherent potential for technical improvement and innovative complementarities. Technologies such as AI, big data and deep learning exhibit GPT characteristics. World International Patent Office, World Intellectual Property Report, 2022: The direction of innovation. Geneva, 2022.

[16] This study relies on digital GPTs patent data provided by the WIPO based on PATSTATS (spring 2023 edition). The identification of digital GPTs patents relies on Cooperative Patent Classification (CPC) codes and keywords. See the Technical note in World International Patent Office, op. cit. (note 14).

[17] Degler, T., Agarwal, N., Nylund, P. A. and Brem., A., Sustainable Innovation Types: a Bibliometric Review, in *International Journal of Innovation Management*, vol. 25, no. 9, pp. 1–34, November 2021, doi: 10.1142/S1363919621500961

[18] Guo, R. et al., 'Classifying Green Technologies for Sustainable Innovation and Investment', in *Resources, Conservation and Recycling*, vol. 153 pp. 1–13, February 2020, doi: 10.1016/j.resconrec.2019.104580

[19] Guo et al., op cit.

[20] This patent methodology can only be applied to patents with a CPC code. It has been widely used by European Commission

TABLE 1: Climate change mitigation technologies and smart grids

CPC	DESCRIPTION	KEYWORDS
Y02	**Technologies or Applications for Mitigation or adaptation against climate change**	
Y02A	Technologies for adaptation to climate change	Adaptation
Y02B	Climate change mitigation technologies related to buildings	Buildings
Y02C	Capture, storage, sequestration, or disposal of greenhouse gasses	Greenhouse gas capture and storage
Y02D	Climate change mitigation technologies in information and communication technologies	Green-ICT
Y02E	Reduction of greenhouse gas emissions related to energy generation, transmission, or distribution	Energy
Y02P	Climate change mitigation technologies in the production or processing of goods	Production
Y02T	Climate change mitigation technologies related to transportation	Transports
Y02W	Climate change mitigation technologies related to wastewater treatment or waste management	Waste
Y04	**Information or communication technologies with an impact on other technology areas**	
Y04S	Systems integrating technologies related to power network operation, communication, or information technologies for improving electrical power generation, transmission, distribution, management or usage, i.e. smart grids	Smart Grids

- Y02 comprises “technologies or applications which in the broadest sense can be considered as countering the effects of climate change, namely technologies or applications which can decrease greenhouse gasses (GHG) emission or remove (and store) GHG from the atmosphere”.

- Y04S comprises Smart Grids and is closely connected to Y02.[21]

Table 1 shows the green technologies, their descriptions and the associated keywords in the Y02/Y04S patent classes. Our dataset includes 66,648 patent applications for digital GPTs assigned to companies or institutions, that were tagged with at least one Y02/Y04 class in the period 2000–2022.[22]

Figure 1 shows the global evolution of digital green technologies since 2000, indicating an increase since the 2010s. Nonetheless, digital technologies marked

---

studies, see Bellucci, A. et al. “Venture Capital Financing and Green Patenting”, in *Industry and Innovation*, vol. 30, no. 7, pp. 947–983, 2023. There are other methodologies for identifying green patents, such as the IPC Green Inventory proposed by WIPO and ENV-TECH proposed by the OECD. All of these are complementary and overlap only partially, see Favot, M. et al., “Green Patents and Green Codes: How Different Methodologies Lead to Different Results”, in *Resources, Conservation & Recycling Advances*, 18, 2023, https://doi.org/10.1016/j.rcradv.2023.200132.

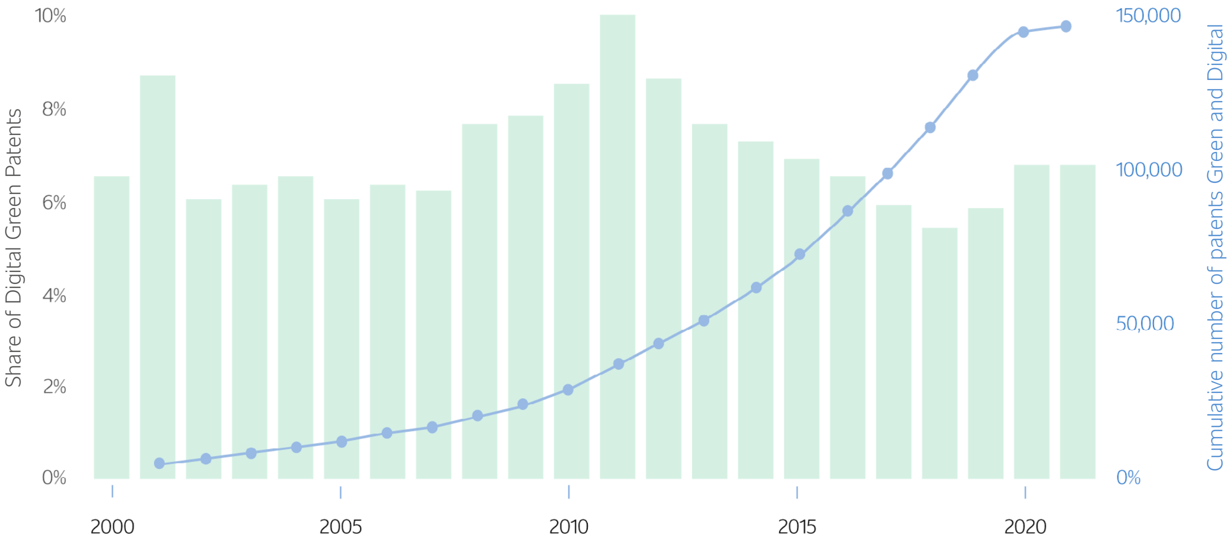
[21] Angelucci S, Hurtado-Albir FJ and Volpe A. “Supporting Global Initiatives on Climate Change: The EPO’s “Y02-Y04S” Tagging Scheme’, in *World Patent Information*, vol, 54, pp. S85-S92, September 2018, doi: 10.1016/j.wpi.2017.04.006

[22] See Appendix 2 for the detailed procedure adopted to build the database.

Y02/Y04S represent on average just 7% of total digital technologies, confirming previous evidence that the digital green transition is still at a very early stage globally.[23] In addition, Figure 1 confirms that green digital patent applications peaked at 10% between 2011 and the end of the study period. One explanation for this decline is that the period coincides with a decline in the price of fossil fuels, which has discouraged innovation related to low-carbon energy supply technologies.[24] Patent applications filed in at least one of three patent offices – the US Patent Office (USPTO), the Japan Patent Office (JPO) and the European Patent Office (EPO) – are included in the dataset. These three patent offices are believed to ensure a certain level of originality and expected commercial value on the global market of the patents they issue.[25]

Figure 2 shows the cumulative evolution of digital green patents by GPT category. Again, a trend of growth can be seen for all technologies since the 2010s. The figure also suggests that integration between digital GPTs and green technologies is more common in technologies such as AI, autonomous systems and robotics, and to a lesser extent in big data, the IoT and cloud computing.[26]

FIGURE 1: Digital green patents and share



Note: This graph includes all digital green patents without considering the national or regional jurisdictions in which they were issued, and thus differs from the rest of the analysis. Source: own elaboration based on PATSTAT.

