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GENERAL REPORT

STRENGTHENING ALLIANCE S&T RESILIENCE

General Report
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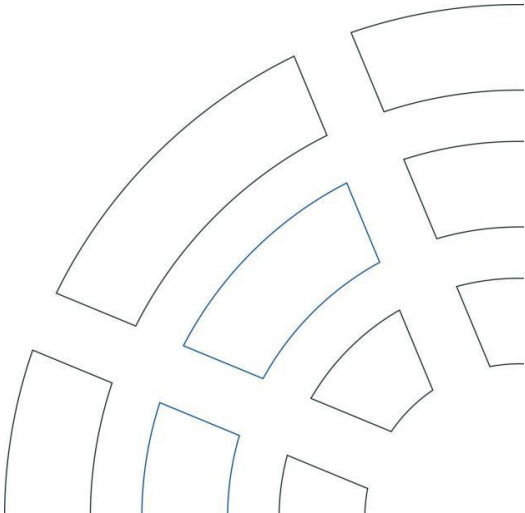

EXECUTIVE SUMMARY

Since the inception of the Alliance, the ability to innovate has been key to NATO's deterrence and defence. Now more than ever, maintaining its technological edge and upholding a competitive pace in Research and Development (R&D) will be instrumental for NATO to dominate future warfighting domains.

NATO's technological edge is challenged on several fronts. Its innovation pipeline needs to adapt to a rapidly changing security environment. Competitors invest considerable resources of their own and use illicit means to challenge the innovation achieved by NATO and like-minded countries. At the same time the leverage of governments to advance technological progress has decreased as today's innovation ecosystem is driven by commercial companies.

This report identifies challenges to NATO's innovation pipeline. In addition to limited Science and Technology (S&T) investment and educational systems that do not necessarily promote STEM (science, technology, engineering and math), these challenges include threats by potential adversaries, particularly the People's Republic of China (PRC) and Russia. These competitors resort to economic and scientific espionage to leverage Western technological advances to their benefit. Another challenge is that they contest internationally agreed (technical and technological) norms and standards. NATO's innovation pipeline is also challenged by the need to secure critical resources for the development of Emerging and Disruptive Technologies (EDTs).

The report provides a short overview of efforts designed to strengthen S&T Resilience in the Alliance. Several concrete examples of how to improve NATO's innovation pipeline and render it more resilient are listed in the conclusion. These include, among others: maintaining NATO's technological edge by increasing investment and cooperation around critical technologies; enhancing and deepening NATO's digitisation processes; strengthening common understanding of ethical standards for these technologies; and encouraging Partner nations to cooperate with NATO more actively.

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I- INTRODUCTION

1. The pace of technological innovation is increasing rapidly, affecting all sectors of society. A trend towards an ever-increasing importance of technology is creating new national security issues for Allies. At the same time, there is increased awareness that the resilience of S&T sectors is crucial to Allied security (Bing and Taylor, 2020) and that a robust holistic approach is needed.

2. Five trends characterise the contemporary technology environment. First, technology is key in ensuring "geopolitical, economic, and military competitiveness". Second, there is a tendency towards decoupling between democratic powers and authoritarian countries. Third, digital authoritarianism is a rising technological risk. Fourth, crises like the COVID-19 pandemic show how new vulnerabilities and dependencies can arise regarding technology. Fifth, states once again prioritise industrial policies, specifically tech-driven ones (Sahin and Barker, 2021). Against this background, many believe we are currently at a new "Sputnik moment" (Størdahl, 2022; Aronhime and Cocron, 2021). The question is whether NATO is prepared to meet this challenge and how the Allies position themselves technologically to meet future security threats.

3. The original Sputnik moment in 1957 led, among others, to a review of the US educational system with focus on STEM subjects, significant increases in R&D funding and the creation of several organisations designed to advance technological progress, such as NASA, DARPA and MITRE. The resulting technology race in space and other areas was guided by clear goals and milestones; such performance goals are once again needed today (Aronhime and Cocron, 2021).

4. NATO's increasing focus on EDTs shows that the Alliance is willing to take on these new realities. This report thus attempts to tackle the question of how NATO's innovation pipeline – and Allied S&T sectors more generally – can be made more resilient. It touches upon current key risks to Allied S&T resilience and takes a broad look at how innovation and R&D are changing and how Allies adapt to these new realities.

II- MAINTAINING THE TECHNOLOGICAL EDGE AND THE IMPORTANCE OF S&T FOR ALLIED SECURITY

5. Scientific innovation is driving geopolitics at an unprecedented speed. It has the power to cause, among others, "new risks to public safety and national security" (Kavanagh, 2019). The dual-use nature (military and civilian) of many crucial emerging technologies magnifies the complexity policymakers face when defining the legal framework for their use. Assessing the impact of new technologies requires both understanding how they will interact with other existing and emerging technologies – for instance, how a new satellite component in space will be vulnerable to new cyber security trends – and how they will affect society, governance and economics altogether.

6. The current discussions around Artificial Intelligence (AI) and its potential and limitations testify to the multi-layered nature of the task. Debates range from discussions around human-machine interaction and ethics to its concrete implementation in a growing number of sectors. Thus, "explosive growth of technological innovation is outstripping the capacity (or willingness) of technology creators, private investors, national governments, and the existing multilateral system to understand, monitor, and effectively govern the attendant effects and consequences" (Kavanagh, 2019). To address these daunting challenges, Allies need first to gain a clear understanding of how their innovation pipelines work in the contemporary socio-political context. This requires an understanding of what might constitute "resilience" of their S&T sectors and of the concrete threats putting stress on them.

7. Within NATO, S&T is defined as the "selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration, and validation of knowledge derived through the scientific method" (NATO STO, 2022).

8. Resilience is a state in which NATO possesses the necessary "resources, infrastructure and systems that allow Allies and their societies to continue to function in the face of the full spectrum of threats and hazards, from natural disasters to cyber-attacks, and from hybrid threats to even an armed attack" (Tarry, 2021). It is the ability to "withstand shocks and surprise – to be prepared for the unexpected" (Tarry, 2021). In an increasingly complex and unpredictable security environment, resilience is key to addressing non-traditional security threats (Tarry, 2021; Levy, 2021).

