TECHNOLOGY CENTRE PRAGUE

Analysis of the challenges in the field of innovation diffusion and digitalisation, and a proposal for focusing the priorities of the National RIS3 Strategy after 2025

Final report

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1 Introduction

The aim of the study prepared by the Technology Centre Prague (TCP) for the Ministry of Industry and Trade (MIT) under the contract "Analysis of challenges in the field of innovation diffusion and digitalisation and proposal of the focus of priorities of the National RIS3 Strategy after 2025" is to identify significant technological and societal challenges that the Czech Republic will face in the future and to assess the relevance of these challenges for the National Research and Innovation Strategy for Smart Specialization of the Czech Republic 2021-2027 (National RIS3 Strategy, NRIS3) [1] The conclusions of the analysis will be used in particular to update of NRIS3 and serve as a valuable resource for defining further missions to be included in the strategy after 2025, or in the subsequent NRIS3 for the next European Structural and Investment Funds (ESIF) financial period.

The final report is structured as follows: Chapter 2 identifies the grand societal challenges (GSCs) that the Czech Republic is facing or is likely to face in the near future. GSCs are based on a search of documents dealing with GSCs that have been developed in the Czech Republic and at the European level. The goal was to ensure that these GSCs align with the societal challenges and missions outlined in the Horizon Europe (HE) framework programme [2]. Furthermore, advanced technologies that could potentially address these GSCs have been identified. The key challenges identified are detailed in Chapter 2.1., while the advanced technologies are discussed in Chapter 2.2.

In the Chapter 3.1, trends in advanced technologies and the links of these technologies to the identified GSCs are analysed. In Chapter 3.2, trends in government support for projects dealing with research and development (R&D) of advanced technologies are assessed. It allows to assess to what extent domestic research follows trends observed in the world. Subsequently, in the Chapter 3.4 the links of advanced technologies to the identified GSCs are assessed. As research on Artificial Intelligence (AI) and its applications has recently gained importance, the Chapter 3.3 assesses how state support of the AI research has evolved in recent years and what the capacity for this research in the Czech Republic is.

In the Chapter 4, attention is paid to emerging trends in advanced technologies. First, current trends in publishing and patent activities are assessed (Chapter 4.1). Then, using an analysis of the main topics of articles in current technology-oriented media, the current trends that are emerging in advanced technologies are evaluated (Chapter 4.2). In Chapter 4.3 information is provided from a search of promising R&D directions in advanced technologies. Chapter 4.4 summarises the findings of the expert workshop at which the results of these analyses were discussed.

In the Chapter 5 the results of the analysis of stakeholders active in R&D in the field of advanced technologies are presented (Chapter 5.1). The most relevant stakeholders were also asked whether they would be interested in nominating vetted researchers in the future under the 2022/2065 Digital Single Market Regulation [3]. An overview of the institutions contacted, and their comments is presented in Chapter 5.2. In Chapter 5.3 the existing connections between actors involved in advanced technology research at both national and international levels are analysed.

In the Chapter 6 the Czech Republic's position in the international comparison of R&D in the field of advanced technologies is evaluated (Chapter 6.1). Then the Czech Republic's position in digital technologies is evaluated based on the indicators tracked in the Policy Programme Digital Decade (PPDD) [4] (Chapter 6.2). In Chapter 6.3 the contribution of advanced technologies to the solution of the identified GSCs is evaluated. The results of all the analyses were discussed at the closing workshop, the conclusions of which are summarised in Chapter 6.4. The Chapter 7 offers an overview of the key findings from the analyses and presents a draft of recommendations that incorporate the insights of experts from the closing workshop. In Chapter 8 an overview of the most relevant information sources is provided. The extensive appendix section of Chapter 9 specifies the most important data sources used in the analysis and the methodology applied. More detailed results of some of the analyses carried out, and other additional information are also included.

2 Grand societal challenges and advanced technologies

2.1 Grand societal challenges

To identify the grand societal challenges (GSC), a search was conducted on strategic and conceptual documents addressing these issues that have been developed in recent years both in the Czech Republic and at the EU level. The key documents included in the search were:

- Outputs of the project "FUTURE-PRO: Megatrends and Grand Societal Challenges" supported by the Technology Agency of the Czech Republic (TA CR) in the years 2020 - 2021, which was implemented by the Czech Priority, z. ú. The end-user of the project results was the Office of the Government of the Czech Republic [5], [6].
- Document Long-term challenges for Czech society (LTCs) [7] which was prepared in 2023 by the Technology Centre Prague based on the assignment of the Office of the Government of the Czech Republic in the project "Conceptual and analytical support to the Research, Development and Innovation Council (RDIC)" in connection with the preparation of new National Priorities of Oriented Research (NPOR) [8].
- National Research and Innovation Strategy for Smart Specialization of the Czech Republic 2021-2027 (National RIS3 Strategy, NRIS3) prepared by the Ministry of Industry and Trade (MIT) in 2021 [1]. In particular, the search included information on two missions, which are in Annex 1.
- Horizon Europe (HE) Framework Programme [2]. In particular, the work programmes for Pillar II "Global Challenges and European Industrial Competitiveness" and the relevant documents setting out the focus of the missions in the HE Framework Programme were included in the search.

The main findings from the searches of the above-mentioned documents are presented in Chapter 2.1.1 to 2.1.5.

2.1.1 Project FUTURE-PRO: Megatrends and grand societal challenges

The aim of the FUTURE-PRO: Megatrends and Grand Societal Challenges project was to develop a methodology to identify megatrends and grand societal challenges of importance to the Czech Republic that require extensive and systematic research. The methodology was used to identify the most significant megatrends and societal challenges on which research should focus in the coming years.

GSC are in FUTURE-PRO: Megatrends and Grand Societal Challenges [5], [6] are defined as "A cluster of problems requiring collective action to solve them in the future." From this perspective, GSCs can be understood as long-term problem areas that society is facing and will face in the future. Therefore, it cannot be expected that there will be a significant shift in GSCs between the current period (i.e. 2023) and 2025, when the NRIS3 update will be undertaken.

The FUTURE-PRO project identified a total of 20 megatrends and 23 grand societal challenges with the involvement of experts. An overview of these is presented in Table 1. Within the FUTURE-PRO project, Global Megatrends and GSC cards have been prepared, which provide more detailed information (development to date, future outlook, expected impacts and related future challenges, global and European objectives, possible directions of solutions, and framework overview of the situation in the Czech Republic). These cards can be found on the project website[1] .

[1] FUTURE-PRO, https://www.megatrendy.cz/

Table 1 Megatrends and grand societal challenges identified in the FUTURE-PRO project. Source: FUTURE-PRO project [5], [6]

Megatrends	**Grand societal challenges**
MT1 - Earth's climate variations	GSC1 - Crucial, yet vulnerable cities
MT2 - Energy consumption growth	GSC2 - Insufficiently addressed climate crisis
MT3 - Environmental degradation	GSC3 - Democracy under pressure
MT4 - Depletion of natural resources	GSC4 - Impacts of digitisation and automation on work and society
MT5 - New migration flows	GSC5 - Education system adaptation
MT6 - Population ageing	GSC6 - Unpreparedness for the new nature of work
MT7 - Population growth	GSC7 - Low-emission energy production and consumption
MT8 - Urban sprawl	GSC8 - Adverse effects of humans on the environment
MT9 - Growing consumerism and responsible consumption	GSC9 - Equal access to high-quality and nutritious food
MT10 - Shifting focus of the world economy	GSC10 - Geopolitical tension
MT11 - Weakening global economic growth	GSC11 - New ethical dilemmas and cultural challenges
MT12 - Decrease in extreme poverty and increase in inequality	GSC12 - Poor health and mental discomfort
MT13 - Increasing interdependence of states	GSC13 - Increasing inequality within states
MT14 - New forms of and reasons for conflicts	GSC14 - Infrastructure failure risks
MT15 - Transformation of liberal democracy	GSC15 - Insufficiently addressed migration
MT16 - Transformation of individual and societal values	GSC16 - Unsustainable use of natural resources and ecosystem
MT17 - Accelerating and ubiquitous digitization and automation	GSC17 - Poverty and the risk of falling into poverty
MT18 - Innovation and technological acceleration	GSC18 - Extensive breadth and speed of technological change
MT19 - Changing importance of education and human	MSC19 - Unpreparedness for the new nature of security threats
MT20 - Improving health and the onset of new health	GSC20 - Social instability
	GSC21 - Sustainable consumption
	GSC22 - Ensuring sustainable economic growth
	GSC23 - Water scarcity

2.1.2 Long-term challenges for Czech society

In the document Long-Term Challenges for Czech Society (LTC) [7], which was discussed by the Research, Development and Innovation Council (RDIC) at its 391st meeting on 30 June 2023, a total of five long-term challenges for Czech society are defined:

- Adaptation to climate change;

- Preparedness for demographic change and an ageing population;
- Energy transition and a sustainable future;
- Trust in democracy, societal resilience, security and defence;
- Technological and digital transformation of society.

The challenges outlined in this document are based, inter alia, on the outputs of the FUTURE-PRO: Megatrends and Grand Societal Challenges project [5] (see Chapter 2.1.1). Compared to the outputs of that project, the LTCs are more broadly defined. As a result, one LTC usually covers several GSCs from the FUTURE-PRO document [5]. The focus of the LTCs generally aligns with the societal challenges and missions outlined in the Horizon Europe Framework Programme. (see Chapter 2.1.4). As the GSCs included in the following analysis will be based on the five LTCs defined in this document, their more detailed characteristics are presented in Chapter 2.1.5.

2.1.3 Missions in the current NRIS3

In the current NRIS3 [1] (see the Annex 1 Thematic Area Cards [9]), two missions are defined:

- Improving the material, energy, and emission efficiency of the economy,
- Strengthening the resilience of society to security threats.

For both missions, their strategic objectives, and the topics for R&D in each strategic objective were also defined. This structuring is briefly described in the following chapters. More detailed information on these missions concerning the objectives of this public contract is described in Chapter 9.2.1.1 a 9.2.1.2.

2.1.3.1 Making the economy more material, energy and emissions efficient

The mission, "Improving the material, energy, and emission efficiency of the economy," was chosen in response to current development trends in energy and raw material resource management. It also addresses the key needs of the Czech economy and society concerning the transformation of the energy sector. The mission is organized into three strategic objectives: Decarbonisation, Decentralisation, and Circularity. To achieve these objectives, relevant Research, Development, and Innovation (R&D&I) topics have been identified through the Entrepreneurial Discovery Process (EDP).

Decarbonisation - The goal is to attain a level of technological readiness within the Czech economy that will enable a reduction of CO2 emissions by at least 44 Mt of CO2 equivalent (compared to 2005 levels) by the year 2030. To support this strategic objective, four key themes for Research, Development, and Innovation (R&D&I) have been established:

- Low-emission energy sources
- Energy storage, transport and transformation
- Energy efficiency and savings
- Low-emission technologies in industry

Decentralisation - The objective is to adapt the electricity system, along with other energy networks, to accommodate the development of local renewable energy sources. This adaptation aims to establish the technological conditions necessary for increasing the share of decentralized energy sources. The strategic objective outlines two primary themes for R&D&I:

- Local manufacturing and hardware for network stability
- Smart control of energy production, distribution and consumption

Circularity - the aim is to achieve a technological level of industrial design, production and processing processes, and the functioning of the secondary raw materials market that will allow to triple the material recycling rate by 2040 compared to 2017 levels. The strategic objective sets out three themes for R&D&I:

- Industrial design and materials
- Sustainable consumption
- 3R Principles[2]

2.1.3.2 Strengthening society's resilience to security threats

Given the current trend towards globalisation, the need to respond to current and emerging security threats is evolving and has a different dynamic than in the past. The mission "Strengthening the Resilience of Society against Security Threats" aims to develop viable solutions that enable a flexible response to societal changes. Specifically, it focuses on predicting and preventing emergencies, and, when emergencies do occur, efficiently mitigating their consequences and restoring normalcy to an even higher standard. This will be achieved through the outcomes of research, development, and innovation (R&D&I).

The goal of the mission is to contribute through R&D&I to the acquisition and effective development of innovative knowledge, methods and technologies that enable the Czech security system and its stakeholders to face current and future risks arising from the changing security environment. The mission defines two strategic objectives.

Stability, reliability and sustainability of social, economic and environmental systems - the aim is to contribute to the stability, reliability and sustainability of social, economic and environmental systems in terms of security and safety innovation. The strategic objective sets out three themes for R&D&I:

- Naturogenic threats
- Ensuring the running of the economy
- Anthropogenic threats

Reducing risks and increasing resilience - This initiative aims to enhance societal resilience through research and development, while simultaneously reducing the risk of emergencies and crises that could negatively impact individuals and society. The strategic objective delineates four key themes for R&D&I:

- Safe public space
- Security of infrastructures
- Environmental safety
- Security aspects of new technologies

2.1.4 Global challenges and missions in Horizon Europe programme

2.1.4.1 Global challenges

Horizon Europe (HE [2]) in its second pillar “Global Challenges and European Industrial Competitiveness” defines six broad thematic clusters representing areas of global challenges. Within each cluster, areas of intervention are also identified:

- Climate, energy and mobility:

[2] Reduce, reuse, recycle

- Climate science and solutions; Communities and cities; Industrial competitiveness in transport; Clean, safe and accessible transport and mobility; Smart mobility
- Energy supply; Energy systems and networks; Buildings and industrial facilities in energy transformation; Energy storage

Food, bioeconomy, natural resources, agriculture and environment:

- Environmental observation; Biodiversity and natural resources; Agriculture, forestry and rural areas; Seas, oceans and inland waters; Food systems; Biotechnology-based innovation systems in the EU bioeconomy; Circulation systems

Health:

- Lifelong health; Environmental and social determinants of health; Non-communicable diseases and rare diseases; Infectious diseases; New tools, technologies and digital solutions for health; Health care systems

Culture, creativity and inclusive society:

- Democracy and Governance; Cultural Heritage; Socio-economic Transformation

Civil security for society:

- Disaster Resilient Societies; Safety and Security; Cyber Security

Digital, industry and space:

- Manufacturing Technologies; Key Digital Technologies; Advanced Materials; Emerging Breakthrough Technologies; Artificial Intelligence and Robotics; Next Generation Internet; Advanced Computing and Big Data; Circular Industry; Low Carbon and Green Industry; Space, including Earth Observation.

2.1.4.2 Missions

The missions within the HE programme consist of portfolios of research, development, and innovation actions designed to make a substantial impact across various disciplines and sectors. These missions aim to address issues relevant to a significant portion of the European population. Each mission features clearly defined, measurable objectives and anticipated impacts that are expected to be achieved within a specified timeframe. Five missions are currently identified in the HE programme:

- Cancer
- Healthy oceans, seas, coastal and inland waters
- Healthy soil and food
- Adaptation to climate change including social transformation
- Climate neutral and smart cities

At the time of writing this report (November 2023), a sixth mission, The New European Bauhaus, is currently in preparation. More detailed information on the HE Framework Programme missions can be found on the European Commission website[3] .

[3] EU Missions in Horizon Europe, https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe_en

2.1.5 Grand societal challenges relevant to the Czech Republic now and in the near future

The structure and characteristics of the GSCs, which will be the focus of further analysis, are based primarily on the document Long-term Challenges for Czech Society [7]. An overview of the long-term challenges defined in this document is given in Table 2 in the first column with blue underlining. As can be seen from this table, the challenges identified in this document always include several of the GSCs identified in the FUTURE-PRO project (second column of the table) and correspond to some extent to the global challenges of the HE Framework Programme and the missions defined in this programme (third and fourth columns of the table). The two GSCs correspond in their focus to the two missions in the current NRIS3 [9] listed in the last column of the table. A more detailed description of the identified GSCs, which was used to generate the set of keywords, is provided in the annex section of the report in the Chapter 9.2.1.

Table 2 Comparison of societal challenges and missions defined in the Long-term Challenges for Czech Society [7], Megatrends and Grand Societal Challenges relevant to the Czech Republic [4][5], the Horizon Europe Framework Programme [2] and in the National Research and Innovation Strategy for Smart Specialisation of the Czech Republic 2021-2027 [1]

Long-term challenges for Czech society	GSC defined in FUTURE-PRO	Global challenges in HE	Missions in Horizon Europe	Missions in the current NRIS3 2021-2027
Adaptation to climate change	GSC 1- Crucial, yet vulnerable cities GSC 2 - Insufficiently addressed climate crisis GSC 23 - Water scarcity GSC 8 - Adverse effects of humans on the environment GSC 9 - Equal access to high-quality and nutritious food GSC 16 - Unsustainable use of natural resources and ecosystem services (part) GSC 21 - Sustainable consumption (part) GSC 22 - Ensuring sustainable economic growth (part)	Climate, energy and mobility– (part) Food, bioeconomy, natural resources, agriculture and environment	Adaptation to climate change including social transformation *New European Bauhaus*[5]	
Preparedness for demographic change and an ageing population (abbreviated as Preparedness for demographic change)	GSC 6 - Unpreparedness for the new nature of work GSC 11 - New ethical dilemmas and cultural challenges	Health	Cancer	

[4] The grand societal challenges from the FUTURE-PRO document are taken from Table 3 - Overall Delphi Results. The "horizontal GSCs" - Education and Employment and Science and Innovation - are not included in the overview.
[5] The "New European Bauhaus" is HE's upcoming mission connecting the Green Deal and "living spaces"

	GSC 12 - Poor health and mental discomfort			
Energy transformation and a sustainable future (abbreviated as Energy Transformation)	GSC 7 - Low-emission energy production and consumption GSC 21 - Sustainable consumption (part) GSC 22 - Ensuring sustainable economic growth (part)	Climate, energy and mobility(part)	Climate-neutral and smart cities	Improving the material, energy, and emission efficiency of the economy
Trust in democracy, societal resilience, security and defence (abbreviated as Trust in Democracy, Societal Resilience)	GSC 3 - Democracy under pressure GSC 10 - Geopolitical tension GSC 13 - Increasing inequality within states GSC 14 - Infrastructure failure risks GSC 15 Insufficiently addressed migration GSC 17 - Poverty and risk of falling into poverty GSC 19 - Unpreparedness for the new nature of security threats GSC 20 - Social instability	Culture, Creativity and Inclusive Society Civil security for society		Strengthening society's resilience to security threats
Technological and digital transformation of society (abbreviated as Technology and Digital Transformation)	GSC 4 - Impacts of digitisation and automation on work and society GSC 18 - Extensive breadth and speed of technological change	Digital, industry and space		

2.2 Advanced technologies

A number of strategic-conceptual and technology-oriented documents deal with the issue of advanced technologies. The selection of advanced technologies for the analysis prepared within the framework of this analysis is mainly based on the set of technologies proposed within the Advanced Technologies for Industry (ATI) project of the European Commission [10]. These technologies are described in more detail in Chapter 2.2.1.

In selecting advanced technologies linked to the GSC, the so-called Key Enabling Technologies (KETs) were also considered. KETs have been taken into account in NRIS3 in the identification of R&I specialization domains and R&D themes with potential for application in NRIS3 application sectors ([1], [9]). These technologies are characterized in more detail in Chapter 2.2.2.

The research on advanced technologies primarily concentrated on digital technologies. These increasingly permeate numerous technological domains, driving their dynamic development and often causing significant disruptions. For this reason, the McKinsey Digital Technology Trends Outlook 2023 which characterises trends in some advanced digital technologies [11], was included in this report.

2.2.1 Advanced technologies for industry

In line with the EU's efforts to enhance the competitiveness of European industry, a project named Advanced Technologies for Industry (ATI) has been launched [6][10]. The project identified 16 advanced technologies. Their overview and brief characteristics are given in Table 3. A more detailed definition of these technologies is given in the annex in Chapter 9.2.2.

These advanced technologies mentioned in Table 3 were the basis for the design of the advanced technologies that are the focus of the analyses carried out in this report (the selection of advanced technologies for the analyses is presented in Table 6. It is also advantageous that a comprehensive methodology document has been developed for analysing these technologies within the ATI project. [12]. It lists, among other things, the keywords for these technologies that were used in the ATI project for the analyses.

Table 3 Advanced technologies for industry and their brief characteristics. A more detailed definition of these technologies is given in Chapter 9.2.2). Source: Advanced Technologies for Industry (ATI) project [10]

Technology	Characteristics
Advanced manufacturing technologies	It encompasses two types of technologies: process technologies, which are used to produce other advanced technologies, and manufacturing technologies based on robotics, automation techniques or computer-integrated manufacturing.
Advanced materials	Advanced materials offer significant improvements in e.g. aerospace, transport, construction and healthcare. They facilitate recycling, reduce the carbon footprint and energy consumption, and also reduce the need for raw materials.
Artificial Intelligence	Artificial intelligence is a term used to describe machines that perform human cognitive functions (e.g., learning, understanding, reasoning, or interacting). It includes various forms of cognition and understanding (e.g. natural language processing) and human interaction (e.g. signal reading, smart controls, simulators).
Augmented and virtual reality	Augmented reality (AR) devices project digital information into reality. In this way, the user sees the surroundings while AR interactively projects virtual objects into real world visual information.
Big Data	Big Data is a term describing the constant increase in the volume of data and the technologies needed to collect, store, manage and analyse it. In technological terms, this term encompasses the hardware and software that integrates, organizes, manages, analyses, and presents this data.
Blockchain	A blockchain is a digitally distributed ledger of transactions or records that stores information or data and exists between multiple participants in a peer-to-peer network. The technology allows new transactions to be added in a decentralized manner to an existing chain of transactions using a secure cryptographic signature.
Cloud computing	Cloud computing involves the provision of tools and applications, such as data storage, servers, databases and software, over the Internet.
Connectivity	The term includes all technologies and services that allow end users to connect to a communications network. It includes data, wireless and wired protocols/standards and combinations thereof. It is divided into standard connectivity and advanced connectivity.

[6] At the time of writing, these technologies have been modified within the European Monitor of Industrial Ecosystems (EMI) project, https://monitor-industrial-ecosystems.ec.europa.eu/

Industrial biotechnology	Refers to the use of biotechnology for the industrial processing and production of chemicals, materials and fuels. It involves utilizing micro-organisms or their components, such as enzymes, to manufacture products that are industrially valuable.
Internet of Things	The Internet of Things (IoT) refers to a network of smart, interconnected devices and services that can sense and respond to user requests.
Micro- and nanoelectronics	Micro and nanoelectronics deals with semiconductor devices and highly miniaturized electronics, and subsystems, and their integration into larger products and systems. It includes the fabrication, design and testing of components ranging from nanoscale transistors to microsystems integrating multiple functions on a chip.
Mobility	Mobility encompasses both information technologies that enable physical mobility and enterprise mobility in the sense of technologies that enable borderless economic activities.
Nanotechnology	Nanotechnology involves the design, characterisation and manufacture of devices and systems by manipulating their shape and size at the nanometre scale.
Photonics	Photonics is a multidisciplinary field that deals with light and includes its generation, detection and conduction. Among other things, it provides the technological basis for the economic conversion of sunlight into electrical energy, which is essential for clean power generation.
Robotics	Robotics involves the design, construction, implementation and operation of robots to perform specific tasks or series of tasks for commercial purposes. These robots can be stationary or mobile.
IT for security/cybersecurity	Security products are designed to enhance the security of an organization's computer and network infrastructure, information systems, Internet communications, networks, transactions, personal data and other information devices, mainframes and the cloud environment.

2.2.2 Key enabling technologies

Key Enabling Technologies (KETs) are defined by the European Commission as "knowledge-intensive technologies associated with intensive R&D, rapid innovation cycles, high capital costs, and highly skilled jobs. They enable innovation in production processes, goods, and services across the economy and are of systemic importance. They are multidisciplinary in nature and cut across many areas of technology with a tendency towards convergence and integration”. In the original definition of the KETs from 2012 to 2014, these technologies included ([13] a [14]):

- Photonics,
- Micro- and nanoelectronics,
- Nanotechnology,
- Advanced materials,
- Biotechnology,
- Advanced manufacturing technologies for other KETs that are considered a "cross-cutting" key technology.

In 2018, the original KETs were expanded to include Artificial Intelligence and Digital Security and Connectivity Technologies as digital technologies evolve, with some of the original technologies merged into one [15]. The resulting KETs and their characteristics are presented in Table 4.

