The Hague Centre
for Strategic Studies

TNO innovation for life

National Security Implications of Quantum Technology and Biotechnology

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Strategic Alert

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1 Key Takeaways

Quantum technology and biotechnology are emerging technologies, impacting security and defence in different ways.

Quantum technology is based on the principles of quantum mechanics and essentially studies the sub-atomic level of particles. The revolutionary essence of this field is that these particles behave differently on microlevel than one would expect based on the well-known laws of physics on macro-level. This will enable things that are impossible with 'traditional' techniques in the fields of computation, communication and sensing.

Biotechnology is about applying engineering principles on biology. It allows for building biological systems that are equipped with abilities that they naturally would not have. With the arrival of synthetic biology, more and more insight is gathered on exactly which genes to change in order to get a certain effect and how to do so. Its use has increased tremendously since the development of the CRISPR-CAS.[1] Relevant subcategories of biotechnology are therapeutics and vaccines, viruses, biomaterials and biosensors.

Developments within these emerging technology areas and corresponding identified threats and opportunities to (inter) national security, impact essentially all six national security interests.[2]

- Quantum computing technology will be able to break current (asymmetric) encryption standards. Also in other ways, quantum computing will be able to facilitate cyber-attacks. Moreover, as society in general and critical infrastructures increasingly rely on digital processes, it is important to think ahead and assess how these processes can be prepared for a future in which it will be easier to get access to protected information using quantum computing. It is therefore critical to prepare for a quantum future and specifically to invest in post-quantum cryptography.

- Moreover, the Netherlands should invest in European cooperation on quantum technology development to strengthen the entire European quantum value chain.

- Concerning biotechnology, it is important for the Netherlands to make clear and early arrangements (preferably at the EU level) on the development of vaccines and therapeutics in preparing for a possible pandemic of a human infectious disease

- The Netherlands is a potential large player in the field of biotechnology, but there are several shortcomings in the current climate. To take a more leading role, biotechnology research should be more centrally coordinated. Furthermore, more (customized) investments are needed to support start-ups and scale-ups, and to foster capacity and skilled workers. Lastly, legal bottlenecks should be identified, in order to streamline law and regulations and bring these up to speed with technological developments.

- Furthermore, the Netherlands should be aware of the possible negative consequences of genetic modification on fragile ecosystems and invest in research into possible applications of biotechnology for creating and improving (production processes of) renewable energy sources.

- Lastly, the Netherlands should be aware of dependencies on industry and other nations for both technologies. Think about priorities (EU and Dutch) with regards to technology development, but also the advantages of international scientific cooperation. This requires that the Netherlands prioritises those elements that are considered vital to develop nationally with regards to strategic autonomy. This also entails protecting 'sensitive' information leaving the EU and/or the Netherlands, through export control regulations or regulations regarding mergers, acquisitions or investments from abroad.

1 CRISPR-CAS stands for clustered regularly interspaced short palindromic repeats – CRISPR associated protein.

2 NCTV, *National Security Strategy* (The Hague: 2019), https://english.nctv.nl/binaries/nctv-en/documents/publications/2019/09/19/national-security-strategy/National+Security+Strategy_2019.pdf.

2 Introduction

Every year, at the request of the Dutch Ministry of Defence and the Dutch Ministry of Foreign Affairs, Clingendael the Netherlands Institute of International Relations and the Hague Centre for Strategic Studies (HCSS) publish the Strategic Monitor. Part of this Strategic Monitor are several Strategic Alerts. This year, TNO contributes to the Strategic Monitor in the form of a Strategic Alert on emerging technologies. This Strategic Alert will highlight two technology areas that will impact security by explaining several important technological developments within these technology areas and assessing their possible impact. The focus is on national security, while acknowledging that national and international security are interconnected.[3]

Emerging, possibly disruptive technologies will impact security in different ways. On the one hand, technology enables organisations in the defence and security domain to work more efficiently, more effectively and more adaptively. Think for instance of the potential enormous computation power of quantum computers, that in the future will be able to solve particular previously practically unsolvable problems. On the other hand, applications of technology can also pose a threat to security. For example, a malicious actor can use biotechnology to develop a bioweapon. Due to the growing impact of technological developments on security, it is important to monitor these developments closely and strategically adapt accordingly.

The Strategic Knowledge and Innovation Agenda (SKIA) 2021-2025 of the Ministry of Defence[4] identifies 15 technology areas that are relevant to security and defence (see Table 1 below). This Strategic Alert will focus on two of them: quantum technology and biotechnology. These topics are chosen due to their possible high impact on society in the coming years.

SKIA 2021-2025 technology areas	
Artificial Intelligence	Biotechnology
Cyber and Electromagnetic Activities (CEMA) technology	Human Performance & Training
Quantum Technology	Simulation & Virtualisation Technology
Sensor Technology	Robotics and Autonomous Systems Technology
Human-System Integration	Information and Communication Technology (ICT) and Networks
Weapon Technology	Behavioural Engineering
Space Technology	Energy Technology
3D-printing and novel materials	

Table 1. SKIA 2021-2025 technology areas

3 See NCTV, *National Security Strategy 2019,* 7, and the underlying integrated risk analysis of the National Network of Safety and Security Analysts (ANV): ANV, *Geïntegreerde Risicoanalyse Nationale Veiligheid 2019* (March 2019), https://www.rivm.nl/sites/default/files/2019-10/Geintegreerde%20risicoanalyse%20Nationale%20Veiligheid%202019.pdf.

4 Ministerie van Defensie, *Strategische Kennis en Innovatie Agenda 2021-2025* (November 27, 2020), 36-39, https://www.defensie.nl/downloads/publicaties/2020/11/25/strategische-kennis--en-innovatieagenda-2021-2025; Marcel-Paul Hasberg, Adelbert Bronkhorst, Rick Meessen, and Carolina van Weerd, *Defensie Technologie Verkenning 2020,* (Den Haag: TNO, 2020).

Quantum technology is based on the principles of quantum mechanics and essentially studies the sub-atomic level of particles.[5] Applications based on quantum technology are at relatively low Technology Readiness Levels (TRL)[6] (see Figure 1 down below), although some applications such as certain sensors are already available. This general low TRL notwithstanding, applications of quantum technology will significantly alter society in general. As such, this technology field is relevant to highlight and to consider in the perspective of security and defence.

Biotechnology entails cellular and biomolecular processes to develop technologies and products for specific use by looking at 'how nature does it'. In the field of biotechnology, several specific applications are at higher TRLs compared to quantum technology. Given these high TRLs and the role of biotechnology in the battle against COVID-19, this is also a relevant field to consider.

TRL 9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)
TRL 8	System complete and qualified
TRL 7	System prototype demonstration in operational environment
TRL 6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 5	Technology validated in relevant environment (industrially relevant)
TRL 4	Technology validated in lab
TRL 3	Experimental proof of concept
TRL 2	Technology concept formulated
TRL 1	Basic principles observed

Figure 1. Technology Readiness Levels as currently in use by the European Commission for Horizon 2020 research programmes[7]

In paragraph 3, relevant trends from the perspective of defence and security in the fields of quantum technology and biotechnology will be highlighted. Besides signalling important developments in both fields, this Strategic Alert will also assess their impact on national security, looking at opportunities as well as threats. This will be elaborated upon in paragraph 4. Paragraph 5 will conclude this Strategic Alert by providing recommendations.

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5 Roland Ortt, *De Technologiemonitor 2020 Quantumtechnologie. Een onderzoek naar de ontwikkeling en verspreiding van quantumtechnologieën* (Den Haag: Stichting Toekomstbeeld der Techniek, 2021), 9-10, https://stt.nl/nl/toekomstverkenningen/97-de-technologiemonitor-2020-quantumtechnologie/nationale-technologiemonitor-2020-quantumtechnologie.

6 The Technology Readiness Level (TRL) of a technology refers to the maturity of a technology. The TRL framework distinguishes 9 levels and is currently widely used.

7 European Commission, *Horizon 2020 – Work Programme 2014-2015. Annex G. Technology readiness levels (TRL)* (Commission Decision C(2014)4995, 2014), https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf.

3 More than 'Super Computers' and 'Super Humans'

3.1 Quantum Technology: Radical Changes on the Horizon

Quantum technology will enable radically different applications and will impact many sectors within society.[8] Worldwide, investment in research and innovation in this technology field is growing fast. After the first scientific breakthroughs on quantum technology in the 20th century (featuring among others the transistor and the laser), the current wave will enable things that are impossible with 'traditional' techniques.[9] Research is not necessarily dominated by one or several actors, as can be seen in Figure 2 down below.[10]

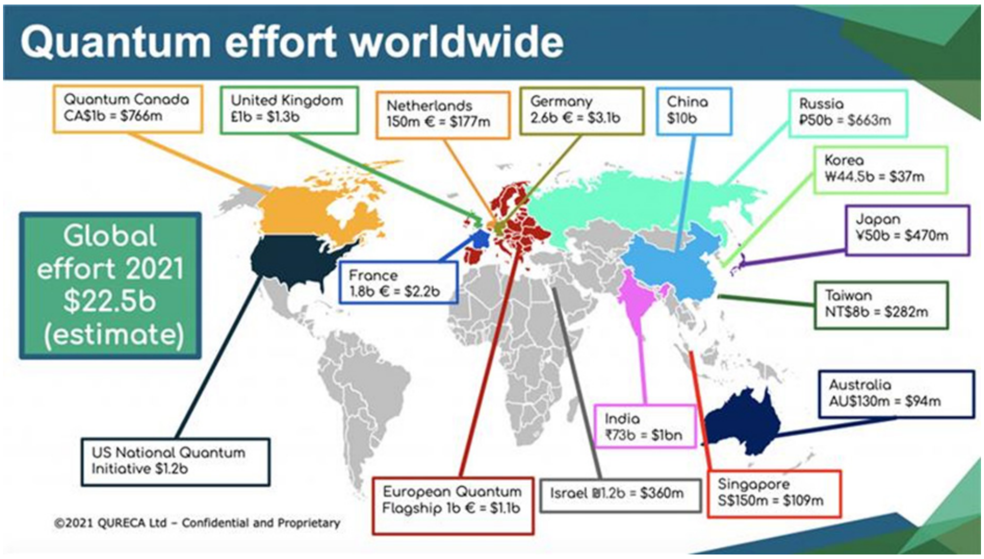

Figure 2. Investments in quantum technology worldwide, 22 January 2021[11]

8 Quantum Delta Nederland, *Nationale Agenda Quantumtechnologie* (Den Haag: September 2019), 13, https://www.rijksoverheid.nl/documenten/brochures/2020/02/17/nationale-agenda-quantumtechnologie.