9. Resilience falls under an Article 3 commitment by Allies to "maintain and develop their individual and collective capacity to resist armed attack" (Washington Treaty). It should be noted, though, that the notion of attack now also includes non-kinetic scenarios such as in the cyber realm. The ability to conduct defensive and offensive cyber operations is a critical element to achieve credible deterrence and defence (NATO, 2016). This was affirmed at the Warsaw Summit in 2016 and reaffirmed most recently through the Strengthened Resilience Commitment in 2021 (NATO, 2016; NATO, 2021). Resilient societies that take a whole-of-government approach involving both the public and private sectors reduce vulnerabilities that adversaries could exploit. This in turn contributes to deterrence by denial – adversaries will not attack if they understand their objectives will not be fulfilled (Roepke and Thankey, 2019).

10. Specifically, S&T resilience relates to the ways in which: (a) NATO's S&T capabilities can support the development of resilience in key areas, such as those outlined at the 2016 Warsaw Summit; and (b) other national capabilities can enhance resilience in critical areas relating to scientific and technological development. Essentially, S&T resilience for NATO is about protecting Allies' capability to address national security concerns through S&T. Building S&T resilience is a crucial element for the protection of NATO's technological and industrial base with secure supply lines within the NATO ecosystem.

III- CHALLENGES TO ALLIANCE S&T RESILIENCE

A. PRIORITY SETTING AND RESOURCING

11. The key function of NATO's innovation pipeline is to produce technological solutions that are needed to address today's and tomorrow's security challenges. S&T resilience is about making sure that NATO's innovation pipeline can function efficiently and effectively, even under pressure. An example of such an external shock has been the COVID-19 pandemic, which tested NATO's STO in general, including the STB and the network of the Cooperation Support Office, as it slowed down NATO's S&T cooperative interactions significantly. NATO was able to establish virtual connections among the members of its network. However, continuing cooperation in Alliance-wide and national S&T networks requires additional investments in secure IT infrastructure if the Allies want to enable ascertain a functioning innovation pipeline during a pandemic.

12. S&T resilience needs to be built and nurtured over time. Economic and financial crises are also likely to put stress on Allied R&D networks. However, strengthening resilience in the S&T realm requires providing continued sufficient financial resources. Unfortunately, spending on state-sponsored R&D has decreased in many Allied countries. By contrast, the PRC's investments in R&D increased by 18% annually over the last 15 years, while the corresponding figure for the US is 4% for the same period. In comparative purchasing power terms, the PRC is now the world's

second-largest R&D player, with total R&D expenditure reaching 80% of that of the United States in 2019 (up from 26% in 2005).

13. This relative lack of public investment of NATO member states in S&T is relevant because it is crucial to produce innovation on lower Technology Readiness Levels (TRL). It is breakthroughs in low TRL work that eventually lead to the development of disruptive technologies (i.e., innovation on high TRLs). Many of these low TRL breakthroughs take place in universities and laboratories. Competitors like the PRC have recognised this; Chinese investments in higher education increased by 291%, compared with 26% in the US and 38% in the European Union. In terms of STEM PhDs, the PRC outnumbered the US by 2.5 to 1. As a result, some competitors, particularly the PRC, are rapidly catching up in R&D.

14. Building and maintaining resilience in NATO and Allied military S&T networks also requires continued access to a pool of expertise. Fortunately, with its Science and Technology Organisation (STO) and its subordinate agencies (particularly the Collaborative Support Office) NATO has the largest international defence science and technology network in the world. The STO is also engaging the next generation of scientists to expand and deepen its pool of expertise. To this end, the STO organises a number of activities, such as the "Young Scientists Awards" which recognise the exceptional contributions of their young scientists to the technical activities under the STO Collective Programme of Work. The contribution and impact of young scientists in maintaining NATO's competitive edge is crucial to ensure the development and adaptation of NATO's knowledge and expertise to future challenges (NATO STO, 2021).

15. However, low recruitment to STEM subjects in NATO nations and the lack of quality of the STEM education in many member states is a considerable challenge to NATO's innovation pipeline. According to the OECD's 2018 PISA study, students in several Chinese provinces/municipalities outperformed their peers in all of the other 78 participating education systems in mathematics and science (Schleicher, 2018). Moreover, the military still faces an uphill battle when it comes to engaging the technology community in defence-related S&T.

16. Finally, The challenge to NATO and Allied S&T ecosystems from cyber-attacks must not be underestimated as they could disrupt the operation of NATO's STO severely. Cyber-attacks are becoming ever more sophisticated and are increasingly targeting research institutes and academic institutions. Cyber-attacks cause significant disruption of the innovation pipelines of NATO and member nations. The attack on the software company SolarWinds, one of the largest cyber-attacks thus far and most likely conducted by Russia, breached many government and private systems around the globe. NATO and member nations need to build strong and resilient cyber defences to protect themselves, including their S&T networks, against cyber-attacks.

B. ECONOMIC ESPIONAGE

17. NATO Secretary General Jens Stoltenberg identified the growing nature of the economic espionage challenge in 2019: "We have seen increased efforts by other nations to try to spy on NATO allies in different ways" (Young, 2019).

18. The PRC poses by far the most pressing threat to Allied security in this regard (Hannas and Tatlow, 2021). Beyond the work carried out by the Chinese intelligence agency and the Ministry of State Security, the country has increasingly resorted to so-called "non-traditional" espionage, involving spies without a formal intelligence background such as university professors, scientists, researchers, enterprise employees and even students (Wong, 2022). This has the added benefit of allowing targeted collection of valuable S&T intelligence, as the spies are "intelligence amateurs, but subject matter experts" (Mattis, 2015). In return, it enables the Chinese government to enhance

their own research and development processes with an accurate sense of what information is needed to undercut foreign competitors, making the Chinese intelligence system uniquely geared towards enhancing the country's economy (Mattis, 2015; Wong, 2022).

19. It should also be noted that several Chinese laws, including the National Intelligence Law, stipulate that Chinese individuals and organisations must, if requested, support Chinese authorities with intelligence work (Yang, 2019). Moreover, the Chinese government is using technology to strengthen control over its population at home and abroad as witnessed in Xinjiang, which Beijing has used as an incubator for increasingly intrusive policing systems (Buckley and Mozur, 2019). The PRC is honing its technological surveillance prowess in Xinjiang where it keeps approximately one million Uyghurs in mass detention. According to some reports, the authorities are testing surveillance techniques in the region before being rolled out in other parts of China (Cadell, 2018).