Table 4 Overview of Key Enabling Technologies (KETs) and their indicative definition. Source: [13], [14], [15])

KET	Characteristics / examples
Photonics and micro-/nanoelectronics	Technologies including light generation, light guiding, light manipulation, light detection, light amplification and light use in applications, highly miniaturized semiconductor components and electronic subsystems, including their integration into larger systems and products. Nanoelectronics is considered to be all areas of electronics with nanometre-level structure.
Advanced materials and nanotechnology	A broad field of materials with difficult-to-define boundaries, including advanced metals, advanced synthetic polymers, advanced ceramics, novel composites, advanced biopolymers and other materials. Nanotechnologies are considered to be technologies for structures between 1 and 100 nanometres in at least one dimension.
Biotechnology[7]	Industrial biotechnology, such as technologies using micro-organisms or enzymes for industrial processing and production of bio-based products in sectors such as chemicals, materials, energy (biofuels), food/nutrition, healthcare, textiles and paper, etc. Another group consists of medical and life sciences technologies such as genomics, genetic engineering, cell and tissue engineering, synthetic biology, biosensors, bioactivators, "Lab on Chip", neurotechnology, etc.
Advanced manufacturing technologies	Manufacturing systems and related services, processes, facilities and equipment for other KETs, including automation, robotics, measurement systems, signal and information processing, production control and other processes.
Artificial Intelligence	Big data analytics, machine learning, neural networks, deep learning, genetic algorithms, software technologies, problem solving, decision making, planning, intelligent robots, virtual agents, distributed systems, autonomous vehicles, etc.
Digital security and connectivity	Authentication, secure connectivity, secure communication, identity theft prevention, data protection and privacy, Internet of Things (IoT), data security, human-machine interfaces, human-computer and robot interaction, 5G, e-Government, e-Administration, cyber-physical systems, blockchain, and more.

2.2.3 Advanced digital technology

The McKinsey Digital Technology Trends Outlook 2023 [11] specifies three broad fields of digital technology and two additional technology areas. Within each field, several specific technologies or technology trends are included (see Table 5) Further information on technology trends and specific technologies can be found in [11].

[7] "Biotechnology" includes industrial biotechnology as well as medical and life science technologies.

Table 5 Broad technology fields, technology trends and specific technologies outlined in the McKinsey Digital Technology Trends Outlook 2023. Source: McKinsey Digital Technology Trends Outlook 2023 [11]

Wider areas of digital technologies and other advanced technologies	**Technological trends**	**Technology**
The AI revolution	Applied AI Industrializing machine learning Generative AI	Machine learning (ML), Computer vision, Deep reinforcement learning, Natural-language processing (NLP) Data management, Model development, Model deployment, Live-model operations Foundation models, Application layer, Integration/tooling layer, Hardware (GPUs)
Building the digital future	Next-generation software development Trust architectures and digital identity Web 3.0	Low- and no-code platforms, Infrastructure as code, AI-generated code, Microservices and APIs, AI-based testing, Automated code review Zero-trust architecture (ZTA), Digital identity, Privacy engineering, Explainable AI (XAI), Technology resilience, Blockchain, Smart contracts, Digital assets and tokens
Compute and connectivity frontiers	Advanced connectivity Immersive-reality technologies Cloud and edge computing Quantum technologies	Optical fiber, Low-power, wide-area networks, Wi-Fi 6 and 7, 5G/6G cellular, High-altitude platform systems (HAPS), LEO satellite constellations, Direct-to-handset satellite connectivity Augmented reality, Virtual reality, Mixed reality, Spatial computing, On-body and off-body sensors, Haptics, Location-mapping software IoT or device edge, On-premises or "close to the action" edge, Operator, network, and mobile edge computing (MEC), Metro edge Quantum computing, Quantum communication, Quantum sensing
Cutting-edge engineering	Future of mobility Future of bioengineering Future of space technologies	Autonomous technologies, Connected-vehicle technologies, Electrification technologies, Shared-mobility solutions, Materials innovation, Value chain decarbonization Omics, Tissue engineering, Biomaterials

		Small satellites, Remote sensing, SWaP-C advancements, Launch technology advancements, Promising new technologies (Laser communications, Nuclear propulsion)
A sustainable world	Electrification and renewables Climate technologies beyond electrification and renewable	Solar-, wind-, hydro-powered renewables and others, Nuclear energy, Hydrogen, Sustainable fuels, Electric-vehicle charging Carbon capture, utilization, and storage (CCUS), Natural climate solutions, Circular technologies, Alternative proteins and agriculture, Water and biodiversity solutions. Technologies to track net-zero progress

2.2.4 Advanced technologies included in the analysis

A review of documents on advanced technologies that have the potential to contribute to development in a number of technology segments and sectors shows that these technologies can be grouped into six broad technology fields:

- Advanced manufacturing technologies;
- Advanced material technologies;
- Biotechnology;
- Digital technologies;
- Information and communication technologies (ICT);
- Other advanced technologies, which includes emerging technologies having a significant potential for the use in the near future.

This division is based on the structure of KETs (see Table 4) and Advanced Technologies for Industry (see Table 3). Each of these broad technology fields encompasses several specific advanced technologies. The above breakdown into broad technology fields and specific advanced technologies was chosen with a view to the feasibility of the analyses, in particular ensuring a sufficient data set for their implementation (granularity). The Other Advanced Technologies group includes quantum technologies, which have received a lot of attention in recent years. Of the sixteen technologies identified in the ATI project, Mobility was excluded and is included in the specific contexts of Climate Change Adaptation and Energy Transformation and Sustainable Future.

An overview of the advanced technologies included in the analysis is given in Table 6. In the first column (dark blue shading) are the broader technology areas listed above. In the second column (light blue shading) are the technologies from the Advanced Technologies for Industry (ATI) project that are assigned to the broader technology areas in the first column. In the third column (light grey shading) are the Key Enabling Technologies, KETs (after update).

Depending on their objectives, the analyses will be carried out at the level of broad technology fields (dark blue shading) or at the level of specific technologies (light blue shading). The breakdown used for the analysis is described in more detail for the particular analyses in the relevant chapters.

Table 6 Advanced technologies included in the analysis. Source: ATI project ([10], [12]), European Commission [15]

Advanced technologies - areas	Advanced Technologies - ATI	KETs
Advanced manufacturing technologies	Advanced manufacturing Robotics[8]	Advanced manufacturing technologies
Advanced material technologies	Advanced materials Nanotechnology Micro- and nanoelectronics Photonics	Advanced materials and nanotechnology Photonics and micro-/nanoelectronics - part
Biotechnology	Biotechnology[9]	Biotechnology
Digital technologies	Artificial Intelligence Augmented/virtual reality Big Data Blockchain Cloud computing	Artificial Intelligence Digital security and connectivity - part
Information and communication technologies	Connectivity Internet of Things (IoT) Cyber security	Digital security and connectivity - part
Other advanced technologies	Quantum technologies	Photonics and micro-/nanoelectronics - part Artificial Intelligence - part

[8] Robotics in this analysis includes robotic devices that are autonomous or use artificial intelligence for their operation
[9] Biotechnology includes industrial biotechnology as well as medical and life sciences technologies (as in the updated version of the KETs)

3 Analysis of technological trends in relation to identified societal challenges for the Czech Republic

This part of the analysis focuses on the identification of trends in advanced technologies and their links to the GSCs described in the previous chapter. In Chapter 3.1 the trends in publication activity in each of the advanced technologies are assessed, providing information on which technologies are strengthening research activity (and therefore where their application may develop in the future). Trends in patent activity are then assessed, allowing the identification of advanced technologies whose application is currently increasing and which could therefore also contribute more to addressing GSCs. The matching of database records to individual GSCs and advanced technologies is described in more detail in the methodological part of the study in Chapter 9.1.2.

In the Chapter 3.2, the evolution of state budget support for R&D programs directed towards advanced technology projects is evaluated. The aim is to assess which advanced technologies are receiving increased state support, which ones are experiencing a decline and the extent to which domestic R&D aligns with global trends evident in publication and patent activities.

In the Chapter 3.3 the state support for artificial intelligence R&D in the Czech Republic is evaluated at a more detailed level. Information is also provided on AI R&D capacities within the public sector and in start-up enterprises active in the field of AI. Data from a study on AI research and capacity in the Czech Republic [16] are used for this particular analysis.

In Chapter 3.4, the connections between advanced technologies and GSCs are evaluated, illustrating their application in GSC-specific R&D projects. The results of this analysis are subsequently utilized in Chapter 6.3, where the role of advanced technologies in addressing GSCs pertinent to the Czech Republic is outlined.

3.1 Trends in advanced technologies and the dynamics of their development

The evolution of the number of publications in each advanced technology from 2016 to 2023 (blue bars) and their share in the total number of publications (dashed red line) are shown in Figure 1. The technologies are ranked and colour-coded according to broad technology areas (see Table 5). The figure shows that the number of publications is increasing in the majority of advanced technologies (the exceptions are micro- and nanoelectronics and cloud computing, where the number of publications is stagnating). As the total annual number of publications exhibits an upward trend, the share of publications in micro- and nanoelectronics and cloud computing in the total number of publications is decreasing (see Figure 1).

Publication activity in advanced manufacturing technologies (brown labels) is growing significantly. The number of publications in these advanced technologies (robotics and manufacturing technologies) more than doubled from 2017 to 2022, and their representation in the total number of publications roughly doubled in this period (see Figure 1). This shows that research activities in these technologies are still growing, and there is clearly still considerable potential for further development.

Although in absolute publication activity is increasing in most of the technologies classified in the advanced materials technologies group (red marking), the increase is not as significant as in advanced manufacturing technologies. Research activity is predominantly advancing in the fields of advanced materials and nanotechnologies. In contrast, the volume of publications in photonics, and particularly in micro- and nanoelectronics, is gradually declining. As a result, research efforts are increasingly shifting towards other technological areas[10]. Publication activity in biotechnology (green label) is growing significantly. The number of publications increased by two-thirds between 2017 and 2022 and

[10] According to the experts participating in the workshops, these research activities are moving into the field of quantum technologies (see Chapter 9.6.1)

its share in the total number of publications increased by a quarter. It indicates that there is potential for further technological development in this technology (see Figure 1).

In most digital technologies (blue markings), publication activity is increasing significantly. The most dynamic increase in publication activity is seen in the blockchain field. The number of publications increased more than eightfold between 2017 and 2022, and their share in the total number of publications increased more than sixfold. According to the development of the publication activity, the field of artificial intelligence has a high potential for further development – the number of publications tripled between 2017 and 2022 and their representation in the total number of publications increased twofold. Publication activity in augmented/virtual reality also grew significantly, somewhat less than in the big data field. Compared to other digital technologies, cloud computing seems to have the lowest potential for further development (see Figure 1).

Although publication activity in ICT is growing, the increase is not as high as in digital technologies (purple marking). As can be seen in Figure 1, the highest potential for further development in terms of growth in publication activity is in IoT, with the number of publications doubling from 2017 to 2022 and its representation in the total number of publications increasing by half. There is also growing publication activity in cybersecurity, where the number of publications increased by three-quarters between 2017 and 2022. Publication activity in connectivity has increased somewhat less (see Figure 1). Publication activity is also increasing in quantum technologies and their share in the total number of publications is also increasing. Publication activity in quantum technologies is increasing more than in other areas, indicating the potential for further development (see Figure 1).

Figure 2 shows the evolution of patent activity in advanced technologies in the period 2016-2022[11] and the share of patent applications in individual advanced technologies in the total number of patent applications. For the graphs in this figure, the data for the first application for a new solution filed (in the text abbreviated as priority patent applications) were used. The figure shows that the number of patent applications is increasing in the majority of advanced technologies, and in some very significantly. High growth is evident in advanced manufacturing technologies (orange markings). In robotics, the number of patent applications increased by around 130% between 2016 and 2021, doubling its representation in the total number of priority patent applications. In advanced manufacturing technologies, the number of patent applications doubled and their share increased by roughly half over this period. This indicates that the application potential of these technologies continues to increase. In the future, it can therefore be expected that they will be used in applications more than other technologies.

The situation is completely different in advanced material technologies (red marking) – the number of priority patent applications is rather stagnant and their share in the total number of priority patent applications is decreasing (see Figure 2). A slight decline in patent activity is evident in micro- and nanoelectronics. Patent activity is also stagnating in biotechnology (green label). The share of such patent applications in the total number of priority applications is slightly decreasing.

In most digital technologies, the number of priority patent applications is growing significantly and their share in the total number of priority patent applications is also increasing (see Figure 2). The largest increase is seen in artificial intelligence (except for blockchain – see the comment below for more details), where the number of priority patent applications has increased almost fourfold and their representation in the total number of priority applications has increased threefold.

[11] As the PATSTAT database from autumn 2023 does not contain complete data from 2022, the time window 2016-2021 (i.e. shifted by one year compared to the development of publication activity) was chosen for the evaluation of patent activity.

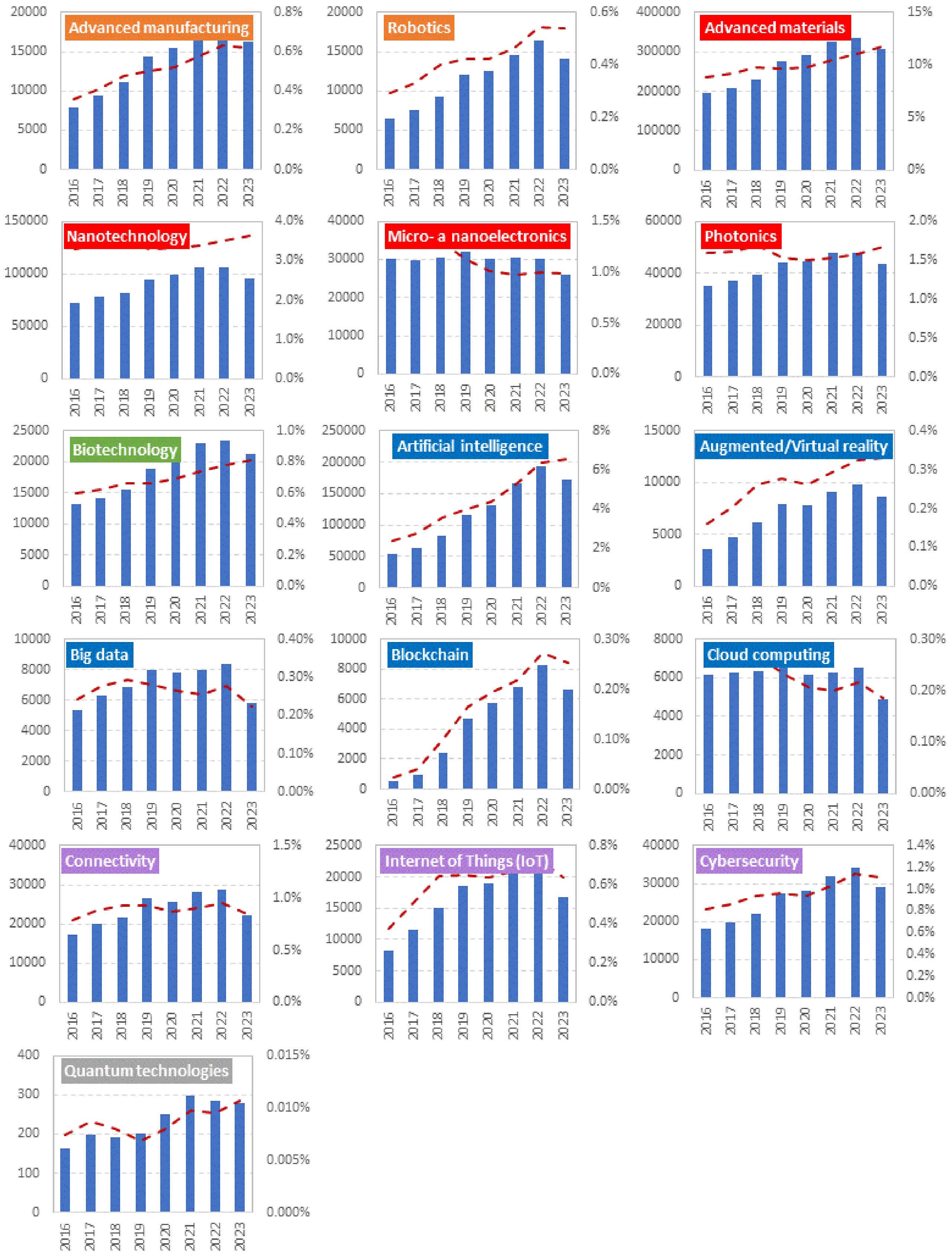

Figure 1 Evolution of publication activity in advanced technologies from 2016 to 2023 - number of publications and their share in the total number of publications. Source: Clarivate Web of Science

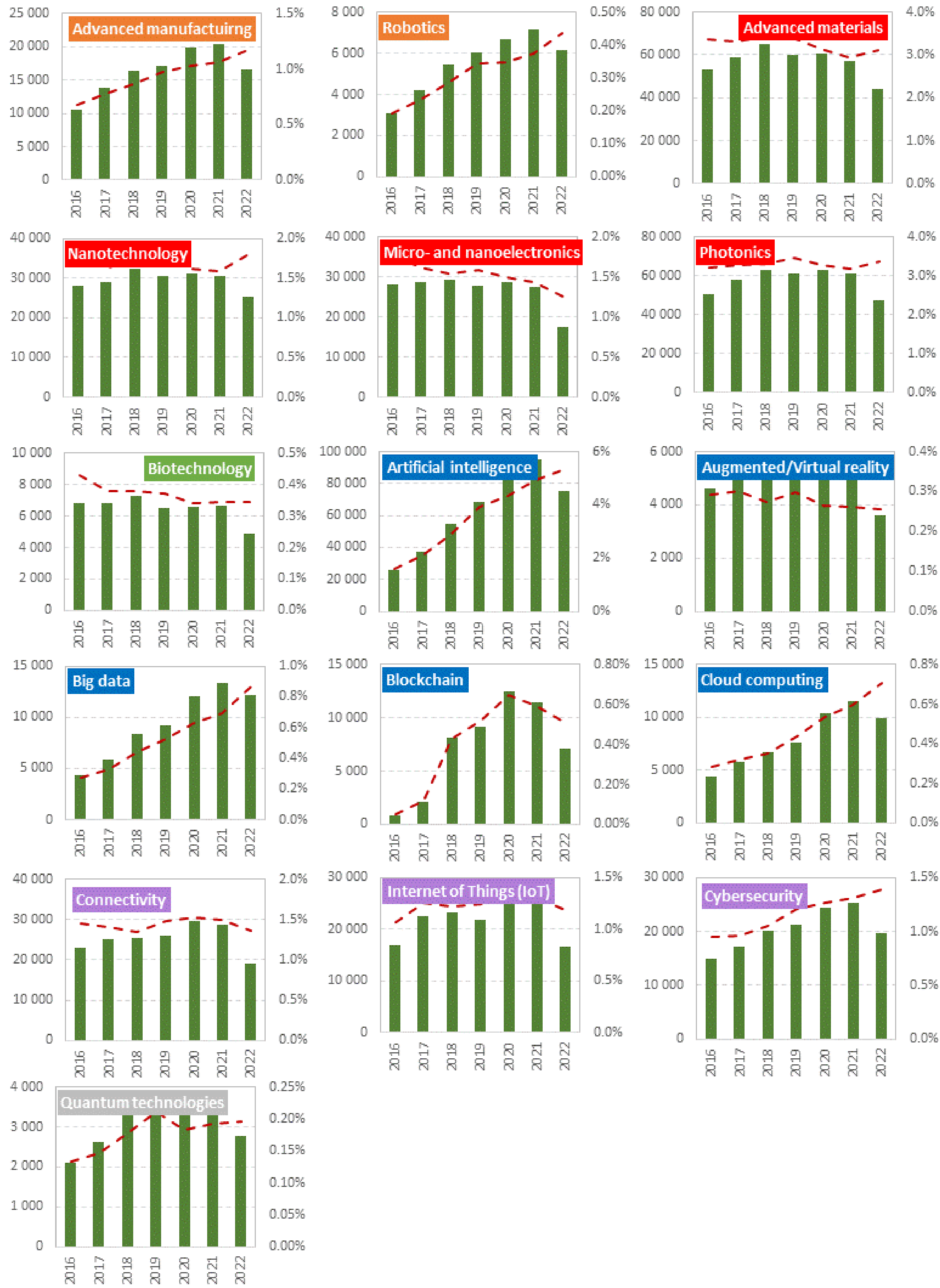

Figure 2 Evolution of patent activity in advanced technologies from 2016 to 2022 - number of priority patent applications and their share in the total. Source: PATSTAT, Autumn 2023b

The very high growth in patent activity is also evident in big data and cloud computing - in both advanced technologies, the number of priority patent applications has roughly tripled and their share has more than doubled. In virtual reality, the number of priority patent applications is slightly increasing and their share in the total number of applications is stagnating. In the case of blockchain, there is a significant increase in patent activity until 2020. Thereafter the number of priority patent applications declines (see Figure 2).

Patent activity is also increasing in quantum technologies, but the increase is not as pronounced as in other digital technologies (see Figure 2). From 2016 to 2021, the number of priority patent applications increased by 70% and their share in the total increased by around 40%.

Figure 3 compares trends in publication and patent activity in each advanced technology over two two-year periods - for publication activity between 2017-2018 and 2021-2022, and for patent activity between 2016-2017 and 2020-2021[12]. The horizontal line in Figure 3 represents the change in the total number of priority patent applications in the period under review and the vertical line represents the change in the total number of publications. If the technology is to the right of the vertical red line, the increase in the number of publications in that advanced technology is higher than the increase in total publications, and vice versa. The same is holds for patent activity.

The colour coding of advanced technologies indicates the broader technology area to which the given technology belongs: advanced manufacturing technologies are represented in orange, advanced materials technologies in red, biotechnology in green, digital technologies in blue, and ICT in purple. Quantum technologies are displayed in grey (i.e. as in Figure 1 and Figure 2).

In terms of trends in advanced technologies, the upper right quadrant in the Figure 3 where the technologies on which research activities are increasingly focused are located, which also creates the conditions for further development of their capabilities and features. At the same time, these technologies are also experiencing a faster increase in patenting activity compared to other technologies and can therefore be expected to become increasingly applied. The advanced technology with the highest potential for further development of its capabilities and use in applications is AI, found in the top right-hand corner of Figure 3.

Advanced manufacturing technologies - robotics and advanced manufacturing, where the number of publications and patent applications is increasing more than in other technological areas, have a significant potential for development. This increase may to some extent be 'driven' by the dynamical growth in artificial intelligence used in these technologies (e.g. autonomous robots, automation and digitalisation of manufacturing technologies, etc.).

Technologies with above-average growth in publication and patent activity also include ICT (see Figure 3). Cybersecurity has the highest potential of these technologies, with the number of publications and patent applications increasing by around 60% more than the average, which seems to be related to the increasing cyber threats.

Some of the advanced technologies are not growing much in terms of publication activity, but their patent applications are increasing significantly (patent activity is growing much more than average). These technologies, located in the upper left quadrant, include big data and cloud computing.

Augmented/virtual reality, biotechnology and advanced materials, on the other hand, are among the technologies where research activity is more concentrated compared to other technologies, but patent activity is increasing less compared to other technologies (see Figure 3, bottom right quadrant). In the future, however, ongoing research and its findings may expand the capabilities of these technologies, thereby enhancing their applications.

[12] The shifted time period for patent activity is related to the fact that even in the latest PATSTAT database from autumn 2023, the data from 2022 are not yet complete

Photonics, nanotechnology and micro- and nanoelectronics included in the group of advanced material technologies in Figure 3 are located in the lower left quadrant. This means that research activities have been focused on other areas in recent years, which may be related to the fact that the number of new findings with potential for application and hence patent activity is decreasing. Despite the decline, these technologies are finding considerable application, as the number of patent applications remains still high (see Figure 2).