9 Quantum Delta Nederland, *Nationale Agenda Quantumtechnologie*, 8.

10 Note that Quantum Delta NL will receive over 600 million euros from the national growth fund (*Nationaal Groeifonds*) for the coming years. See "Quantum Delta NL-programma krijgt 615 miljoen euro uit Nationaal Groeifonds," Quantum Delta the Netherlands, April 2021, https://quantumdelta.nl/quantum-delta-nl-programma-krijgt-615-miljoen-euro-uit-nationaal-groeifonds-2/.

11 "Overview on quantum technologies worldwide," QURECA quantum resources & careers, January 22, 2021, https://www.qureca.com/overview-on-quantum-initiatives-worldwide/.

Quantum technology is based on the principles of quantum mechanics and essentially studies the sub-atomic level of particles.[12] The revolutionary essence of this field is that these particles behave differently on microlevel than one would expect based on the well-known laws of physics on macro-level. Therefore, the principles of quantum technology can be difficult to grasp.[13] It is for instance not possible to measure multiple specific properties of a quantum particle at the same time, because the quantum state of the particle containing the other information will collapse the moment we measure the first property.[14]

There are two main principles that set quantum technology apart: superposition and entanglement. The basic unit of quantum information is the quantum bit (qubit), which can be both 0 and 1, while regular bits are either 0 or 1. A qubit that is in the state of both 0 and 1, is called to be in superposition.[15] Entanglement means that two entangled qubits behave like one, irrespectively of distance. Manipulating one particle will have an immediate impact on the other entangled particle.[16]

Quantum technology is a technology area encompassing different technologies. As such, the development of the technology area is not linear. There currently are already some applications of quantum technology commercially available (see paragraph 4.2.1), while some applications are at the very early (conceptual) stages of development.[17]

There are several subcategories within the field of quantum technology. For the purpose of this Strategic Alert, we focus on the following three (see also Figure 3):

- Quantum computation;
- Quantum communication;
- Quantum sensing.

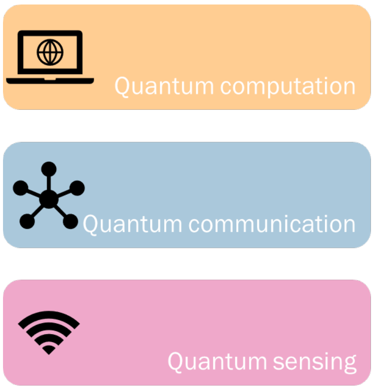

Figure 3. The main subcategories of quantum technology

Quantum computation

Quantum computation is fundamentally different compared to 'traditional' computation. Because of superposition, a quantum computer can run many calculations simultaneously in order to find the one right answer.[18] Thanks to the potential enormous computation power of quantum computers, particular previously practically unsolvable problems can be solved. Important to note is that quantum computers will not replace classical computers in our everyday lives and will only be used for complex calculations.[19]

Quantum simulation is a specific application of quantum computation. A quantum simulator is tasked for one specific purpose, to perform dedicated simulations of the quantum

12 Ortt, *De Technologiemonitor 2020 Quantumtechnologie,* 9-10.

13 Ortt, *De Technologiemonitor 2020 Quantumtechnologie,* 10; ECP Platform voor de InformatieSamenleving, *Essay Verkenning Quantumtechnologie. Aanbevelingen ter voorbereiding op een gezamenlijke toekomst met quantumtechnologie* (2019), 4, https://ecp.nl/publicatie/essay-verkenning-quantumtechnologie/.

14 Ortt, *De Technologiemonitor 2020 Quantumtechnologie,* 12.

15 Ortt, *De Technologiemonitor 2020 Quantumtechnologie,* 11; Quantum Delta Nederland, *Nationale Agenda Quantumtechnologie*, 11; Niels Neumann, Maran van Heesch, Patrick de Graaf, "Quantum Communication for Military Applications," (*International Conference on Military Communication and Information Systems (ICMCIS)*, 2020), 1.

16 ECP Platform voor de InformatieSamenleving, *Essay Verkenning Quantumtechnologie*, 13; Neumann, van Heesch, de Graaf, "Quantum Communication for Military Applications," 1.

17 Ortt, *De Technologiemonitor 2020 Quantumtechnologie,* 4; ECP Platform voor de InformatieSamenleving, *Essay Verkenning Quantumtechnologie*, 4, 7.

18 Ortt, *De Technologiemonitor 2020 Quantumtechnologie,* 17; Quantum Delta Nederland, *Nationale Agenda Quantumtechnologie*, 11; ECP Platform voor de InformatieSamenleving, *Essay Verkenning Quantumtechnologie*, 11.

19 Niels Neumann, Maran van Heesch, Frank Philipson, Antoine Smallegange, "Quantum Computing for Military Applications" (International Conference on Military Communications and Information Systems (ICMCIS), 2020), 1.

world.[20] Another well-known application of quantum computing is that in the future, quantum computers can break most current cryptography and as such among others decode encrypted data and undermine authentication processes in place.[21]

An important development in this subcategory is the improvement in the stability of a qubit, because currently, manipulating qubits (for measurements) only works when executed at extremely low temperatures. This is because interacting with quantum particles (for example changing the temperature), leads to changes in the particles themselves.[22] Other developments in this subcategory include increasing the number of connected qubits in order to run algorithms for larger problems, error correction[23] and post processing[24].[25]

Quantum communication

Quantum communication networks will form the foundation of the quantum internet, which will allow us to connect quantum computers and sensing technologies, just like we currently connect 'classical' devices via the Internet.[26] A specific, and first commercially available, application of quantum communication is Quantum Key Distribution, which enables two parties to create a shared, secure key in such a manner that eavesdropping can be detected.[27]

Eventually (probably in about 20 years), a network of connected nodes using shared entanglement will become a quantum internet. However, it is still very difficult to have quantum communication over longer distances and with higher bit rates. Quantum repeaters can be used to distribute the entanglement over longer distances, but this research is still at the early stages.[28] China is currently front-runner in this field and has, among others, tested a quantum network over about 4500 kilometres, using space-based laser.[29]

Quantum sensing

There are many different types of quantum sensors possible that can measure different variables, such as temperature, radiation and time. The main advantage of using quantum sensors is that the measurements are extremely precise. Traces of various variables such as magnetic fields and vibrations can be detected by quantum sensors at a level that is unachievable by traditional sensors. Scientific progress in this area has been developing for over a few decades and while some sensors are already commercially available, others are still at very low TRL.[30]

20 Quantum Delta Nederland, *Nationale Agenda Quantumtechnologie*, 13.

21 Ortt, *De Technologiemonitor 2020 Quantumtechnologie,* 16.

22 ECP Platform voor de InformatieSamenleving, *Essay Verkenning Quantumtechnologie*, 11.

23 Currently, there are still many errors with programming and processing qubits. This error margin should be reduced in order to have a more efficient quantum computer.

24 This needs to be fastened in order to benefit from the increase in computation power of quantum computers.

25 Neumann, van Heesch, Philipson, Smallegange, "Quantum Computing for Military Applications," 3.

26 ECP Platform voor de InformatieSamenleving, *Essay Verkenning Quantumtechnologie*, 13.

27 Neumann, van Heesch, de Graaf, "Quantum Communication for Military Applications," 2; Quantum Delta Nederland, *Nationale Agenda Quantumtechnologie*, 14, 17.

28 Neumann, van Heesch, de Graaf, "Quantum Communication for Military Applications," 3; ECP Platform voor de InformatieSamenleving, *Essay Verkenning Quantumtechnologie*, 39.

29 YA. Chen, Q. Zhang, TY. Chen et al., "An integrated space-to-ground quantum communication network over 4,600 kilometres," *Nature* 589 (January 2021), https://doi.org/10.1038/s41586-020-03093-8.

30 Ortt, *De Technologiemonitor 2020 Quantumtechnologie,* 14; Quantum Delta Nederland, *Nationale Agenda Quantumtechnologie*, 15; Aimee Gunther, Peter Mason, Julie Lefebvre, *Department of National Defence and Canadian Armed Forces Quantum S&T Strategy: Preparing for Technological Disruptions in the Future Operating Environment* (Defence Research and Development Canada, February 2021), 9, https://cradpdf.drdc-rddc.gc.ca/PDFS/unc356/p812809_A1b.pdf.