20. Economic espionage can be facilitated when foreign companies provide components for critical infrastructure, particularly in the telecommunication sector. The debate around the implementation of 5G broadband cellular network technology highlights the possible trade-off between using foreign, or foreign-controlled, state-of-the-art technology and shielding one's economy against outside interference. To this end, NATO stressed the importance of "the security of communications, including 5G" and acknowledged "the need to rely on secure and resilient systems" (Gilli and Bechis, 2019) to prevent backdoor access to corporate and mass communications.

21. Near-peer competitors such as China also push their digital infrastructure and products into markets in the rest of the world. China's Belt and Road Initiative allows it to sell IT products abroad (such as basic ICT infrastructure up to advanced policing and surveillance technology), which could enable it to collect more diverse data to train its algorithms in many key sectors, geared towards the economy or national security (Pauwels, 2019). NATO should thus realise that its technological edge in data and intelligence collection can also be contested outside of its borders and seek to actively counteract or prevent such behaviour.

22. NATO's and Allied S&T pipelines must be protected against outside interference. In the digital age, the protection of investments in R&D is of paramount importance. Cyber-attacks and other tools used for the theft of intellectual property (IP) have recurrently undermined research efforts undertaken by Allies. Notable examples include a data breach, attributed to the PRC, at the US Department of Defense's subcontractor Lockheed Martin, which was opened in 2007 and used for years to steal information regarding the development of the fighter jet F-35. The similarity of the F-35 to the PRC's J-31 stealth fighter jet (Gady, 2015) shows how crucial it is to put in place effective security monitoring, including for sub-contractors working on technology with government. Moreover, targeting the private sector can seriously undermine national security assets, as was the case when Chinese hackers targeted the pharmaceutical company Moderna while it was developing its vaccine against the COVID-19 virus in 2020 (Bing and Taylor, 2020).

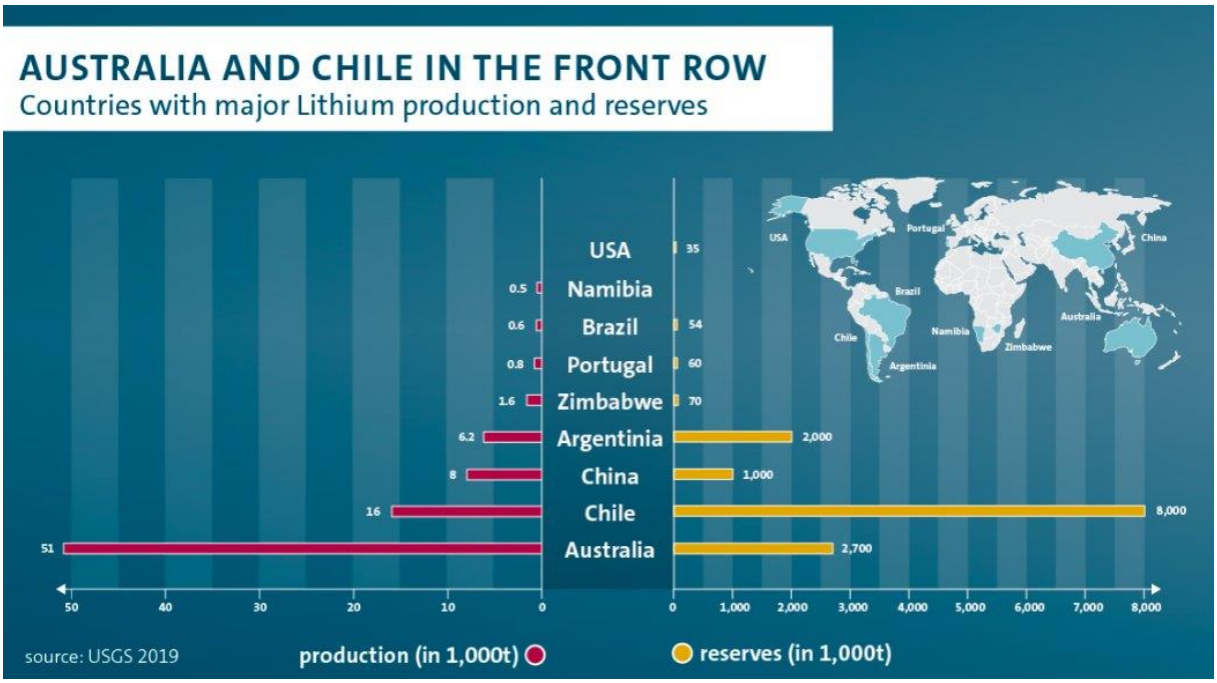
23. The Chinese military also takes advantage of the academic freedom of the open societies of Allied and like-minded countries, including from academic collaboration with Western universities. Some 3000 of the approximately 350,000 research collaborations between European and Chinese universities since 2000 have been with researchers at Chinese military universities according to the investigative platform "Follow the Money" (De Bruijn et al, 2022). Western scientists, universities and research institutions are either still not aware of all the dangers arising from cooperation with Chinese academic institutes or are deliberately ignoring the issue.

24. European universities are collaborating on a large scale with Chinese military institutes. Most notably, this concerns the National University of Defence Technology (NUDT), which is directly overseen by the Chinese Central Military Commission. The consortium also found studies done in