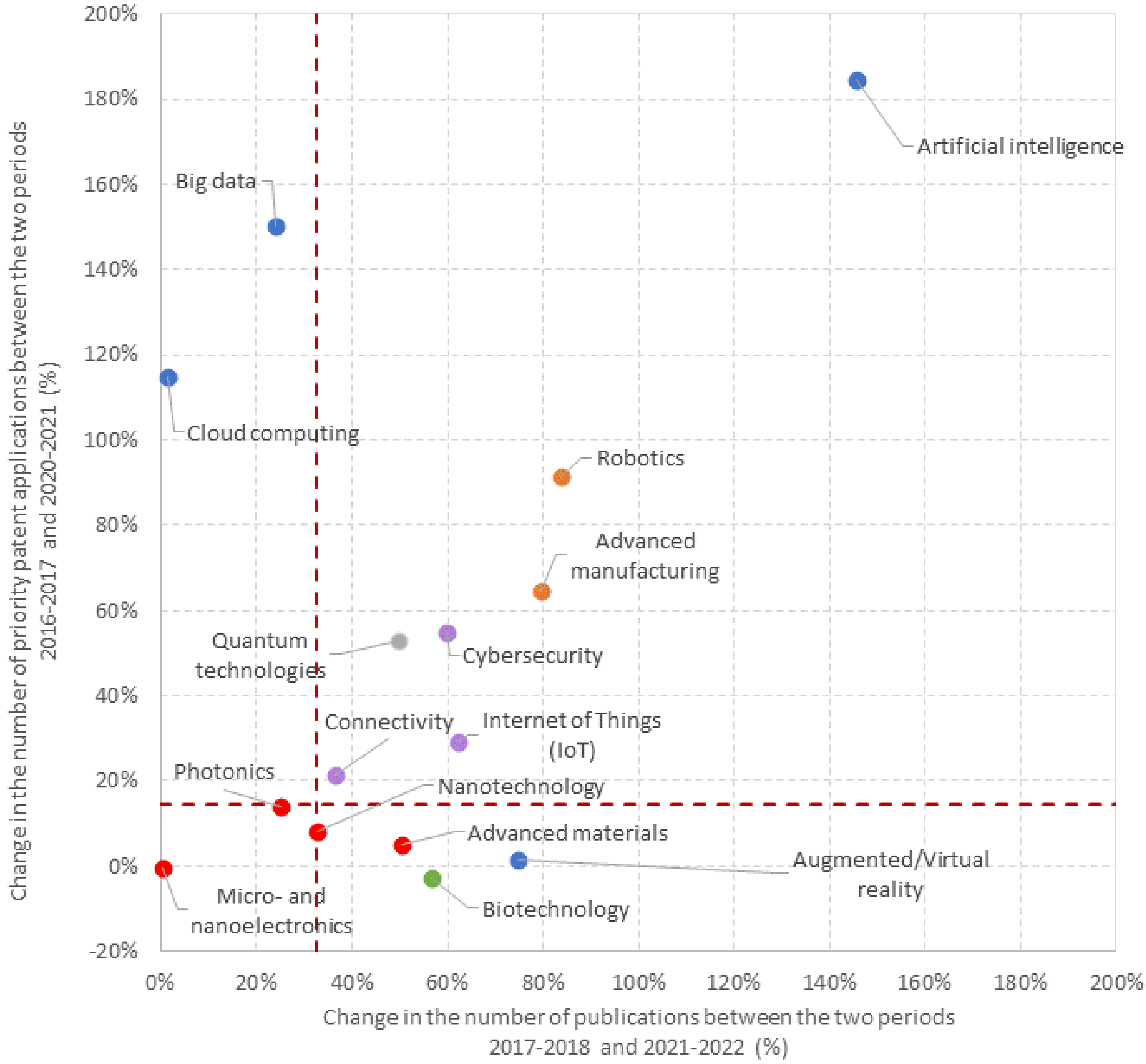

Figure 3 Comparison of trends in publication and patent activity in advanced technologies. Further information on the figure is provided in the text. Source: Clarivate Web of Science, PATSTAT. autumn 2023

3.2 Trends in state support of R&D in advanced technologies

Trends in the number of projects in national R&D programmes between 2016 and 2023 in broader fields of advanced technologies and state support provided for their implementation are presented in Figure 4 to Figure 9. Trends in the number of projects and state support follow to some extent the trends seen in publication and patent activities in advanced technologies - the number of projects and their budgets are increasing in advanced manufacturing technologies, digital technologies, and ICT. In advanced material technologies, and biotechnologies, project numbers and government support are rather stagnant.

The most dynamic increase is seen in the total cost of digital technology projects (especially funds from sources outside the state budget), which is probably related to the fact that enterprises participate in these projects. An increasing share of non-state budget resources is also evident in advanced manufacturing technologies, and ICT.

For more detailed information on the development of the project budgets in the individual advanced technologies, see Figure 10. Total project expenditures increased significantly between 2016 and 2023 in both advanced manufacturing and robotics, which are classified as advanced manufacturing technologies, with increases primarily in non-state budget resources.

In most of the technologies classified as advanced material technologies, project budgets are stagnating or slightly decreasing over the period under review. The exception is photonics, where there is a noticeable increase in other resources, especially in 2023. The situation is reversed in digital technologies. Here, on the other hand, project budgets are increasing between 2016 and 2023, both from state budget and non-state budget resources. The most significant increase is found in AI, where the rate of growth is also increasing, especially from funds outside the state budget (expenditure on R&D of AI and its development is evaluated in Chapter 3.3). High growth is also evident in cloud computing and blockchain, especially in the last years of the period under review.

In ICT, state and non-state funding is also growing significantly. The highest growth is seen for the Internet of Things, which also shows the highest increase in non-state funding. There is also a significant increase in spending in projects focused on cyber security issues throughout the period under review, which will be related to the increasing cyber threats and attacks. Growth is also evident in quantum technologies. Here, however, the dominant component of the budget is made up of state budget resources, which is related to the complexity of this research and the fact that the results of R&D are still far from market application.

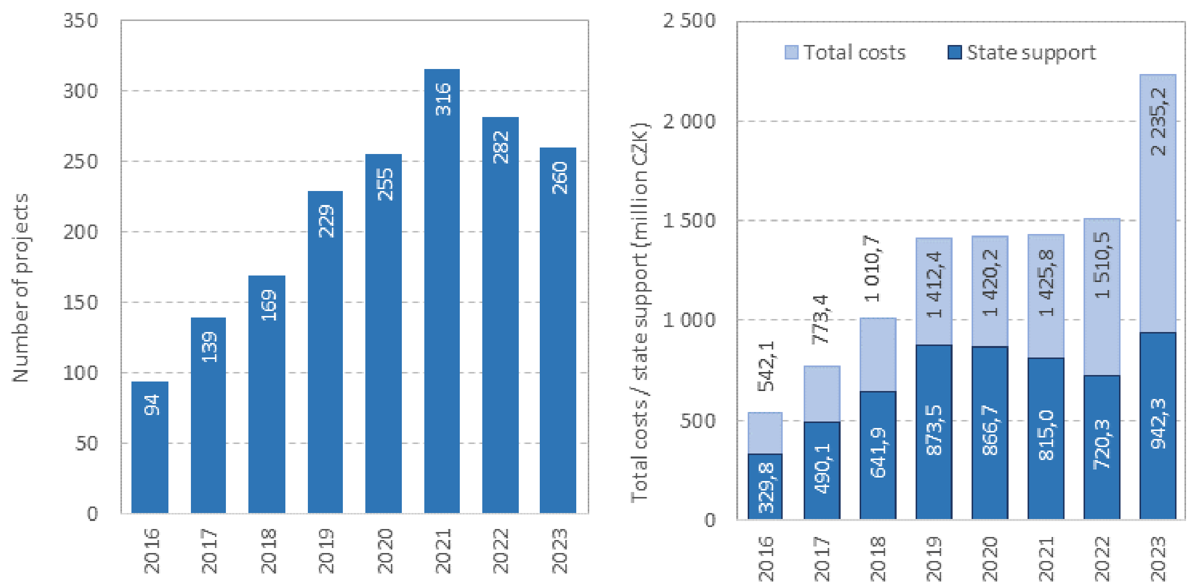

Figure 4 Advanced manufacturing technologies - evolution of the number of projects, their total costs and state support in 2016-2023. CZK. Source: R&D&I Information system

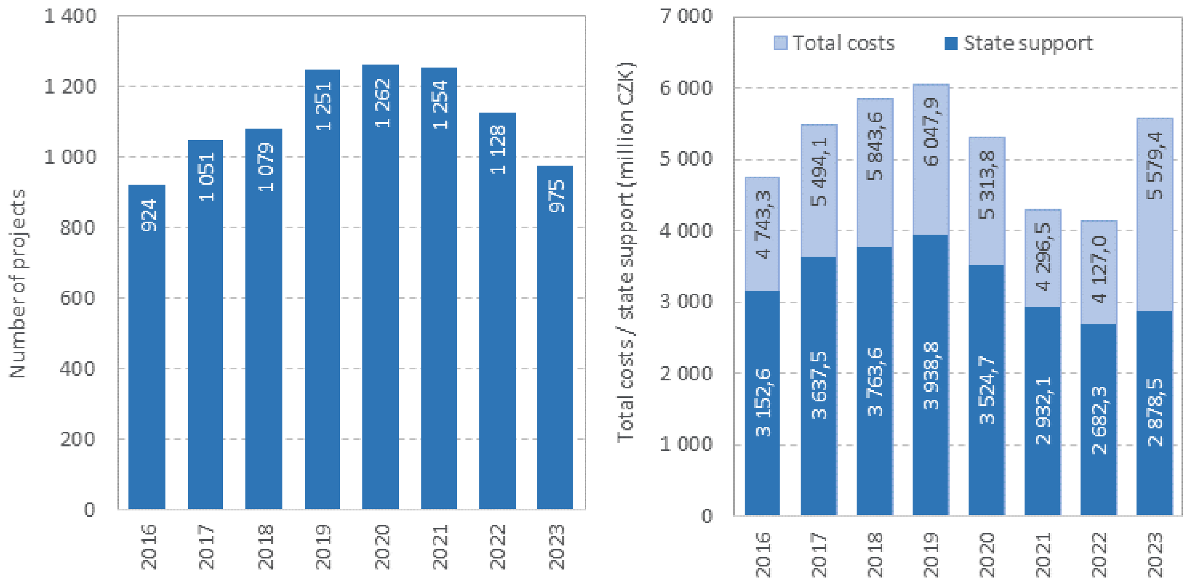

Figure 5 Advanced material technologies - evolution of the number of projects, their total costs and state support between 2016 and 2023. CZK. Source: R&D&I Information system

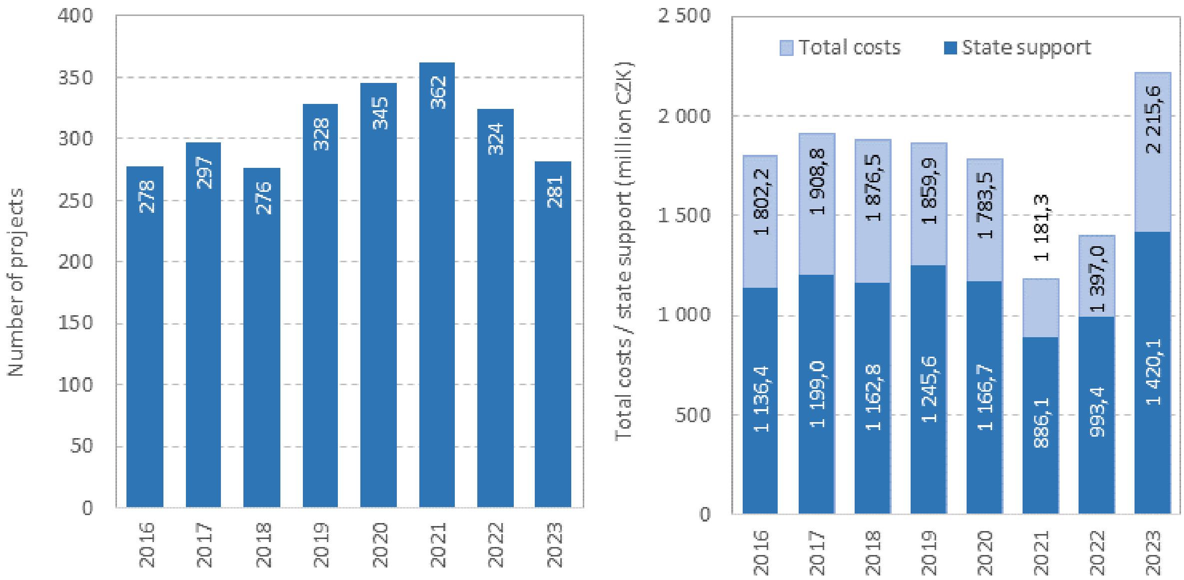

Figure 6 Biotechnology - development of the number of projects, their total costs and state support in 2016 - 2023. CZK. Source: R&D&I Information system

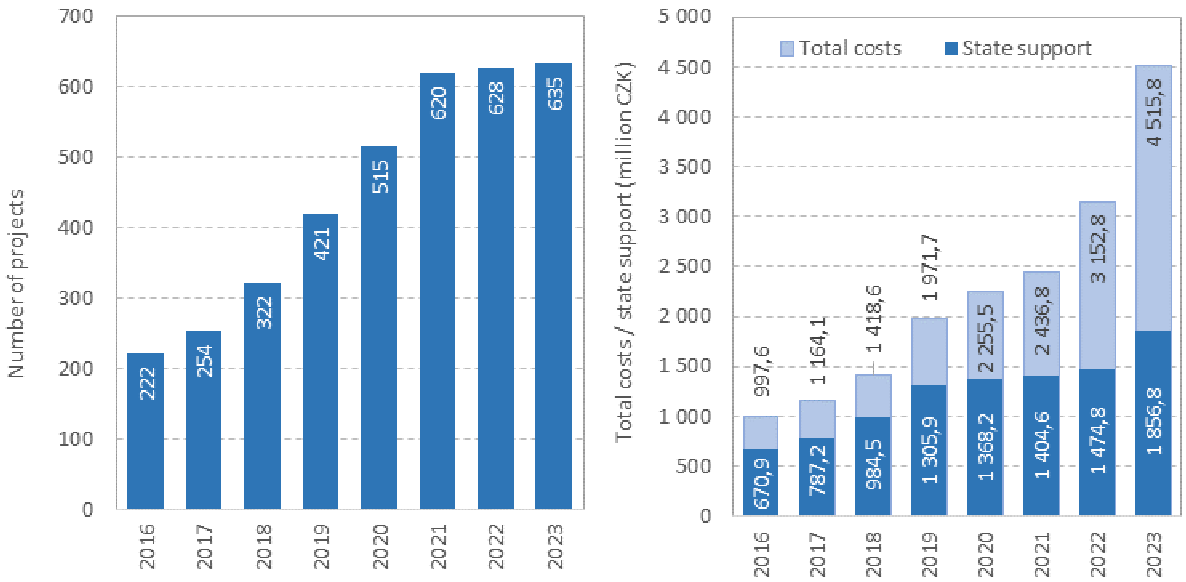

Figure 7 Digital technologies - evolution of the number of projects, their total costs and state support between 2016 and 2023. CZK. Source R&D&I Information system

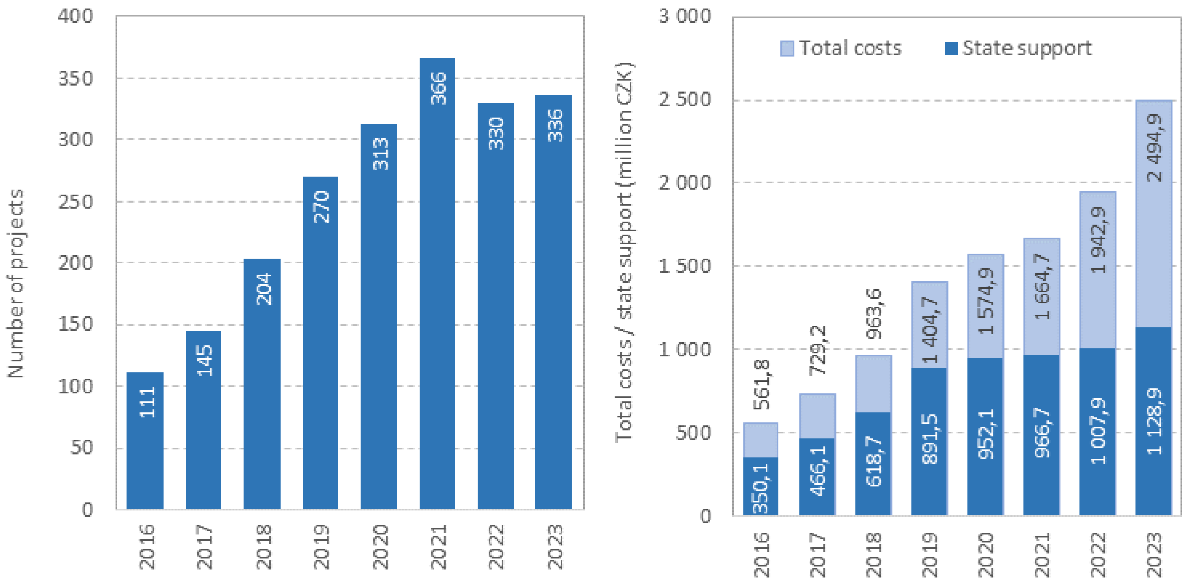

Figure 8 Information and communication technologies - evolution of the number of projects, their total costs and state support in 2016-2023. CZK. Source: R&D&I Information system

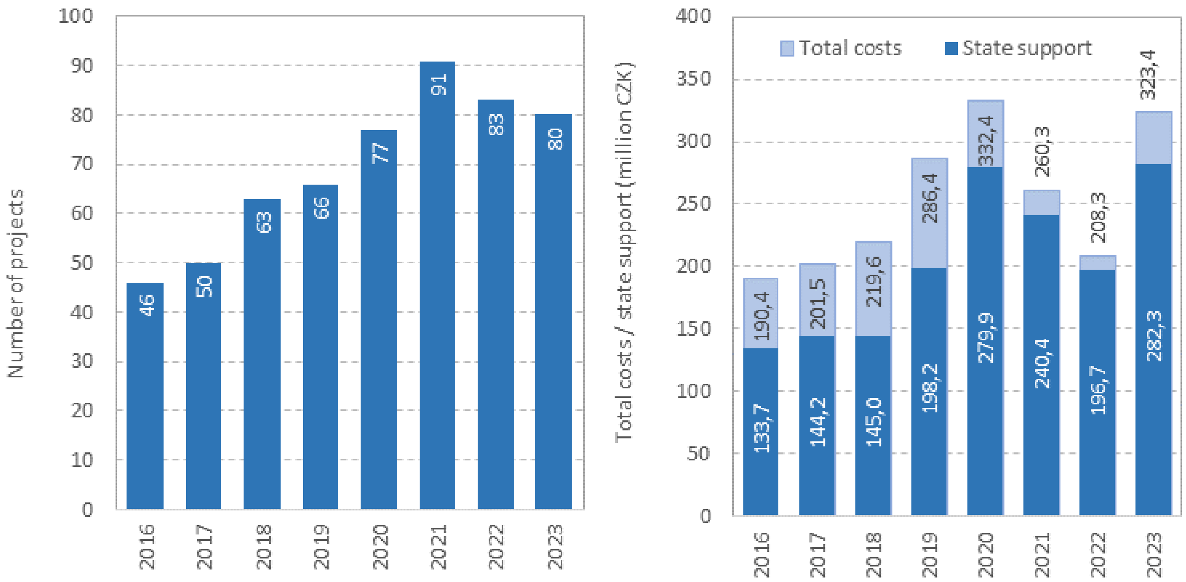

Figure 9 Quantum technologies - evolution of the number of projects, their total costs and state support between 2016 and 2023. CZK. Source: R&D&I Information system

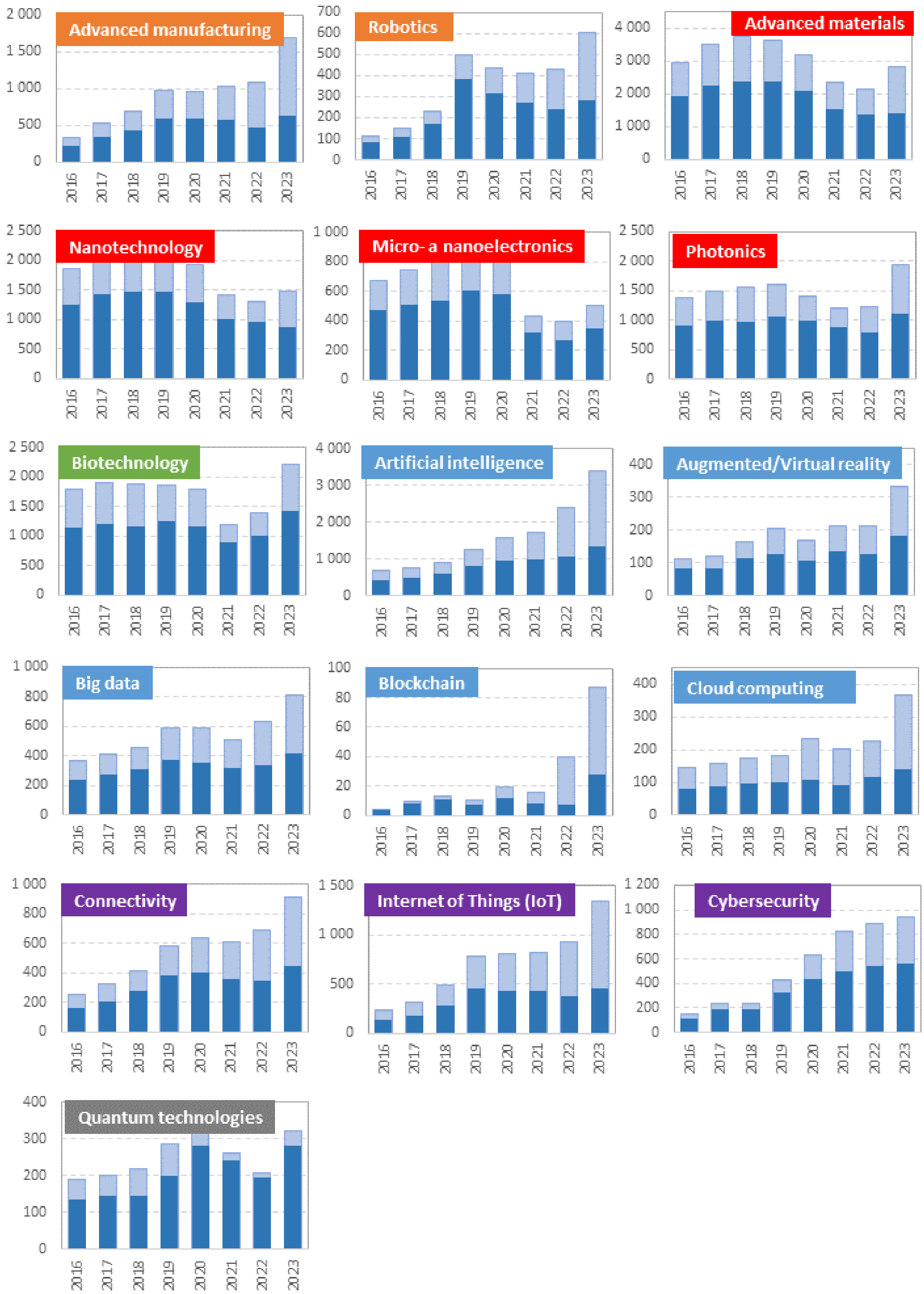

Figure 10 Evolution of total costs and state support of projects focused on individual advanced technologies in 2016-2023. The dark blue columns indicate the amount of state support in the total cost of projects (excluding so-called infrastructure projects, see methodological section in Chapter 9.1.3.1). The data are in CZK million. Source: R&D&I Information system

3.3 Financial investment in AI in the Czech Republic

The study [16] shows that more than eight hundred projects addressing AI have been initiated from the beginning of 2017 until about mid-2023[13] . By 2028, the support from the state budget of the Czech Republic provided for these projects should exceed CZK 11 billion and their total cost should reach approximately CZK 15 billion. Almost a thousand participants from various sectors are involved in the projects (see Table 7). A total of 818 projects have carried out R&D aimed at the development of AI or its use in specific applications (research projects). These projects will receive approximately CZK 8.8 billion of support from the state budget by the end of their implementation and their total cost will reach almost CZK 15 billion. 29 projects supported the development of R&D&I infrastructure in the field of AI. The total costs and state support provided to these projects amounted to around CZK 2.7 billion.

Table 7 The number of projects addressing AI launched since 2017, the state budget support that will be granted to these projects from 2017 to 2028 and their total costs (after 2023 these are projected figures)[14] . The last column shows the number of participants in these projects. Source: Research and development in the field of artificial intelligence in the Czech Republic [16]

	Number of projects	Support from the state budget (CZK million)	Total costs (CZK million)	Number of participants
Projects found using keywords, of which:	847	11 441.5	17 586.4	956
- research projects	818	8 794.6	14 805.4	628
- projects supporting the development of research infrastructure	29	2 646.9	2 781.0	328

Drawing on the knowledge and experience of AI experts, the study [16] projects were divided into six groups (see Table 8). 126 projects, i.e. 15 % of the total number of projects, were categorised as basic AI research. These projects received almost CZK 2 billion in support. Their total costs exceeded CZK 2.2 billion, and the state support thus amounted to about 86 % of the total project costs (see Table 8).

[13] The evaluation was carried out in mid-2023

[14] With regard to

A further 160 projects dealt with applied AI research (i.e. almost 20% of the total). State support was roughly the same as for basic research projects, but their total costs were more than half as high. This is because the projects involved companies, which have a smaller share of their costs covered by public funds. Most of the projects were projects where the research was only related to AI issues (e.g. the use of AI in specific technological areas). More than 350 projects of this type received support of approximately CZK 3.8 billion. Almost thirty projects dealt with the ethical and legal aspects of AI. The remaining projects dealt with the development of R&D infrastructure or only touched on AI issues (see Table 8).