An important trend in this subcategory is the development of new types of quantum sensors, for example regarding positioning, navigation and timing (PNT) (even in those areas where Global Navigation Satellite System (GNSS) signals such as GPS cannot be received).[31] Other possible applications of quantum sensing are sensors that can detect objects behind walls and sensors for the detection of specific chemicals, even in very low quantities.[32]

While quantum radar (which would detect stealth fighter jets and missiles) is often seen as a critical application for the military domain, this is probably not feasible in at least the coming 30 years – if feasible at all. Quantum-assisted radar (which does not entail entanglement, but involves quantum devices that excel in bandwidth and noise performance among others) on the other hand, is expected to be feasible in the coming 10 years.[33]

3.2 **Biotechnology: Learning from Nature**

Biotechnology entails cellular and biomolecular processes to develop technologies and products for user-defined purposes by copying and modifying how 'nature does it'. It allows building biological systems that are equipped with abilities that they naturally would not have,[34] for example by transferring small amounts of genetic material from one biological species to another. In traditional biotechnology one does not know exactly which genes are changed in the process and to what effect. One only executes an intervention in the environment of the biological system or at the biological system itself and observes the result.[35]

Thanks to technological developments, a new discipline arrived within biotechnology: synthetic biology.[36] The difference with traditional biotechnology is that with synthetic biology, the knowledge is present of exactly which genes need to be changed and one is capable to change those genes directly themselves. This enables researchers to intentionally construct an organism or to provide an organism with new functions.[37] In other words, the genetic modification is in that case not forced upon the organism itself by changing the environment but done by a scientist in a lab, and with a specific intent in mind. Since synthetic biology can be quite labour intensive and is performed in a lab, large scale processes such as in industry still depend mostly on traditional biotechnological processes, but this may change in the near future.

31 ECP Platform voor de InformatieSamenleving, *Essay Verkenning Quantumtechnologie*, 13, 38.

32 Gunther, Mason, Lefebvre, *DND/CAF Quantum S&T Strategy*, 9.

33 ECP Platform voor de InformatieSamenleving, *Essay Verkenning Quantumtechnologie*, 37; Fred Daum, "Quantum Radar Cost and Practical Issues," *IEEE Aerospace and Electronic Systems Magazine* 35, no. 11 (November 2020), 10.1109/MAES.2020.2982755.

34 Colin O'Leary, Pam Silver, Edward van Opstal, Michelle Rozo, *Tech factsheets for policy makers - Spring 2020 series - Synthetic Biology* (Cambridge: Hardvard Kennedy School - Belfer Center for Science and International Affairs, 2020), 2, https://www.belfercenter.org/sites/default/files/2020-10/tappfactsheets/SyntheticBiology.pdf.

35 An example is a research from 2011, executed by among others the Erasmus Medical Center. A virus was made more transmissible by passing a virus from one ferret to another multiple times, in order to make a pathogen (a microorganism that can cause disease) adapt to a new host. Passing the virus from one ferret to another multiple times resulted in the virus becoming "airborne": healthy ferrets became infected simply by being housed in a cage next to a sick one. The virus has mutated: the airborne strain had five mutations in two genes, each of which have already been found in nature, just never all at once in the same strain. Martin Enserink, "Scientists Brace for Media Storm Around Controversial Flu Studies," Science, November 23, 2011, https://www.sciencemag.org/news/2011/11/scientists-brace-media-storm-around-controversial-flu-studies; Sander Herfst, et al., "Airborne Transmission of Influenza A/5H5N1 Virus Between Ferrets," Science 336, no. 6088 (June 22, 2012), 10.1126/science.1213362.

36 J. Jordan Steel, Katherine Bates, Michael Barnhart, "Investing in our nation's future military leaders' synthetic biology knowledge to understand and recognize threats and applications," *Synthetic Biology* 4, no. 1 (October 2019), https://doi.org/10.1093/synbio/ysz024.

37 O'Leary, Silver, van Opstal, Rozo, *Tech factsheets for policy makers - Spring 2020 series - Synthetic Biology*.

Synthetic biology is also defined as ‘the application of engineering principles to biology’, as it combines insights from biology, chemistry, computer science and engineering.[38] Its use has increased tremendously since the development of the CRISPR-CAS[39] technology which is a simple yet powerful tool for editing genomes.[40]

Biotechnology in general offers many interesting applications. For example for health and medicine by creating DNA-specific medicine, for sustainable energy production by designing more powerful biofuels, for environmental recovery by modifying the DNA of invasive species[41], or for food production by creating crops that grow in harsh circumstances. It is also possible to apply biotechnology to humans, as a method for *human enhancement*, but this is highly controversial and restricted by ethical and legal regulations. As far as can be judged from open literature, genetic modification of humans shows little scientific progress, not only as a result of the abovementioned barriers, but also because editing human genes is extremely complex: small alterations can have large and unexpected consequences. However, there are some exceptions[42], and there are also signs that regulations are being relaxed.[43] Human enhancement in general is often considered a sensitive topic but it is, in fact, much more common than one would think,[44] although its effectivity is in most cases limited.[45] For example, body-brain interaction by implants, such as chips that interact with the brain, is still at a very early stage of development due to the complicated texture of the brain.

38 Ibid., 1.

39 CRISPR-CAS stands for clustered regularly interspaced short palindromic repeats – CRISPR associated protein.

40 Two co-developers received the 2020 Nobel Prize in chemistry for their contribution. See Aparna Vidyasagar, “What is CRISPR?,” Live Science, April 21, 2018, https://www.livescience.com/58790-crispr-explained.html; Future Today Institute, *2021 Tech Trends Report* (New York: Future Today Institute, 2021), 483, https://futuretodayinstitute.com/trends/.

41 In 2020, millions of genetically engineered mosquitoes were released in Florida Keys. It was a pilot project to introduce male mosquitoes that have been engineered to pass on a gene making it difficult for their offspring to reproduce. Wrestling with steadily growing cases of dengue fever and West Nile viruses that are spread through these mosquitoes, local authorities hope to curb these diseases this way without having to use insecticides or poisonous chemicals. See Future Today Institute, *2021 Tech Trends Report*, 487.

42 A Chinese researcher has been the first to be reported who edited the genomes of human embryos in 2018. The affair led to legal and ethical debates and speculations on creation of super soldiers. At a scientific level, the discussion started when the technique used seemed to cause many unwanted mutations questioning its applicability. However, since 2018 several improvements have been made, making it a feasible pathway for clinical translation of human germline gene editing. Meanwhile, the Chinese researcher has been convicted and sent to prison for his research. See Jing-ru Li, Simon Walker, Jing-bao Nie and Xin-qing Zhang, “Experiments that led to the first gene-edited babies: the ethical failings and the urgent need for better governance,” *Journal of Zhejiang University-SCIENCE B (Biomedicine & Biotechnology)* 20, no. 1 (January 2019), 10.1631/jzus.B1800624; Michael Kosicki, Kärt Tomberg, Allan Bradley, “Repair of double-strand breaks induced by CRISPR-Cas9 leads to large deletions and complex rearrangements,” *Nature Biotechnology* 36 (July 2018), https://doi.org/10.1038/nbt.4192.

43 In May 2021, the International Society for Stem Cell Research – an independent non-profit organization – has relaxed their previous recommendation that scientist should not culture human embryos for more than two weeks after fertilization. There is no new limit set. The ISSCR now suggests that studies should be considered on a case-by-case basis and be subjected to several phases of review to determine at what points experiments, whereby human embryos are grown, should be stopped. In addition, the group does advise against editing genes in human embryos, since the safety of genome editing is not yet sufficiently established. This development means that developments concerning embryo research could speed up in the coming years. See Nidhi Subbaraman, “Limit on lab-grown human embryos dropped by stem-cell body,” Nature, May 26, 2021, https://www.nature.com/articles/d41586-021-01423-y.

44 Think of the yoghurt drink Yakult, which is meant to alter your intestinal flora. It can be found in every supermarket. Human enhancement is often divided into the following categories which follow the method that is being used: *Chemical enhancement* is about drugs to improve performance. An ordinary example is Ritalin. *Genetic enhancement* is about editing genes to improve performance. This can be quite controversial, especially when it concerns embryo-research. *Physical enhancement* is about implants, such as implants to overcome blindness or deafness. This field is strongly connected to the fields of electronics and mechanics, and to the field of biomaterials (see more explanation on that topic below).

45 An exception might be made for physical enhancement, which is expected to reach high TRL levels sooner than for development in genetic enhancement. The topic of biomaterials will cover this.

Furthermore, drugs to chemically enhance humans, those that are stronger than already known vitamins, pharmaceuticals, and amphetamines, can quickly become addictive and even deadly for the user, so there are many barriers in pursuing the development of these kind of human performance enhancers. Lastly, research shows that large improvement in human performance can already be realised by 'simple' interventions such as improved training of body and brain.

Therefore, in this Alert, we will focus on four subcategories of biotechnology in which large developments are expected in the next five years: therapeutics and vaccines; viruses; biomaterials; and biosensors (see also Figure 4). These subcategories are explained below.