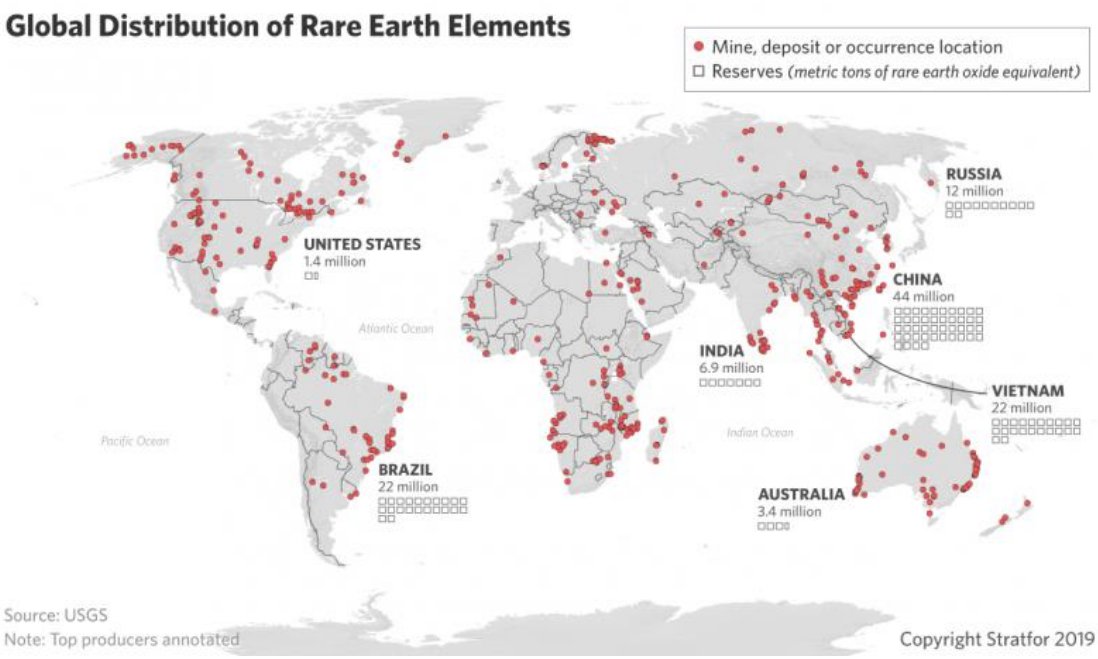
collaboration with the Chinese Academy of Engineering Physics, which focuses on nuclear weapons. The studies deal with militarily sensitive topics such as unmanned vehicles, radar technology and artificial intelligence (De Bruijn et al, 2022).

C. Critical Resources for the Development of Emerging and Disruptive Technologies

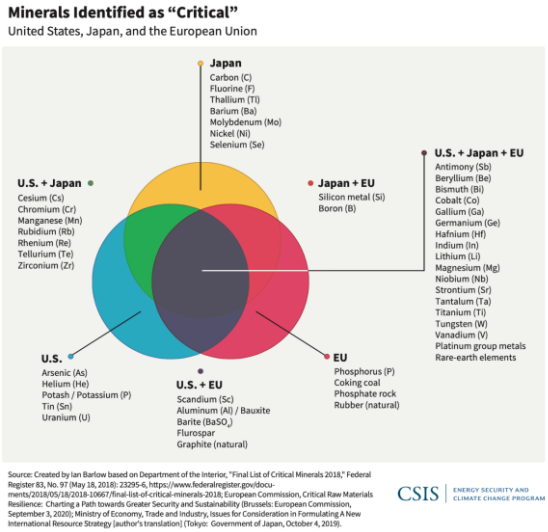
25. Due to the increasing digitisation of society and the development of EDTs, the demand for critical materials – such as component minerals for batteries or semiconductors for instance (such as aluminium, cobalt, lithium, manganese, and nickel) – will see a dramatic surge in the coming decades (Nakano, 2021). The defence sector is particularly exposed to these supply chain risks. For example, the production of a single Lockheed Martin F-35 Lightning II requires 417kg of rare earths. The corresponding figures for the production of a missile destroyer Burke DDG-51 and for a nuclear-powered submarine SSN-774 Virginia, state that they require 2,359kg and 4,173 kg of rare earths respectively (Richiello, 2021). NATO's S&T resilience – but also its basic ability to produce state-of-the-art weaponry, vehicles, and equipment – relies heavily on maintaining access to an affordable and secure supply of rare earth minerals.



26. Global supply, however, is limited and the geographical location of rare earth minerals does not necessarily favour Allied countries. About half the global supply of cobalt comes from the Democratic Republic of the Congo (DRC); over 80% of the global supply of lithium comes from Australia, Chile, and Argentina; and 60% of the global supply of manganese comes from South Africa, China, and Australia. Most notably, over 85% of the global supply of rare-earth elements comes from China (Nakano, 2021). China controls a major part of the global supply chain for rare earths, encompassing production, extraction and refining. It thus poses a major challenge to the S&T resilience of Allied nations (Bonelli, 2021). Russia disposes of 10% of the world's rare earth mineral reserves and is looking to increase its production to become self-sufficient and export some of its output, although it remains to be seen if it succeeds with this plan (Lyrchikova and Stolyarov, 2020).



27. Allies already pinpointed these vulnerabilities linked to rare earths back in 2010, when sanctions on rare earth trade were imposed by China on Japan as a retaliation against a territorial dispute (Nakano, 2021). Since then, the United States, the EU and Japan have developed "national and joint strategies to reduce Chinese dominance in this field" (Nakano, 2021), including the publication of several lists surveying critical raw materials for the future (European Commission, 2020). The US also published a similar list in 2018 (USGS, 2018) and initiated public-private partnerships to secure supplies. Europe, for instance, has set up projects such as the EURARE project and the European network of expertise on rare earths (ERECON) (Nakano, 2021). Allied nations should give higher priority to securing supply of rare earth minerals in their relationships with countries that mine rare earth minerals.



(Nakano, 2021)

28. External supply shocks can also test Allied S&T resilience. The COVID-19 pandemic showed how supply chains for raw materials could crumble. For example, in 2020 the transport of cobalt from the Democratic Republic of the Congo was delayed for months after South Africa imposed a lockdown to prevent the further spread of COVID" (Nakano, 2021). However, more downstream goods that are crucial to S&T resilience can also be impacted. This is for instance the case with semiconductors, which have been recognised as crucial elements for technological sovereignty

and national security (Csernatoni (a), 2021). It should be noted that the highest concentration of cutting-edge semiconductor fabrication and assembly is located in a geopolitically volatile region, particularly in Taiwan and in the Republic of Korea (Csernatoni (b), 2021). Several NATO Allies and the European Union have meanwhile started initiatives to "onshore" parts of the manufacturing of semiconductors. It is important to recognise, though, that no single country will be able to "onshore" the whole process of high-tech semiconductor production. The production of high-tech computer chips requires an extensive supply chain network, which includes a vast array of equipment, raw materials and other items.