---

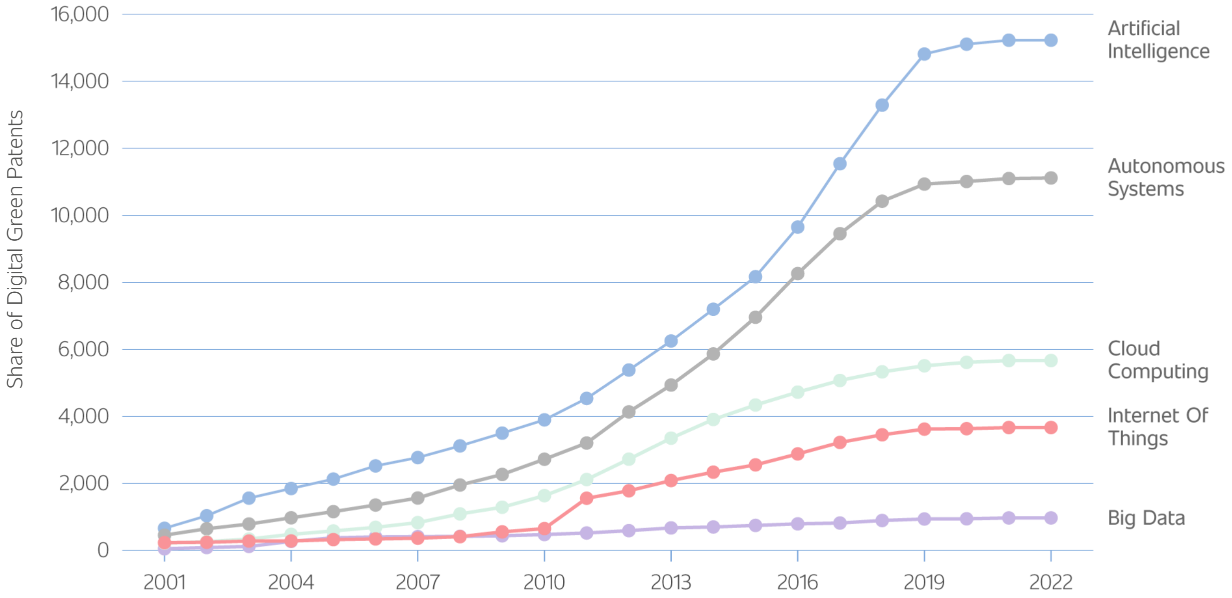
[23] Jindra, B. and Leusin, M., *The Development of Digital Sustainability Technologies By Top R&D Investors*. Publications Office of the European Union: Luxembourg, JRC130480, 2022.

[24] See IEA, *Patents and the Energy Transition*, IEA: Paris, 2021, accessed 28 March 2024, at https://www.iea.org/reports/patents-and-the-energy-transition and EIB, *Investment report 2020/2021: Building a Smart and Green Europe in the Covid-19 Era*. 2021 doi:10.2867/904099

[25] We therefore exclude from the dataset patents only filed at the China National Intellectual Property Administration (CNIPA). The increase in Chinese patents filed abroad is a relatively recent phenomenon: at USPTO Chinese applications have increased from 0.11% in 1995 to 11% in 2019 as a proportion of total patents granted. Wu, H., Lin, J. and Wu, H. M., “Investigating the real effect of China’s patent surge: New Evidence from Firm-level Patent Quality Data”, in *Journal of Economic Behavior & Organization*, no. 204, pp. 422–442, 2022. Although China has become a major patent player, applications filed solely at the CNIPA are considered less technologically relevant, due to controversies related to uncertainties over the rule of law and patent intellectual property rights protection. Hu, A. G. and Jefferson, G. H., “A Great Wall of Patents: What is Behind China’s Recent Patent Explosion?”, in *Journal of Development Economics*, vol. 90, no. 1, pp. 57–68, 2009.

[26] The stagnation in the number of patents at the end of the period is explained by the usual time lag of approximately 18 months between when the patent is filed and when it is published.

FIGURE 2: Cumulative evolution of digital green technologies by GPTs categories



Note: This graph includes patents applied for in the US, Japan or European PO. Source: own elaboration based on WIPO.

Country analysis

Table 2 shows the number of digital green GPTs patents at the country level.[27] It shows that Chinese applications represent just 5% of the total while the joint share of the European Union and the United Kingdom's patents is 18% – slightly more than Japan. Within Europe, there are significant disparities in digital green patenting. Germany is the country with the most patents, followed by France, the Netherlands, Italy and Sweden.[28] It also shows that almost half the patent applications associated with the digital green transition are located in the USA.

Analysis by technologies

Among the different green technologies, 20% of digital green GPT applications are related to smart grid technologies (Y04S), followed by 18% of applications related to technologies to reduce the impact on climate change in the production of goods (Y02P). The share of Climate change technologies related to buildings (Y02B) is 14% and applications related to clean transport (Y02T) 13%. The remaining technologies are shown in Figure A1 in the Appendix.

An interesting picture of digital green GPTs can be obtained by accounting for their different categories. Figure 3 shows the distribution of patents with the Y02/Y04S tag by GPTs category. It shows that most of the classes of green technology combine with AI technologies. However, in the case of green technologies related to Information and Communication Technologies (Y02D), there is a more balanced integration with other technologies such as cloud computing and the IoT. In the case of green technologies related to the production of goods, there is a greater integration with robotics technologies. It is no surprise that the dominant technologies in green transport-related technologies (Y02T) are those related to autonomous systems.

Figure 4 shows the distribution of Y02/Y04S by applicant country. Applicants in the jurisdictions under consideration focus their applications on different mixes of climate change mitigation technologies. Chinese applications for digital green GPTs are more focused on green ICT technologies. The picture is different in the case of Germany, where applications are concentrated on climate change mitigation technologies in the production

---

[27] For a detailed explanation of how patents are attributed to countries see Appendix 2.

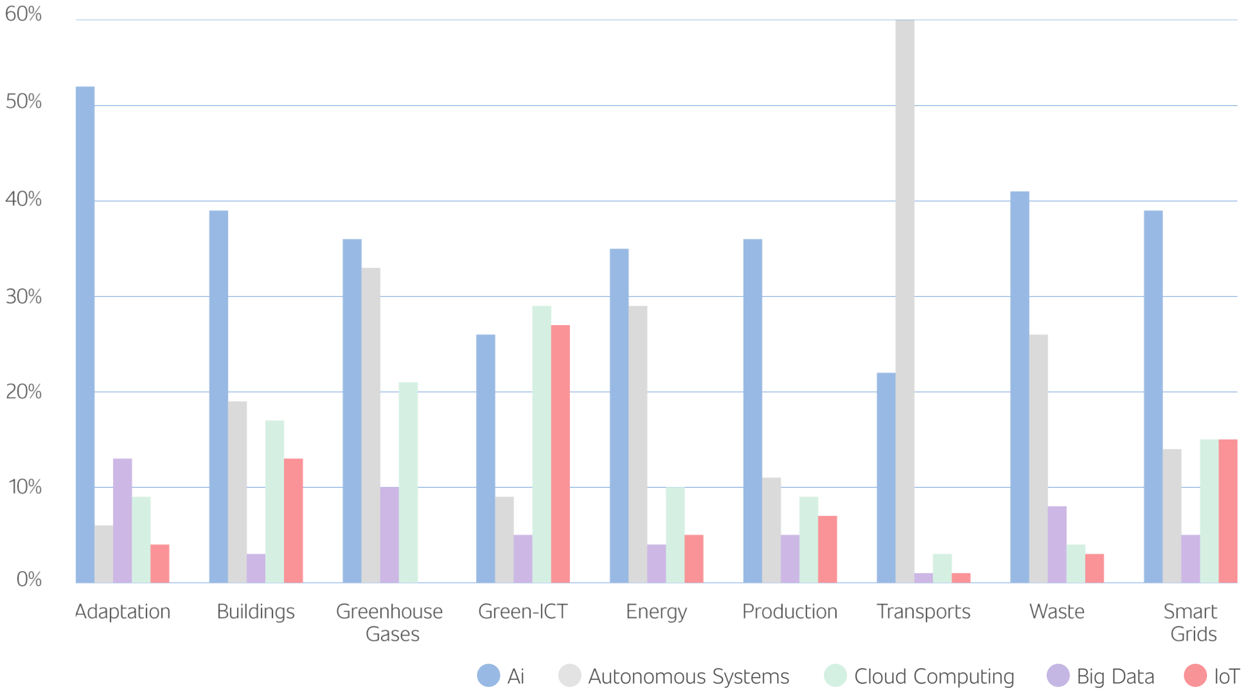
[28] For the distribution of patents among EU member states see Table A1.