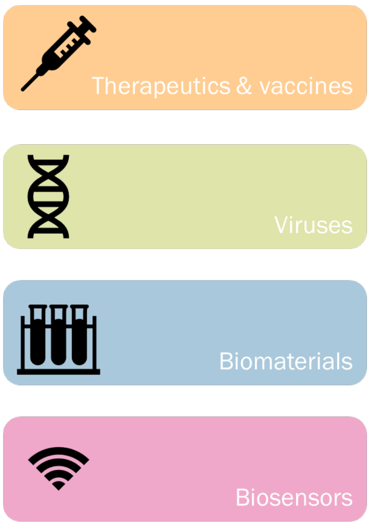

Figure 4. The main subcategories of biotechnology

Therapeutics and vaccines

In 2020, it was the first time vaccines, in this case for COVID-19, were created using synthetic biology, by using the method of messenger RNA (in short: mRNA).[46] [47] This method was already developed in the search for Ebola vaccines. Other methods for creating vaccines use viral vectors. It is noteworthy that the time-to-market of the mRNA method was originally not that short. SARS-CoV-1, to which SARS-CoV-2 that causes COVID-19 is closely related, was already discovered in 2002-2003. For a long time, vaccines were at TRL 3-4 (development phase). Only since the enormous worldwide effort in response to the current pandemic, scientists succeeded to develop a vaccine in less than a year. In fact, the creation of the vaccines itself was done in a shorter period, soon after January 2020 when the genetic code of COVID-19 was shared publicly. Most time was taken up by experiments in the approval phase and by scaling up the production. Thus, if the type of organism is known, vaccines can be created and approved for safe use in a remarkably short period of time given that enough resources are made available.

Viruses

For vaccines, parts of viruses are used to trigger the natural defence system of humans in order to activate the creation of antibodies. As mentioned, a different technique is mRNA, which is used to recreate a small part of a virus. One step further is the (re)creation of a complete virus. This can be done by taking a sample from an infected patient or by creating it from scratch. The TRL of these kind of techniques is high: scientists succeeded in recreating already extinct viruses, such as horsepox, a relative of smallpox.[48]

46 Messenger RNA (mRNA) is a single-stranded RNA molecule. It is complementary to one of the DNA strands of a gene. The mRNA is an RNA version of the gene that leaves the cell nucleus and moves to the cytoplasm. That is where proteins are made. During this protein synthesis, an organelle called a ribosome moves along the mRNA. It reads its base sequence, and uses the genetic code to translate each three-base triplet, or codon, into its matching amino acid. "Messenger RNA (mRNA)," National Human Genome Research Institute, https://www.genome.gov/genetics-glossary/messenger-rna.

47 Unlike traditional vaccines, which use weakened pieces of a live virus or of a dead virus to activate our immune system, the COVID-19 vaccines of Pfizer-BioNTech and Moderna used mRNA to overwrite the code in our cells. Researchers believe that in the future, sending new instructions into our cells could help protect us against a number of viruses. An mRNA vaccine to fully immunize people against malaria is for example in the making. Future Today Institute, *2021 Tech Trends Report,* 484.

48 The researchers recreated a relative of smallpox, namely the horsepox virus, since this virus is not known to be harmful for humans. However, the same technique could be used to recreate smallpox. Kai Kupferschmidt, "How Canadian researchers reconstituted an extinct poxvirus for $100,000 using mail-order DNA," Science, July 6, 2017, https://www.sciencemag.org/news/2017/07/how-canadian-researchers-reconstituted-extinct-poxvirus-100000-using-mail-order-dna.

Biomaterials

This subcategory concerns materials whereby biotechnology has been used in its creation. A useful distinction is between bio-inspired and bio-executed materials. If biotechnology is indeed used to achieve the results, one speaks of bio-executed materials. If one is only mimicking nature, for example by designing a drone that uses the same technique to fly as a colibri, one speaks of bio-inspired materials. Knowledge from the physical, biological and chemical sciences is used to create biomaterials.

The benefits of improving and creating materials using biotechnology are multiple. Firstly, one can think of medical applications. Examples are drug delivery systems and tissue engineering. Growing bone and livers is already at a high TRL (8-9). Other organs turn out to be more difficult, as is the creation of artificial blood, which is still only at TRL 3-4. Another medical application is the use of biotechnology to adapt materials in order to prevent the human body from rejecting it. Secondly, there are applications outside the medical domain, where materials are adapted by biotechnology in order to have biological characteristics that make them better suited for their purpose or to facilitate the production process. An example is the use of chitin, a substance coming from the shell of a beetle, to harden protective gear.[49] These applications in most cases are at moderate TRL, around 4-5.

Biosensors

The fourth subcategory within biotechnology and synthetic biology is biosensors. This term is sometimes used for sensors that measure variables such as blood pressure or heart rate, in order to assess one's physiological state (e.g. in a smartwatch), but this is not meant here. This subcategory concerns sensors that use biological materials, for example bacteria or enzymes, to signal the presence of certain chemicals or micro-organisms. Such sensors can be implemented in dedicated test sets but, depending on the application, also in clothes or protective gear. Biosensors that signal the presence of toxic chemicals function in a similar way as a canary in a coalmine, giving an early warning before humans experience any harm. A recent development in this area is to genetically edit the sensitive biological material to respond to specific substances.

In general, the technology used for creating biosensors is at a high TRL. It depends on the area of application: a pregnancy test is a very commonly used example of a biosensor, while a test for recognizing cholera in water is still more in a developmental phase. Also at a high TRL are several types of biosensors (self-tests) able to test infection with COVID-19.

49 Jesus Rivera, Maryam Sadat Hosseini, David Restrepo, et al., "Toughening mechanisms of the elytra of the diabolical ironclad beetle," *Nature* 586 (October 2020), https://doi.org/10.1038/s41586-020-2813-8; Brian Bell, "What makes an insect indestructible?," University of California, October 22, 2020, https://www.universityofcalifornia.edu/news/what-makes-insect-indestructible.

4 Impact on National Security

4.1 Method

In order to assess the impact of quantum technology and biotechnology on national security, a qualitative impact assessment method was used, see Annex A for a more elaborate explanation.

Scope

The scope of the assessment concerned the Netherlands, while acknowledging that internal and external security are interconnected (the so-called 'nexus' internal-external security). This means that developments abroad can impact Dutch national security and vice versa. Also, the focus was on relevant effects for the defence and security domain. Developments and possible impact of the two technology areas from now up until roughly 5 years in the future were considered. Where relevant, important developments that have an effect on the longer term were also included. While both opportunities and threats were considered in the impact assessment, it is important to acknowledge that those cannot be seen as independent from one another. Something assessed as a threat when used by (possible) opponents can also constitute an opportunity for the Netherlands, and the other way around.

Method

Essentially, the main question in the impact assessment was whether developments in the fields of quantum technology and biotechnology would impact (positively or negatively) risks that are already considered a threat to national security (following the National Security Strategy). Besides these known possible threats to national security, it was considered whether technological developments within quantum technology and biotechnology could impact the six national security interests[50] (see Table 2 down below) in any other way.

Territorial security	The unimpeded functioning of the Netherlands and its EU and NATO allies as independent states in a broad sense, or territorial security in a narrow sense.
Physical security	The ability of people to go about their lives in an unimpeded manner within the Netherlands and their own physical environment.
Economic security	The unimpeded functioning of the Dutch economy in an effective and efficient manner.
Ecological security	The unimpeded continued existence of the natural living environment in and around the Netherlands.
Social and political stability	The continued and unimpeded existence of a social climate in which individuals are free to go about their lives and groups are able to coexist within and in accordance with the Netherlands' democratic and lawful state and its shared values.
International rule of law	The functioning of the international system of rules, standards and agreements established for the purposes of international peace and security

Table 2. Dutch national security interests

50 NCTV, *National Security Strategy*.

For the impact assessment on opportunities, the extent to which the developments in the technology areas can offer solutions to critical societal challenges and whether the technologies can be applied in the domains of security and defence, including intelligence and critical infrastructure were considered.

Below, several important threats and opportunities to national security will be highlighted for both quantum technology and biotechnology. Where relevant, the specific subcategories as discussed in paragraph 3 will be discussed separately.

4.2 Quantum Technology

4.2.1 General remarks

As said, in general, quantum technology is at a low TRL, which means that the technology is still in the development phase, although there are some applications of the technology commercially available. Depending on the application, TRL varies.

In the field of quantum computing, there is already a quantum annealer (a specific type of computer) with a few thousand qubits available for specific optimalisation questions. Interestingly, various quantum algorithms have already been developed, so when a full-fledged quantum computer sees the light of day (expected in about 15 years), scientists already have an idea of how to use this computer. Quantum Key Distribution within quantum communication is also at a relatively high TRL, especially China is leading in this field and various commercial parties exist. Within quantum sensing, quantum magnetometers measuring magnetic fields are commercially available and especially France is at the forefront of this development. Notwithstanding these (and more) applications, there are still many ideas that only exist in laboratories.

4.2.2 Critical vulnerabilities in different sectors

Digital

Probably one of the most critical threats (in about 15+ years) is that quantum technology will break current cryptographic protocols. Shor's algorithm (a quantum algorithm) will break traditional asymmetric encryption.[51] Many different (governmental) services use Public Key Infrastructure (PKI) to ensure safe digital authentication, for instance the Tax & Customs Administration (*Belastingdienst*). Encrypted data, sent today, is being stored by (state) actors and when encryption can be broken, this data will be decrypted. This is a serious threat to (governmental) classified information.

Another threat related to the digital domain is that quantum computing could enable automated cyberattacks because finding vulnerabilities in software will become very efficient. As quantum computing will also become cloud based, cybercriminals can 'hire' quantum computing capacity for malicious purposes. So, besides states and the private sector, also non-state actors such as criminals and extremist organisations might be able to use quantum computing applications, specifically related to quantum-enabled cyber-attacks.