Table 8 AI projects by type and focus of the project - number of projects in each category, their total cost and allocated state support. The table includes only projects launched in 2017 and subsequent years. Source: Research and development in the field of artificial intelligence in the Czech Republic [16]

Type of research	Number of projects	Percentage of total	Total costs (million CZK)	State support (CZK million)	Share of state support in total costs
Basic AI research	126	15.0%	2 221.2	1 909.5	86.0%
Applied AI research	160.5	19.2%	3 599.2	1 865.3	51.8%
AI-related research	356	42.5%	5 887.3	3 829.2	65.0%
Infrastructure for AI research	11	1.3%	640.4	614.4	95.9%
Ethical and legal aspects of AI	29	3.5%	632.2	233.4	36.9%
Unrelated or only slightly related	155.5	18.6%	4 205.1	2 593.7	61.7%
Total	**838**		**17 185.3**	**11 045.4**	**64.3%**

The Technology Agency of the Czech Republic (TA CR) has supported the largest number of projects addressing AI issues since 2017, providing over CZK 4.5 billion for AI projects. The Ministry of Education, Youth and Sports (MEYS) also provided high state support of approximately CZK 3.3 billion, which, in addition to research projects, also supported a number of projects where the development of research infrastructure was supported. Their budget was very high and exceeded CZK 2.6 billion in the period under review. More than CZK 1 billion of state support for AI research projects was also provided by the Czech Science Foundation (GA CR) and the Ministry of Interior (see Table 9). According to the study [16] basic AI research projects were mainly supported by the GA CR and the MEYS, while applied AI research projects were supported by the MIT, TA CR and MEYS.

Table 9 AI-focused projects launched from 2017 onwards. Breakdown by provider. Source: Research and development in the field of artificial intelligence in the Czech Republic [16]

Provider	Number of projects	Total costs (CZK million)	State support (CZK million)	Average project support (CZK million)
Technology Agency of the Czech Republic	278	6 449.2	4 582.8	16.5
Ministry of Industry and Trade	178	4 061.0	524.7	2.9
Czech Science Foundation	162	1 289.1	1 195.1	7.4
Ministry of Education, Youth and Sports, of which:	139	3 768.4	3 296.1	23.7
- Research projects	*110*	*987.4*	*649.2*	*5.9*
- research infrastructure development projects	*29*	*2 781.0*	*2 646.9*	*91.3*
Ministry of the Interior	53	1 149.3	1 048.5	19.8
Ministry of Health	16	153.9	153.6	9.6
Ministry of Culture	10	244.9	244.6	24.5
Ministry of Defence	7	415.2	345.6	49.4
Ministry of Agriculture	4	55.5	50.5	12.6
Total excluding research infrastructure development projects	**818**	**14 805.4**	**8 794.6**	**10.8**
Total	**847**	**17 586.4**	**11 441.5**	**13.5**

In the study [16] the projects were also assigned to the application sectors of the National Research and Innovation Strategy for Smart Specialization of the Czech Republic 2021-2027 (NRIS3) [1], and for this purpose the classification of their participants into NACE economic activity sectors was used. Table 10 shows that the majority of the research projects involved at least one entity that lists NACE 85 - Education or NACE 72 - Research and Development as its main activity sector (i.e. it is a higher education institution, a public research institution or an entrepreneurial entity primarily focused on R&D).

Except for R&D and education, most projects were assigned to the key application sector Digital Technologies and Electrical Engineering and the application sector Digital Economy and Digital Content. Projects assigned to this application sector also received the highest state support and had the highest total costs. A relatively high number of projects were also assigned to Mechanical Engineering and Mechatronics in the key application sector Advanced Machinery and Technology, and to the New Cultural and Creative Industries.

Table 10 AI-focused projects launched since 2017 (excluding infrastructure projects). Breakdown by NRIS3 application sectors. Source: Research and development in the field of artificial intelligence in the Czech Republic [16]

Key Application Sectors / NRIS3 Application Sectors (abbreviated)	Number of projects	State support (CZK million)	Total costs (CZK million)
Advanced machinery and technology	**90.1**	**265.1**	**792.9**
- Mechanical engineering, mechatronics	73.3	234.7	675.1
- Industrial Chemistry	7.0	3.5	28.2
- Metallurgy	3.0	4.5	10.7
- Power Engineering	6.8	22.4	78.8
Digital technology and electrical engineering	**283.6**	**1 275.2**	**4 108.0**
- Electronics and electrical engineering	27.0	78.2	315.4
- Digital economy and digital content	256.6	1 197.0	3 792.6
Transport for the 21st century	**34.0**	**137.0**	**382.9**
- Automotive	28.0	99.9	276.6
- Rail and rolling stock	2.0	28.9	66.6
- Aerospace	4.0	8.1	39.8
Healthcare	**35.1**	**113.5**	**170.0**
- Pharmaceuticals, Biotechnology, Medical Devices and Life Sciences	35.1	113.5	170.0
Cultural and Creative Industries	**92.3**	**414.5**	**898.2**
- Traditional cultural and creative industries	28.9	126.3	270.8
- New cultural and creative industries	63.4	288.2	627.4
Sustainable agriculture and environmental industries	**44.2**	**128.9**	**344.0**
- Sustainable management of natural resources	7.0	8.7	58.3
- Sustainable agriculture and forestry	4.4	6.5	41.8
- Sustainable food production	1.8	2.7	9.8
- Ensuring a healthy and quality living environment, biodiversity. and natural ecolo	1.5	1.2	11.7
- Sustainable construction, human settlements and technical environmental prot	29.5	109.7	222.4
Other	**844.8**	**6 418.3**	**7 995.6**
- Research and development, education	744.8	5 853.6	6 840.5
- Other	100.0	564.7	1 155.1
Total	*818*	**8 752.5**	**14 691.5**

Research focused on AI issues (basic research and R&D of its applications) is carried out mainly at faculties and departments of universities. Some institutes of the Czech Academy of Sciences (CAS) and departmental research institutes are also dealing with AI issues. An overview of the most important institutions active in digital technology research, including AI, is presented in the stakeholder analysis in Chapter 5.1.4.

ESIF funding has significantly contributed to the establishment of numerous research centers and infrastructure facilities in recent years. TA CR, under its National Centres of Competence programme, has supported several centres bringing together public research institutions and business entities that can carry out R&D in the field of AI and its applications. A comprehensive overview of these research centres and infrastructure facilities, along with their specific focus areas, is provided in the study [16]. Many of these centres are equipped with high-quality instruments, enabling them to undertake challenging projects encompassing all stages of the innovation process.

According to the study [16] a relatively high number of start-ups in the field of AI have been established in recent years and have applied for support in the Technology Incubation programme of the CzechInvest agency. These start-ups are active in various sectors, notably healthcare, marketing, production optimization, and predictive tools.

According to the study [16], there are several groups in the field of AI that bring together entities active in the field of AI or facilitate their activities in the Czech Republic. These clusters can also contribute to the use of AI for addressing GSC. According to the study, the most important ones include [16]:

- The prg.AI platform[15] brings together research institutions (or their staff) and companies with activities in the field of AI. The platform supports talents and companies, and strengthens relationships between academia, research, and application.
- The Brno.AI platform[16] brings together representatives of companies and institutions, leaders and others interested in AI. The platform aims to discover innovative applications for AI, foster collaboration, and contribute to the growth of the AI community.
- Platform for Artificial Intelligence[17] , founded by the Confederation of Industry of the Czech Republic, which deals with AI-related challenges and proposes, among other things, specific possibilities of AI use.
- The national initiative AICzechia[18] supports the collaboration of Czech AI institutes and teams to foster synergies in interdisciplinary basic and applied research, teaching and education.

3.4 Links of advanced technologies to identified GSC

The results of the assessment examining the connections of the broader categories of advanced technologies and GSC, without a breakdown into specific individual areas, are presented in Table 11 to Table 13. A more detailed evaluation of the connections between specific advanced technologies and GSC, including their categorization into individual areas, is provided in Chapter 9.3 in the annex of the study. For the analysis of the linkages, data on projects supported in the H2020 and HE Framework Programmes and in the targeted R&D support programmes since 2014 were used[19] . The percentages given in the tables indicate the share of projects assigned simultaneously to a given GSC and to a given broader area of advanced technologies ("intersection") out of the total number of projects assigned to that GSC.

The linkages of advanced technologies to Science and technology (S&T) projects supported by the HE Framework Programme are given in Table 11. Advanced technologies have been addressed most frequently in the HE programme in projects focussed on the GSCs issues of Trust in Democracy, Resilient Society, Security and Defence, Technological and Digital Transformation of Society and Energy Transformation and Sustainable Future. The uptake of advanced technologies is somewhat lower in the Adaptation to Climate Change and Preparedness for Demographic Change and Ageing GSCs (see first column of the table).

Digital Technologies and ICT have the highest contribution to the GSC solution. The highest application of both technologies is in the GSCs Trust in Democracy, Societal Resilience and Technology and Digital Transformation. The high uptake of Digital and Information Technologies in GSC Trust in Democracy, Societal Resilience is probably related to the strengthening of security in the context of cyber threats

[15] prg.ai, https://prg.ai/
[16] Brno.AI, https://www.brno.ai/
[17] SPCR, https://www.spcr.cz/aktivity/z-hospodarske-politiky/11799-svaz-zalozil-platformu-pro-umelou-inteligenci
[18] AICzechia, https://www.aiczechia.cz
[19] I.e. for the entire duration of the H2020 and HE Framework Programmes

and the introduction of digital technologies in government and business. The higher contribution of digital technologies is also evident in GSC Energy Transformation. Advanced material technologies have the highest contribution to the Energy Transformation GSC. Advanced manufacturing technologies find a higher contribution in the Technology and Digital Transformation GSC and also in the Energy Transformation and Trust in Democracy, Societal Resilience GSCs (see Table 11).

Table 11 Links between advanced technologies and GSCs. Data are for projects supported by the Horizon Europe Framework Programme. Source: e-CORDA

Projects supported in the Horizon Europe Framework Programme ------------------------------------ **Grand Societal Challenges (abbreviated)**	Advanced technologies	Advanced manufacturing technologies	Advanced material technologies	Biotechnologies	Digital technologies	Information and communication technologies
Trust in democracy, societal resilience	65%	8%	16%	7%	37%	37%
Adaptation to climate change	35%	1%	10%	8%	16%	10%
Energy transformation	61%	8%	34%	12%	20%	12%
Technological and digital transformation	65%	11%	13%	6%	43%	31%
Preparedness for demographic changes	29%	2%	5%	3%	18%	8%

The contribution of advanced technologies to addressing GSC is similar to that of projects supported in the H2020 Framework Programme (Table 12).

Table 12 The contribution of advanced technologies to addressing GSCs. Data are for projects supported under the Horizon 2020 Framework Programme to date. Source: e-CORDA

Projects supported in the Horizon 2020 Framework Programme ------------------------------------ **Grand Societal Challenges (abbreviated)**	Advanced technologies	Advanced manufacturing technologies	Advanced material technologies	Biotechnologies	Digital technologies	Information and communication technologies
Trust in democracy, societal resilience	62%	8%	15%	7%	32%	36%
Adaptation to climate change	26%	1%	9%	6%	9%	6%
Energy transformation	54%	6%	31%	10%	12%	12%
Technological and digital transformation	69%	15%	12%	3%	40%	35%
Preparedness for demographic changes	39%	4%	8%	5%	21%	12%

Similar advanced technologies are also used in national programmes of targeted R&D support in projects focused on individual GSCs (see Table 13). The application of advanced technologies in addressing GSC in these projects is somewhat lower than in EU Framework Programme projects (first column of the table). This may, however, be related to the different focus of the calls in the EU Framework Programmes and the objectives of the programmes and individual calls in the national R&D programmes.

Table 13 The contribution of advanced technologies to addressing GSCs. Data are for projects supported under earmarked support programmes since 2014. Source: R&D&I Information System

Projects supported in targeted support programmes ------------------------------------ **Grand Societal Challenges (abbreviated)**	Advanced technologies	Advanced manufacturing technologies	Advanced material technologies	Biotechnologies	Digital technologies	Information and communication technologies
Trust in democracy, societal resilience	51%	6%	11%	1%	26%	32%
Adaptation to climate change	9%	0%	5%	0%	2%	2%
Energy transformation	38%	4%	25%	2%	6%	6%
Technological and digital transformation	47%	14%	4%	1%	21%	21%
Preparedness for demographic changes	11%	1%	5%	0%	5%	2%

The uptake of advanced technologies (at the level of broader fields) is relatively low in some GSCs. This is mainly since this assessment is made for all projects assigned to GSCs, which are relatively broadly defined. However, in the more detailed linkage assessment carried out at the level of individual GSC areas and specific advanced technologies, the linkages are quite strong. The results of this more detailed assessment of the linkages at the level of individual GSC areas and specific advanced technologies is presented in the annex part of the report in Chapter 9.3. The lower uptake of some advanced technologies in some GSCs may also be related to the focus of calls in the EU Framework Programmes or the focus of national programmes of targeted R&D support.

4 Identification of advanced research directions responding to future societal challenges and reflecting current technological trends and expected future technological developments

To identify advanced research directions, a textual analysis of patent applications in selected advanced technologies was prepared. In this analysis, technological directions were identified that have shown an increasing trend over the last five years, indicating that their potential for use in applications is growing. The results of this analysis are presented in Chapter 4.1. In Chapter 4.2 the topics that have been mentioned in the technology-oriented media in recent months are evaluated.

To identify emerging technological trends in advanced technologies, a search of documents published by renowned institutions dealing with technological trends and development perspectives was also prepared. The effort was to identify the directions that will be applied in the future in advanced technologies and that will contribute to improving their "capabilities" for addressing GSC. In particular, the focus of this analysis was on the area of digital technologies. The most significant findings from this research are summarised in Chapter 4.3. An expanded version of this research is in the annex part of the report in Chapter 9.4.

The findings of the analysis were discussed at a workshop attended by representatives of national innovation platforms and experts in the field of digital technologies. The most important findings from this workshop are presented in Chapter 4.4, a clear summary of the views of the experts at the workshop is given in the annex section in Chapter 9.4.3.

4.1 Analysis of emerging trends in selected advanced technologies

For the selected advanced technologies that show an increasing trend in patent applications, emerging trends that are becoming more widely adopted were evaluated using text analysis. This analysis included *advanced manufacturing*, *robotics*, *artificial intelligence*, *big data*, *cloud computing* and *cyber security*, i.e. in particular digital technologies with an overlap into advanced manufacturing and security. The approach to this analysis is described in more detail in the methodological part of the report in Chapter 9.1.4.1. The figures show the blending of primarily artificial intelligence and digital technologies into other advanced technologies.

In **advanced manufacturing**, growth has been identified for the terms *laser*, *mechanical arm*, *welding*, *walking* (in the sense of robot walking), and *robot body*, highlighting the importance of industrial robotics (see Figure 11). In **robotics, a** growing trend is evident in terms such as *machine vision*, *recognition* (recognition of objects, images, letters, behaviour, emotions, faces, etc. from robot sensors), *realtime* (meaning immediate response), *storage medium*, *mechanical arm*, *industrial* or *target detection* (see Figure 12).

In **artificial intelligence,** the main terms with a growing tendency are *neural network*, *training*, *storage medium*, *deep learning*, i.e. words related to the field of models (including large language models), as well as the terms *cloud*, *internet of things*, *text* or *blockchain*. The terms *autonomous vehicle* and *autonomous driving* have a significantly decreasing trend (not shown) (see Figure 13). In **big data**, the words *realtime* (in the sense of real-time data acquisition and processing), *database*, *storage medium*, *historical* (dealing with older data), *prediction*, *early warning*, *artificial intelligence* and *finance* are growing (see Figure 14).

In the advanced technology of **cloud computing**, the words and phrases *storage medium* and *artificial intelligence* appear to be growing (see Figure 15). In **cybersecurity**, the words and phrases *encryption*, *storage medium*, *network security*, *blockchain*, *privacy*, *realtime*, *big data,* or *artificial intelligence* are on the rise (see Figure 16).

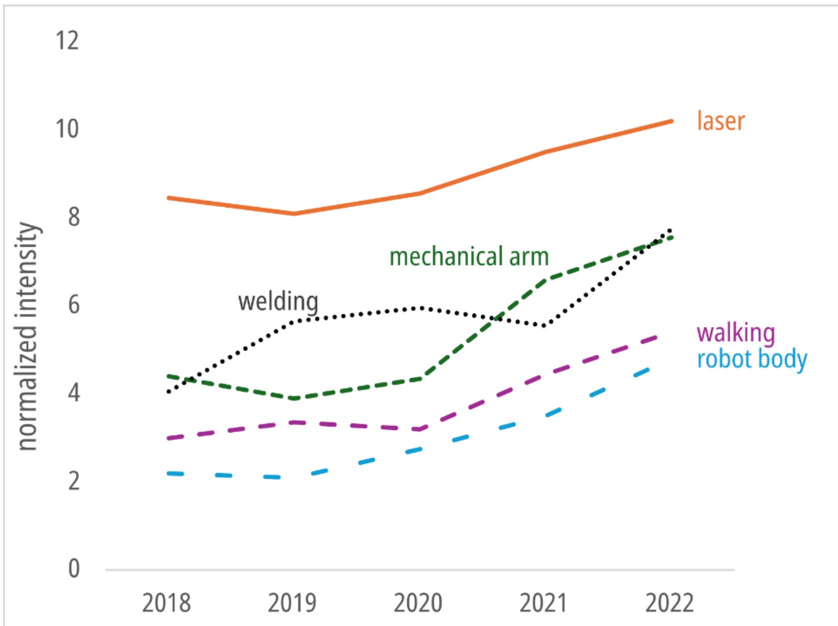

Figure 11 Advanced manufacturing - increasing trends in the occurrence of selected keywords and phrases in patent applications. Source: PATSTAT, Autumn 2023

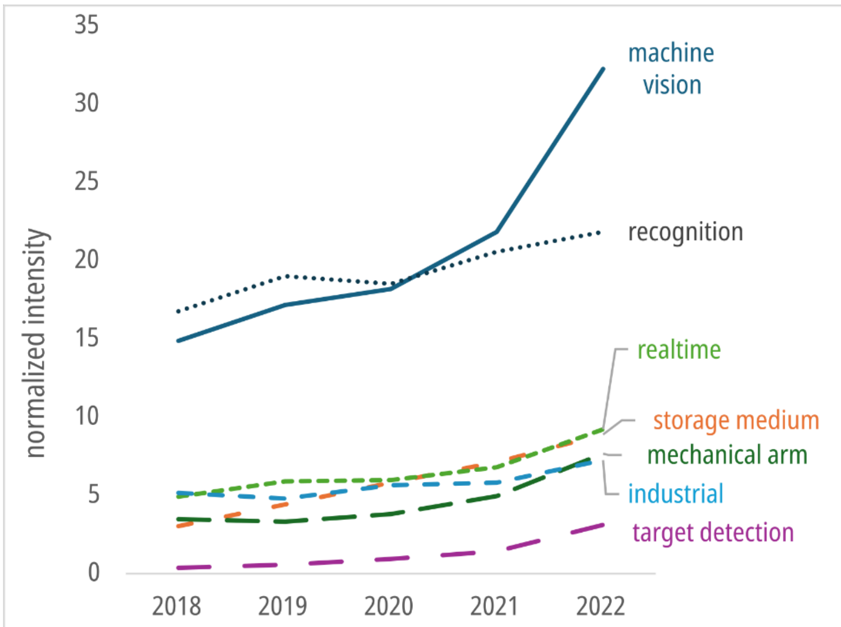

Figure 12 Robotics - increasing trends in the occurrence of selected keywords and phrases in patent applications. Source: PATSTAT, Autumn 2023

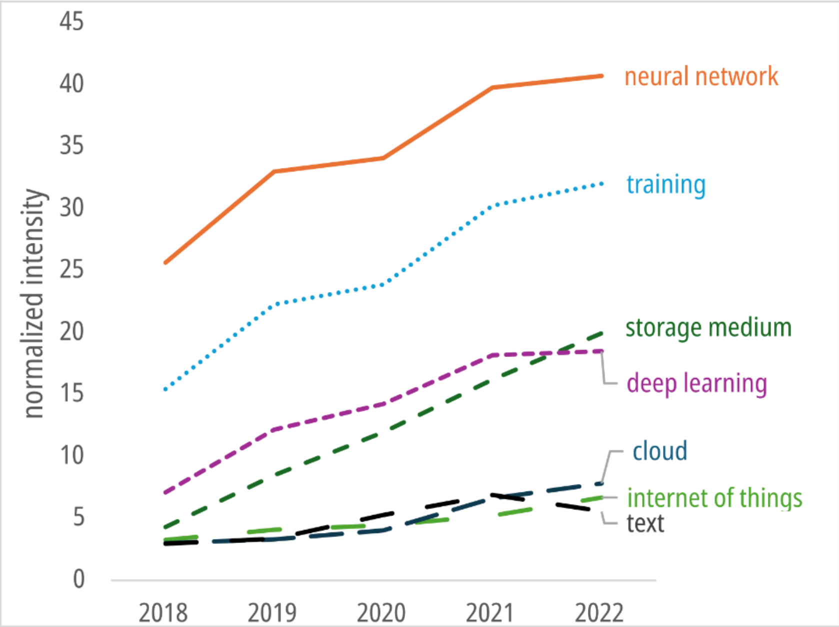

Figure 13 Artificial intelligence - increasing trends in the occurrence of selected keywords and phrases in patent applications. Source: PATSTAT, Autumn 2023

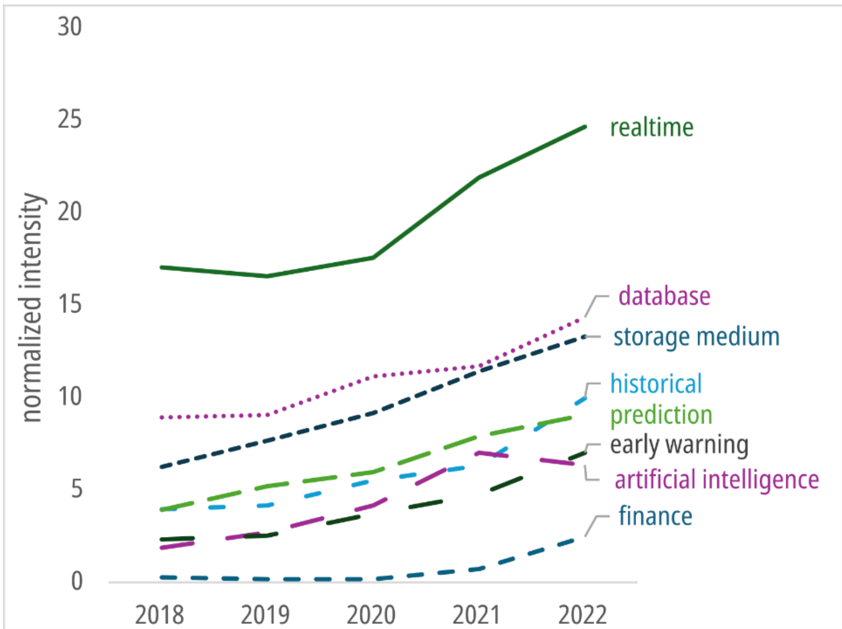

Figure 14 Big data - increasing trends in the occurrence of selected keywords and phrases in patent applications. Source: PATSTAT, Autumn 2023

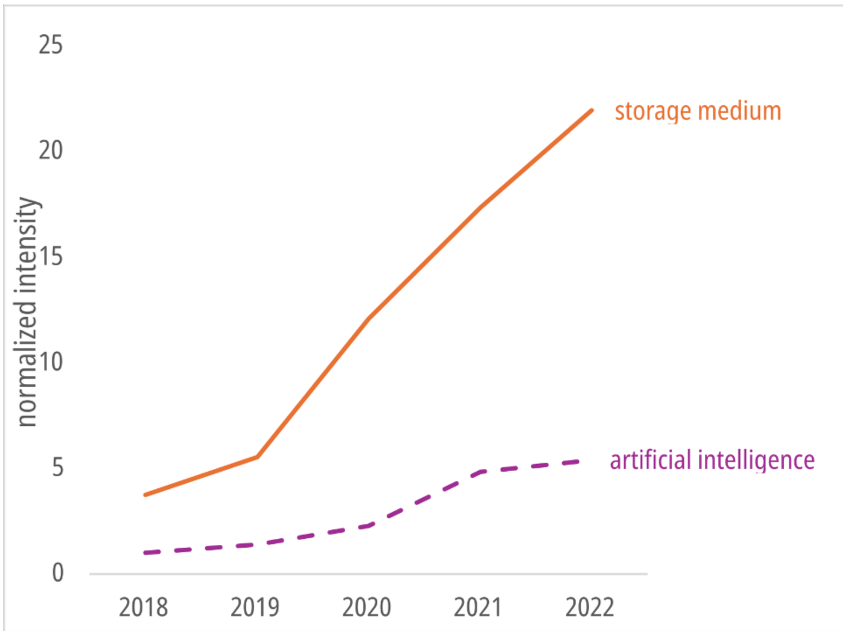

Figure 15 Cloud computing - increasing trends in the occurrence of selected keywords and phrases in patent applications. Source: PATSTAT, Autumn 2023

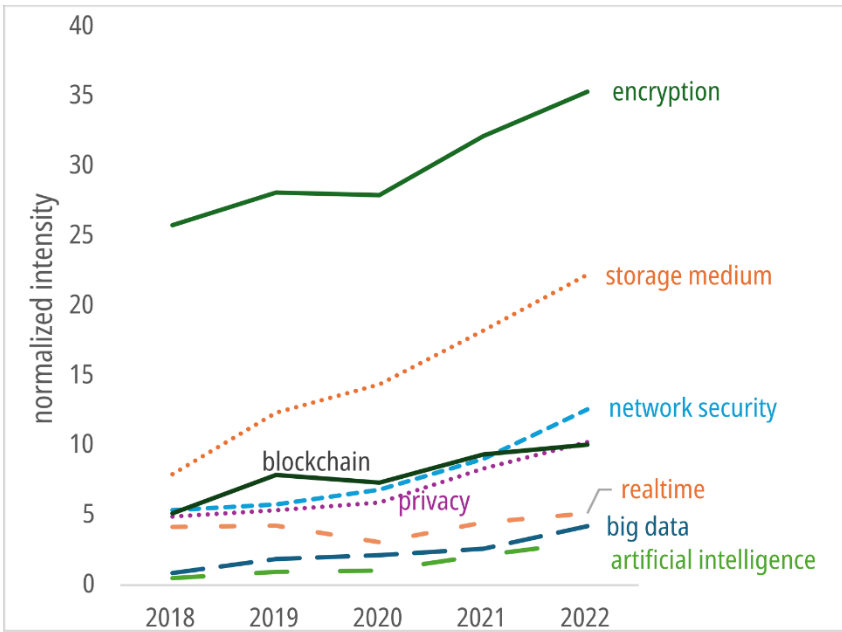

Figure 16 Cybersecurity - increasing trends in the occurrence of selected keywords and phrases in patent applications. Source: PATSTAT, Autumn 2023

4.2 Current main topics of articles in selected technology media

Current topics of articles in selected technology media are listed in Figure 17. The media are divided into four categories in the figure - academic media, technology media, technology sections of established media, and news on EU policies related to technology. An overview of the media included in each category is given in the annex to the Chapter 9.4.2. The approach to identifying the main themes is described in more detail in the annex to the Chapter 9.1.4.1.