TABLE 2: Digital green patent applications by countries, 2000–2022

COUNTRY	NUMBER OF PATENTS	SHARE
United States	30,873.3	46.32%
Japan	11,858.7	17.79%
Europe	10,138.0	15.21%
• Germany	4,508.9	6.8%
• France	1,633.8	2.5%
• Netherlands	803.5	1.2%
• Italy	713.3	1.1%
• Sweden	702.0	1.1%
• Rest of Europe	1,776.5	2.67%
South Korea	3,714.2	5.57%
China	3,321.0	4.98%
United Kingdom	1,879.4	2.82%
Canada	1,228.1	1.84%
Switzerland	1,068.3	1.60%
Israel	796.3	1.19%
Australia	448.5	0.67%
Rest of the World	1,322.3	1.98%
Total	66,648	100%

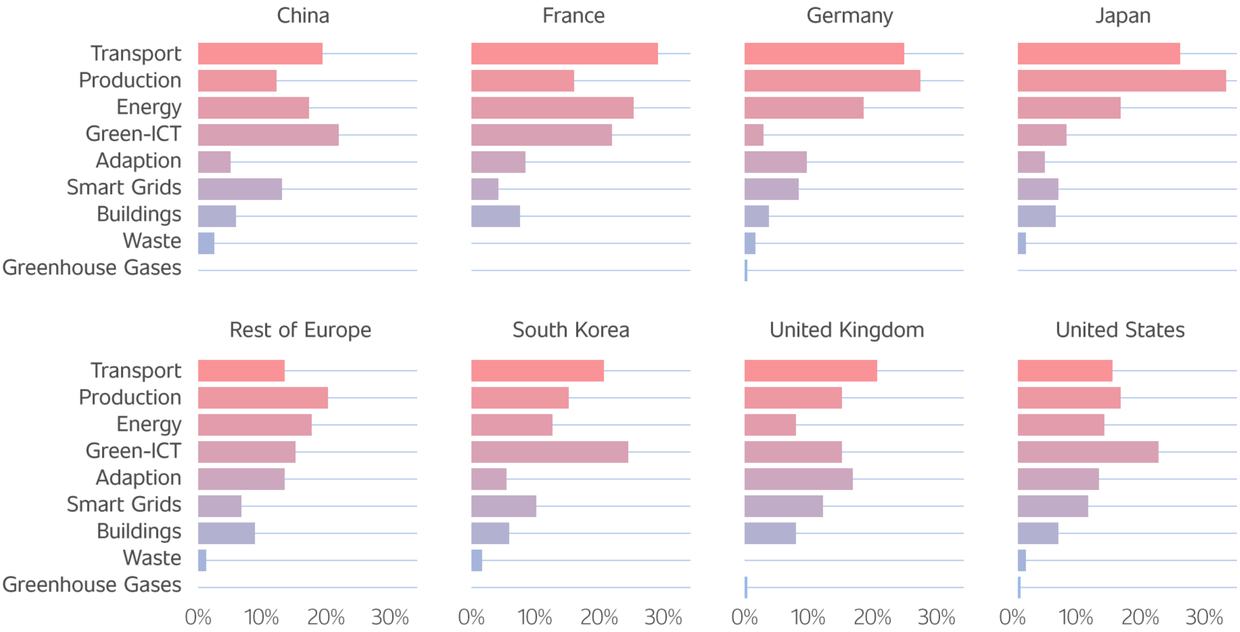
Source: own elaboration based on WIPO.

FIGURE 3: Digital green technologies with Y02/Y04 tag by GPTs category (% applications)



Source: own elaboration based on PATSTAT.

FIGURE 4: Distribution of Y02 per applicant country



Source: own elaboration based on PATSTAT.

of goods and green transport technologies. In the case of the UK, while the main specialisation is in green transport, applications cover all types of technologies evenly. Of the remaining competing countries, Japanese patent specialisation is even more skewed towards green goods production. South Korea's specialisation, like China's, is localised on green ICT. A similar picture can be observed in the United States, where green ICTs are the most important.

Technological specialisation

Revealed Technology Advantage (RTA) is a measure of the relative technological specialisation of a country with respect to other countries. Box 1 explains the index in more detail.

In tables 3 to 5, the countries under analysis are relatively specialised in one of the nine green technologies if their RTA is positive. The same index is calculated for the GPT categories. It is worth noting that this index sheds some light on the technological capabilities of each country but does not provide any information about the quality of these capabilities.

Table 3 shows that the EU member states are relatively specialised in technologies related to buildings (Y02B), greenhouse gas (GHG) capture and storage technologies (Y02C), technologies related to energy (Y02E), clean transport (Y02T) and waste management (Y02W). Tables A2 and A3 in the Appendix show the

WHAT IS REVEALED TECHNOLOGY ADVANTAGE?

Revealed Technology Advantage (RTA) is defined as the share of a technology in a country's overall patents divided by the global share of this technology in all patents. For example, Denmark is highly specialised in wind technology. Although the country accounted for less than 0.7% of all patents globally between 2012 and 2014, Danish inventors developed around 16% of all wind technology patents in this period.

Source: The RTA in a technological sub-class "i" (e.g. Y0A) in the country "j" is calculated as the share of a country "j" patents in "i" technological subclass relative to the share of country in total patents. The RTA is re-scaled (RTA-1)/(RTA+1) to obtain continuous and more symmetric values.