51 Neumann, van Heesch, Philipson, Smallegange, "Quantum Computing for Military Applications," 5.

Critical infrastructure

As mentioned above, traditional asymmetric encryption will be broken in the future. Besides the threat this poses to classified information, probably more disruptive will be the threat to critical infrastructures when (state) actors get access to these processes to install malware for instance.[52]

Moreover, when relying on quantum technology (especially communication and computing), novel vulnerabilities will most certainly arise. For quantum communication, availability will be an issue, because a direct line of sight in the air or a telecom fibre is needed. Also, quantum computers currently only work at very low temperatures (just above the absolute zero) to keep the qubits stable and have other technical implementation requirements. Important to realise is that dependency on electricity and the telecom sector (both critical infrastructures) will only increase when quantum technology applications will be available. Quantum networks can therefore become a critical process in themselves, with their own vulnerabilities.

Military

Various serious threats lie in the military domain. Quantum technology has many applications in sensing and command and control. In this regard, applied quantum technology can enhance the effectivity of a weapon system. Perhaps more critically, applications of quantum technology can shorten the OODA-loop[53]. States such as China have a quantum technology strategy for the military, in the sense that quantum technology is seen as a critical element in the strategic support force and acting in the information domain. So, when potential opponents have quantum sensors, they have better situational awareness that shortens their OODA-loop and sensor-to-shooter time. In short, they would have the upper hand.

Moreover, considering the above mentioned concept that traditional asymmetric encryption will be broken, military communication will also not be secure anymore. Looking for post-quantum cryptography (note that this does not necessarily involve quantum technology) is therefore critical to ensure information dominance for the military.[54]

Economic

A critical gap relating to the development of quantum technology in the Netherlands and the European Union is the lack of large companies able to commercially develop quantum technology at a larger scale, such as quantum computers. Although the Netherlands (and the EU) hosts many important research institutes and universities that are involved in quantum research, the Netherlands will not fully be able to transfer that scientific knowledge to companies within the Netherlands. The Netherlands invests a lot in research, but the result of that will not necessarily benefit the Netherlands, as this knowledge will be exported elsewhere.

Besides this gap, it is difficult to keep skilled researchers and developers in the Netherlands, because large companies abroad (especially in the US) tend to offer better salaries.

52 Quantum vision team, “Quantum Internet | The internet’s next big step,” issuu, June 3, 2019, https://issuu.com/tudelft-mediasolutions/docs/quantum_magazine_june_2019.

53 Observe, Orient, Decide, Act.

54 Neumann, van Heesch, de Graaf, “Quantum Communication for Military Applications,” 5.

4.2.3 Quantum technology as a an enabling technology

Quantum technology is a key enabling technology. For instance, quantum algorithms can be applied in machine learning and neural networks[55] and quantum communication applications can provide new security solutions. Quantum computing can spur developments in the field of Artificial Intelligence (machine learning), by reducing the total running time of an algorithm, reducing the learning iterations for improving the algorithm and increasing network capacity.[56]

Developments in quantum technology not only lead to processes and systems being more efficient, faster and/or effective, quantum technology fundamentally changes traditional concepts. Quantum computing is a case in point, as the drastically changed computing power enables many different other technological innovations.

Examples

As quantum technology (as an enabling technology) impacts many different sectors, opportunities are also diverse and many are still unknown. In principle, a quantum computer can model very complex processes and substances. Quantum technology (all three subcategories) therefore offers opportunities from the ecological domain (climate prediction models, efficient fertilizers) to the healthcare domain (development of novel (personalised) medicines, greater MRI sensitivity) and the defence & security domain (Positioning, Navigation and Timing without GNSS signals, modelling cybercrime networks, real-time information gathering and analytics). Other possible relevant sectors benefiting from quantum technology are the financial services sector (credit/asset scoring, fraud detection) and manufacturing (materials discovery, fabrication optimization).

More specifically, quantum computing used for optimisation problems can be applied to determine for instance which lots to search for illegal activity in harbours. This inherently means more efficient customs as searching all possible locations is often too time-consuming.[57] Another specific application of quantum computing is enhanced pattern recognition algorithms to recognise enemy vehicles in footage from a drone camera for instance. While this kind of information dominance from an opponent's point of view (thus constituting a threat) was considered above, the same principle constitutes an important opportunity as well.[58]

In the short term, Quantum Key Distribution, allowing the secure distribution of a key, will lead to safer communication. This is because the encryption keys cannot be broken, even with unlimited computational power. This is a 'quantum solution', while it is also possible to resort to post-quantum cryptography.[59]

While some possible opportunities of applying quantum technology in innovations have been highlighted, it is important to realise that many opportunities are still largely theoretical or even unknown. Still, it is important to start thinking about the future with quantum technology applications now, in order to be prepared.[60]

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55 Frank Phillipson, "Quantum Machine Learning: Benefits and Practical Example" (International Workshop on QuANtum SoftWare Engineering & pRogramming (QANSWER), 2020), https://www.researchgate.net/publication/340233722_Quantum_Machine_Learning_Benefits_and_Practical_Example.

56 Neumann, van Heesch, Philipson, Smallegange, "Quantum Computing for Military Applications," 4.

57 Neumann, van Heesch, Philipson, Smallegange, "Quantum Computing for Military Applications," 3.

58 Neumann, van Heesch, Philipson, Smallegange, "Quantum Computing for Military Applications," 5.

59 Neumann, van Heesch, de Graaf, "Quantum Communication for Military Applications," 2; Quantum vision team, "Quantum Internet | The internet's next big step".

60 Neumann, van Heesch, Philipson, Smallegange, "Quantum Computing for Military Applications," 6.

4.3 Biotechnology

4.3.1 General remarks

The disruptive effects on security by developments within biotechnology are expected to be moderate, but should at the same time not be overlooked. Although biotechnology may affect many fields such as the food industry, agriculture and biobased industry, the focus here will be on fields related to security. Many useful applications are expected in the field of medicine, and new biomaterials could lead to significant changes in production processes for military as well as civilian use. A concern is that several techniques developed for beneficial purposes can also be used maliciously.

COVID-19 has demonstrated the strategic importance of anticipating pandemics and vaccines. Biotechnology is a crucial technology for developing vaccines and therapeutics. Although there are many countries and institutes who can apply this technology, the COVID-19 crisis has shown that those who are first have a significant advantage. Situations of scarcity can put countries in a dependency relationship towards the pharmaceutical industry or towards other states willing to provide scarce goods or medicine. The need to provide fast solutions in order to avoid casualties and public unrest can force governments to make disadvantageous agreements with other nations or to provide privileges to the pharmaceutical industry, such as favourable production conditions, handing out exclusive licences and guarantee financial support when claims would be filed.[61]

4.3.2 Disruption of (human) ecosystems

The creation of new viruses

The most serious threat in the upcoming years to be expected from biotechnology is the other side of the vaccine-coin: the creation of new viruses. Biotechnology offers the tools to make these more deadly and contagious than already existing ones, or to recreate previously extinct ones. Both approaches require the knowledge of which part of the virus is most deadly. If one wants to create a vaccine, one way to do so is using this knowledge to make the virus as weak as possible, so that a human can get a small portion of it to start the production of antibodies. The key to creating a bioweapon is the same: to know which part of the virus is most dangerous and therefore should be strengthened. However, it should be noted that not only knowledge of making vaccines, but also knowledge of genetic engineering is required. The population of researchers that is capable of this is growing though. These insights could be expanded to enable precise targeting: to create a virus that only affects a specific person or group of people. However, this is not easy. Fears of unforeseen consequences and unintended effects are probably reasons why these kind of bioweapons have not been used yet at a large scale. The most dangerous scenario might be the creation of viruses which can survive a long time outside a host, for example at surfaces, or that have a long incubation time, causing people to contaminate many others without knowing it.

The technology to create viruses is already available for exploitation. The worldwide effort for vaccines for COVID-19 has demonstrated how fast these kind of biotechnological concepts can be brought from exploration to exploitation.

61 Joep Engels, "'Wij zijn in de clausules gedoken voor de vaccincontracten en ons dood geschrokken'," Trouw, March 7, 2021, https://www.trouw.nl/zorg/wij-zijn-in-de-clausules-gedoken-voor-de-vaccincontracten-en-ons-dood-geschrokken~b59be089/.

Disturbing ecosystems and food chains

Important to note is that the manipulation of micro-organisms does not only constitute a threat to humans, but also to animals or crops. It can disturb ecosystems and food chains, for example by creating novel plant diseases (agro-terrorism). This could also happen unintentionally: pathogens[62] can destroy ecosystems by taking out life forms that are essential in the food chain. An example is the mosquito that spreads malaria by carrying the plasmodium parasite. There are initiatives to kill this specific mosquito species using genetic modification.[63] However, the mosquito is also the main ingredient of the diet of many birds.

Another risk to ecosystems are uncontrolled genetic chain reactions, due to developments around Gene Drive Organisms (GDO's).[64] GDO's are organisms containing engineered 'gene drives' or 'genetic forcers', with the aim of spreading their engineered genes across whole habitats and ecosystems. While first generation Genetically Modified Organisms (GMO's) spread engineered genes by chance, GDO's are designed to do their own engineering among wild populations out in the real world by making use of engineered selfish genes.[65] However, it is not clear what would happen if the genes aren't quite as well behaved as predicted in the models. This makes GDO's a far more dangerous potential biohazard than GMO's.[66] Furthermore, biosafety regulations for developing new GDO's are still at a very early stage, which means that the framework for monitoring and controlling these kinds of developments is weak.[67] This while released GDO's could constitute a transboundary problem, raising many challenges and dilemmas for governance.