The main topic, which significantly overshadows other topics, is generative artificial intelligence, whose use is penetrating into various fields not only of digital technologies but also more broadly into various research activities. The representation of the topic of AI compared to other advanced digital technologies in the technology media assessed over the period under review is shown in the figure below. The main themes identified for each technology media category are summarised below.

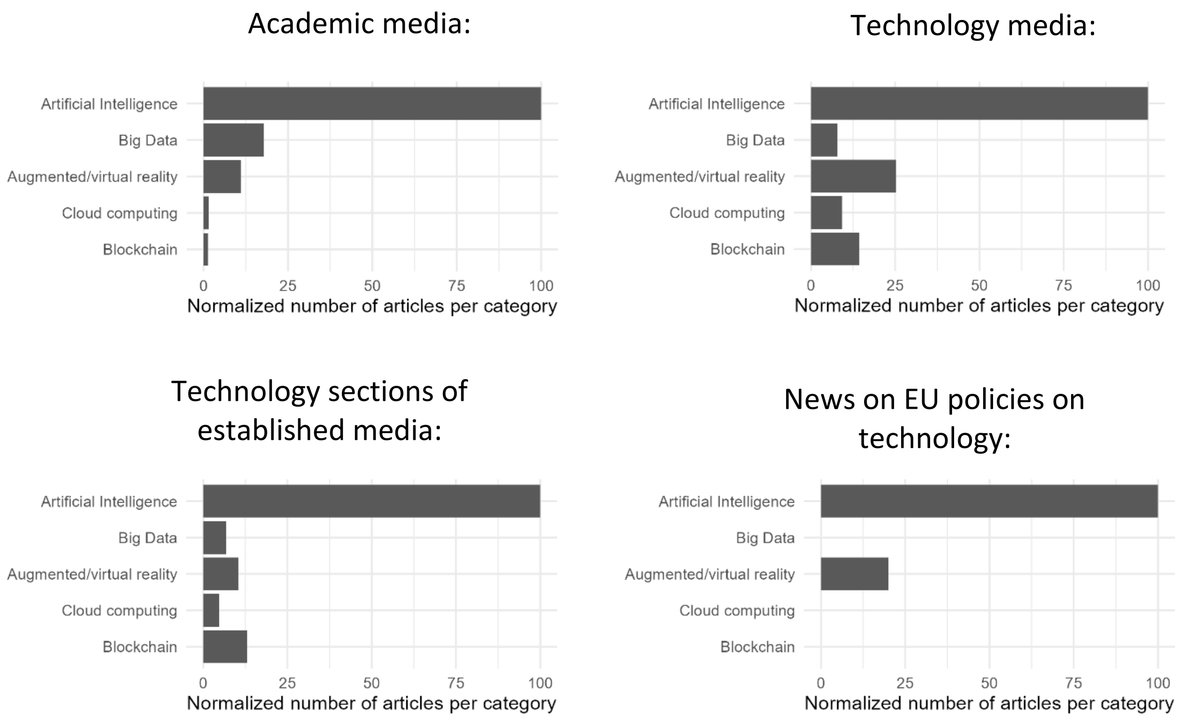

Figure 17 Main themes identified in each category of technology media. Source: media included in the analysis (see annex in Chapter 9.4.2), TCP

4.2.1 Academic Media

In the academic media, the topic of artificial intelligence is mainly focused on solving societal challenges such as improving climate models, diagnosing diseases or promoting inclusivity in healthcare. More broadly, the impact of digital technologies on society and the growing need for better cyber security to protect sensitive data and infrastructure from attack are highlighted. The use of big data in conjunction with artificial intelligence tools helps to gain a deeper understanding of complex systems such as the brain, the environment, or social networks and helps to translate complex data into accessible visual or multimedia forms to convey insights to a wider audience.

With regard to AI, there is a need for more user-friendly and transparent AI systems, especially in areas such as healthcare and education. Furthermore, trust and security is a serious issue, to enable people to understand and trust AI tools, to address concerns about data privacy and security, and to develop new methods and technologies to protect sensitive information. The impact of AI on labour markets and the need to develop the workforce to address skills shortages and prepare for new types of jobs are addressed, and the growing awareness of the potential harms caused by the misuse of AI, including bias against minorities or the spread of misinformation, is highlighted. Artificial intelligence and the use of data helps in the innovation of new materials and hardware components for various applications, including energy storage, environmental remediation or the development of quantum computing, and more broadly as a tool in various fields STEM (science, technology, engineering and mathematics), including medicine, climate change and energy research, in improving the capabilities of robots in areas such as manipulation, navigation and manufacturing, also more broadly for resource and production management, but also proving beneficial in deepening interdisciplinary collaboration, including links with the arts and humanities, where the importance of open source tools and data is seen as crucial.

4.2.2 Technology media

Technology media focuses mainly on the technical aspects of the technologies under scrutiny. A big topic is generative artificial intelligence and its applications in various fields such as writing, translation and image generation. Attention is given to AI assistants to facilitate various sub-activities. Concerns about data breaches, misuse of user data and the overall impact of AI on privacy are highlighted, as well as emerging cyber threats, malware and the use of AI for defence and security. Much attention is also paid to the dominance of a few major cloud providers and their strategies for AI development and deployment in a context where AI integration is accelerating, a global race for AI is underway, and demand for powerful hardware to support AI workloads is growing, with significant environmental implications. Blockchain technology and digital asset management also continue to receive attention, and the concept of metaverse is being developed, particularly in computer games, as well as virtual and augmented reality.

4.2.3 Technology sections of established media

In the technology sections of established media, attention is paid to the capabilities of AI in various fields such as entertainment, agriculture, healthcare and fashion, but also to the role of AI in war. Technology is seen as augmenting human capabilities and changing the skill sets needed for the future success of a person, company or other organization. The limitations of AI and the potential negative impacts, especially job creation or the spread of misinformation, are discussed. There are calls for regulatory measures and ethical rules. The environmental impact of the technology is highlighted as well as the business side of things.

4.2.4 News on EU policies on technology

EU policies emphasise the potential of AI for research and innovation, noting that the development of credible AI is needed to enable its responsible adoption. Promoting ethical principles, raising public awareness of AI and digital technologies, and involving citizens in the development of these technologies are thus important. Significant emphasis is placed on the regulation and development of data markets (beyond personal data), the development of robust data governance rules, interoperability, and the strengthening of cyber security. The role of digital technologies is essential for a successful ecological transformation of the economy and society. International cooperation and the involvement of all stakeholders to set up good governance in digital technologies is a prerequisite for success in these areas.

4.3 Main findings from the survey of promising R&D directions in advanced technologies

The research aimed to gather information on promising advancements in advanced technologies and their potential application to GSC solutions. In line with the terms of reference, the primary focus was on digital technologies and their connections to the identified GSCs The main sources used for this research were studies prepared by the McKinsey Global Institute [11], [17] a [18]. In this Chapter, only the main findings of the research are presented. The extended version is in the appendix part of the report in Chapter 9.4.

The research showed that digital technologies have a high potential for future applications. The study [17] identifies digital technologies that are applied in virtually all sectors and that can make a significant contribution to their transformation. An overview of these technologies, together with promising directions and possible applications in addressing GSC, is given in the following paragraphs.

Advanced automation (Next level automation). This includes, for example, robotic hardware, additive manufacturing and virtualization. These technologies can help shorten the development cycle and make production more efficient. The use and application for GSC solutions is therefore quite broad.

Connectivity. In the context of the development of networks of intercommunicating devices, 5G and Internet of Things technologies are gaining importance. Connectivity is a prerequisite for cloud and edge computing as well as Industry 4.0. These technologies reduce energy consumption and thus contribute to solving the issues in the Energy Transformation and Adaptation to Climate Change GSCs (smart grids, smart settlements), and are also used in mobility and healthcare.

Distributed infrastructure. Includes cloud/edge computing. Allows for increased computing power and reduced costs for users. The application of these technologies is broad, and they are already used in projects targeting all GSCs.

New generation computing. It includes quantum computing using quantum mechanical principles and neuromorphic hardware. They promise to allow to overcome the limits of existing computing systems while reducing energy consumption. They will find applications in a number of technological areas and can contribute to the solution of most of the identified GSCs (in particular Digital Transformation and Energy).

Trust Architecture. Includes zero trust architecture, digital identity and privacy engineering, blockchain, and more. It is expected to become an integral part of life. These technologies may find application in the Trust in Democracy, Societal Resilience GSC, among others.

Applied AI. We can expect expanding applications of computer vision, natural language understanding and generation, virtual assistants, robotic process automation and advanced machine learning, and general human-machine interaction. As the analyses in this study show, AI also has the highest potential to address all GSCs, such as crisis management, economics, education, environmental challenges, social, healthcare, security, infrastructure management, public and social sector management, and more. The rise of AI will have a significant impact on the labour market and current education systems need to be reformed.

The future of programming (Software 2.0). These are machine-written programs, platforms for this interactive way of programming (low-no-code platforms), algorithms requiring less manual coding, etc. It reduces the demands on programmers. AI will be applied in code creation, code review and testing. The implementation of these approaches holds significant promise in the context of digital transformation.

In addition to the digital technologies mentioned above, the study [17] identifies the following technologies or technology areas that can contribute to the transformation of a number of sectors.

New generation materials. The materials are based on significant innovations in terms of their properties, manufacturing processes and potential applications. In particular, they have a major impact on a number of sectors:

- Nanomaterials (carbon nanotubes, nanoparticles, graphene, titanium dioxide and others). They have applications in cleantech, aerospace, medical technology and other industries.
- Composites (fibre reinforced polymers, ceramic or metal matrix composites, reinforced concrete, etc.). These materials have a wide range of applications in many industries.
- New generation construction materials. They can make a significant contribution to reducing the carbon footprint and emissions of their production. Examples include cross-laminated timber (CLT) or green cement.

Bio-revolution. It is the result of significant advances in the life sciences and accelerating developments in computing, automation, artificial intelligence and data analysis. Promising areas include molecular, cellular, tissue and organ engineering, bio-machines, the interface between biology and machines, and biocomputing. The impact is expected not only in health but also in agriculture and consumer products.

Clean technologies of the future. They include established technologies such as solar, wind and hydro power, as well as new and breakthrough technologies such as nuclear fusion, energy storage and storage, and hydrogen generation. Carbon capture, use and storage (CCUS), smart grids and next generation batteries are also promising. They will impact energy, transport, construction, infrastructure and other areas.

4.4 Expert workshop

The aim of the first expert workshop was to discuss trends in advanced technologies and the links between these technologies and GSC, and to verify or refine some of the conclusions resulting from the analyses carried out[20]. The discussion at the workshop clearly confirmed the **importance of digitalisation and the use of digital technologies** in businesses, public administration, and society in general. The workshop confirmed that AI-based technologies are gaining in importance and can be expected to continue to do so in the future. Current trends in the use of AI include, in particular, an emphasis on greater interactivity and predictability, the use of AI in the data economy and user help, and the development of communication. In the opinion of experts, AI can be expected to be applied in industry (e.g. autonomous robots, individualisation of production, design for 3D printing), healthcare (personalised medicine), agriculture, energy (smart grids, smart cities, transport).

The Czech Republic is in a good position in some areas, such as healthcare, the sharing economy, digitisation of government, education, and applications using big data. Smart cities are also an opportunity for the Czech Republic, as confirmed by the results of data analyses. There is potential in the Czech Republic in the production of drones, 3D printing, and in the research and construction of high-altitude platform systems (atmospheric satellites) used for communication, monitoring, etc.

In GSC **Energy Transformation and Sustainable Futures** can make a significant contribution to creating greener and more efficient energy systems, reducing greenhouse gas emissions and promoting sustainable development of advanced technology. Advanced manufacturing technologies will enable the development and production of more efficient and environmentally friendly renewable energy devices (e.g. solar panels and wind turbines). Advanced material technologies can lead to the development of lighter and more durable materials for the construction of more energy-efficient buildings and infrastructure. Biotechnology can be used to produce biofuels and biochemicals that

[20] The conclusions of the analyses were clearly summarized in a document that was sent to the participants before the workshop.

reduce dependence on fossil fuels and minimise greenhouse gas emissions. Digital technologies and ICT can provide smart solutions for managing energy networks, optimising energy consumption and monitoring environmental impacts. AI has an important role to play in the decentralisation of energy production and distribution. As the Czech Republic is one of the countries with high energy intensity, the goal should be "smart" energy, where AI should play a significant role.

In GSC **Adaptation to climate change,** the protection of water resources and water management, biodiversity protection and ecosystem restoration using biotechnology will become increasingly important in the context of rising temperatures. Robotics is becoming increasingly important in agriculture and can help to reduce impacts (spraying, harvesting, pest detection, etc.). Biotechnology can help, for example, by developing more resilient plants or by improving agricultural techniques for sustainable farming. Advanced manufacturing technologies can be used in this GSC in the production of equipment for monitoring and predicting climate change, digital technologies, and ICTs will be used in platforms for collecting, analysing and sharing climate change data. Advanced materials will be used in reducing the consumption of raw material resources.

In GSC **Preparedness for demographic change and ageing of the population**, biotechnologies such as genetics (genetic medicine, gene technology) are of great importance in the context of population ageing. There are good prerequisites and potential for the development of these areas in the Czech Republic. Personalized medicine will also play an important role in the future. The Czech Republic has good conditions for the development of techniques using virtual reality. Another opportunity is the gene editing technology known as CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats), which is used for targeted genome interventions with high precision.

Experts confirmed the great importance of digital technologies and ICT for addressing the issues included in the GSC **Trust in democracy, societal resilience, security and defence**, which provide, among others, tools for improving transparency of public administration, strengthening communication between government and citizens, and increasing resilience to disinformation and cyber threats. They are also important in strengthening democratic institutions and increasing transparency and accountability in public administration. In the future, quantum technologies (e.g. quantum computers in cryptography) can be expected to be more widely used in cybersecurity. Quantum communication is also gaining importance. Advanced manufacturing technologies have the potential to develop and produce sophisticated devices for monitoring and protecting public space.

In a **general discussion,** the workshop participants highlighted the importance of training, including in the context of the retirement of older experienced workers. Digital technologies, in AI, are of great importance for the "preservation" of knowledge. Attention should also be paid to the development of companies to increase their competitiveness (digitalisation and digital technologies can be seen as a tool rather than a goal, according to the experts). Material research is also important for the development of competitiveness, as advanced materials are used in a wide range of technologies (as is clear from the analyses carried out). The problematic quality of Czech management (in international comparison) can be a limiting factor for the development of companies. Some of the opinions and comments of the workshop participants were reflected in the methodological part of the report in Chapter 9.1.

5 Analysis of stakeholders, entities with the status of "vetted researcher", and networking of research and innovation entities.

In the first part of the analysis, the most important entities involved in R&D projects addressing advanced technologies implemented in national support programmes and EU Framework Programmes from 2019 to 2023 were identified.

Using the data from the stakeholder analysis, research organisations active in digital technologies and ICT that are intensively involved in R&D projects implemented in the programmes of targeted support and EU framework programmes were subsequently identified. These institutions were approached with a questionnaire asking if they would be willing to nominate a vetted researcher in line with the Digital Single Market Regulation 2022/2065 [3]. An overview of the institutions contacted, and their responses is given in Chapter 5.2.

In the Chapter 5.3 the links between actors at national and international level are assessed. For this purpose, maps of collaborative networks in projects supported by national R&D programmes and EU Framework Programmes are used.

5.1 Stakeholder analysis

In the following subsections, entities that are research active in advanced technologies are identified. For each entity, the number of projects carried out in national R&D programmes since 2019 and the state budget support received, the number of projects in the H2020 Framework Programme since 2019, and the number of projects in the HE programme to date are listed. The table also provides data on the EC contribution to these projects. The institutions are ranked in descending order of the number of projects in the national R&D programmes. The stakeholder analysis is broken down by broader areas of advanced technologies (see Table 6) and by the economy sectors stakeholders belong to.

In the annex part of the report in Chapter 9.5.1, an overview of the most important stakeholders from the research sector in individual regions of the Czech Republic is included, as well as tables showing selected bibliometric indicators characterising the quality of the research carried out in institutions with the highest number of publications produced in R&D projects (Chapter 9.5). The annex part of the report also lists the institutions that have filed patent applications in each of the broad fields of advanced technologies between 2018 and 2022 (Chapter 9.5.3).

5.1.1 Advanced manufacturing technologies

The faculties and institutes in the higher education institutions (HEI) sector that are most involved in projects focused on R&D of advanced manufacturing technologies and their application are those in the fields of mechanical engineering, electrical engineering and ICT, as well as some more general faculties and institutes. The Faculty of Mechanical Engineering at Czech Technical University (CTU) in Prague, the Faculty of Mechanical Engineering at Brno University of Technology (BUT), and the Faculty of Electrical Engineering at CTU in Prague were involved in the highest number of projects. (see Table 14).

The Czech Institute of Informatics, Robotics and Cybernetics of CTU in Prague (CIIRC) and the Central European Institute of Technology (CEITEC) of BUT, i.e. research centres whose foundation was supported by the European Investment and Structural Funds (ESIF), have the highest potential for involvement in international research in the field of advanced manufacturing technologies. CEITEC was involved in a total of ten projects supported by the H2020 and HE programmes, and CIIRC in eight projects (see Table 14).

Table 14 The most important participants in projects from higher education institutions (HEIs) focused on advanced manufacturing technologies - number of projects implemented in national R&D programmes since 2019 and support received from the state budget since 2019 (first two columns of the table), number of projects supported in the Horizon 2020 framework programme since 2019[21] and in the Horizon Europe framework programme to date and the EC contribution to their solution (third to sixth columns of the table). Only HEIs that have been involved in five or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

University and Faculty (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
CTU in Prague - Faculty of Mechanical Engineering	45	228.0	0	0.0	0	0.0
Brno University of Technology - Faculty of Mechanical Engineering	40	284.6	0	0.0	1	718.8
CTU in Prague - Faculty of Electrical Engineering	36	651.8	1	36.8	1	0.0
CTU in Prague - Czech Institute of Informatics, Robotics and Cybernetics	24	329.8	2	7 391.1	6	4 378.7
University of West Bohemia in Pilsen - Faculty of Applied Sciences	22	258.4	1	345.6	1	305.2
Brno University of Technology - Central European Institute of Technology	21	130.0	5	4 756.5	5	1 224.3
BUT in Brno - Faculty of Information Technology	20	153.8	5	1 512.5	0	0.0
BUT Brno - Faculty of Electrical Engineering and Communication Technologies	18	97.7	0	0.0	1	415.0
University of West Bohemia in Pilsen - Faculty of Mechanical Engineering	15	165.4	0	0.0	0	0.0
Czech Technical University in Prague - Faculty of Civil Engineering	13	49.2	0	0.0	1	237.0
VSB - TUO - Faculty of Mechanical Engineering	13	255.4	0	0.0	0	0.0
Charles University - Faculty of Mathematics and Physics	12	49.8	0	0.0	2	170.2
University of West Bohemia in Pilsen - Faculty of Electrical Engineering	11	171.9	0	0.0	0	0.0
VSB - TUO - Faculty of Electrical Engineering and Computer Science	11	104.9	0	0.0	0	0.0
TUL - Institute for Nanomaterials, Advanced Technologies and Innovations	9	50.8	1	222.4	0	0.0
UCT in Prague - Faculty of Chemical Technology	8	31.0	0	0.0	1	150.4
University of West Bohemia in Pilsen - New Technologies - Research Centre	7	22.0	0	0.0	0	0.0
Palacky University in Olomouc - Faculty of Science	6	12.7	0	0.0	1	0.0
Czech Technical University in Prague - Faculty of Transport	6	17.1	0	0.0	1	1 392.4
Brno University of Technology - Faculty of Civil Engineering	6	13.2	0	0.0	1	49.1
CTU in Prague - Faculty of Nuclear and Physical Engineering	6	50.7	0	0.0	1	0.0
Technical University of Liberec - Faculty of Mechanical Engineering	5	54.7	0	0.0	0	0.0
Tomas Bata University in Zlín - Faculty of Applied Informatics	5	34.3	0	0.0	0	0.0
Czech University of Agriculture in Prague - Faculty of Technology	5	13.9	0	0.0	0	0.0
University of South Bohemia in České Budějovice - Faculty of Agriculture	5	21.0	0	0.0	0	0.0
CTU in Prague - Faculty of Biomedical Engineering	5	16.7	0	0.0	0	0.0

Institutes of the CAS are less involved in projects focused on advanced manufacturing technologies, which is related to their focus on basic research (see Table 15). The Institute of Physics of the CAS, and the Institute of Physics of Materials of the CAS were involved in the highest number of projects supported in national R&D&I programmes. The involvement of CAS institutes in R&D projects on advanced manufacturing technologies in EU framework programmes is somewhat lower than in other technological areas. The Institute of Physics of the CAS and the Institute of Plasma Physics of the CAS were involved in three projects of the Framework Programmes (see Table 15).

Furthermore, research institutes established by ministries and other government agencies are not heavily involved in such projects. The Czech Metrology Institute and Institute of Criminalistics of the Police of the Czech Republic have been involved in three or more projects supported by national R&D programmes. Research institutes beyond CAS are not involved in projects focusing on advanced

[21] The limitation of H2020 data to the period after 2019 is for reasons of timeliness and consistency with the data from projects in the CEP IS R&D&I (holds for all tables in this chapter)

manufacturing technologies in EU framework programmes (see Table 16). The business sector was also heavily involved in projects focused on advanced manufacturing technologies (see Table 17). COMTES FHT a.s., SVÚM a.s., and ProSpon, spol. s r.o. were involved in the highest number of projects.