D. CONTESTS AROUND NORMS AND STANDARDS

29. The introduction of new technologies, particularly disruptive ones, often raises important economic, societal and ethical questions. Technical standards have become critical to how technology shapes our societies (Park, 2022). "Standards set the pace for innovation, providing shared platforms for industry participants to work together to bring new technological solutions to the marketplace. Current developments in AI for national security for instance will have significant impact on international law. Russia, for instance, is contemplating the use of partly autonomous drones for its ongoing war in Ukraine" (Knight, 2022). Easy solutions seem unlikely, as the tense international security environment hampers constructive discussions of how best to coordinate responses to the complex, cross-border dilemmas emerging around new technologies. Some also consider existing multilateral platforms unsuitable for resolving these challenges (Abendroth-Dias, 2020). Moreover, international rulemaking has a slow pace in contrast to the fast pace of innovation. In addition, the private sector is the main driver of technological change nowadays, which further separates the processes from the public debate and the needs of the public sector (Abendroth-Dias, 2020). It thus seems crucial to find better ways to co-decide what norms and ethics for science and technology should look like with a broader spectrum of actors, both internationally and across sectors.

30. Near-peer competitors, particularly the PRC, are investing considerable financial resources in developing military-related technologies and are in some areas catching up with the Allies. Regarding the development of Artificial Intelligence, for instance, the PRC is rapidly closing the gap with the US and is surpassing EU countries (Castro and McLaughlin, 2021). The PRC is currently ranked second in the Tortoise Media's Global AI Index (Tortoise Media, 2022). Russia has much more limited means in this regard on the other hand and only ranks at 32 (Tortoise Media, 2022).

31. As countries compete for the development of new technologies, an emerging flashpoint is IP policy. The PRC has drastically increased its quantity of patent applications in fields such as AI, even surpassing the pace of countries with large innovative hubs such as the US (NSCAI, 2021). This bears the risk of hurting Allied innovators "by creating a vast reservoir of 'prior art' (the term in patent law for the worldwide scientific and technical knowledge by which an invention is evaluated to determine if it is new)", by increasing "the quantity of prior art that must be reviewed in examining a patent application" (NSCAI, 2021).

32. Furthermore, while Allied and like-minded nations firmly stand by the rule of law, near-peer competitors undercut the norms, laws and patents in S&T innovation. For example, following its unprovoked war against Ukraine, Russia legalised on March 6, the use of foreign patents without the consent of the patent holders and without paying royalties. According to some observers, "the zero per cent remuneration is not only retaliation against the so-called unfriendly states, but also a way for Russia to grab strategically important technologies to compete with the west" (Love, 2022).

33. Allies and like-minded states thus need to cooperate more on technology and norm and standard setting by forming coalitions. This would help to "promote the design, development, and use of emerging technologies according to democratic norms and values; coordinate policies and

investments to counter the malign use of these technologies by authoritarian regimes" (NSCAI, 2021). A first step was made in this direction with the organisation of a Pittsburgh EU-US Trade and Technology Council agenda in September 2021 (Csernatoni, 2021).

34. This need is made more pressing as authoritarian countries already seek to undermine established norms borne out of the liberal international order. The trend of creating separate internets (dubbed "splinternet"), i.e., cutting networks off the open global internet, poses a threat to the free flow of information and interconnectivity of networks and systems (Park, 2022). This is not only inefficient but might also make it harder to monitor the state of human rights and promote open and free societies in the future.

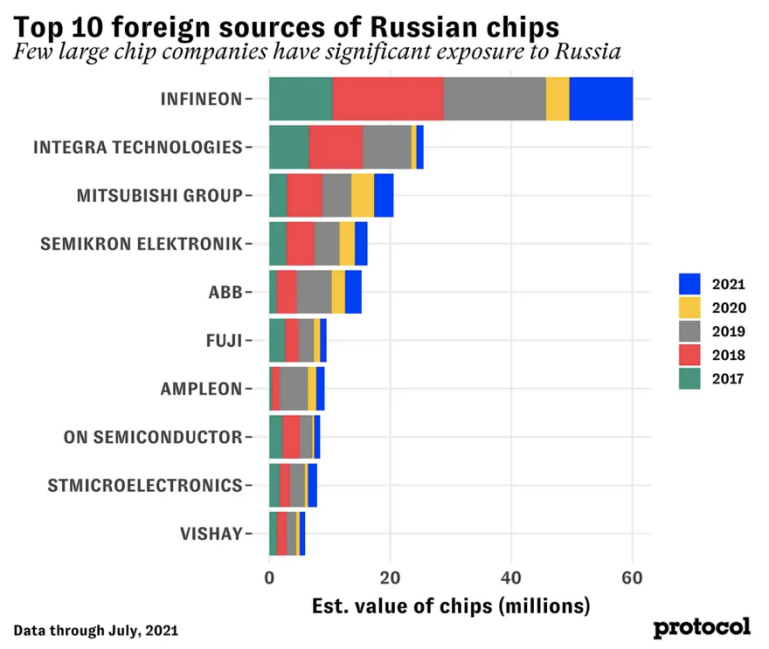
THE STATE OF S&T SECTORS FOR NATIONAL SECURITY IN RUSSIA & CHINA

Russia

Russia's S&T sector still strongly resembles the system inherited from the Soviet era. This has hampered the development of a more modern and agile innovation pipeline for the country (NATO ACT, 2021). As a result, Russia suffers from an ageing research infrastructure, outdated legal frameworks, insufficient state support and complete separation between R&D and the production side of the industry (NATO ACT, 2021). Many structural challenges are not addressed, such as a lack of funding and a continuing brain drain. These trends are bound to accelerate under the pressure of the current Western sanction regime imposed for Russia's war in Ukraine (Ivanova and Foy, 2022).

The defence industry remains the main driver of R&D in Russia, with about 30–40% of total R&D funding spent on military and defence projects. This greatly exceeds the equivalent figures in most Allied countries (2.8% in Germany, 6.4% in France). The military industry amounts to 70% of the high-tech output in the country and around half of the employed engineers (NATO ACT, 2021). This focus gives Russia some comparative advantages in certain very specific R&D sectors – such as hypersonics or narrow AI for military purposes – which it actively pursues. These innovations rest on a strong technological base built up over the last decades with products such as Russia's own positioning system GLONASS or a strong drone sector. Yet the overreliance on outdated legacy systems and the weak integration between the civilian and military R&D sectors pose long-term challenges (NATO ACT, 2021). The attempts to create "innovation hubs" modelled after the US's Silicon Valley have so far proved insufficient to overcome the lack of venture capitalism investments and maintain a steady pace of patent filings (NATO ACT, 2021).