4.3.3 From vaccines to detection by biosensors and the use of biomaterials

'Virus resistant super cells'

The most significant opportunity offered by biotechnology is the creation of vaccines and other therapeutics such as antibiotics. Other examples within medical therapy are synthetic biology research for creating 'virus resistant super cells'[68], gene therapy to mitigate the consequences of deadly nerve agents[69], and curing deafness or blindness by gene therapy

62 Pathogens can be viruses, bacteria, fungi or protozoa.

63 Megan Scudellari, "Self-destructing mosquitoes and sterilized rodents: the promise of gene drives," Nature, July 9, 2019, https://www.nature.com/articles/d41586-019-02087-5; Tony Nolan, "Control of malaria-transmitting mosquitoes using gene drives," *Phil. Trans. R. Soc. B* 376, no. 1818 (February 2021), https://doi.org/10.1098/rstb.2019.0803.

64 ETC Group and Heinrich Böll Stiftung, *Forcing The Farm: How Gene Drive Organisms Could Entrench Industrial Agriculture and Threaten Food Sovereignty* (ETC Group and Heinrich Böll Stiftung, October 2018), https://www.etcgroup.org/sites/www.etcgroup.org/files/files/etc_hbf_forcing_the_farm_web.pdf.

65 Hereby, a gene drive or genetic forcer is used. A gene drive is a technique to alter the genetic make-up of populations or a whole species by release of 'engineered selfish genes'. Normally, offspring of sexually reproducing organisms have a 50:50 chance of inheriting a gene. Gene drives are designed to ensure that, within a few generations, an organism's entire offspring will bear the desired engineered gene. ETC Group and Heinrich Böll Stiftung, *Forcing The Farm*, 5.

66 Ibid., 5.

67 Ibid., 3.

68 Elie Dolgin, "Scientists downsize bold plan to make human genome from scratch," Nature, May 1st, 2018, https://www.nature.com/articles/d41586-018-05043-x.

69 Venkaiah Betapudi, Reena Goswami, Liliya Silayeva, Deborah M. Doctor and Nageswararao Chilukuri, "Gene therapy delivering a paraoxonase 1 variant offers long-term prophylactic protection against nerve agents in mice," *Science Translational Medicine* 12, no. 527 (January 2020), 10.1126/scitranslmed.aay0356.

and CRISPR strategies.[70] There seem to be many possibilities in this field but, at the same time, significant problems and barriers.[71]

Faster detection by biosensors

As mentioned before, an important opportunity provided by biosensors is quick and accurate detection and identification of dangerous substances. Examples are improvements in the monitoring of critical infrastructures such as water supply[72], sensors in clothes that light up when a toxic fluid is detected[73] and remote detection of buried explosive devices by micro-organisms engineered to respond to specific chemicals.[74] Other potential applications are the detection of harmful PFAS in soil, groundwater and surface water[75] or pathogen detection by sensors to protect divers from toxins in the water.[76] Biosensors are also increasingly used for medical diagnoses, for example in self-tests and point-of-care diagnostic devices, which can be applied locally (e.g. in remote areas), without medical knowledge, and which generate results very quickly. This will significantly improve medical care and can even be life-saving. Lastly, it would be interesting to see if synthetic-biological sensors could be used to execute forensics, for example to distinguish between man-made or -engineered viruses and naturally evolved biological agents.

The endless possibilities of biomaterials

Lastly, the development of new biomaterials offers many opportunities in various application areas that are also highly relevant for the military, such as medicine, logistics and infrastructure. The possibilities seem only limited by the imagination of researchers and developers. Biotechnology can for example be used to:

- Generate bone, organ tissue and skin for medical use;
- Improve personal protection, for example by developing clothing that blocks UV, has antimicrobial properties, or repels insects;
- Create more stable explosive materials that are safer during transport[77], thereby improving logistical processes;
- Facilitate on-site production of materials, which severely reduces the need for transport;
- Make building materials with attributes of living systems such as the ability to rapidly grow, self-repair and adapt to the environment (e.g. self-healing paint or concrete that heals itself in a durable and environmentally friendly way).[78]

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70 Hemant Khanna, "Gene therapy and CRISPR strategies for curing blindness," UMASS Medical School, June 25, 2020, https://www.umassmed.edu/news/news-archives/2020/06/gene-therapy-and-crispr-strategies-for-curing-blindness/.

71 It matters though if an impairment or damage is at the genetic level of every cell or at a specific place in the body. Concerning the first, genetic modification is only possible on embryos, concerning the impossibility of changing the structure of all cells by hand for an entire living organism. The genetic modification of embryos is, as mentioned before, a sensitive topic.

72 A side note is that this also brings with it new vulnerabilities, as biosensors can also be affected in a biological way, for example by impurities in the water.

73 Luis Rubén Soenksen Martinez, "Cell-free freeze-dried synthetic biology for wearable biotechnology applications," *Massachussetts Institute of Technology* (February 2020), https://hdl.handle.net/1721.1/127730.

74 Yirat Henshke, Benjamin Shemer, Shimshon Belkin, "The Escherichia coli azoR gene promoter: A new sensing element for microbial biodetection of trace explosives," *Current Research in Biotechnology* 3 (2021), https://doi.org/10.1016/j.crbiot.2021.01.003.

75 Nathaniel A Young, et al., "A Synthetic Biology Approach Using Engineered Bacteria to Detect Perfluoroalkyl Substance (PFAS) Contamination in Water," *Military Medicine* 186, no. 1 (January-February 2021), https://doi.org/10.1093/milmed/usaa367.

76 Ying Wu, Chien-Wei Wang, Dong Wang, and Na Wei, "A Whole-Cell Biosensor for Point-of-Care Detection of Waterborne Bacterial Pathogens," *ACS Synthetic Biology* 10, no. 2 (January 2021), https://doi.org/10.1021/acssynbio.0c00491.

77 Adam Meyer et al., "Organism Engineering for the Bioproduction of the Triaminotrinitrobenzene (TATB) Precursor Phloroglucinol (PG)," *ACS Synthetic Biology* 8, no. 12 (November 2019), https://doi.org/10.1021/acssynbio.9b00393.

78 Chelsea M. Heveran et al., "Biomineralization and Successive Regeneration of Engineered Living Building Materials," *Matter* 2, no. 2 (February 2020), https://doi.org/10.1016/j.matt.2019.11.016.

5 Conclusions and Recommendations

This paragraph will translate the insights from the previous paragraphs into conclusions and recommendations for the defence and security domain. Some recommendations are technology-specific, others can be applied for both technologies.

Besides a negative impact on the national security interests distinguished in the National Security Strategy (see Table 2 above), developments in the fields of quantum technology and biotechnology can also positively impact these national security interests, making use of the opportunities identified. Therefore, this paragraph will use the framework of the national security interests to discuss the most important aspects of national security in which impact of both technologies is to be expected.

5.1 Quantum Technology

The two most important national security interests impacted by quantum technology developments are territorial security and economic security.

Concerning territorial security, the main impacted element is digital security. Quantum computing technology will be able to break current (asymmetric) encryption standards. Also in other ways, quantum computing will be able to facilitate cyber-attacks (which will possibly impact economic security and social and political stability as well). Moreover, as society in general and critical infrastructures (such as governmental personal and organisational record databases and drinking water supply) increasingly rely on digital processes, it is important to think ahead and assess how these processes can be prepared for a future in which it will be easier to get access to protected information using quantum computing.

Recommendation 1:
It is critical to prepare for a quantum future and specifically to invest in post-quantum cryptography.

From an economic security perspective, several angles are important. It is necessary to think about the ecosystem of actors involved in quantum technology. While the Netherlands, and the EU in general, certainly has top-notch research institutes and universities, this valuable knowledge is only limitedly being transferred to companies in the EU. Within the EU, there is a lack of large companies that can develop and supply quantum technology commercially at a large scale and as such, the EU can be easily out-competed at the global stage. This certainly has economic repercussions and effects with regards to strategic autonomy in this technology (see paragraph 5.3). The other angle concerning economic security here is that the EU (and individual member states) could lag behind compared to potential opponents. In the future, opponents could apply quantum technology to the (virtual and physical) battle field. This does not necessarily entail direct effects in the physical dimension, but being outcompeted with regards to situational awareness and situational understanding most definitely has repercussions in the security domain. In short, this would mean that opponents have information superiority, possibly impacting physical security and social and political stability as well.

Recommendation 2:
Invest in European cooperation on quantum technology development to strengthen the entire European quantum value chain. This requires that the Netherlands prioritises those elements that are considered vital to develop nationally with regards to strategic autonomy.

5.2 Biotechnology

The three most important national security interests impacted by biotechnology are physical security, ecological security and the international rule of law.

When speaking about physical security, biotechnology can have an impact that reaches as far as the physical integrity of the human body. Here another national security interest, namely that of social and political stability, can also be impacted. This is because the physical environment of people can be impacted as well, as the COVID-19 crisis has shown. Travel restrictions, the need to wear protective materials in public spaces, and having to restrain oneself from physical contact, are only some examples that show how the everyday-live of people can be impacted by a new virus (and governmental regulations in the effort of battling the spread of the virus).