Table 15 The most important participants in projects from CAS institutes focused on advanced manufacturing technologies - the number of projects implemented in national R&D programmes since 2019 and support received from the state budget since 2019 (the first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (the third to sixth columns of the table). Only institutes that have been involved in three or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Institute of Physics of Materials of the CAS, v. v. i.	8	57.2	2	543.6	0	0.0
Institute of Physics of the CAS, v. v. i.	8	151.0	1	157.0	2	5 731.2
Institute of Plasma Physics of the CAS, v. v. i.	7	68.5	0	0.0	3	429.5
Institute of Thermomechanics of the CAS, v. v. i.	6	31.2	0	0.0	2	237.0
Institute of Instrumentation of the CAS, v. v. i.	6	26.0	0	0.0	0	0.0
Institute of Information Theory and Automation of the CAS, v. v. i.	5	32.3	0	0.0	1	177.5
Institute of Macromolecular Chemistry of the CAS, v. v. i.	4	7.3	0	0.0	0	0.0
Institute of Computer Science of the CAS, v. v. i.	3	27.8	0	0.0	0	0.0

Table 16 The most important participants in projects from research institutes outside CAS and other government institutions focused on advanced manufacturing technologies - the number of projects implemented in national R&D programmes since 2019 and the support received from the state budget since 2019 (first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (third to sixth columns of the table). Only institutions that have been involved in three or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Czech Metrology Institute	4	2.1	0	0.0	0	0.0
Ministry of the Interior - Police of the CR, Criminalistics Institute	3	3.7	0	0.0	0	0.0

Table 17 The most important participants in projects from enterprises and private non-profit organisations that focused on advanced manufacturing technologies - the number of projects implemented in national R&D programmes in the period from 2019 and the support received from the state budget since 2019 (the first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (the third to sixth columns of the table). The table only includes entities that have been involved in five or more projects supported by national programmes. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (CZK Mill.)	Number of projects	Support (CZK Mill.)
COMTES FHT a.s.	16	94.3	0	0.0	0	0.0
SVÚM a.s.	10	30.0	1	157.0	0	0.0
ProSpon, spol. s r.o.	10	34.8	0	0.0	0	0.0
VÚTS, a.s.	6	33.0	0	0.0	0	0.0
LaserTherm spol. s r.o.	6	14.3	0	0.0	0	0.0
Výzkumný a zkušební ústav Plzeň s.r.o.	6	24.5	0	0.0	0	0.0
MEDIN, a.s.	5	13.5	0	0.0	0	0.0
CAMEA, spol. s r.o.	5	13.6	2	195.4	0	0.0
One3D s.r.o.	5	12.5	0	0.0	0	0.0
Červenka Consulting s.r.o.	5	13.0	0	0.0	0	0.0
Institut mikroelektronických aplikací s.r.o.	5	11.0	3	337.8	2	176.6

The results of the bibliometric analysis of publications focused on advanced material technologies are presented in the appendix in Chapter 9.5.2.1. Most of the publications were produced by the VSB - Technical University of Ostrava (TUO) - IT4Innovations department, and the Faculty of Information Technology of BUT. Other HEIs with a high number of projects also have a higher number of publications in the field of advanced manufacturing technologies. The quality of publications measured by the field normalized citation index is below average compared to the world. The only exception are publications produced by the Faculty of Electrical Engineering and Communication Technologies of BUT, whose citation index exceeds the world average.

There are not many priority patent applications focused on advanced manufacturing technologies in the Czech Republic. New solutions are applied for by several companies, mostly by COMTES FHT a.s. and Škoda Auto a.s. In non-commercial field, two patent applications have been filed by Tomas Bata University in Zlín (see Table 52 in the Annex).

5.1.2 Advanced material technologies

A high number of projects focused on advanced material technologies involved faculties and departments of universities. The focus of the faculties (departments) is quite broad, which is related to the wide use of these materials in various products and industries. In Table 18 can be seen that the faculties and departments are active in physical, material and natural sciences as well as in engineering, construction, electrical engineering, ICT and healthcare, where, in addition to R&D of advanced materials, attention is paid to their use in applications in various sectors.

The Faculty of Mathematics and Physics of Charles University (CU) was involved in the highest number of projects funded by the national budget. The Faculty of Chemical Technology of the UCT Prague, the CEITEC of BUT, the Faculty of Civil Engineering of the CTU in Prague and the Faculty of Science of Palacky University in Olomouc also participated in a high number of these projects.

The European Centre of Excellence CEITEC BUT was involved in the largest number of projects supported by the EU Horizon 2020 and Horizon Europe framework programmes, which shows its potential to participate in challenging projects in the field of materials research carried out in international cooperation. Additionally, all the aforementioned faculties have participated in EU Framework Programme projects at an above-average rate compared to other HEIs.

More than forty institutes of the CAS have been involved in R&D in the field of advanced material technologies, covering a wide range of scientific areas. The Institute of Physics of the CAS was involved in the highest number of projects (210 projects, the highest number of all institutions involved in projects focused on advanced material technologies, see Table 19). The Institute of Macromolecular Chemistry of the CAS and the J. Heyrovsky Institute of Physical Chemistry of the CAS were also participated in a high number of projects.

The Institute of Physics of the CAS was also involved in the highest number of projects of the H2020 and HE framework programmes (nine projects in H2020 and 14 projects in the current course of HE). The J. Heyrovsky Institute of Physical Chemistry of the CAS were involved in eight H2020 and HE projects, and the Institute of Organic Chemistry and Biochemistry of the CAS were involved in six H2020 and HE projects.

Among other government institutions, the Czech Metrology Institute was involved in the highest number of projects addressing advanced materials technologies. The Research Institute of Veterinary Medicine, v. v. i., and the Institute of Clinical and Experimental Medicine were also involved in a higher number of projects. Sectoral institutes and other governmental institutions are not very involved in EU framework programmes on advanced material technologies, as in other advanced technologies (see Table 20).

The involvement of companies in advanced material technology projects is very high. COMTES FHT a.s. was involved in thirty projects, SYNPO, joint stock company, ÚJV Řež, a. s., Research Centre Řež s.r.o., SVÚM a.s., and CRYTUR, spol. s r.o. were involved in twenty or more projects. Some companies are also involved in EU framework programmes. Research Centre Řež s.r.o. and CRYTUR, spol. s r.o. were involved in the three supported in the H2020 and HE framework programmes (see Table 21).

The number of publications produced in projects supported by targeted R&D support programmes is very high compared to other advanced technologies (see Chapter 9.5.2.2). Almost a thousand publications have a co-author from the Institute of Physics of the CAS, where research in material science is strong. In the HEI sector, the majority of publications was produced by the University of Chemistry and Technology (UCT) Prague (720 publications) and CEITEC BUT (around 600 publications). More than 500 publications were produced by the Faculty of Mathematics and Physics of CU and the Faculty of Science of Masaryk University (MU). The field normalized citation rate of most departments is below the world average. Above-average citation rates are achieved by the Czech Advanced Technology and Research Institute at Palacký University in Olomouc, the Veterinary University in Brno and the Faculty of Fisheries and Protection of Waters of the University of South Bohemia in České Budějovice (however, the number of papers of the last two institutions is relatively low). The Biology Centre of the CAS, the Institute of Experimental Botany of the CAS and the Institute of Biotechnology produced highly cited publications.

Table 18 The most important participants in projects from HEIs focused on advanced materials technologies - number of projects implemented in national R&D programmes since 2019 and support received from the state budget since 2019 (first two columns of the table), number of projects supported in Horizon 2020 since 2019 and in the Horizon Europe framework programme so far and the EC contribution to them (third to sixth columns of the table). Only HEIs that have been involved in ten or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

University and Faculty (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Charles University - Faculty of Mathematics and Physics	128	586.4	5	2 858.7	3	2 240.7
UCT - Faculty of Chemical Technology	122	498.8	4	1 021.5	6	966.0
BUT - Central European Institute of Technology BUT	116	904.6	11	3 023.1	13	4 326.6
Czech Technical University in Prague - Faculty of Civil Engineering	101	399.3	4	1 845.4	1	237.0
Palacký University in Olomouc - Faculty of Science	89	707.7	4	1 424.6	3	752.5
Brno University of Technology - Faculty of Civil Engineering	71	315.9	0	0.0	0	0.0
Brno University of Technology - Faculty of Mechanical Engineering	68	409.3	1	379.0	1	718.8
Masaryk University - Faculty of Science	66	483.6	3	605.6	0	0.0
Charles University - Faculty of Science	65	272.9	0	0.0	2	594.8
TUL - Institute for Nanomaterials, Advanced Technologies and Inn	63	290.2	1	222.4	0	0.0
Czech Technical University in Prague - Faculty of Electrical Enginee	61	348.1	2	228.9	1	237.0
Czech Technical University in Prague - Faculty of Mechanical Engin	60	571.5	1	180.6	0	0.0
Brno University of Technology - Faculty of Electrical Engineering an	60	245.6	0	0.0	1	415.0
University of Pardubice - Faculty of Chemical Technology	54	307.9	1	253.8	3	645.7
UCT - Faculty of Chemical Engineering	48	218.9	0	0.0	1	0.0
Tomas Bata University in Zlín - University Institute	45	163.8	0	0.0	1	303.8
CTU in Prague - Faculty of Nuclear and Physical Engineering	44	236.2	1	343.4	2	0.0
Brno University of Technology - Faculty of Chemistry	33	99.9	1	340.8	0	0.0
Charles University - 1st Faculty of Medicine	28	69.3	0	0.0	0	0.0
University of West Bohemia in Pilsen - Faculty of Electrical Enginee	27	185.0	0	0.0	2	529.0
Czech Technical University in Prague - University Centre for Energy	27	149.4	2	996.8	0	0.0
Technical University of Liberec - Faculty of Textiles	26	56.1	1	110.4	0	0.0
Mendel University in Brno - Faculty of Agronomy	26	118.7	0	0.0	0	0.0
University of West Bohemia in Pilsen - Faculty of Mechanical Engin	24	117.5	0	0.0	0	0.0
Masaryk University - Central European Institute of Technology	22	273.7	1	656.5	0	0.0
VSB - TUO - Faculty of Electrical Engineering and Informatics	21	65.3	0	0.0	0	0.0
University of West Bohemia in Pilsen - Faculty of Applied Sciences	20	164.5	1	280.9	0	0.0
CTU - Faculty of Biomedical Engineering	20	75.4	1	79.5	0	0.0
UJEP in Ústí nad Labem - Faculty of Science	20	187.7	0	0.0	0	0.0
UCT in Prague - Faculty of Food and Biochemical Technology	20	60.6	1	303.3	0	0.0
Technical University of Liberec - Faculty of Mechanical Engineering	16	208.3	0	0.0	0	0.0
JCU in České Budějovice - Faculty of Science	16	75.9	0	0.0	0	0.0
TUL - Faculty of Science, Humanities and Pedagogy	13	22.9	0	0.0	0	0.0
Czech Technical University in Prague - Klokner Institute	13	30.9	0	0.0	0	0.0
UPOL - Czech Institute of Research and Advanced Technologies	13	51.5	0	0.0	11	8 297.8
Masaryk University - Faculty of Medicine	13	42.3	0	0.0	0	0.0
VSB - TUO - IT4Innovations	12	409.0	1	310.0	2	282.5
Palacky University in Olomouc - Faculty of Medicine	12	43.3	0	0.0	1	237.0
VSB - TUO - Faculty of Materials Science and Technology	12	56.8	0	0.0	0	0.0
UCT in Prague - Faculty of Environmental Technology	12	39.2	1	640.8	0	0.0
TUL - Faculty of Mechatronics, Informatics and Interdisciplinary St	11	32.5	0	0.0	0	0.0
BUT in Brno - Faculty of Information Technology	11	104.8	2	436.5	2	294.9
Charles University - Faculty of Pharmacy in Hradec Kralove	10	42.0	0	0.0	0	0.0
University of Chemical Technology in Prague - Rectorate	10	122.5	0	0.0	0	0.0
Brno University of Technology	10	38.9	0	0.0	0	0.0

Table 19 The most important participants in projects from CAS institutes focused on advanced materials technologies - the number of projects implemented in national R&D programmes since 2019 and the support received from the state budget since 2019 (first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (third to sixth columns of the table). Only institutes that have been involved in ten or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Institute of Physics of the CAS, v. v. i.	210	3 669.0	9	4 586.9	14	13 909.5
Institute of Macromolecular Chemistry of the CAS, v. v. i.	118	347.9	2	188.0	0	0.0
J. Heyrovsky Institute of Physical Chemistry of the CAS, v. v. i.	96	384.9	5	1 240.6	3	736.5
Institute of Physics of Materials of the CAS, v. v. i.	43	187.4	2	543.6	1	162.5
Institute of Plasma Physics of the CAS, v. v. i.	43	328.6	1	351.3	3	527.2
Institute of Instrumentation of the CAS, v. v. i.	39	435.1	3	762.5	0	0.0
Institute of Organic Chemistry and Biochemistry of the CAS, v. v. i.	39	168.6	4	1 105.4	2	1 714.5
Institute of Photonics and Electronics of the CAS, v. v. i.	33	159.3	0	0.0	0	0.0
Institute of Experimental Medicine of the CAS, v. v. i.	32	223.0	4	862.4	0	0.0
Institute of Inorganic Chemistry of the CAS, v. v. i.	30	76.1	0	0.0	2	489.0
Institute of Chemical Processes of the CAS, v. v. i.	28	73.5	0	0.0	0	0.0
Institute of Microbiology of the CAS, v. v. i.	27	79.9	0	0.0	1	0.0
Institute of Physiology of the CAS, v. v. i.	21	64.2	0	0.0	1	0.0
Institute of Nuclear Physics of the CAS, v. v. i.	21	388.4	1	174.8	2	128.2
Institute of Thermomechanics of the CAS, v. v. i.	20	94.9	0	0.0	1	0.0
Biological Centre of the CAS, v. v. i.	19	60.3	0	0.0	0	0.0
Institute of Biophysics of the CAS, v. v. i.	13	47.5	0	0.0	0	0.0
Institute of Biotechnology of the CAS, v. v. i.	12	58.2	1	419.1	0	0.0
Institute of Analytical Chemistry of the CAS, v. v. i.	11	32.9	0	0.0	0	0.0
Institute of Global Change Research of the CAS, v. v. i.	10	10.2	0	0.0	1	0.0
Institute of Molecular Genetics of the CAS, v. v. i.	10	27.0	0	0.0	0	0.0
Institute of Theoretical and Applied Mechanics of the CAS, v. v. i.	10	35.9	1	234.9	0	0.0

The number of priority patent applications focused on advanced material technologies is very high (the highest of all advanced technologies). Patent applications are filed by entities from all sectors. In public research, the most active are large universities with faculties and centres active in materials research, such as the Czech Technical University in Prague, the Technical University in Liberec and the Tomas Bata University in Zlín. Of the Czech Academy of Sciences, the Institute of Physics of the CAS, where materials R&D is very strong, has filed the most patent applications. From the business sector, the companies that filed the most patent applications were PO LIGHTING CZECH s.r.o. and Škoda Auto a.s. (see Table 53 in the Annex).

Table 20 The most important participants in projects in research establishments beyond CAS and other government institutions focused on advanced material technologies - number of projects implemented in national R&D programmes since 2019 and support received from the state budget since 2019 (first two columns of the table), number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (third to sixth columns of the table). Only institutions that have been involved in five or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Czech Metrology Institute	31	50.6	0	0.0	0	0.0
Research Institute of Veterinary Medicine, v. v. i.	13	92.0	0	0.0	0	0.0
Institute of Clinical and Experimental Medicine	11	31.1	1	214.1	0	0.0
State Institute of Radiation Protection, v. v. i.	7	39.2	0	0.0	0	0.0
Transport Research Centre, v. v. i.	6	18.1	0	0.0	0	0.0
Extreme Light Infrastructure ERIC (ELI ERIC)	6	42.3	1	4 699.4	1	150.4
State Institute of Health	5	18.0	0	0.0	0	0.0
Czech Geological Survey	5	23.2	0	0.0	0	0.0
Research Institute of Geodesy, Topography and Cartography, v. v. i.	5	6.5	0	0.0	0	0.0

Table 21 The most important participants in projects from companies and private non-profit organisations that focused on advanced material technologies - the number of projects implemented in national R&D programmes since 2019 and the support received from the state budget since 2019 (the first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (the third to sixth columns of the table). The table only includes entities that have been involved in ten or more projects supported by national programmes. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
COMTES FHT a.s.	30	263.4	1	573.5	0	0.0
SYNPO, joint stock company	25	60.7	2	96.6	0	0.0
ÚJV Řež, a. s.	24	100.3	2	515.0	0	0.0
Centrum výzkumu Řež s.r.o.	22	344.0	3	1 173.5	0	0.0
SVÚM a.s.	22	72.5	1	157.0	0	0.0
CRYTUR, spol. s r.o.	20	103.7	1	244.2	2	0.0
PREFA KOMPOZITY, a.s.	14	28.2	0	0.0	0	0.0
Research Institute of Building Materials, a.s.	14	35.8	0	0.0	0	0.0
Centre of Organic Chemistry s.r.o.	14	31.8	1	355.6	0	0.0
UJP PRAHA a.s.	14	69.5	0	0.0	0	0.0
NANOPROGRESS, z.s.	13	11.1	0	0.0	0	0.0
Military Research Institute, s.p.	11	50.6	0	0.0	0	0.0
DEKONTA, a.s.	11	62.9	0	0.0	0	0.0
INOTEX spol. s r.o.	10	18.7	0	0.0	0	0.0
Meopta - optika, s.r.o.	10	50.0	0	0.0	0	0.0
ORLEN UniCRE a.s.	10	82.7	0	0.0	0	0.0

5.1.3 Biotechnology

In the HEI sector, mainly faculties and institutes active in the field of (bio)chemical, natural and health sciences have been involved in projects focused on biotechnology (see Table 22). The Faculty of Food and Biochemical Technology at the UCT Prague was involved in the highest number of projects, participating in almost forty projects supported by national R&D&I programmes as of 2019 (see Table 22). The Faculty of Science of CU and CEITEC MU were also involved in thirty or more projects. Twenty or more projects supported by national programmes involved the Faculty of Science of MU, the Faculty of Science of the University of South Bohemia in České Budějovice and the Faculty of Science of Palacký University in Olomouc.

CEITEC MU, Faculty of Science of MU and St. Anne's University Hospital in Brno have the highest potential for international cooperation in biotechnology. The first and third institutions are European Centres of Excellence supported by ESIF (Table 22).

Among the institutes of the CAS, the Institute of Microbiology was involved in the largest number of projects supported by national programmes (84 projects, state support of over CZK 0.5 billion). The Biology Centre of the CAS was involved in more than forty projects, and the Institute of Biotechnology of the CAS was involved in twenty projects. The Institute of Molecular Genetics of the CAS, the Institute of Organic Chemistry and Biochemistry of the CAS, and the Biology Centre of the CAS were involved in the highest number of projects supported in the EU framework programmes (see Table 23).

Other research institutes were much less involved in projects dealing with biotechnology than institutes of the CAS (see Table 24). The Research Institute of Veterinary Medicine was involved in the highest number of projects supported by national programmes (19 projects in total, state support amounting to CZK 140 million). Twelve projects involved the Research Institute of Plant Production, which received state support of approximately CZK 58 million. The potential of departmental institutes for involvement in international projects is lower, which is related to the nature of the research carried out.

The involvement of enterprises in projects focused on biotechnology is lower than in projects addressing advanced material technologies (see Table 25). EPS biotechnology, s.r.o. was involved in 16 projects supported by national programmes, and the Research Institute of Brewing and Malting, a.s. was involved in ten projects. NAFIGATE Corporation, a.s. and Agricultural Research, spol. s r.o. were involved in three projects supported by the H2020 and HE framework programmes.

Table 22 The most important participants in projects from HEIs focused on biotechnology - the number of projects implemented in national R&D programmes since 2019 and the support received from the state budget since 2019 (first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (third to sixth columns of the table). Only HEIs that have been involved in five or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

University and Faculty (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
UCT - Faculty of Food and Biochemistry. Technology	38	212.2	1	303.3	1	340.1
Charles University - Faculty of Science	34	310.8	0	0.0	3	652.7
MU - Central European Institute of Technology	30	709.9	8	4 299.0	4	2 617.5
Masaryk University - Faculty of Science	29	92.0	6	10 646.9	1	0.0
USB in České Budějovice - Faculty of Science	22	164.2	0	0.0	1	150.4
UP in Olomouc - Faculty of Science	20	240.9	1	265.0	1	0.0
Mendel University in Brno - Faculty of Agronomy	17	108.0	1	270.6	1	276.0
TUL - Institute for Nanomater., Pokr.technol. and Innovations	16	60.6	1	200.0	0	0.0
UCT in Prague - Faculty of Chemical Technology	15	49.3	1	157.0	1	150.4
Palacký University in Olomouc - Faculty of Medicine	15	111.2	1	96.3	0	0.0
CZU - Faculty of Agrobiology	15	42.6	0	0.0	0	0.0
Brno University of Technology - Faculty of Chemistry	15	56.8	1	340.8	0	0.0
Charles University - 1st Faculty of Medicine	15	63.7	1	0.0	2	0.0
St. Anne's University Hospital in Brno	12	450.4	5	1 880.3	1	150.0
Brno University of Technology - Central European Institute of Technolog	10	58.9	2	1 638.2	1	421.1
UCT in Prague - Faculty of Environmental Technology	10	67.6	2	942.3	0	0.0
Masaryk University - Faculty of Medicine	10	32.7	1	0.0	1	10 000.0
BUT in Brno - Faculty of Mechanical Engineering	9	93.0	0	0.0	0	0.0
General University Hospital in Prague	9	24.2	0	0.0	0	0.0
BUT in Brno - Faculty of Electrical Engineering and Com. Technology	8	38.8	0	0.0	0	0.0
CZU in Prague - Faculty of Environment	7	31.5	0	0.0	0	0.0
USB in České Budějovice - Faculty of Agriculture	7	22.5	0	0.0	0	0.0
University Hospital Brno	7	19.8	0	0.0	0	0.0
Mendel University in Brno - Faculty of Horticulture	7	20.8	0	0.0	0	0.0
UCT in Prague - Faculty of Chemical Engineering	7	24.6	0	0.0	0	0.0
Tomas Bata University in Zlín - University Institute	6	15.1	0	0.0	0	0.0
CEITEC - Central European Institute of Technology, VFU Brno	6	49.6	0	0.0	0	0.0
Czech Technical University in Prague - Faculty of Civil Engineering	6	21.8	3	1 306.6	0	0.0
VSB - TUO - Institute of Environmental Technologies	6	149.5	0	0.0	0	0.0
University of Ostrava - Faculty of Science	6	25.0	0	0.0	0	0.0
University Hospital Hradec Králové	5	8.5	0	0.0	0	0.0
VSB - TUO	5	46.5	0	0.0	0	0.0
VSB - TUO - Centre for Energy Utilisation of Non-Traditional Resources	5	4.4	0	0.0	0	0.0
Veterinary University Brno - Faculty of Veterinary Medicine	5	7.1	0	0.0	0	0.0
University Hospital Olomouc	5	15.3	0	0.0	0	0.0
University of Veterinary Medicine Brno - Faculty of Veterinary Hygiene	5	14.7	0	0.0	0	0.0
University of Pardubice - Faculty of Chemical Technology	5	10.7	0	0.0	0	0.0
UJEP in Ústí nad Labem - Faculty of Science	5	5.0	0	0.0	0	0.0
Czech Technical University in Prague - Faculty of Electrical Engineering	5	80.3	2	626.9	0	0.0

Table 23 The most important participants in projects from CAS institutes focused on biotechnology - the number of projects implemented in national R&D programmes since 2019 and the support received from the state budget since 2019 (first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (third to sixth columns of the table). Only institutes that have been involved in five or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Institute of Microbiology of the CAS, v. v. i.	84	541.2	3	3 469.3	0	0.0
Biological Centre of the CAS, v. v. i.	41	223.2	2	314.0	2	297.6
Institute of Biotechnology of the CAS, v. v. i.	20	173.7	1	419.1	0	0.0
Institute of Molecular Genetics of the CAS, v. v. i.	18	531.1	4	903.7	2	474.1
Institute of Physiology of the CAS, v. v. i.	16	53.2	1	145.0	1	0.0
Institute of Chemical Processes of the CAS, v. v. i.	15	137.3	0	0.0	0	0.0
J. Heyrovsky Institute of Physical Chemistry of the CAS, v. v. i.	15	47.7	2	246.0	0	0.0
Institute of Organic Chemistry and Biochemistry of the CAS	13	196.3	2	614.7	2	1 647.4
Institute of Macromolecular Chemistry of the CAS, v. v. i.	12	50.6	1	69.0	0	0.0
Institute of Experimental Botany of the CAS, v. v. i.	11	115.6	0	0.0	1	80.8
Institute of Botany of the CAS, v. v. i.	10	61.1	0	0.0	0	0.0
Institute of Experimental Medicine of the CAS, v. v. i.	9	51.3	2	289.8	0	0.0
Institute of Physics of the CAS, v. v. i.	9	133.8	0	0.0	1	422.0
Institute of Biophysics of the CAS, v. v. i.	7	18.5	0	0.0	0	0.0
Institute of Instrumentation of the CAS, v. v. i.	7	23.5	1	402.5	0	0.0
Institute of Animal Physiology and Genetics of the CAS, v. v. i.	5	24.5	0	0.0	0	0.0

Table 24 The most important participants in projects from research institutes outside CAS and other government institutions focused on biotechnology - the number of projects implemented in national R&D programmes since 2019 and the support received from the state budget since 2019 (the first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (the third to sixth columns of the table). Only institutions that have been involved in five or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Research Institute of Veterinary Medicine, v. v. i.	19	140.3	1	363.8	1	379.7
Research Institute of Plant Production, v. v. i.	12	58.0	0	0.0	1	80.6
Food Research Institute Prague, v. v. i.	6	17.7	0	0.0	0	0.0
Research Institute of Melioration and Soil Protection, v. v. i.	4	11.7	0	0.0	0	0.0
State Institute of Health	4	11.0	0	0.0	0	0.0
Silva Taroucy Institute, v.v.i.	3	12.9	0	0.0	0	0.0
Research Institute of Agricultural Technology, v. v. i.	3	12.3	0	0.0	0	0.0
Czech Geological Survey	3	12.3	0	0.0	1	437.9
Institute of Haematology and Blood Transfusion Prague	3	12.4	0	0.0	0	0.0
Research Institute of Animal Production, v. v. i.	3	10.5	0	0.0	0	0.0

The number of publications is not high compared to advanced material technologies. More than two hundred publications have been produced in projects of the Faculty of Science of CU and St. Anne's

University Hospital in Brno. The Institute of Microbiology of the CAS has 300 publications. The citation rate of publications of these institutions is above the world average (see Annex in Chapter 9.5.2.3). Very few priority patent applications have been filed in biotechnology. Two applications were filed by the VSB - TUO (see Table 54 in the Annex).