Some of these shortcomings are most visible in the space industry, where endemic corruption has led to a chronic underfunding of research projects (Tangermann, 2022). Furthermore, due to increasingly limited access to crucial technology from the West – such as semiconductors – the Russian aerospace sector is likely to fall further behind. Due to sanctions, "Airports and seaports across the West are now closed to Russian commercial travel while imports of Korean "strategic items" as well as American computers, semiconductors, lasers, navigation and avionics – all vital components to Russia's space program – have been banned" (Tarantola, 2022). Since most semiconductor imports in Russia come from Western (or western aligned) countries (see below), the current disruptions caused by the sanctions will likely disrupt Russia's S&T sector for the short to mid-term.



(*Source:* Protocol, 2022)

China

China's roadmap for Science & Technology development is laid out in its 14th Five Year Plan (2021–2025). Technological innovation is one of the key ambitions of the Chinese Communist Party. China seeks to become world leader in Science and Technology by 2035 and aims to increase "research and development (R&D) spending by at least 7% annually between 2021 and 2025" (Sun and Cao, 2021). The current focus of the PRC's innovation activities is on robotics, new energy vehicles, aerospace, and agricultural machinery. The goal is self-reliance for its industrial sectors. (Sun and Cao, 2021) The "Made in China 2025" roadmap as well as the "Thousand Talents Plan" are further landmark documents setting out Beijing's S&T innovation ambitions (Wübbeke et al., 2016; Wong, 2022). The "Thousand Talents Plan" especially, with the aim to strengthen and broaden China's research base and S&T experts, has come under scrutiny in Allied countries for being linked to espionage cases (Rej, 2021).

China is in a favourable position industry-wise, in that is has been able to draw from its major influence on global overseas markets to enhance its geopolitical standing in the S&T sector. This has allowed it to catch up for some critical technology fields, partly by using unfair practices to force technology transfers. This is done for instance by tariffs, gatekeeping Western companies if they do not agree to share crucial information with the Chinese government, or through economic espionage (Wong, 2022). But China also draws resilience from a growing entrepreneurial spirit, as well as a "huge internal market of 1.4 billion people connected by well-developed transportation systems, advanced communication networks, and flexible and efficient supply chains" (Jun, 2021).

China's military and defence sectors benefit greatly from its technological innovation. Through its so-called "Military-Civil Fusion", the country aims to leverage effectively the dual-use nature of new technologies by bringing the PRC's military closer to the academic and private sectors (Kahn, 2022). China wants to be a leader in AI by 2030 and to have modernised the People's Liberation Army by 2027.

This entails the process of so-called “intelligentisation”, meaning the implementation of concepts “of future warfare based on emerging and disruptive technologies, particularly AI and autonomous and unmanned systems” (Kahn, 2022). Other priorities include “semiconductors and advanced computing, quantum, biotechnology, hypersonic and directed energy weapons and advanced materials and alternative energy” (Kahn, 2022). The PRC is committed to achieving these goals, as it has “increased its annual military budget by 6.8% in 2021 and is investing enormous resources into the research and development of emerging technologies” (Kahn, 2022). China is currently thus the most serious competitor to Allied nations in the S&T field. Yet it is still unclear how fruitful these investments will turn out to be in the mid- to long-term.

It seems likely that cooperation between Russia and China will deepen as a result of President Putin’s war of choice against Ukraine. Increased cooperation between the two counties may also extend to the technology sector. However, whether increased cooperation in the S&T realm may pose a more serious threat to NATO’s technology edge remains to be seen.

IV- EFFORTS TO STRENGTHEN S&T RESILIENCE IN THE ALLIANCE

A. A CHANGING INNOVATION LANDSCAPE

35. In the past, military R&D used to spearhead technological advances in the civil sector, generating important spin-offs for civilian use. In 1960, roughly every third dollar spent on R&D globally went into US defence projects (von Petersdorff, 2022). Silicon Valley was for a large part birthed out of the Pentagon’s DARPA (Defense Advanced Research Projects Agency) money. Through contracts and direct research, the public sector, mostly through the US Department of Defense, was driving innovation in the United States (Lewis (b), 2021). Major inventions that are the cornerstone of today’s private tech sector, like the internet or AI, were derived from DOD-funded projects (von Petersdorff, 2022). The main R&D strategy then was to make “big bets” on certain key technologies and fund them with public money such as rockets, which led to space exploration (Lewis (b), 2021).

36. However, the drivers of research and technology have changed since the 1990s, recalibrating toward entrepreneurs and technology companies, which primarily focus on the more profitable commercial market (Lewis (b), 2021). The fact that the bulk of technological advances is happening outside of government facilities has obviously a profound impact on Allied military and defence innovation.

37. Some areas, like software development, commercial space activities or quantum computing receive much more private than public funding (Lewis (b), 2021). Allies need to recognise those trends, harness them and adapt them to the needs of their military and defence sectors (Scharre and Riikonen, 2020). Some experts anticipate the most dramatic changes in warfare originating from advances in the information-centric capabilities of military systems (Scharre and Riikonen, 2020).

38. Embracing the already vibrant start-up culture in Allied countries makes for a more open and diverse innovation model, which embraces disruption and incentivises fresh and plural thinking, thus making the pipeline innovation more resilient over time (Murray, 2020).

39. However, as mentioned above, the public sector continues to play an important role in driving fundamental research. Moreover, the public sector has not entirely lost the monopoly over some

key strategic "bets" that are specific to defence needs, such as hypersonic missile technology or stealth technology. At the same time, it needs to find efficient ways to incentivise private companies to develop products suited for national security purposes in key areas and adapt existing technologies.

40. Essentially, this requires leveraging innovation efforts developments more effectively towards dual use, from the commercial to the military and vice-versa, which strengthens both sides for innovation. It also requires communicating the needs of the public sector clearly to the private sector and encouraging action regarding these needs. This requires the public sector to develop a deep understanding of the current state of the art and a deep connection with the S&T industry, in a similar fashion to what venture capital funds do (Lewis (b), 2021). Navigating public investments and the harnessing of private innovation efficiently should allow the public sector to save up on R&D costs overall. Successful public sector examples already exist, such as the US Department of Defense's Defense Innovation Unit (DIU). NATO recently launched its own version of such an accelerator platform, in the form of the Defence Innovation Accelerator for the North Atlantic (DIANA). DIANA is a significant step forward in strengthening NATO's R&D infrastructure.