TABLE 3: Positive RTAs: Green Technologies

Y02A	Adaptation	UK, USA
Y02B	Buildings	UK, EU
Y02C	GHG capture and storage	UK, EU, USA
Y02D	Green-ICT	China, USA
Y02E	Energy	China, EU, Japan
Y02P	Production	Japan
Y02T	Transport	China, UK, EU, Japan
Y02W	Waste	China, EU
Y04S	Smart Grids	UK, USA

TABLE 4: Positive RTAs: General Purpose Technologies

ARTIFICIAL INTELLIGENCE	USA
AUTONOMOUS SYSTEMS	EU, China, Japan
BIG DATA	EU, USA
CLOUD COMPUTING	USA
INTERNET OF THINGS	UK, China, USA
ROBOTICS	EU, UK, Japan

Source Table 3: own elaboration based on WIPO | Source Table 4: XXX

detailed calculations. The UK achieves the highest RTA for GHG capture and storage technologies (Y02C) and is relatively specialised in technologies related to climate change adaptation (Y02A), buildings (Y02B), clean transport (Y02T) and smart grids (Y04S). China has a relative technological specialisation in climate change technologies in ICT (Y02D), technologies related to energy (Y02E), transport (Y02T) and waste management (Y02W).

On GPTs, Table 4 (and Table A4) confirms that the relative specialisation of countries in these technologies varies widely. The EU has high RTA scores in autonomous systems, big data and robotics. The UK is technologically specialised in the IoT and robotics. China has a relative technological specialisation in autonomous systems and the IoT. More disaggregated figures for the EU member states (Table A5) confirm a technological specialisation in autonomous systems and robotics, mainly led by technologies linked to the production of products, energy and transport. Among the EU member states, France has a high RTA only in autonomous systems, Germany has an RTA above zero in autonomous systems and robotics while Finland stands out for having an advantage in cloud computing and the IoT, which is strongly related to connectivity and can be explained by Nokia, a key player in this field.[29]

Finally, Tables A.6 and A.7 combine a specialisation in green technologies with GPTs. The EU stands out for its integration of big data with technologies related to buildings, energy and transport, as well as the IoT in combination with waste management. The UK has a relative specialisation in combining digital technologies with green technologies in climate change adaptation (robotics and the IoT), and with GHG capture and storage technologies (i.e. cloud computing and AI). China's relative technological specialisation combines technologies related to waste management with autonomous systems, robotics and AI, as well as big data with technologies related to transport and buildings.

---

[29] EPO, Patents and the Fourth Industrial Revolution: The Global Technology Trends Enabling the Data-Driven Economy. 2020.

Analysis by patent value

This section evaluates the commercial potential and technological impact of digital and green innovations by analysing patents' forward citations. Forward citations occur when a patent refers to another one, signalling that the original patent has been influential in the development of subsequent technologies.[30] The higher the number of forward citations, the more valuable the patent.[31]

Table 5 provides a detailed look at the 10% most cited patents to explore the disparities between China, the EU and the UK concerning their influence and contributions to green and digital technologies. "Share of most-cited patents" is the number of most-cited patents for each country in each technology divided by the total number of most-cited patents in that technology. Although, as expected, the USA has a superior role in all digital technologies, European patents are clearly more influential than Chinese ones.

The digital green patents in which the EU is more influential are in autonomous systems. In these technologies, 22% of the most cited patents are produced in the EU, while only 11% are from China. In the AI global landscape, 17% of the EU patents fall into the top 10% in terms of citation distribution, while China has a much lower share of high-impact patents in AI, as only about 3.5% of its AI patents achieve similar recognition. In cloud computing, again 17% of EU patents are among the most cited while only 1% of Chinese patents are in the same category of high value. In robotics, the EU share of top cited patents reaches 15%, while only 3% of Chinese patents are highly cited. In the remaining technologies, big data and the IoT, the EU has respectively 13% and 12% of top-cited patents while for China the shares are 1.5% and 2%. The UK's share of impactful patents is less than 1% in all the technologies investigated.

For the technologies patented by Europe, China and the UK that are in the top 10% of the most cited patents, we investigated which digital green technologies have the highest technological impact.[32] EU innovations in Table 5 have a technological focus on technical processes and systems, automation and control systems and wireless energy transfer. One example is patent US2007112475A1, "Devices, systems, and methods for managing the power consumption of an automotive vehicle, and thereby for optimising the power consumption of the vehicle". This technology acts like a smart brain for cars, helping them to use battery power or fuel more efficiently and in an eco-friendly way. It optimises the way to run the car's engine based on weather conditions, how the car is currently being used and what the driver wants it to do, as well as how the car is performing.

We identified some coincidence between the Chinese patents and the European topics. For example, Chinese innovations have a technological focus on technology and communication, as well as transport and logistics. Automation integration, energy and sustainability are also key focuses of Chinese innovations. For instance, one example of a technology linking the digital and the green is found in the Chinese patent, "Charging and discharging scheduling method for electric vehicles in microgrids under time-of-use price" (US10026134B2). This technology optimises when EVs charge or discharge in a microgrid, factoring in the entire system's make-up and behaviour, battery costs and fluctuating daily electricity prices. This helps to use electricity more wisely and can save money by charging when it is cheaper and giving power back to the grid when it is needed.

For the UK, an example of technology linking digital and green technologies is patent US2010076615A1, Systems, devices and methods for electricity provision, usage monitoring, analysis, and enabling improvements in efficiency. This is a smart assistant for home electricity that manages how power is distributed to gadgets, ensuring they get just the right amount of energy they need. It also helps to use electricity in an eco-friendlier way, making it easier to switch to green and energy-saving devices.

---

[30] Trajtenberg, M., "A Penny for Your Quotes: Patent Citations and the Value of Innovations", in *Rand Journal of Economics*, vol. 21, no. 1, pp. 172–187, Spring 1990, doi: 10.2307/2555502; and Jaffe, A. B. and De Rassenfosse, G., "Patent Citation Data in Social Science Research: Overview and Best Practices", in *Journal of the Association for Information Science and Technology*, vol. 68, no.6, January 2017, pp.1360–1374, doi: 10.1002/asi.23731

[31] For our analysis of forward citations, we considered only patents registered at the US PTO. This choice has the advantage of avoiding geographical bias in the case of EU and Chinese patents but introduces a possible positive bias in the case of US patents. EU patents include those applied for in Belgium, Denmark, Finland, France, Germany, Italy, Spain, Sweden and the Netherlands, which are the EU countries also shown in the tables in Appendix 1.

[32] The analysis was carried out on the titles of the patents shown in Table 3, identifying common characteristics using the language processing tools of ChatGPT.

TABLE 5: Top 10% most cited digital green patents by GPTs, 2011–2020

GPTS	COUNTRY	# OF PATENTS	# OF MOST-CITED PATENTS	SHARE OF MOST-CITED PATENTS (%)
Artificial Intelligence	China	676	21	3.51
	EU	1076	100	16.72
	UK	185	4	0.67
	Japan	1234	58	9.70
	USA	5285	415	69.40
Autonomous Systems	China	478	31	10.76
	EU	967	64	22.22
	UK	138	2	0.69
	Japan	954	8	2.78
	USA	3001	183	63.54
Big Data	China	68	1	1.49
	EU	196	9	13.43
	USA	731	57	85.07
Cloud Computing	China	209	4	1.16
	EU	329	58	16.81
	Japan	270	12	3.48
	USA	2639	271	78.55
Internet of Things	China	211	6	1.97
	EU	223	36	11.80
	UK	96	2	0.66
	Japan	371	48	15.74
	USA	1814	213	69.84
Robotics	China	242	11	2.61
	EU	720	63	14.93
	UK	159	3	0.71
	Japan	920	45	10.66
	USA	2205	300	71.09

Note: this table only considers patents registered at USPTO.