Table 25 The most important participants in projects from companies and private non-profit organisations that focused on biotechnology - the number of projects implemented in national R&D programmes since 2019 and the support received from the state budget since 2019 (the first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (the third to sixth columns of the table). The table only includes entities that have been involved in five or more projects supported by national programmes. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
EPS biotechnology, s.r.o.	16	29.3	0	0.0	0	0.0
Research Institute of Brewing and Malting, a.s.	10	29.2	0	0.0	0	0.0
Research Institute of Dairy, s.r.o.	8	45.6	0	0.0	0	0.0
EcoFuel Laboratories s.r.o.	8	13.9	0	0.0	0	0.0
ORLEN UniCRE a.s.	8	28.5	0	0.0	1	314.9
C2P s.r.o.	7	59.7	0	0.0	1	0.0
FAGOFARMA s.r.o.	6	56.5	0	0.0	0	0.0
agriKomp Bohemia s.r.o.	6	5.4	0	0.0	0	0.0
Research Institute of Potato Growing Havlíčkův Brod, s.r.o.	6	23.4	0	0.0	0	0.0
NAFIGATE Corporation, a.s.	5	8.2	3	1 038.7	0	0.0
Enantis s.r.o.	5	12.4	0	0.0	1	237.0
Agricultural Research, spol. s r.o.	5	16.9	1	20.8	2	410.9
RABBIT Trhový Štěpánov a.s.	5	10.3	0	0.0	0	0.0

5.1.4 Digital technology

In the HEI sector, electrical engineering faculties, ICT faculties, and science and physics faculties are the most involved in digital technology projects. The Faculty of Electrical Engineering of CTU was involved in the highest number of projects (more than 90 projects). The Faculty of Electrical Engineering and Communication Technologies of BUT, the Faculty of Mathematics and Physics of CU and the Faculty of Information Technology of BUT were involved in more than 50 projects (see Table 26).

In Table 26 It is also evident that in the field of digital technologies, the faculties of HEIs are relatively intensively involved in projects funded in the EU Framework Programmes compared to other technological areas. In the highest number of projects participates CU - Faculty of Mathematics and Physics (twenty projects) and the research centres of VSB - TUO - IT4Innovations and the CIIRC of CTU in Prague. The Faculty of Science of MU, the Faculty of Information Technology of BUT and the CEITEC of BUT also have considerable potential for involvement in international projects.

Among the institutes of the CAS, the Institute of Information Theory and Automation of the CAS participated in the highest number of projects. The Institute of Informatics of the CAS and the Institute of Physics of the CAS were also involved in a high number of projects in digital technologies. The institutes of the CAS are less involved in Framework Programme projects than universities, with the Institute of Physics of the CAS participating in the highest number of projects (see Table 27.

Among research institutes outside of the CAS and other government institutions, the National Institute of Mental Health and the Transport Research Centre were the most actively involved in nationally funded projects focused on digital technologies (15 and 14 projects, respectively). Both institutions also participated in several projects supported by EU Framework Programmes (see Table 28).

Some businesses and private non-profit organisations participated in digital technology projects (see Table 29). The Institute of Microelectronic Applications Ltd. was involved in 18 projects supported in national programmes, and CESNET was involved in 14 projects. These two entities were also frequently involved in EU framework programmes - the Institute of Microelectronic Applications participated in nine projects in the H2020 and HE programmes, CESNET was involved in ten projects (see Table 29).

The Faculty of Electrical Engineering at the Czech Technical University in Prague, the Faculty of Mathematics and Physics at CU and the IT4Innovations Centre at VSB - TUO have the largest number publications. The Institute of Physics of the CAS has the most publications. Publications of the Institute of Physics of the CAS, the General University Hospital in Prague, the Faculty of Nuclear and Physical Engineering of the CTU in Prague and the 1st Faculty of Medicine of CU achieved highest citation rates (see Annex in Chapter 9.5.2.4).

The Czech Technical University in Prague filed the most priority patent applications in digital technologies. The company AVAST Software s.r.o. filed the most applications within the business sector (see Table 55 in the Annex).

Table 26 The most important participants in projects from HEIs that focused on digital technologies - number of projects implemented in national R&D programmes since 2019 and support received from the state budget since 2019 (first two columns of the table), number of projects supported in Horizon 2020 since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (third to sixth columns of the table). Only HEIs that have been involved in ten or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

University and Faculty (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
CTU in Prague - Faculty of Electrical Engineering	93	734.8	2	626.9	7	2 063.8
BUT - Faculty of Electrical Engineering and Communication Tech.	73	253.9	1	704.6	2	1 106.3
Charles University - Faculty of Mathematics and Physics	63	436.5	11	5 015.1	9	5 393.5
Brno University of Technology - Faculty of Information Technology	55	332.5	10	2 356.9	3	1 038.1
University of West Bohemia in Pilsen - Faculty of Applied Sciences	42	208.2	4	694.7	0	0.0
VSB - TUO - Faculty of Electrical Engineering and Computer Science	34	171.1	0	0.0	0	0.0
CTU in Prague - Czech Institute of Informatics, Robotics and Cybernetics	32	432.4	6	8 592.7	9	5 295.2
Brno University of Technology - Central European Institute of Technology	25	161.9	6	5 013.0	5	1 323.3
Masaryk University - Faculty of Informatics	24	73.3	0	0.0	3	2 312.2
VSB - TUO - IT4Innovations	24	951.3	11	4 581.7	7	2 821.2
Brno University of Technology - Faculty of Civil Engineering	22	70.8	0	0.0	0	0.0
CTU in Prague - Faculty of Information Technology	22	103.8	0	0.0	0	0.0
Czech Technical University in Prague - Faculty of Transport	20	45.3	2	395.7	1	1 392.4
Czech Technical University in Prague - Faculty of Mechanical Engineering	20	186.1	0	0.0	0	0.0
Brno University of Technology - Faculty of Mechanical Engineering	20	153.4	1	200.0	0	0.0
Palacký University in Olomouc - Faculty of Science	18	45.4	2	0.0	2	435.0
CTU - Faculty of Nuclear and Physical Engineering	16	129.3	1	198.6	1	0.0
TUL - Faculty of Mechatronics, Informatics and Interdisciplinary Studies	16	54.6	0	0.0	0	0.0
University of West Bohemia in Pilsen - Faculty of Electrical Engineering	15	125.4	0	0.0	0	0.0
Czech Technical University in Prague - Faculty of Civil Engineering	15	64.0	1	359.8	0	0.0
Charles University - Faculty of Science	14	40.7	0	0.0	7	1 630.1
Masaryk University - Faculty of Arts	13	47.7	1	1 991.9	1	864.8
Masaryk University - Faculty of Science	13	203.0	5	3 454.5	8	3 212.4
CTU - University Centre for Energy Efficient Buildings	13	37.9	1	550.8	0	0.0
Charles University - Faculty of Social Sciences	13	21.6	0	0.0	0	0.0
Masaryk University - Central European Institute of Technology	11	76.7	4	432.3	3	885.7
Masaryk University - Institute of Computer Science	10	214.1	3	2 270.4	0	0.0
St. Anne's University Hospital in Brno	10	35.5	0	0.0	3	768.5
University of South Bohemia in České Budějovice - Faculty of Agriculture	10	36.6	0	0.0	0	0.0
Tomas Bata University in Zlín - Faculty of Applied Informatics	10	36.8	0	0.0	0	0.0

Table 27 The most important participants in projects from CAS institutes focused on digital technologies - the number of projects implemented in national R&D programmes since 2019 and the support received from the state budget since 2019 (first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (third to sixth columns of the table). Only institutes that have been involved in five or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Institute of Information Theory and Automation of the CAS, v. v. i.	25	84.2	1	180.8	3	490.2
Institute of Informatics of the CAS, v. v. i.	20	54.9	0	0.0	0	0.0
Institute of Physics of the CAS, v. v. i.	14	308.9	2	215.6	3	5 897.5
Biological Centre of the CAS, v. v. i.	11	41.3	0	0.0	0	0.0
Institute of Philosophy of the CAS, v. v. i.	10	27.7	0	0.0	1	2 236.0
Institute of Physiology of the CAS, v. v. i.	8	24.6	0	0.0	0	0.0
Institute of Instrumentation of the CAS, v. v. i.	7	32.5	1	446.7	0	0.0
Institute of Archaeology of the CAS, Prague, v. v. i.	7	44.0	1	80.4	0	0.0
Library of the CAS, v. v. i.	7	26.1	0	0.0	0	0.0
Institute for the Czech Language of the CAS, v. v. i.	6	21.8	0	0.0	0	0.0
Institute of Sociology of the CAS, v. v. i.	6	34.3	0	0.0	1	0.0
J. Heyrovsky Institute of Physical Chemistry of the CAS, v. v. i.	6	60.1	1	283.4	1	0.0
Institute of Archaeology of the CAS, Brno, v. v. i.	6	39.7	1	0.0	0	0.0
Institute of State and Law of the CAS, v. v. i.	6	15.7	0	0.0	0	0.0
Institute of Global Change Research, CAS, v. v. i.	5	6.8	0	0.0	1	160.0
Institute of Organic Chemistry and Biochemistry of the CAS, v. v. i.	5	40.3	1	237.8	2	2 764.6
Institute of Biotechnology of the CAS, v. v. i.	5	16.5	0	0.0	0	0.0
Institute of Molecular Genetics of the CAS, v. v. i.	5	26.2	0	0.0	1	0.0

Table 28 The most important participants in projects from research institutes outside CAS, and other government institutions that focused on digital technologies - the number of projects implemented in national R&D programmes in the period from 2019 and the support received from the state budget since 2019 (first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (third to sixth columns of the table). Only institutions that have been involved in three or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
National Institute of Mental Health	15	43.7	1	127.4	1	423.0
Centre for Transport Research, v. v. i.	14	38.5	1	283.8	2	89.2
Moravian Library in Brno	8	19.0	0	0.0	0	0.0
Czech Metrology Institute	8	9.1	0	0.0	0	0.0
Research Institute of Geodesy, Topography and Cartography, v. v. i.	7	15.9	0	0.0	0	0.0
National Library of the Czech Republic	6	21.3	0	0.0	0	0.0
Ministry of the Interior - Police of the CR, Institute of Criminalistics	5	6.8	0	0.0	0	0.0
National Gallery in Prague	3	6.2	0	0.0	0	0.0
State Institute of Radiation Protection, v. v. i.	3	16.8	0	0.0	0	0.0
National Film Archive	3	6.8	0	0.0	0	0.0

Table 29 The most important participants in projects from enterprises and private non-profit organisations that focused on digital technologies - the number of projects implemented in national R&D programmes since 2019 and the support received from the state budget since 2019 (the first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (the third to sixth columns of the table). The table only includes entities that have been involved in five or more projects supported by national programmes. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Institute of Microelectronic Applications s.r.o.	18	50.8	6	611.1	3	253.4
CESNET, interest association of legal entities	14	1 575.7	6	2 041.4	4	978.8
CEDA Maps a.s.	9	17.9	0	0.0	0	0.0
CAMEA, spol. s r.o.	9	17.1	2	234.1	0	0.0
Research and Testing Institute Plzeň s.r.o.	7	22.1	0	0.0	0	0.0
SAFIBRA, s.r.o.	6	21.2	0	0.0	0	0.0
Červenka Consulting s.r.o.	6	18.7	0	0.0	0	0.0
COGNITECHNA s.r.o.	6	16.0	1	250.3	1	273.0
Unicorn Systems a.s.	6	6.3	0	0.0	0	0.0
VDT Technology a.s.	6	17.4	0	0.0	0	0.0
Eyedea Recognition s.r.o.	6	15.1	0	0.0	0	0.0
ÚJV Řež, a. s.	5	9.9	3	333.1	0	0.0
Eaton Elektrotechnika s.r.o.	5	0.2	0	0.0	0	0.0
GINA Software s.r.o.	5	18.3	1	23.6	0	0.0
SpeechTech, s.r.o.	5	7.1	0	0.0	0	0.0
GreyCortex s.r.o.	5	19.3	0	0.0	0	0.0
RCE systems s.r.o.	5	22.3	0	0.0	0	0.0
ELTODO, a.s.	5	6.6	0	0.0	0	0.0
AGROSOFT Tábor, s.r.o.	5	20.7	0	0.0	0	0.0

5.1.5 Information and communication technologies

Similar to the case of digital technologies, electrical engineering faculties and faculties active in the field of ICT are the most involved in projects focused on information and communication technologies from the higher education sector. The Faculty of Electrical Engineering and Communication Technologies of BUT participated in the highest number of projects (74 projects supported from national sources as of 2019, state support of almost 400 million CZK). The Faculty of Electrical Engineering of CTU in Prague was also involved in a high number of projects (see Table 30). The Faculty of Information Technology at BUT, along with the research centres supported by the European Structural and Investment Funds—namely, the CIIRC at CTU in Prague, and CEITEC BUT—were the principal participants in projects funded by the Framework Programmes.

Table 30 The most important participants in projects from HEIs focused on ICT - the number of projects implemented in national R&D programmes since 2019 and the support received from the state budget since 2019 (first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (third to sixth columns of the table). Only HEIs that have been involved in five or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

University and Faculty (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
BUT in Brno - Faculty of Electrical Engineering and Comm. Tech.	74	386.9	2	1 156.8	1	691.3
CTU in Prague - Faculty of Electrical Engineering	52	188.1	1	131.5	2	897.7
BUT in Brno - Faculty of Information Technology	31	212.2	8	1 911.4	4	1 089.8
BUT in Brno - Central European Institute of Technology BUT	23	148.1	4	955.6	3	861.2
CTU - Faculty of Transport	20	60.4	0	0.0	0	0.0
VSB - TUO - Faculty of Electrical Engineering and Computer Scienc	19	117.3	0	0.0	0	0.0
Charles University - Faculty of Mathematics and Physics	19	87.9	2	41.4	1	641.8
Masaryk University - Faculty of Informatics	17	144.9	1	466.6	2	1 607.3
Masaryk University - Institute of Computer Science	15	205.4	3	2 270.4	0	0.0
Palacky University in Olomouc - Faculty of Science	15	50.4	0	0.0	3	331.6
University of West Bohemia in Pilsen - Faculty of Applied Sciences	13	81.3	3	542.0	1	305.2
University of West Bohemia in Pilsen - Faculty of Electrical Enginee	13	148.0	0	0.0	0	0.0
CTU - University Centre for Energy Efficient Buildings	12	63.5	0	0.0	2	661.3
Brno University of Technology - Faculty of Mechanical Engineering	11	140.2	1	200.0	0	0.0
CTU - Czech Institute of Informatics, Robotics and Cybernetics	11	208.9	6	1 566.6	3	3 680.8
TUL - Institute for Nanomaterials, Advanced Technologies and Inno	9	101.7	0	0.0	0	0.0
BUT in Brno - Faculty of Civil Engineering	9	29.5	0	0.0	0	0.0
Charles University - Faculty of Social Sciences	7	15.7	0	0.0	1	382.1
CTU - Faculty of Information Technology	7	25.3	0	0.0	0	0.0
VSB - TUO - IT4Innovations	6	438.8	3	889.8	1	311.9
Charles University - Faculty of Science	6	44.7	0	0.0	1	429.4
UWB in Pilsen - New Technologies - Research Centre	6	36.0	0	0.0	0	0.0
CTU - Faculty of Civil Engineering	6	16.6	1	628.8	0	0.0
CTU - Faculty of Mechanical Engineering	6	48.1	0	0.0	0	0.0
Tomas Bata University in Zlín - Faculty of Applied Informatics	6	33.3	0	0.0	0	0.0
CTU - Faculty of Biomedical Engineering	5	24.6	0	0.0	0	0.0
Masaryk University - Faculty of Science	5	84.3	2	417.9	1	65.0
CTU - Faculty of Nuclear and Physical Engineering	5	54.8	0	0.0	0	0.0
Mendel University in Brno - Faculty of Operations and Economics	5	3.7	0	0.0	0	0.0

Among the institutes of the CAS, the Biology Centre and the Institute of Information Theory and Automation were the most actively engaged in projects addressing ICT issues. Notably, the latter institute also participated in a greater number of projects funded by the European Union Framework Programmes (see Table 31).

The Czech Metrology Institute, Institute of Criminalistics of the Police of the Czech Republic, and the Research Institute of Geodesy, Topography and Cartography participated in five to six projects financed from national sources (see Table 32). Only the Transport Research Centre and the National Institute of Mental Health were involved in several Framework Programme projects.

Among enterprises and private non-profit organizations, the Institute of Microelectronic Applications Ltd. led the way in ICT-focused projects, participating in a total of 25 projects. CESNET was involved in 20 projects, while Flowmon Networks a.s. contributed to 10 projects. Additionally, the former two entities were significantly engaged in a substantial number of EU Framework Programme projects focused on ICT issues. (see Table 33).

The Faculty of Electrical Engineering and Communication Technologies of BUT and IT4Innovations of VSB-TUO created the majority publications in the projects. The publications of the Faculty of Mathematics and Physics of CU have an above average citation index (see the appendix in Chapter 9.5.2.5). The highest number of priority patent applications focused on ICT was filed by AVAST Software s.r.o. In the HEI sector, several patents were filed by CTU in Prague (see Table 56 in the Annex).

Table 31 The most important participants in projects from CAS institutes focused on ICT - the number of projects implemented in national R&D programmes since 2019 and support received from the state budget since 2019 (the first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (the third to sixth columns of the table). Only institutes that have been involved in three or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Biological Centre of the CAS, v. v. i.	8	42.0	0	0.0	0	0.0
Institute of Information Theory and Automation of the CAS, v. v. i.	7	40.2	3	329.8	3	490.2
Institute of Physics of the CAS, v. v. i.	4	39.7	3	355.5	0	0.0
Institute of Global Change Research of the CAS, v. v. i.	4	9.2	0	0.0	1	177.6
Institute of Archaeology of the CAS, Prague, v. v. i.	4	26.0	0	0.0	0	0.0
Institute of Microbiology of the CAS, v. v. i.	4	20.8	1	843.3	0	0.0
Library of the CAS, v. v. i.	4	21.6	0	0.0	0	0.0
Institute for Czech Literature of the CAS, v. v. i.	4	78.3	0	0.0	0	0.0
Institute of State and Law of the CAS, v. v. i.	3	4.3	0	0.0	0	0.0
Institute of Organic Chemistry and Biochemistry of the CAS, v. v. i.	3	36.2	0	0.0	0	0.0
Institute of Philosophy of the CAS, v. v. i.	3	4.8	0	0.0	0	0.0
Institute of Archaeology of the CAS, Brno, v. v. i.	3	19.0	0	0.0	0	0.0
Institute of Sociology of the CAS, v. v. i.	3	12.0	0	0.0	1	0.0
Institute for Contemporary History of the CAS, v. v. i.	3	4.2	0	0.0	0	0.0

Table 32 The most important participants in projects from research institutes outside CAS, and other government institutions focused on ICT - number of projects implemented in national R&D programmes in the period from 2019 and support received from the state budget since 2019 (first two columns of the table), number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (third to sixth columns of the table). Only institutions that have been involved in three or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Czech Metrology Institute	6	4.3	0	0.0	0	0.0
Ministry of the Interior - Police of the CR, Criminalistics Institute	5	11.4	0	0.0	0	0.0
Research Institute of Geodesy, Topography and Cartography, v. v. i.	5	6.8	0	0.0	0	0.0
Transport Research Centre, v. v. i.	4	14.1	1	283.8	2	89.2
National Library of the Czech Republic	4	20.7	0	0.0	0	0.0
Institute for the Study of Totalitarian Regimes	3	10.8	0	0.0	0	0.0
National Institute of Mental Health	3	27.7	0	0.0	1	423.0
National Heritage Institute	3	9.6	0	0.0	0	0.0
Research Institute of Agricultural Technology, v. v. i.	3	4.0	0	0.0	0	0.0

Table 33 The most important participants in projects from enterprises and private non-profit organisations focused on ICT issues - the number of projects implemented in national R&D programmes in the period from 2019 and the support received from the state budget since 2019 (the first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (the third to sixth columns of the table). The table only includes entities that have been involved in five or more projects supported by national programmes. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Institute of Microelectronic Applications s.r.o.	25	60.4	5	586.3	3	388.4
CESNET, interest association of legal entities	20	1 374.4	4	1 439.0	3	742.4
Flowmon Networks a.s.	10	25.1	1	351.3	0	0.0
GreyCortex s.r.o.	6	26.1	0	0.0	0	0.0
CAMEA, spol. s r.o.	6	12.7	4	362.2	0	0.0
T-Mobile Czech Republic a.s.	5	4.0	0	0.0	0	0.0

5.1.6 Other advanced technologies - quantum technologies

The Faculty of Science at Palacký University in Olomouc, along with the Faculty of Mathematics and Physics at CU, have been prominently engaged in projects centred around quantum technologies. Furthermore, both faculties have actively participated in numerous projects under the Horizon 2020 (H2020) and Horizon Europe (HE) framework programmes (see Table 34).

Among the institutes of the CAS, the Institute of Physics of the CAS was the most active in this technological area (more than twenty projects in national programmes, four projects in the H2020 and

HE programmes, see Table 35). Among other governmental institutions, the Czech Metrology Institute and the European Research Infrastructure Extreme Light Infrastructure ERIC (ELI ERIC) participated in national projects. (Table 36). Of the private non-profit organisations, CESNET was involved in four projects (see Table 37).