41. These fundamental changes in innovation culture in Allied countries need to be accompanied by a change of mindset. Adapting to the harnessing of innovation with and from the private sector also means developing a deeper culture of risk tolerance. Still today, roughly 90% of start-ups in the Silicon Valley fail (Sahin and Barker, 2021). These odds should be understood from day one by the public sector investors, while being cognisant of the fact that working with the private sector also allows for a greater distribution of the risks among stakeholders. Young start-ups also do not function in the same way established defence industrial companies do: "If start-ups cannot close deals in a matter of weeks and months rather than quarters and years, then they would not attempt to (opportunity cost)." (Murray, 2020). This implies the need to re-evaluate the pace and logic of investments from the public sector into the private.

42. Overall, states can envisage multi-tiered approaches to technology investments, where they simultaneously: (a) embrace the private sector's pace and methods for the adoption of new information technologies; (b) keep publicly investing in some key military-only technologies as previously (where the private sector can provide solutions only with difficulty, like optics or nuclear technology); and (c) also invest in areas which could produce revolutionary technologies, but in which private companies find to risky to engage (Scharre and Riikonen, 2020).

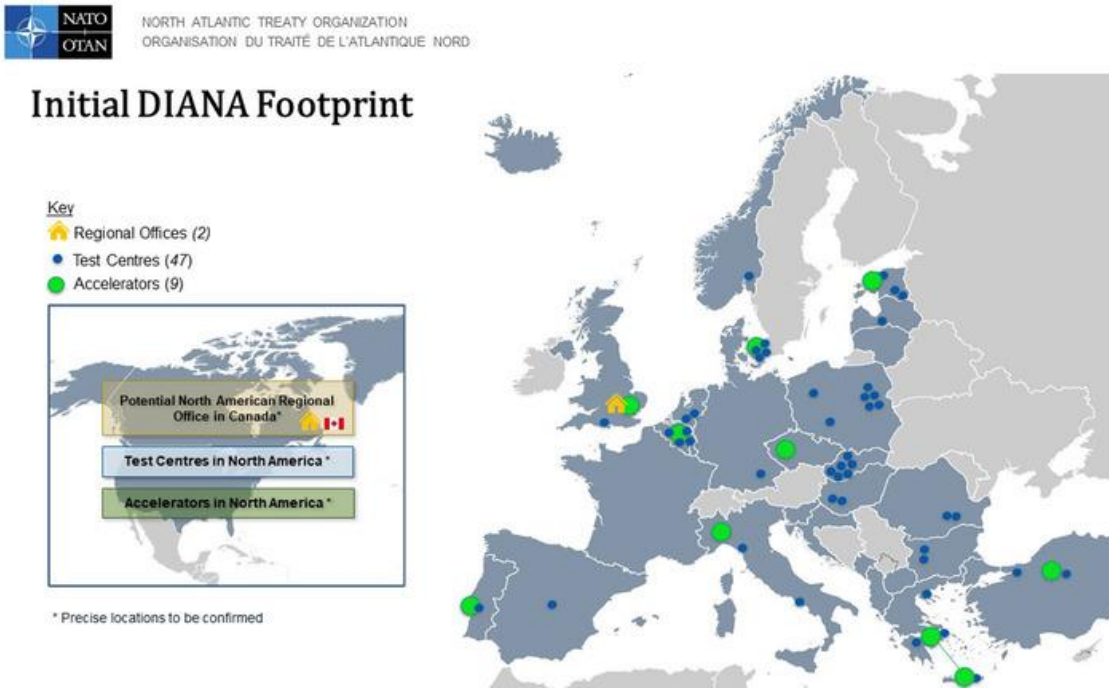
43. An important element of an efficient innovation pipeline is the adoption of new technologies. Armed forces only profit from the development of the latest technology if they can adopt it correctly, with the right doctrines and training for the personnel who supervise and use these technologies. "First adopter advantage for emerging disruptive tech could not be more prevalent in the world of geopolitics and deterrence. Indeed, the nations that win this race may be those with the most agile bureaucracy rather than those with the best technology" (Murray, 2020).

B. NATO'S ADAPTION TO A NEW INNOVATION ECOSYSTEM

44. Defence innovation is crucial to maintain NATO's technological edge. Since 2018, the Alliance has stepped up its efforts regarding EDTs. The Emerging and Disruptive Technologies Roadmap identified seven critical technologies: AI and machine learning; big data; autonomy; hypersonics; space technologies; quantum computing; and biotechnologies (Soare, 2021). In 2021, Allies decided to add "Energy and Propulsion" as well as "Novel Materials and Advanced Manufacturing" to this list of relevant technologies. NATO's innovation initiatives are coordinated by the Innovation Board, which is chaired by the Deputy Secretary General. Moreover, the NATO 2030 process translates the effort to "future proof" the Alliance regarding technological competition (Soare, 2021). Under NATO 2030, Allies agreed on the establishment of a NATO Innovation Fund

and DIANA, NATO's Defence Innovation Accelerator for the North Atlantic, which was launched in April 2022 (NATO (a), 2022).

45. DIANA is a new NATO body that will be jointly funded by all Allies and will have its separate governance and funding mechanisms, which equip it with a high degree of freedom of operation and agility (Zimmermann, 2022). It will run numerous test centres and accelerators across the Alliance, as shown below.



(NATO (a), 2022)

46. DIANA closes a gap in NATO's outreach to the private sector, specifically start-ups. While both the STO and ACT also engage with the private sector, they are generally more concerned with very early stages of research and development processes (for the STO) or later stages (implementation for ACT). DIANA's strength will lie in the fact that it covers the middle ground, where start-ups and defence companies take findings from fundamental research and turn them into actual products (Zimmermann, 2022).

47. The focus on EDTs is geared towards fostering the interoperability of military capabilities across the Atlantic, through "streamlining standardization and testing, evaluation, verification, and validation procedures" (Soare, 2021). Nascent projects like DIANA are a further step in this direction, yet the Advisory Group on Emerging and Disruptive Technologies and the NATO 2030 Reflection Group have also advocated for more possible measures in the future, such as establishing a similar NATO Advanced Technology Projects Agency or a NATO Investment Bank (Soare, 2021).

48. Under NATO 2030, Allies also launched a EUR 1 billion NATO Innovation Fund. Backed by NATO Allies, this venture capital fund will provide strategic investments into start-ups developing cutting-edge technological solutions, leveraging the enormous potential for commercial innovation to address critical defence and security challenges.