Summary of findings

The EU, the UK and China have all managed to develop some degree of technological specialisation in green digital technologies. The analysis of relative technology specialisation shows that among the different green technologies, the EU and China share a few common areas of technological specialisation in technologies related to energy, transport and waste management. The EU is also technologically specialised in GHG capture technologies (like the UK) and buildings, while China has a specialisation in climate change technologies in ICT. For combined digital and green patents, big data and green technologies related to transport and buildings are common areas of specialisation for both China and the EU.

Nonetheless, the quality of patents measured in terms of the number of forward citations clearly shows that the EU has more impactful digital and green patents compared to China. This means that EU patents are more influential than Chinese patents in all the different technologies investigated. In green AI, Europe has produced five times as many highly cited patents as China. In the field of autonomous systems, Europe has twice as many high-impact patents. Based on our analysis of the value of patents, we can conclude that in the twin transition, Europe has an advantage in all the technological areas investigated compared to China.

Some domains could become the focus of aims to turn Europe into a strategically indispensable player.

- In renewable energy technologies, “peak capabilities” are at the global forefront and this forefront is increasingly connected to the use and integration of digital technologies. Developing innovative energy storage solutions such as next-generation batteries or hydrogen storage systems could provide Europe with a strategic advantage.

- Smart grids and energy storage that facilitate the integration of renewable energy sources into the grid are highly information intensive. Enhancing smart grid technologies and developing sophisticated grid management systems could offer Europe a competitive edge in ensuring the stability and efficiency of its energy networks.

- Finally, European countries have made significant strides in implementing circular economy practices and technologies aimed at reducing waste and maximising resource efficiency. Investing in advanced recycling technologies or developing new materials with a focus on sustainability could position Europe as a leader in the circular economy.

- From the European perspective, the aim should be to combine these areas with digital technologies where Europe has comparative strengths. The digital technologies that could be strategically applied to these domains are AI, cloud computing and autonomous systems.

EUROPEAN LEVEL OF AMBITION AND POLICY RECOMMENDATIONS

In terms of policy implications, in the field of the twin transition technologies there is a delicate balance between cooperation on common challenges and competition to safeguard economic interests and values. The patent analysis suggests that innovative capabilities in most twin transition technologies in China are still a distance behind matching those in Europe.

In this concluding section, we reflect on the potential relevance of the four types of potential ambitions outlined in the introduction to this report. The results of this chapter can form the basis of an analysis to support the identification of general policy ambitions and objectives.

One potential ambition outlined in the introduction to this report is to prevent probable threats understood in terms of the dual-use application of technologies. However, whereas AI, for example, could possibly be applied for dangerous purposes, the use of AI to address environmental objectives poses few dangers. Potential military applications of AI are not the subject of this chapter and few if any digital green technologies fall into this category of dual-use application. Hence, this potential objective has limited relevance.

The potential ambition to create co-dependency in which Europe and China are mutually reliant on each other for their economic development opportunities is more relevant in this context, although there are of course many other countries engaged in twin transition technologies, as this report shows. The patent analysis suggests that Europe is placed strongly enough in several fields of the digital green technologies to make it reflect further on such an ambition of mutual reliance. There are some areas of technology where China and Europe are both relatively specialised, such as big data and green technologies related to transport and buildings, and developing relationships in these fields is a realistic scenario. The EU and the UK could therefore reflect on potential areas for collaboration and on mechanisms for relationship-building that make them relevant cooperation partners in a multi-polar world.

The introduction to this report refers to an ability to act in ways that create or maintain an edge in Europe vis-à-vis the rest of the world. The ambition in terms of

EU- and UK-China relations is to use this edge in ways that would allow Europe to influence or even help to shape technological development in China. The patent analysis provides at least some indication that this level of ambition might be relevant in some digital green technological areas in which Europe has a technological superiority, combining green technology domains with AI, autonomous systems and robotics. It might be in the interests of the EU that China use these digital green technologies, not only from a European economic perspective, but also from a global environmental one.

Finally, the potential ambition to limit technological interactions in digital green technologies, for example by means of export controls, seems both unrealistic and counterproductive. These technologies aim to tackle climate change and biodiversity loss, and to enhance resource efficiency and environmental sustainability in the global interest.

From a European perspective, there may be significant competition in terms of developing the best digital technologies (as shown in many companion studies in this report), but there seems to be significant room to strengthen existing areas of green digital technological strength. It will therefore be important to increase public R&D investments and provide tax incentives to private investors to strengthen the existing areas of technological leadership in this field. Moreover, the EU and the UK should deepen innovation cooperation with relevant partners in the green digital area. This could involve joint projects, knowledge-sharing platforms and funding opportunities aimed at developing green digital technologies.

Another key area of intervention is the contribution of the EU and the UK to defining international technology standards. For example, the EU has expressed concern about the general environment for AI development in China, related to weaker regulation on data protection, thereby undermining the GDPR. Given the EU's emphasis on regulatory frameworks to promote citizens' rights, it could push for collaboration on international standards and regulations, as well as common standards on ethical AI use in environmental monitoring, conservation efforts and sustainable development projects. In general, harmonising digital and green standards and regulations is in the interests of the EU, the UK and China, none or which would benefit from technological decoupling. Joint digital and green standards and a harmonisation of existing ones should be higher up the agenda, despite the complexities this might bring about.

In general, the twin transition technologies present an enormous opportunity for technology to drive global sustainability goals. The EU, the UK and China are investing heavily in green digital technologies and are major competitors in technologies that are expected to become increasingly important in the future. Nonetheless, competition needs to be combined with collaboration, especially in non-competitive fields. To accelerate the green transition, ambitious public policies are needed in both Europe and China to drive innovation, incentivise private sector involvement and ensure that regulatory frameworks support new technology adoption and diffusion. In addition, addressing global challenges, such as cybersecurity in energy systems, to take one example, will require collaborative efforts on shaping international norms and agreements. The EU, the UK and China, as major global actors, will need to collaborate on shaping such international agreements, norms and institutions to promote sustainable development and technological innovation.

Even amid political disagreement, cooperation at the technical level and exchanges in concrete domains should remain possible. It is essential to maintain a long-term perspective, which might offer a different set of opportunities in a rapidly changing global environment.