Recommendation 3:
Be prepared for a pandemic by making clear and early arrangements on the development of vaccines and therapeutics. Preferably this should be done at the EU level, since it is an international playing field: crucial technologies are held by various players and development and production often takes place at different locations. Here, lessons should be learned from the current COVID-19 crisis.[79]

79 See for example "How Europe has mishandled the pandemic," The Economist, March 31st, 2021, https://www.economist.com/leaders/2021/03/31/how-europe-has-mishandled-the-pandemic; "Why Europe Is Failing in Covid Vaccination," Wall Street Journal Opinion, March 25, 2021, https://www.wsj.com/articles/why-europe-is-failing-in-covid-vaccination-11616709454.

Recommendation 4:

The Netherlands is a potential large player (think about the Janssen COVID-19 vaccine and Batavia biosciences), but there are several shortcomings in the current climate. To take a more leading role, biotechnology research should be more centrally coordinated. Furthermore, more (customized) investments are needed to support start-ups and scale-ups, and to foster capacity and skilled workers. Lastly, legal bottlenecks should be identified, in order to streamline law and regulations and bring these up to speed with technological developments.[80]

Concerning ecological security, the genetic modification of crops can have an impact on fragile ecosystems, threatening the continued existence of the natural living environment in and around the Netherlands. At the same time, biotechnology offers opportunities for mitigating the effects of global warming on agriculture. The Netherlands has world leading institutes in this field, think of Wageningen University and several seeds development companies. Furthermore, biotechnology offers opportunities for improving the production, transport and storage of renewable energy sources. An example is hydrogen, which production process is in need of improvement in order to be a serious alternative for fossil fuels.

Recommendation 5:

Be aware of the possible negative consequences of genetic modification on fragile ecosystems.

Recommendation 6:

Invest in research into possible applications of biotechnology for creating and improving (production processes of) renewable energy sources.

80 VNO-NCW, *Toekomstpact Biotechnologie Nederland 2025* (VNO-NCW, February 2021), https://www.vno-ncw.nl/sites/default/files/toekomstpact_biotechnologie_nederland_2025.pdf.

5.3 **In general**

At a strategic level, there are three themes of recommendations that apply to both quantum technology and biotechnology.

First, the Netherlands is home to research institutes and universities that perform internationally renowned research into quantum technology and biotechnology. Besides investing in the ecosystems surrounding these technology areas, it is important to keep attracting skilled researchers and developers.

Recommendation 7:
Invest in a healthy and interesting work climate for skilled workers in these areas, to avoid 'brain drain' (of experts and start-ups for instance) to countries where salaries are higher, possibilities for development are better or other more preferable conditions.

Second, for quantum technology as well as biotechnology, there are ethical, legal and social aspects (ELSA) to consider. Public debates should be conducted in time, especially about the consequences of these aspects on and their integration in society, and the possibilities for 'dual use'.[81] This is especially relevant in the light of recent international developments in loosening restrictions on genetic modification. Here, the Netherlands could support efforts at the international level to continue and strengthen ethics governance and regulation in biotechnology, for example by pushing the establishment of technical and ethical guidelines. This includes the establishment of verification regimes in order to monitor compliance.

Recommendation 8:
Make sure to have the public debate on ethical, legal and social aspects of quantum technology and biotechnology ahead or at least in pace with developments in these fields, as to not be caught off guard.

81 Think for instance about the military research agency of the United States, DARPA, which is one of the largest funders of gene drive projects, next to for example the Bill and Melinda Gates Foundation. The altruistic intent of the research (increasing food security) is sometimes questioned. See for example on the 'Insect Allies' programme, on the use of insects for dispersing genetically modified viruses to agricultural plants in fields. ETC Group and Heinrich Böll Stiftung, *Forcing The Farm*, 2; R. G. Reeves, S. Voeneky, D. Caetano-Anollés, F. Beck, C. Boëte, "Agricultural research, or a new bioweapon system?," *Science* 362, no. 6410 (October 2018), 10.1126/science.aat7664.

Third, from an economic security perspective, it is necessary to create means to safeguard sufficient strategic autonomy with regards to these technologies (and 'sensitive technologies' in general). On the one hand, this means that investment choices need to be made: which applications or research fields of both technologies are considered to be critical to develop nationally? How to approach certain dependencies on research and development suppliers? On the other hand, this also means that choices need to be made with regards to intellectual property and export control. What knowledge can be shared internationally and which restrictions should be in place to protect sensitive information (sensitive from an economic perspective, but also from a security perspective) for both technologies?

Recommendation 9:

Be aware of dependencies on industry and other nations for both technologies. Think about priorities (EU and Dutch) with regards to technology development, but also the advantages of international scientific cooperation. This means a consideration with regards to protecting 'sensitive' information leaving the EU and/or the Netherlands as well.

Bibliography

Analistennetwerk Nationale Veiligheid. *Geïntegreerde Risicoanalyse Nationale Veiligheid 2019.* March 2019. https://www.rivm.nl/sites/default/files/2019-10/Geintegreerde%20risicoanalyse%20Nationale%20Veiligheid%202019.pdf.

Bell, Brian. "What makes an insect indestructible?." University of California. October 22, 2020. https://www.universityofcalifornia.edu/news/what-makes-insect-indestructible.

Betapudi, Venkaiah; Goswami, Reena; Silayeva, Liliya; Doctor, Deborah M. and Chilukuri, Nageswararao. "Gene therapy delivering a paraoxonase 1 variant offers long-term prophylactic protection against nerve agents in mice." *Science Translational Medicine* 12, no. 527 (January 2020). 10.1126/scitranslmed.aay0356.n.d.

Chen, YA.; Zhang, Q.; Chen, TY. et al. "An integrated space-to-ground quantum communication network over 4,600 kilometres." *Nature* 589 (January 2021). https://doi.org/10.1038/s41586-020-03093-8.

Daum, Fred. "Quantum Radar Cost and Practical Issues." *IEEE Aerospace and Electronic Systems Magazine* 35, no. 11 (November 2020). 10.1109/MAES.2020.2982755.

Dolgin, Elie. "Scientists downsize bold plan to make human genome from scratch." Nature. May 1st, 2018. https://www.nature.com/articles/d41586-018-05043-x.

ECP Platform voor de InformatieSamenleving. *Essay Verkenning Quantumtechnologie. Aanbevelingen ter voorbereiding op een gezamenlijke toekomst met quantumtechnologie* (2019). https://ecp.nl/publicatie/essay-verkenning-quantumtechnologie/.

Engels, Joep. "'Wij zijn in de clausules gedoken voor de vaccincontracten en ons dood geschrokken'." Trouw. March 7, 2021. https://www.trouw.nl/zorg/wij-zijn-in-de-clausules-gedoken-voor-de-vaccin-contracten-en-ons-dood-geschrokken~b59be089/.

Enserink, Martin. "Scientists Brace for Media Storm Around Controversial Flu Studies." Science. November 23, 2011. https://www.sciencemag.org/news/2011/11/scientists-brace-media-storm-around-controversial-flu-studies.

ETC Group and Heinrich Böll Stiftung. *Forcing The Farm: How Gene Drive Organisms Could Entrench Industrial Agriculture and Threaten Food Sovereignty.* ETC Group and Heinrich Böll Stiftung, October 2018. https://www.etcgroup.org/sites/www.etcgroup.org/files/files/etc_hbf_forcing_the_farm_web.pdf.

European Commission. Horizon 2020 – Work Programme 2014-2015. Annex G. Technology readiness levels (TRL). Commission Decision C(2014)4995, 2014. https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf.

Future Today Institute. *2021 Tech Trends Reports.* New York: Future Today Institute, 2021. https://future-todayinstitute.com/trends/.

Gunther, Aimee; Mason, Peter; Lefebvre, Julie. *Department of National Defence and Canadian Armed Forces Quantum S&T Strategy: Preparing for Technological Disruptions in the Future Operating Environment*. (Defence Research and Development Canada, February 2021). https://cradpdf.drdc-rddc.gc.ca/PDFS/unc356/p812809_A1b.pdf.

Hasberg, Marcel-Paul; Bronkhorst, Adelbert; Meessen, Rick; van Weerd, Carolina. *Defensie Technologie Verkenning 2020.* Den Haag: TNO, 2020.

Henshke, Yirat; Shemer, Benjamin; Belkin, Shimshon. "The Escherichia coli azoR gene promoter: A new sensing element for microbial biodetection of trace explosives." *Current Research in Biotechnology* 3 (2021). https://doi.org/10.1016/j.crbiot.2021.01.003.

Herfst, Sander et al. "Airborne Transmission of Influenza A/5H5N1 Virus Between Ferrets." Science 336, no. 6088 (June 22, 2012), 10.1126/science.1213362.

Heveran, Chelsea M. et al. "Biomineralization and Successive Regeneration of Engineered Living Building Materials." *Matter* 2, no. 2 (February 2020). https://doi.org/10.1016/j.matt.2019.11.016.

"How Europe has mishandled the pandemic." The Economist. March 31st, 2021. https://www.economist.com/leaders/2021/03/31/how-europe-has-mishandled-the-pandemic.

Khanna, Hemant. "Gene therapy and CRISPR strategies for curing blindness," UMASS Medical School. June 25, 2020. https://www.umassmed.edu/news/news-archives/2020/06/gene-therapy-and-crispr-strategies-for-curing-blindness/.

Kosicki, Michael; Tomberg, Kärt; Bradley, Allan. "Repair of double-strand breaks induced by CRISPR-Cas9 leads to large deletions and complex rearrangements." *Nature Biotechnology* 36 (July 2018). https://doi.org/10.1038/nbt.4192.

Kupferschmidt, Kai. "How Canadian researchers reconstituted an extinct poxvirus for $100,000 using mail-order DNA." Science. July 6, 2017. https://www.sciencemag.org/news/2017/07/how-canadian-researchers-reconstituted-extinct-poxvirus-100000-using-mail-order-dna.