49. The STO, particularly the CSO, provides a safe area for sharing, collaboration and joint efforts. Thus, NATO plays an important role in addressing the "fragmentation of researchers, academia, start-ups and government at the beginning" of the innovation pipeline and its capacity to adopt quickly new technologies (Murray, 2020). In 2022, for instance, NATO launched "PROJECT X" in cooperation with Dutch universities to see how students and researchers can collaborate regarding rapid-prototyping initiatives for NATO's innovation pipeline (NATO (b), 2022).

50. Pooling and sharing knowledge across the Alliance have a particularly positive effect on Allies with a smaller innovation sector, as they can concentrate on niche areas. Norway's biggest export partner for some critical technologies for defence is the US for instance, which would not have been possible without NATO's innovation ecosystem (Størdal, 2022). This fosters resilience, as it also helps build a more tight-knit Alliance that can focus on being less dependent on imports from competitors (Zimmermann, 2022).

51. An area where further progress is possible is NATO-EU cooperation in the S&T realm. Both the EU and NATO have been evolving quickly in the past years regarding their understanding and policies towards EDTs. Yet there are still fundamental disconnects in which technology policy are envisioned on both sides of the Atlantic (Clüver Ashbrook and Sanger, 2021). In very general terms, European nations tend to emphasise the need to establish legal frameworks for EDTs and the companies developing these, while the United States focuses on developing the technologies. These disconnects will have to be addressed by NATO and the EU. In the area of technology policy, the EU has concentrated on platform regulation issues, whereas the US have been mostly focused on countering the PRC's influence in technology (Clüver Ashbrook and Sanger, 2021).

52. The inclusion of Microsoft in Europe's GAIA-X project (a European for Europeans cloud-based data storage) is an encouraging step towards more transatlantic cooperation (Clüver Ashbrook and Sanger, 2021). Projects like the EU's "Innovation Union", Horizon Europe and its earlier iteration Horizon 2020 have the capacity to enhance greatly R&D processes across the European continent. Horizon Europe allocates a budget of EUR 95 billion to R&D over a span of seven years (Lewis (a), 2021). The European Defence Fund is another crucial European project for defence-related R&D, with a budget of roughly EUR 8 billion (Csernatoni (c), 2021). Enhancing Europe's technological "open strategic autonomy" – as framed in the EU's industrial strategy (Lewis (a), 2021) – is therefore not antithetical to strengthening NATO. The US–EU Trade and Technology Council (TTC) is another step towards the closer NATO-EU coordination in the technology field.

53. Allies need to deepen their common understanding of relevant technological developments and their security and economic implications. More cooperation among Allies can help protect their technology bases and improve their performance. This applies to space technology, among others. Space is a critical enabler of security and defence. According to the UK think tank "Policy Exchange", it is essential to safeguard Allies' space-industrial competitiveness as this critical industry will undergo consolidation, as fewer large-scale players will dominate this sector in the future. More particularly, NATO Allies must prevent a Huawei-type situation, i.e., a situation where critical parts of its space technology could be controlled by foreign-backed companies.

54. NATO Allies need to respond to Beijing's aggressive build-up in global tech markets, including key space sectors, by developing viable Western alternatives to Chinese players (Sheldon, 2021). In addition, NATO could improve the sector's resilience through competition and industrial cooperation among Allies and like-minded partners.

55. "Innovation requires open networks, unlike the twentieth century industrial base, which was closely tied to physical infrastructure such as steel mills or coal mines" (Lewis (a), 2021). Potential future avenues for cooperation include AI ethics, foreign investment screenings and technology

transfer rules (such as the Wassenaar Arrangement) (Lewis (a), 2021). First and foremost, more consultations should be sought for NATO specifically, as the EU and NATO have consulted on their respective EDTs agendas only twice (Soare, 2021).

V- CONCLUSIONS

56. Maintaining and further developing NATO's technological edge will be pivotal to the Alliance's future. Ensuring the resilience of NATO's S&T sectors is an essential element in our ability to deter and defend ourselves.

57. Near-peer competitors are actively trying to undermine NATO's S&T resilience. At the same time, the Alliance has to succeed in making a careful transition to the 21st century playbook of how innovation works. New projects like DIANA and the innovation fund are important steps in the right direction. However, NATO also needs to strengthen cooperation with the EU and key partners such as Australia, Japan, the Republic of Korea and New Zealand.

58. More specifically, the Allies need to:

- Maintain a focus on NATO's technological edge. A strong understanding for just how important technology will be to the Alliance is emerging. Yet this is only the first step, which must be followed by successful implementation and adoption of new technologies. For the organisation specifically, it will have to make sure NATO's DIANA is fine-tuned, for instance, to function in strong synergy with the STO and ACT.

- Increase investment in critical technologies, particularly in enabling technologies such as cybersecurity, maritime technology, and satellite technology to prevent potential adversaries gaining an edge in these areas. Allies also should deepen cooperation amongst themselves and with like-minded partner nations in this field.

- Continue enhancing and deepening NATO's digitisation processes. This does not only require more secure networks, but also more qualified personnel with STEM skills, who are able to grasp, oversee, manipulate and fix the increasingly digital assets required to operate armed forces and organisations such as NATO. Allies need to ensure they incentivise the recruitment and education of future STEM talents.

- Raise awareness among technology experts, academics and students that their research can be relevant for national security and needs to be protected. Allies should evaluate the feasibility of introducing security training similar to Finland's national defence courses, which aim at improving cooperation between different sectors of society and facilitate networking of people working in the various fields of comprehensive security.

- Deepen their understanding of the implications of a further decoupling of global supply chains, economies and innovation systems, both in their positive aspects (i.e., facing less pressure from potential leverage near-peer competitors might have over Allies) and negative ones (i.e., losing an open system). This also entails identifying critical supply chains and seeing if and how NATO can protect them.

- Increase awareness of NATO militaries' dependency on foreign producers of defence-related equipment and components. Allies should also monitor and improve supply-

chain security for critical components and materials. More particularly, Allies need to develop strategies to mitigate China's dominance over rare earth minerals.

- Strengthen their common understanding of ethical standards for EDTs, which can then form the basis for a common ground for international legal frameworks and strengthen interoperability through a shared vision of how military concepts should evolve.

- Enhance inter-institutional and international cooperation on EDTs, for instance through a deepened dialogue with the EU and other international partners such as Asia-Pacific democracies.

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