SCORECARD 2 TECHNOLOGY FIELD: DIGITAL AND GREEN TRANSITIONS

	Threat prevention	Ability to deny	Ability to act	Curtailment
Feasibility of level of ambition	○ Not feasible	● High	● Medium	○ Not feasible
Core policy recommendations	• None	• Innovation cooperation for strategic technology development with like-minded countries	• Public R&D investment • Tax incentives to private investors • European contributions to international technical standards	• None

AUTHORS

Davide Bonaglia is a Research Fellow at WIPO and PhD Fellow at UNU-MERIT.
Contact: davide.bonaglia@wipo.int
Rasmus Lema is Associate Professor at UNU-MERIT. Contact: lema@merit.unu.edu
María de las Mercedes Menéndez is a PhD Fellow at UNU-MERIT.
Contact: menendez@merit.unu.edu
Roberta Rabellotti is a Professor of Economics at University of Pavia.
Contact: roberta.rabellotti@unipv.it

APPENDIX 1: ADDITIONAL TABLES AND FIGURES

TABLE A.1: Digital green patent applications by EU countries, 2000–2022

	# OF PATENTS	% OF TOTAL
DE	4509	44.48%
FR	1634	16.12%
NL	804	7.93%
IT	713	7.04%
SE	702	6.92%
BE	337	3.32%
FI	318	3.14%
ES	305	3.01%
DK	237	2.34%
AT	203	2.00%
IE	200	1.97%
LU	41	0.40%
PT	24	0.23%
HU	24	0.23%
GR	24	0.23%
PL	20	0.20%
CZ	12	0.12%
LT	10	0.10%
SI	9	0.09%
BG	6	0.05%
CY	3	0.03%
HR	3	0.03%
RO	3	0.03%
Total	**10.138**	**100.00%**

Source: own elaboration based on WIPO

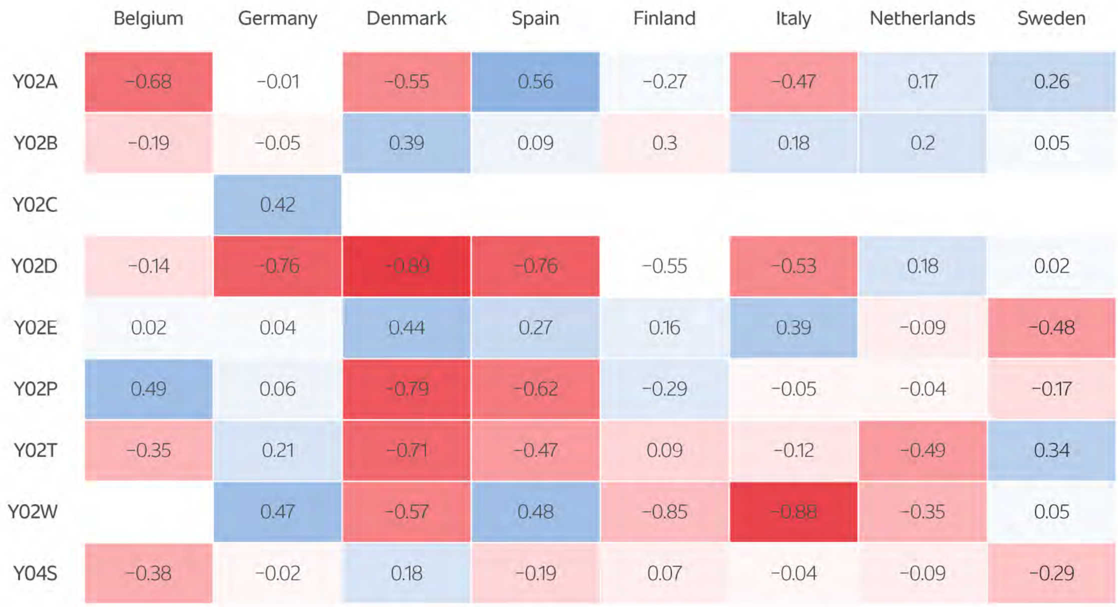
TABLE A.2: RTA by green technologies

	EU	UK	China	USA	Japan
Y02A	−0.02	0.18	−0.22	0.08	−0.48
Y02B	0.07	0.13	−0.15	−0.02	0
Y02C	0.09	0.59		0.13	−0.86
Y02D	−0.31	−0.22	0.14	0.1	−0.44
Y02E	0.08	−0.11	0.12	−0.05	0.12
Y02P	0	−0.23	−0.19	−0.03	0.18
Y02T	0.09	0.08	0.19	−0.08	0.13
Y02W	0.24	−0.23	0.43	−0.2	−0.51
Y04S	−0.04	0.08	−0.08	0.02	−0.02

○ NA ● Low RTA ● High RTA

Note: EU21: Austria, Belgium, Cyprus, Czech Republic, Germany, Denmark, Spain, Finland, France, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Sweden, and Slovenia.

TABLE A.3: RTA by green technologies (Top EU countries)



	Belgium	Germany	Denmark	Spain	Finland	Italy	Netherlands	Sweden
Y02A	−0.68	−0.01	−0.55	0.56	−0.27	−0.47	0.17	0.26
Y02B	−0.19	−0.05	0.39	0.09	0.3	0.18	0.2	0.05
Y02C		0.42						
Y02D	−0.14	−0.76	−0.89	−0.76	−0.55	−0.53	0.18	0.02
Y02E	0.02	0.04	0.44	0.27	0.16	0.39	−0.09	−0.48
Y02P	0.49	0.06	−0.79	−0.62	−0.29	−0.05	−0.04	−0.17
Y02T	−0.35	0.21	−0.71	−0.47	0.09	−0.12	−0.49	0.34
Y02W		0.47	−0.57	0.48	−0.85	−0.88	−0.35	0.05
Y04S	−0.38	−0.02	0.18	−0.19	0.07	−0.04	−0.09	−0.29

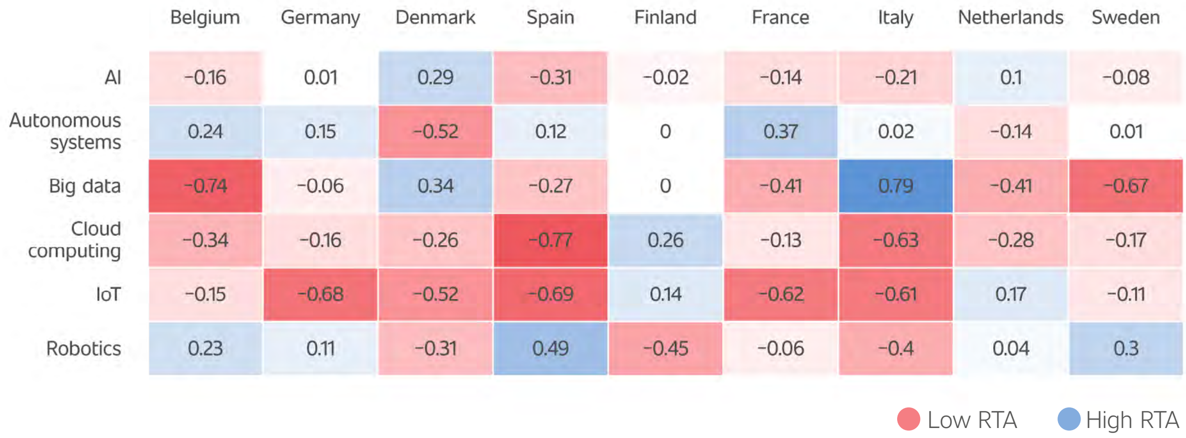
○ NA ● Low RTA ● High RTA

TABLE A.4: RTA by General Purpose Technologies

	EU	UK	China	USA	Japan
AI	−0.03	−0.08	−0.01	0.01	−0.03
Autonomous systems	0.12	−0.02	0.09	−0.07	0.14
Big data	0.09	−0.17	−0.22	0.09	−0.55
Cloud computing	−0.15	−0.06	−0.02	0.09	−0.18
IoT	−0.38	0.1	0.11	0.06	−0.2
Robotics	0.11	0.17	−0.12	−0.1	0.15

Note: EU21: Austria, Belgium, Cyprus, Czech Republic, Germany, Denmark, Spain, Finland, France, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Sweden, and Slovenia.