Li, Jing-ru; Walker, Simon; Nie, Jing-bao; Zhang, Xin-qing. "Experiments that led to the first gene-edited babies: the ethical failings and the urgent need for better governance." *Journal of Zhejiang University-SCIENCE B (Biomedicine & Biotechnology)* 20, no. 1 (January 2019). 10.1631/jzus.B1800624

Meyer, Adam et al. "Organism Engineering for the Bioproduction of the Triaminotrinitrobenzene (TATB) Precursor Phloroglucinol (PG)." *ACS Synthetic Biology* 8, no. 12 (November 2019). https://doi.org/10.1021/acssynbio.9b00393.

Ministerie van Defensie. *Strategische Kennis en Innovatie Agenda 2021-2025.* November 27, 2020. https://www.defensie.nl/downloads/publicaties/2020/11/25/strategische-kennis--en-innovatieagenda-2021-2025.

National Human Genome Research Institute. *Messenger RNA (mRNA).* https://www.genome.gov/genetics-glossary/messenger-rna.

NCTV. *National Security Strategy.* The Hague: 2019. https://english.nctv.nl/binaries/nctv-en/documents/publications/2019/09/19/national-security-strategy/National+Security+Strategy_2019.pdf.

Neumann, Niels; van Heesch, Maran; Philipson, Frank; Smallegange, Antoine. "Quantum Computing for Military Applications." *International Conference on Military Communications and Information Systems.*

Neumann, Niels; van Heesch, Maran; de Graaf, Patrick. "Quantum Communication for Military Applications." *International Conference on Military Communication and Information Systems (ICMCIS).*

Nolan, Tony. "Control of malaria-transmitting mosquitoes using gene drives." *Phil. Trans. R. Soc. B* 376, no. 1818 (February 2021). https://doi.org/10.1098/rstb.2019.0803.

O'Leary, Colin; Silver, Pam; van Opstal, Edward; Rozo, Michelle. *Tech factsheets for policy makers - Spring 2020 series - Synthetic Biology*. Cambridge: Hardvard Kennedy School - Belfer Center for Science and International Affairs, 2020. https://www.belfercenter.org/sites/default/files/2020-10/tappfactsheets/SyntheticBiology.pdf.

Ortt, Roland. *De Technologiemonitor 2020 Quantumtechnologie. Een onderzoek naar de ontwikkkeling en verspreiding van quantumtechnologieën.* Den Haag: Stichting Toekomstbeeld der Techniek, 2021. https://stt.nl/nl/toekomstverkenningen/97-de-technologiemonitor-2020-quantumtechnologie/nationale-technologiemonitor-2020-quantumtechnologie.

Phillipson, Frank. "Quantum Machine Learning: Benefits and Practical Example." *International Workshop on QuANtum SoftWare Engineering & pRogramming (QANSWER).* https://www.researchgate.net/publication/340233722_Quantum_Machine_Learning_Benefits_and_Practical_Example.

Quantum Delta Nederland. *Nationale Agenda Quantumtechnologie*. Den Haag: September 2019. https://www.rijksoverheid.nl/documenten/brochures/2020/02/17/nationale-agenda-quantumtechnologie.

Quantum Vision Team TU Delft. *Quantum Internet | The internet's next big step.* Issuu. June 3rd, 2019. https://issuu.com/tudelft-mediasolutions/docs/quantum_magazine_june_2019.

QURECA quantum resources & careers. "Overview on quantum technologies worldwide." QURECA quantum resources & careers. January 22, 2021. https://www.qureca.com/overview-on-quantum-initiatives-worldwide/.

Reeves, R. G.; Voeneky, S.; Caetano-Anollés, D.; Beck, F.; Boëte, C. "Agricultural research, or a new bioweapon system?." *Science* 362, no. 6410 (October 2018). 10.1126/science.aat7664.

Rivera, Jesus; Hosseini, Maryam Sadat; Restrepo, David, et al. "Toughening mechanisms of the elytra of the diabolical ironclad beetle." *Nature* 586 (October 2020). https://doi.org/10.1038/s41586-020-2813-8.

Scudellari, Megan. *Self-destructing mosquitoes and sterilized rodents: the promise of gene drives.* Nature. July 9, 2019. https://www.nature.com/articles/d41586-019-02087-5.

Soenksen Martinez, Luis Rubén. *Cell-free freeze-dried synthetic biology for wearable biotechnology applications.* Cambridge: Department of Mechanical Engineering, Massachusetts Institute of Technology, February 2020. https://dspace.mit.edu/handle/1721.1/127730.

Steel, J. Jordan; Bates, Katherine; Barnhart, Michael. "Investing in our nation's future military leaders' synthetic biology knowledge to understand and recognize threats and applications." *Synthetic Biology* 4, no. 1 (October 2019). https://doi.org/10.1093/synbio/ysz024.

Subbaraman, Nidhi. "Limit on lab-grown human embryos dropped by stem-cell body." Nature. May 26, 2021. https://www.nature.com/articles/d41586-021-01423-y.

Vidyasagar, Aparna. "What is CRISPR?." Live Science. April 21, 2018. https://www.livescience.com/58790-crispr-explained.html.

VNO-NCW. *Toekomstpact Biotechnologie Nederland 2025.* VNO-NCW, February 2021. https://www.vno-ncw.nl/sites/default/files/toekomstpact_biotechnologie_nederland_2025.pdf.

"Why Europe Is Failing in Covid Vaccination." Wall Street Journal Opinion. March 25, 2021. https://www.wsj.com/articles/why-europe-is-failing-in-covid-vaccination-11616709454.

Wu, Ying; Wang, Chien-Wei; Wang, Dong; Wei, Na. "A Whole-Cell Biosensor for Point-of-Care Detection of Waterborne Bacterial Pathogens." *ACS Synthetic Biology* 10, no. 2 (January 2021). https://doi.org/10.1021/acssynbio.0c00491.

Young, Nathaniel A et al. "A Synthetic Biology Approach Using Engineered Bacteria to Detect Perfluoroalkyl Substance (PFAS) Contamination in Water." *Military Medicine* 186, no. 1 (January-February 2021). https://doi.org/10.1093/milmed/usaa367.

Annex A – **Impact Assessment Method**

In order to assess the impact of quantum technology and biotechnology on national security, a qualitative impact assessment method was used.

Scope

The scope of the assessment concerned the Netherlands, while acknowledging that internal and external security are interconnected (the so-called 'nexus' internal-external security). This means that developments abroad can impact Dutch national security and vice versa. Also, the focus was on relevant effects for the defence and security domain. Developments and possible impact of the two technology areas from now up until roughly 5 years were considered. Where relevant, important developments that have an effect on the longer term were also included.

While both opportunities and threats were considered in the impact assessment, it is important to acknowledge that those cannot be seen as independent from one another. Something assessed as a threat when used by (possible) opponents can also constitute an opportunity for the Netherlands, and the other way around.

Method

Experts from TNO in quantum technology and biotechnology were asked several questions in separate expert sessions. Essentially, the main question in the impact assessment on threats was whether developments in the fields of quantum technology and biotechnology would impact (positively or negatively) the risks that are already considered a threat to national security. The national security interests and threat categories were used as the foundation for the impact assessment from the threat perspective (see Table 3).[82]

82 See ANV, *Geïntegreerde Risicoanalyse Nationale Veiligheid 2019*.

Theme	Threat Category
Threats to health and environment	Human infectious diseases, animal diseases and zoonotic diseases
Natural disasters	Extreme weather, flooding, wildfires, earthquakes
Critical national infrastructure	Disruption of critical national infrastructure
Serious accidents	Radiation accidents, chemical accidents
Cyber threats	Digital sabotage, impairment of internet services, cyberespionage, cybercrime
Undermining democratic rule of law	Non-violent extremism, subversive crime, undesirable foreign influence (via hybrid operations)
Violent extremism and terrorism	Violent extremism, terrorism
Financial-economic threats	Criminal interference, flow security, disruption of international trade, destabilisation financial system
Threats to international peace and security	Instability around Europe, military threats, CBRN proliferation, pressure on international security arrangements

Table 3. Threats to national security

Besides these known possible threats to national security, it is also important to look at possible threats that are not yet identified as such. For this, the TNO experts were asked to consider whether the technological developments within quantum technology and biotechnology could impact the six national security interests[83] (see Table 4 down below) in any other way in the short term (up to about 5 years in the future).

Territorial security	The unimpeded functioning of the Netherlands and its EU and NATO allies as independent states in a broad sense, or territorial security in a narrow sense.
Physical security	The ability of people to go about their lives in an unimpeded manner within the Netherlands and their own physical environment.
Economic security	The unimpeded functioning of the Dutch economy in an effective and efficient manner.
Ecological security	The unimpeded continued existence of the natural living environment in and around the Netherlands.
Social and political stability	The continued and unimpeded existence of a social climate in which individuals are free to go about their lives and groups are able to coexist within and in accordance with the Netherlands' democratic and lawful state and its shared values.
International rule of law	The functioning of the international system of rules, standards and agreements established for the purposes of international peace and security

Table 4. Dutch national security interests

For the impact assessment on opportunities, we mainly looked at the extent to which the developments in the technology areas can offer solutions to critical societal challenges and whether the technologies can be applied in the domains of security and defence, including intelligence and critical infrastructure. Also, we considered the global economic position of the Netherlands in quantum technology and biotechnology.

83 NCTV, *National Security Strategy*.

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