TABLE A.5: RTA by GPTs (Top EU countries):



	Belgium	Germany	Denmark	Spain	Finland	France	Italy	Netherlands	Sweden
AI	−0.16	0.01	0.29	−0.31	−0.02	−0.14	−0.21	0.1	−0.08
Autonomous systems	0.24	0.15	−0.52	0.12	0	0.37	0.02	−0.14	0.01
Big data	−0.74	−0.06	0.34	−0.27	0	−0.41	0.79	−0.41	−0.67
Cloud computing	−0.34	−0.16	−0.26	−0.77	0.26	−0.13	−0.63	−0.28	−0.17
IoT	−0.15	−0.68	−0.52	−0.69	0.14	−0.62	−0.61	0.17	−0.11
Robotics	0.23	0.11	−0.31	0.49	−0.45	−0.06	−0.4	0.04	0.3

Note: EU21: Austria, Belgium, Cyprus, Czech Republic, Germany, Denmark, Spain, Finland, France, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Sweden, and Slovenia.

Table A.6: RTA combining green technologies and GPTs

AI

	EU	UK	China	USA	Japan
Y02A	−0.03	0.03	−0.37	0.08	−0.49
Y02B	−0.09	0.3	−0.25	0.05	−0.22
Y02C	0.23	0.78		0.07	
Y02D	−0.23	−0.34	0.29	0.11	−0.67
Y02E	0.08	−0.22	0.24	−0.13	0.21
Y02P	0.02	−0.24	−0.27	−0.05	0.26
Y02T	−0.03	0.18	0.08	−0.09	0.18
Y02W	0.28		0.45	−0.31	−0.24
Y04S	−0.24	0.05	0.06	0.04	−0.09

AUTONOMOUS SYSTEMS

Y02A	0.18	−0.11	0.28	−0.03	−0.04
Y02B	0.23	−0.04	−0.22	−0.13	0.06
Y02C	0.01			0.2	−0.56
Y02D	−0.41	−0.48	−0.08	0.16	−0.13
Y02E	0.14	−0.13	0.11	−0.05	0.05
Y02P	0.32	−0.62	−0.03	−0.1	−0.04
Y02T	0.12	0.09	0.12	−0.12	0.26
Y02W	0.29		0.38	−0.18	−0.97
Y04S	0.19	−0.2	0.22	−0.08	−0.18

BIG DATA

	EU	UK	China	USA	Japan
Y02A	−0.01	0.15	−0.68	0.09	−0.82
Y02B	0.37		0.46	−0.02	−0.89
Y02C				0.3	
Y02D	−0.04		0	0.07	−0.4
Y02E	0.48	−0.23	0.04	−0.03	−0.48
Y02P	0.17		−0.62	0.13	−0.35
Y02T	0.39	−0.06	0.47	−0.08	−0.56
Y02W				0.26	−0.1
Y04S	−0.38		0.15	0.19	−0.54

○ NA 🔴 Low RTA 🔵 High RTA

CLOUD COMPUTING

	EU	UK	China	USA	Japan
Y02A	0.02	−0.02	−0.57	0.05	−0.28
Y02B	−0.09	−0.12	0.11	0.07	−0.59
Y02C	0.17	0.7		0.01	
Y02D	−0.29	−0.03	−0.08	0.11	−0.2
Y02E	0.05	−0.38	0.05	0.02	0.15
Y02P	−0.06	−0.81	−0.06	0.1	−0.06
Y02T	0.02	0.28	−0.05	0.06	0.04
Y02W	−0.32			0.06	0.48
Y04S	−0.55	−0.04	−0.18	0.19	−0.55

IOT

Y02A	−0.76	0.51	−0.8	0.19	−0.95
Y02B	−0.72	−0.48	0.18	0.12	−0.35
Y02C					
Y02D	−0.26	0.15	0.11	0.04	−0.37
Y02E	−0.56		0.26	0.05	0.3
Y02P	−0.5		−0.45	0.08	0.12
Y02T	−0.53		0.29	−0.02	0.28
Y02W	0.44			0.07	
Y04S	−0.67	0.12	0.16	0.06	0.01

ROBOTICS

	EU	UK	China	USA	Japan
Y02A	0.11	0.71	−0.84	−0.01	−0.66
Y02B	0.01	0.09	−0.22	−0.03	−0.29
Y02C					
Y02D	−0.23		−0.77	0.17	−0.77
Y02E	0.16	−0.14	0.05	−0.04	−0.09
Y02P	0.08	0.24	−0.19	−0.19	0.38
Y02T	0.2	0.23	0.16	−0.05	−0.26
Y02W	0.28		0.46	−0.28	−0.56
Y04S	−0.13	−0.56	−0.24	0.07	−0.24

○ NA 🔴 Low RTA 🔵 High RTA

Table A.7: RTA combining green technologies and GPTs (EU countries)

AI

	Belgium	Germany	Denmark	Spain	Finland	France	Italy	Sweden	Netherlands
Y02A	-0.8	0	-0.03	-0.44	-0.07	-0.19	-0.68	0.26	0.26
Y02B		-0.31	0.35	-0.66	0.22	-0.03	-0.04	0.42	0.23
Y02C		0.51							
Y02D	-0.58	-0.87		-0.8	-0.07	-0.34	-0.24	0.18	0.37
Y02E		0.13	0.8	0.33		0.24	0.03	-0.49	-0.38
Y02P	0.49	0.08	-0.16	-0.83	0.15	-0.24	-0.24	-0.39	0.1
Y02T	-0.34	0.13	-0.5	-0.37	-0.68	0.04	-0.53	-0.27	-0.31
Y02W		0.48	0.35	0.03			-0.65	0.13	-0.25
Y04S		-0.14	-0.15	-0.48	-0.13	-0.41	-0.25	-0.34	-0.39

AUTONOMOUS SYSTEMS

Y02A	0.02	0.15	-0.01	0.7	-0.16	0.49	-0.67		0.29
Y02B	0.18	-0.03	-0.3	0.7		0.58	-0.13		0.64
Y02C		0.33							
Y02D	-0.54	-0.76		-0.68	0.46	0.1	-0.79	-0.08	
Y02E	0.34	0.05		0.47	0.19	0.54	0.22	-0.57	-0.1
Y02P	0.8	0.36		0.07	0.02	0.26	0.12	-0.36	0.01
Y02T	-0.26	0.18	-0.34	-0.36	-0.03	0.38	-0.1	0.22	-0.53
Y02W		0.48		0.77					0.07
Y04S		0.38		-0.14	0.35	-0.2	-0.63	-0.66	0.12

BIG DATA

	Belgium	Germany	Denmark	Spain	Finland	France	Italy	Sweden	Netherlands
Y02A	-0.4	0.05	0.09	0.2	0.15	-0.07	0.07	-0.5	-0.19
Y02B			0.92			0.5	0.94		
Y02C									
Y02D		-0.93					0.05	-0.45	
Y02E		-0.6	0.81			-0.24	0.96		
Y02P		0.08	0.19		-0.09		0.85		-0.31
Y02T		-0.08					0.94		0.2
Y02W									
Y04S		-0.64	0.83		0.34	-0.19	0.26		

○ NA 🔴 Low RTA 🔵 High RTA

CLOUD COMPUTING

	Belgium	Germany	Denmark	Spain	Finland	France	Italy	Sweden	Netherlands
Y02A		0.12			0.39	−0.11		0.45	−0.65
Y02B		−0.4	0.66		0.1	0.33		0.48	−0.62
Y02C		0.46							
Y02D	−0.03	−0.63		−0.57	−0.01	−0.35	−0.67	−0.26	−0.27
Y02E		0.07			0.77	0.33			−0.13
Y02P	0.04	−0.05			0.62	−0.56	−0.14	−0.49	0.31
Y02T		0.22			0.45			0.13	−0.71
Y02W								0.74	
Y04S		−0.42		−0.76		−0.43			−0.89

IOT

Y02A					0.27			0.06	
Y02B		−0.94		0.23		−0.36			−0.2
Y02C									
Y02D	0.27	−0.83	−0.19	−0.89	0.23	−0.6	−0.41	0.14	0.48
Y02E		−0.72			0.43			−0.14	−0.13
Y02P		−0.51			0.02	−0.81	−0.87		−0.38
Y02T		−0.51				0.12			
Y02W								0.94	
Y04S		−0.72		−0.19	−0.45	−0.58		−0.69	−0.44

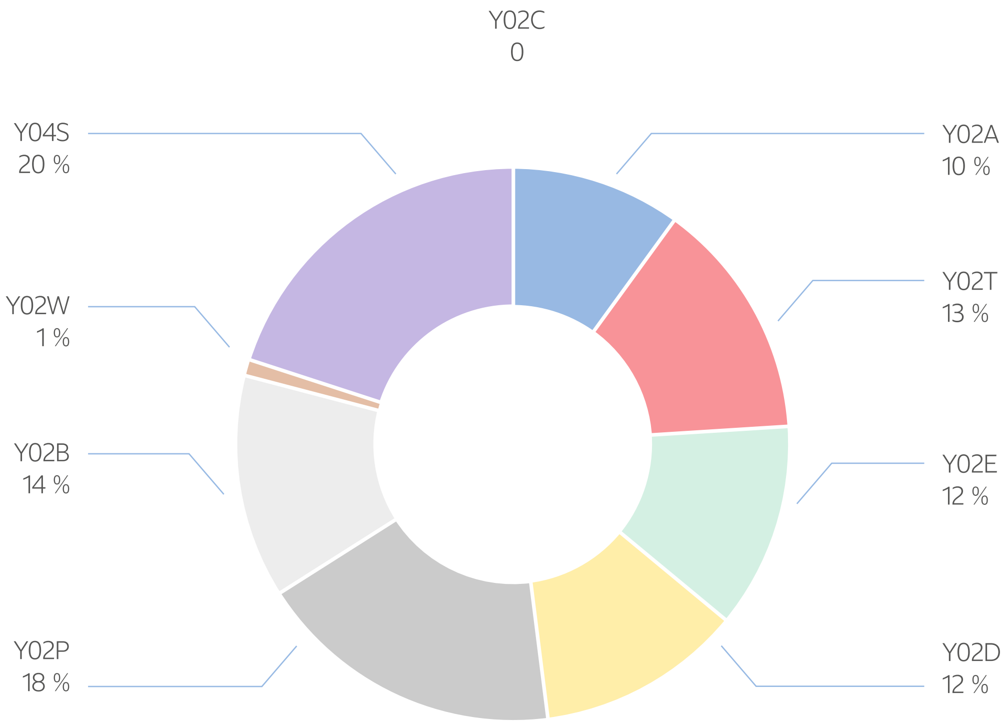
ROBOTICS

	Belgium	Germany	Denmark	Spain	Finland	France	Italy	Sweden	Netherlands
Y02A	−0.78		−0.04	0.92	−0.48	−0.57		0.19	0.64
Y02B		−0.36						0.51	0.7
Y02C									
Y02D		−0.59		−0.62					
Y02E	0.45	0.25	0.24	0.43		0.19	−0.07	−0.26	−0.01
Y02P	0.48	0.14	−0.82	−0.67	−0.2	0.02	−0.31	0.17	−0.24
Y02T		0.31	−0.13			−0.14		0.65	−0.47
Y02W		0.55							

○ NA ● Low RTA ● High RTA

Note: EU21: Austria, Belgium, Cyprus, Czech Republic, Germany, Denmark, Spain, Finland, France, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Sweden, and Slovenia.

FIGURE A1: Digital-green technologies Y02/Y04 tag (% applications)



Source: own elaboration based on WIPO

APPENDIX 2: PROCEDURE FOR IDENTIFYING DIGITAL GREEN PATENTS USING THE WIPO DATABASE

WIPO provides two files of data about the digital GPTs: file 1, appln_id +CPC codes and IPC codes; and file 2, fam_id. appln_id. dgt_category. year. We merged both files and selected those applications that are tagged with Y02/Y04S codes to obtain a dataset with appln_id. Y02-Y04S codes. ipr type. dgp category.

This information was uploaded to PATSTAT[33] to obtain additional information about the companies (name and industry) as well as the number of family id according to PATSTAT because the family id provided by WIPO is not the same as the docdb_family id[34] provided by PATSTAT. This ensures that all the applications belong to companies, universities, government, non-profits, hospitals, and their combinations and not from individuals or “unknown”.

Based on the query run in PATSTAT, we generated a subset including information about the doccdb_family id. all the patent authorities in which the patent has been applied and the appln_id. Only applications to the Japan (JPO), US (USPTO) and European (EPO) patent offices are included in the database. Finally. we merged the appln_id and the patent authorities with file 2 provided by WIPO.

To attribute the patents to countries, the origin of the invention was assigned using the applicant’s address or country information from the applicant’s name; or using information from matched corporations, from the most frequent first applicant country of residence within the same patent family, from the most frequent first inventor’s country of residence within the same patent family, or from remaining historical records. The IP office of first filing should be considered a proxy for origin.

Given that several applicants may co-own a unique patent, we considered fractional counts to improve the contribution of each country and avoid multiple counts.[35] If, for instance, a patent has two applicants – one from the USA and one from Germany – it is counted as 0.5 for the USA and 0.5 for Germany.

This is an example:

APPLICATION ID	ORIGIN	YEAR	DGP CATEGORY	APPLN AUTHORITIES
1496	CH	2004	Smart cities	EPO. USPTO
1549	SE	2003	Robotics	EPO. SE. WO. USPTO
4958	JP	2007	Autonomous systems	EPO. USPTO

---

[33] PATSTAT query available on request.

[34] According to PATSTAT a DODCDB patent family is a collection of patent documents that are considered to cover a single invention.

[35] De Rassenfosse, G., Dernis, H. and Boedt, G. ‘An Introduction to the Patstat Database with Example Queries’, Australian Economic Review, vol. 47, no. 3 (September 2014), pp. 395–408, doi: 10.1111/1467-8462.12073

Imprint

Publisher: Digital Power China (DPC)

Editor: Tim Rühlig

Editing: Andrew Mash

Layout: Carl-Friedrich Richter

Publishing date: 7 May 2024

This report has been generously funded by the United Kingdom's Department for Science, Innovation, and Technology, and the China Knowledge Network (CKN) of the government of the Netherlands, with support from the EU Cost Action "China in Europe Research Network" (CHERN). It does not reflect the views of the funders.

Digital Power China
A European research consortium