Table 34 The most important participants in projects from HEIs focused on quantum technologies - the number of projects implemented in national R&D programmes since 2019 and the support received from the state budget since 2019 (first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (third to sixth columns of the table). Only HEIs that have been involved in five or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

University and Faculty (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Palacky University in Olomouc - Faculty of Science	44	229.2	2	873.4	3	649.1
Charles University - Faculty of Mathematics and Physics	31	95.3	0	0.0	3	2 243.1
CTU in Prague - Faculty of Nuclear and Physical Engineering	13	94.9	0	0.0	0	0.0
BUT - Central European Institute of Technology	11	166.9	1	157.0	1	421.1
Masaryk University - Faculty of Science	7	18.7	0	0.0	2	644.3

Table 35 The most important participants in projects from the CAS institutes focused on quantum technologies - the number of projects implemented in national R&D programmes in the period from 2019 and the support received from the state budget since 2019 (first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (third to sixth columns of the table). Only institutes that have been involved in five or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Institute of Physics of the CAS, v. v. i.	23	233.0	1	145.0	3	2 442.6
J. Heyrovsky Institute of Physical Chemistry of the CAS, v. v. i.	9	60.8	0	0.0	0	0.0
Institute of Instrumentation of the CAS, v. v. i.	8	237.4	1	211.3	0	0.0
Institute of Organic Chemistry and Biochemistry of the CAS, v. v. i.	6	12.1	1	145.0	0	0.0
Institute of Macromolecular Chemistry of the CAS, v. v. i.	5	17.9	0	0.0	0	0.0
Institute of Physics of Materials of the CAS, v. v. i.	5	11.3	0	0.0	0	0.0

Table 36 The most important participants in projects from research institutes outside CAS, and other government institutions focused on quantum technologies - the number of projects implemented in national R&D programmes since 2019 and the support received from the state budget since 2019 (the first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (the third to sixth columns of the table). Only institutions that have been involved in five or more projects supported by national programmes are included in the table. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
Czech Metrology Institute	7	12.0	0	0.0	0	0.0
Extreme Light Infrastructure ERIC (ELI ERIC)	2	4.8	0	0.0	1	150.4

Table 37 The most important participants in projects from companies and private non-profit organisations focused on quantum technologies - the number of projects implemented in national R&D programmes since 2019 and the support received from the state budget since 2019 (the first two columns of the table), the number of projects supported in the Horizon 2020 framework programme since 2019 and in the Horizon Europe framework programme to date and the EC contribution to their solution (the third to sixth columns of the table). The table only includes entities that have been involved in three or more projects supported by national programmes. Source: R&D&I Information System, e-CORDA

Institution (abbreviated)	National programmes		Horizon 2020		Horizon Europe	
	Number of projects	Support (CZK Mill.)	Number of projects	Support (€ thous.)	Number of projects	Support (€ thous.)
CESNET, interest association of legal entities	4	359.3913	0	0	0.0	0

Faculty of Science of Palacký University in Olomouc published the majority of publications in this field (290 publications). The Faculty of Mathematics and Physics of CU also published around one hundred publications. The Institute of Physics of the Czech Academy of Sciences has produced the largest number of publications. The citation rate of publications of these institutions is, however, below average in the world comparison (see Annex in Chapter 9.5.2.6). As the knowledge of R&D of quantum technologies is still far from the market application, no new solutions were submitted by entities from the Czech Republic in the period under review.

5.2 Analysis focused on vetted researchers

In the stakeholder analysis presented in Chapter 5.1, institutions engaged in R&D of digital technologies were identified. These institutions concentrate their research activities on digital technologies and are actively participating in the EU Framework Programmes. Consequently, they are conducting R&D in digital technologies that meet international quality standards. These institutions were approached to ask if they would be willing to nominate a vetted researcher under the Digital Single Market Regulation 2022/2065 [3]. In addition to these institutions, and in coordination with staff from the Ministry of Industry and Trade, research organizations specializing in the social sciences and humanities were also engaged. It is anticipated that these organizations will play a significant role in assessing the impact of artificial intelligence and digital technologies, including potential threats associated with their deployment and their broader societal implications. A comprehensive overview of all the institutions contacted is provided in Table 38.

Out of a total of 28 institutions, comprising 21 universities, five institutes of the CAS, and two additional organizations, we received 11 responses. Nine of these institutions expressed willingness to nominate vetted researchers under the requirements of Regulation 2022/2065 on the Digital Single Market (see Table 38).

Table 38 Nomination of vetted researchers under the Digital Single Market Regulation 2022/2065 and the responses received in the questionnaire survey

Institution	Nomination of a vetted researcher
Universities	
CTU in Prague - Faculty of Electrical Engineering	
CTU in Prague - Czech Institute of Informatics, Robotics and Cybernetics	
CTU in Prague - Faculty of Transport	yes
CTU in Prague - Faculty of Information Technology	
CTU in Prague - Faculty of Nuclear and Physical Engineering	
Masaryk University - Faculty of Informatics	
Masaryk University - Faculty of Science	
Masaryk University - Central European Institute of Technology	
Masaryk University - Institute of Computer Science	ne
Charles University - Faculty of Mathematics and Physics	yes
Charles University - Faculty of Science	
Palacký University in Olomouc - Faculty of Science	
University of Pardubice - Faculty of Electrical Engineering and Computer Science	no
Charles University - Faculty of Social Sciences	
Masaryk University - Faculty of Social Studies	yes
VSB - TUO - Faculty of Electrical Engineering and Informatics	yes
VSB - TUO - IT4Innovations	
Brno University of Technology - Faculty of Electrical Engineering and Communication Technolo	yes
Brno University of Technology - Faculty of Information Technology	
Brno University of Technology - Central European Institute of Technology BUT	
University of West Bohemia in Pilsen - Faculty of Applied Sciences	
Academy of Sciences of the Czech Republic	
Institute of Physics of the CAS, v. v. i.	
Institute of Computer Science of the CAS, v. v. i.	yes
Institute of Information Theory and Automation of the CAS, v. v. i.	
Institute of Sociology of the CAS, v.v.i.	yes
Institute of State and Law of the CAS, v.v.i.	
Other institutions	
Transport Research Centre, v. v. i.	yes
Center for Environmental and Technology Ethics (CETE:P), Institute of Philosophy of the CAS	yes

5.3 Networking research and innovation actors

The cooperation between entities in projects financed by national programmes of R&D support from 2019 in the broader areas of advanced technologies is illustrated in the form of maps on Figure 18 to Figure 22. In addition to the maps depicting the cooperation in broader areas of advanced technologies, the online version at https://svizualizace.tc.cas.cz/NRIS3/ also includes maps showing the cooperation in individual advanced technologies in this period (see Table 6). The web versions of maps of cooperation in Horizon 2020 from 2019 and Horizon Europe projects are presented as well. The advantage of the online versions is that they can be interactively enlarged and scrolled. The web version of the maps also provides more detailed information on the cooperation of the different actors. The methodology for creating the maps and their interpretation is described in more detail in the methodological part of the Chapter. 9.1.4.3.

A significant role of engineering faculties (CTU, BUT, University of West Bohemia, VSB-TUO) can be seen on the advanced manufacturing technology cooperation map at Figure 18. Faculties and centres active in electronics, electrical engineering, informatics and robotics also play an important role in cooperation related to the application of digital technologies and artificial intelligence in production. The above institutions can be considered as knowledge centres in the field of advanced manufacturing technologies.

In the field of advanced materials technologies, several knowledge institutions have an important role in national collaborations (see Figure 19). They are active in materials research or have a strong materials research presence. Important knowledge centres include some faculties and centres of universities, institutes of the CAS (in particular the Institute of Physics of the CAS, the Institute of Macromolecular Chemistry of the CAS and the Institute of Physical Chemistry of the CAS) and research centres within the business sector (e.g. COMTES and SVÚM).

In the field of biotechnology, chemistry and natural science-oriented universities and their faculties (UCT Prague, Faculty of Science of CU and others) and some institutes of the CAS focused on biosciences (for example, the Institute of Microbiology of the CAS and the Biology Centre of the CAS) act as knowledge centres (see Figure 20).

In the field of digital technologies, electronics-oriented university faculties and research centres play the predominant role. Figure 21 shows that the key knowledge institutions in this area of advanced technologies include, for example, the Faculty of Electrical Engineering and Communication Technologies at BUT, the Faculty of Electrical Engineering at CTU in Prague and the Faculty of Electrical Engineering and Informatics at the VSB – TUO.

The situation is similar in the field of information and communication technologies (see Figure 22). The most important role is played by faculties and departments of universities, such as the Faculty of Electrical Engineering and Communication Technologies at BUT, the Faculty of Electrical Engineering at CTU in Prague, and the Faculty of Information Technology at BUT. Some centres, such as CEITEC in Brno, also play an important role in the cooperations. The map depicting the inter-institutional collaborations in quantum technologies is available only on the web site (https://svizualizace.tc.cas.cz/NRIS3/).

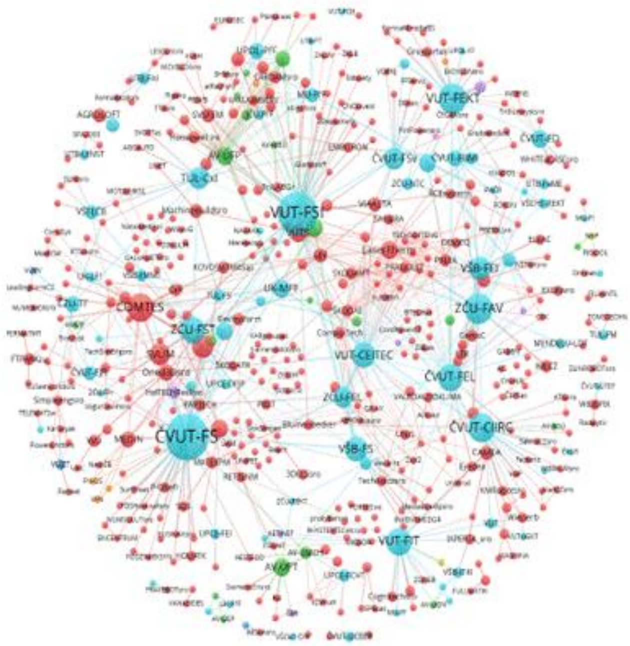

Figure 18 Map of cooperation between entities in projects supported by national R&D programmes focused on advanced manufacturing technologies. Projects running in 2019 and further are included. Source: R&D&I Information System

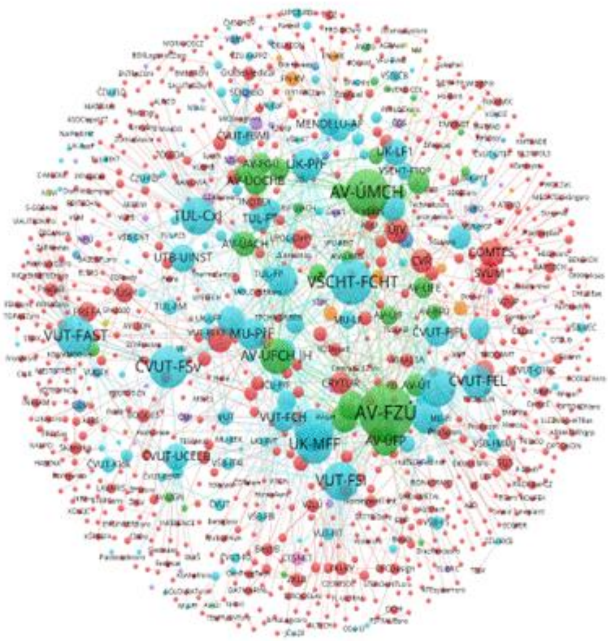

Figure 19 Map of collaboration between entities in projects supported by national R&D programmes focused on advanced materials technologies. Projects running in 2019 and further are included. Source: R&D&I Information System

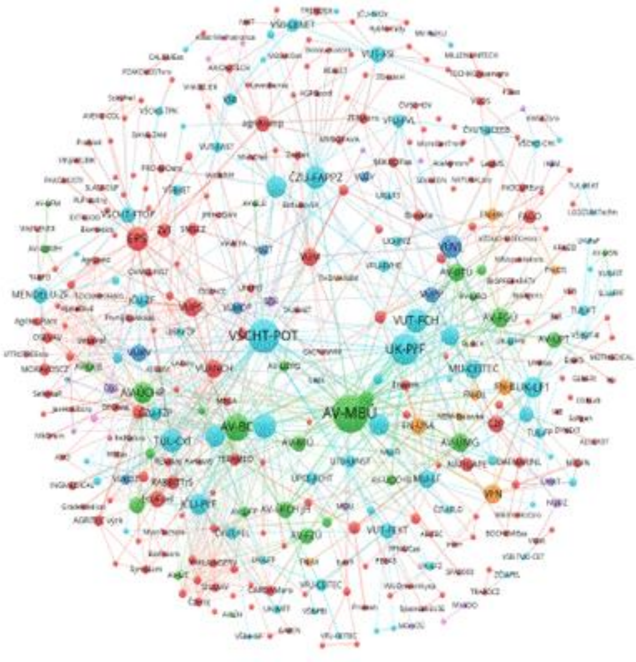

Figure 20 Map of collaboration between subjects in projects supported by national R&D programmes focused on biotechnology topics. Projects running in 2019 and further are included. Source: R&D&I Information System

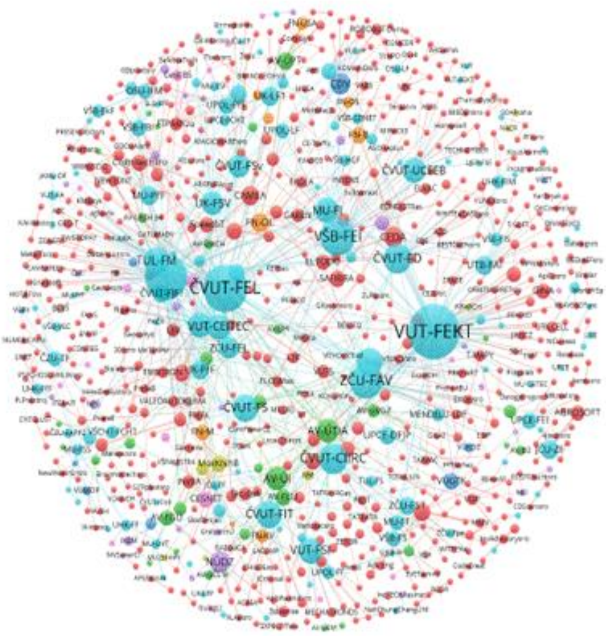

Figure 21 Map of cooperation between subjects in projects supported by national R&D programmes focused on digital technologies Projects running in 2019 and further are included. Source: R&D&I Information System

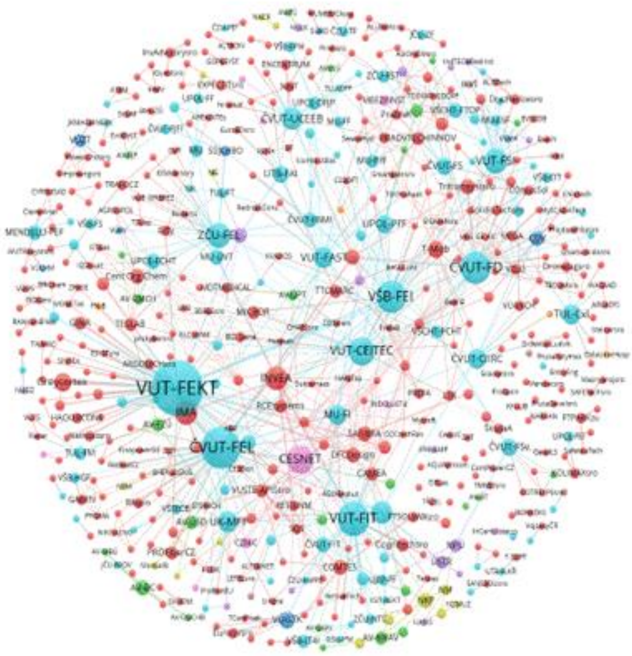

Figure 22 Map of cooperation between subjects in projects supported by national R&D programmes focused on ICT topics. Projects running in 2019 and further are included. Source: R&D&I Information System

6 Mapping and empirical analysis

The mapping and empirical analysis is divided into three parts. First, the position of the Czech Republic in advanced technologies is assessed by making use of indicators. Subsequently, the position of the Czech Republic in the field of digitisation and digital technologies is assessed in relation to the goals of the European Digital Decade ([19], [20]) and the Digital Europe program [4]. The results of these evaluations are presented in Chapter 6.1 a 0, the indicators used and the method of their evaluation are described in more detail in the methodological part of the study in Chapter 9.1.4.4. Finally, the contribution of advanced technologies to the solution of the identified GSCs is evaluated (see Chapter 6.3).

6.1 Assessment of the position of the Czech Republic in advances technological fields

6.1.1 Publication activity

Data presented in Table 39 compare the share of individual fields of advanced technologies in the total publication output in the Czech Republic with the world, the average of EU-28 Member States, and selected EU Member States (this indicator is referred to as "significance", see the methodological part in Chapter 9.1.4.4). The position of the Czech Republic in the world comparison is quite satisfactory - the importance of most of the monitored areas of advanced technologies in the publication output is higher in the Czech Republic than in the world, and in some technological areas even higher than in the EU-28. On the contrary, the Czech Republic is in the worst position in digital technologies, where it lags behind the world, the EU-28 and all Member States included in the international comparison (see Table 39).

Table 39 International comparison of the Czech Republic with the world, EU-28 and selected EU Member States in the importance of individual areas of advanced technologies in the total publication output. The values in the table show the representation of publications focused on a given area of advanced technologies in the total number of publications of a given country (group of countries) between 2019 and 2023. If a field in the table is underlined in green, the importance of that area of advanced technologies is higher in that country than in the world. The indicator is described in more detail in the methodology section in Chapter 9.1.4.4. Source: Clarivate Web of Science

Country	Advanced manufacturing technologies	Advanced material technologies	Biotechnologies	Digital technologies	Information and communication technologies	Quantum technologies
Total (world)	**0.8%**	**14.4%**	**0.8%**	**4.8%**	**1.7%**	**0.009%**
EU-28	0.8%	11.8%	0.8%	5.1%	2.0%	0.008%
Czech Republic	0.9%	17.7%	0.8%	4.1%	1.8%	0.011%
Denmark	0.5%	10.3%	1.2%	4.8%	3.3%	0.006%
Finland	1.0%	12.8%	0.8%	7.1%	5.9%	0.008%
Netherlands	0.5%	9.2%	0.7%	5.2%	3.1%	0.007%
Austria	1.0%	12.6%	0.9%	5.5%	4.1%	0.008%
Germany	1.1%	14.9%	0.7%	6.0%	3.6%	0.010%
Ireland	0.9%	11.1%	1.0%	6.6%	5.1%	0.007%
Portugal	1.2%	14.0%	1.2%	6.4%	4.6%	0.006%
Slovenia	0.9%	15.0%	0.8%	5.0%	3.1%	0.000%
Italy	1.0%	12.1%	0.6%	5.5%	4.1%	0.009%

The good position of the Czech Republic is also evident in Table 40, which compares the specialisation of countries in publishing activity in advanced technologies (see methodological section in Chapter 9.1.4.4). The Czech Republic exceeds the world average in this indicator in the majority of technological areas. The only exception is digital technologies, where the Czech Republic lags behind the world, the EU-28 average, and all countries included in the international comparison (i.e. research activities are less focused on this technological area in the Czech Republic than in other countries).

Table 40 International comparison of publication activity of the Czech Republic, EU-28, and selected EU Member States in individual areas of advanced technologies in the specialization indicator. The values in the table show the percentage difference in the importance of advanced technology areas in a given country (group of countries) and in the world average. The figure is set for the number of publications between 2019 and 2023. The indicator is described in more detail in the methodology section in Chapter 9.1.4.4. Source: Clarivate Web of Science

Country	Advanced manufacturing technologies	Advanced material technologies	Biotechnologies	Digital technologies	Information and communication technologies	Quantum technologies
EU-28	-6.2%	-18.1%	-0.3%	5.5%	20.8%	-12.3%
Czech Republic	14.1%	22.9%	2.2%	-14.4%	9.9%	21.8%
Denmark	-35.8%	-28.5%	52.6%	0.1%	95.5%	-36.2%
Finland	20.6%	-11.0%	8.4%	46.2%	255.2%	-8.1%
Netherlands	-39.1%	-36.0%	-6.3%	6.7%	84.1%	-19.0%
Austria	24.0%	-12.6%	12.2%	14.7%	148.2%	-9.8%
Germany	29.6%	3.6%	-3.7%	23.5%	114.4%	14.0%
Ireland	14.1%	-23.0%	29.5%	36.9%	207.9%	-26.1%
Portugal	48.0%	-2.8%	54.3%	31.8%	176.8%	-31.1%
Slovenia	6.1%	4.1%	4.3%	4.3%	82.5%	-100.0%
Italy	20.2%	-16.1%	-17.8%	13.6%	143.6%	-1.8%

Figure 23 compares the change in the importance of individual progressive technologies in the total number of publications in the Czech Republic and in the world in the two three-year periods 2016 – 2018 and 2020 – 2022. The importance of the most progressive technologies in the publication output of the Czech Republic is increasing. The exceptions are micro- and nanoelectronics, and cloud computing and connectivity whose importance in the publication output of the Czech Republic is somewhat decreasing. The highest growth is seen in advanced manufacturing and robotics. High growth is also evident in most of the advanced technologies included in the broad areas of digital technologies and ICT. However, the importance of artificial intelligence in the world is growing faster than in the Czech Republic (see Figure 23).

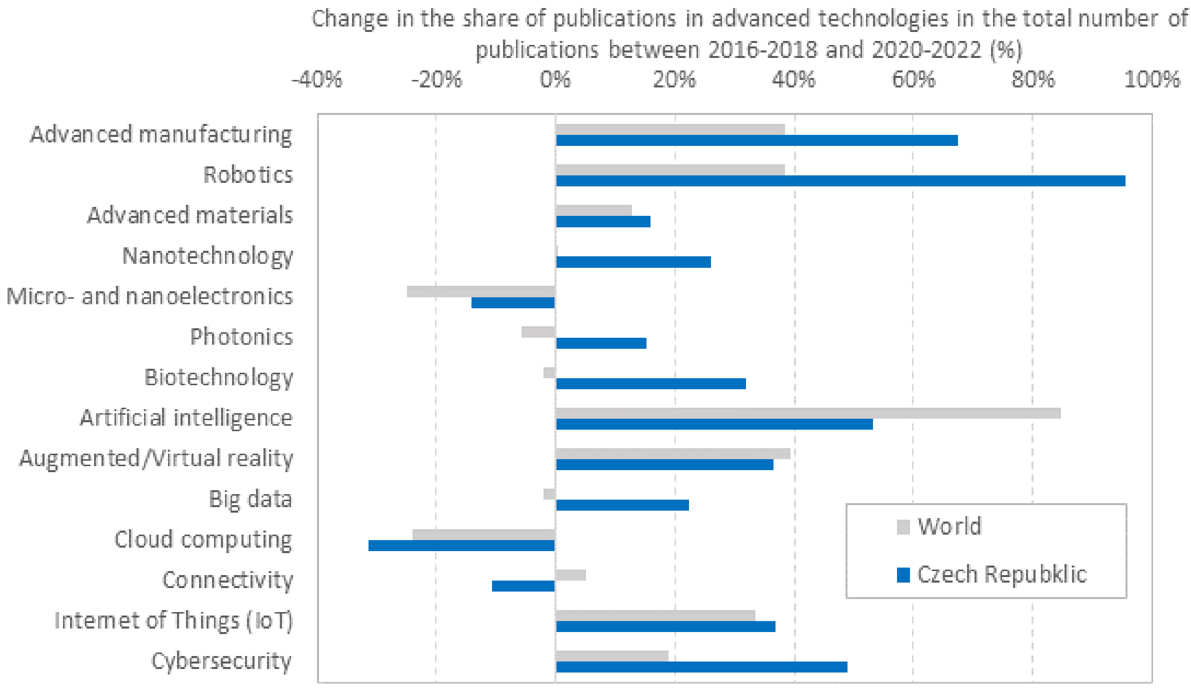

Figure 23 Change in the share of publications in individual advanced technologies in the total number of publications between two three-year periods 2016-2018 and 2020-2022 - comparison of the Czech Republic with the world. Source: Clarivate Web of Science

6.1.2 Patent activity

The position of the Czech Republic in patent activity in advanced technologies is somewhat different. The importance of most areas of advanced technologies in priority patent applications is lower in the Czech Republic than in the world. The only exception is advanced material technologies, which are more important in the Czech Republic than in the world, the EU-28, and all countries included in the international comparison. However, the differences between the Czech Republic and the EU-28 average in the importance of most areas of progressive technology in patent activity are not very significant – the Czech Republic is slightly above or around the European average in most technological areas. The exception is digital technologies, where the Czech Republic is relatively below the EU-28 average (see Table 42).

The Czech Republic's unsatisfactory position in patent activity in advanced technologies is more clearly visible in Table 43, which compares the specialization indicator, which shows the importance of a given advanced technology in a given country compared to the importance of this technology in the world (this indicator is described in more detail in the methodological part of Chapter 9.1.4.4). Only in advanced material technologies the specialisation of the Czech Republic is higher than in the world. On the other hand, the Czech Republic's highest lag behind the world is evident in digital technologies. It is impossible to assess the development of patent activity, as the number of priority patent applications in the Czech Republic is low.

Table 41 International comparison of the Czech Republic with the world, the EU-28 average, and selected EU Member States in the importance of individual areas of advanced technologies in the total number of priority patent applications. The values in the table show the share of priority patent applications in a given area of advanced technologies in the total number of priority patent applications of a given country (group of countries) between 2018 and 2021. If a field in the table is underlined in green, the importance of that area of advanced technology is higher in that country than in the world. The indicator is described in more detail in the methodology section in Chapter 9.1.4.4. Source: PATSTAT, autumn 2023

Country	Advanced manufacturing technologies	Advanced material technologies	Biotechnologies	Digital technologies	Information and communication technologies	Quantum technologies
Total (world)	**1.3%**	**8.9%**	**0.4%**	**5.5%**	**3.4%**	**0.2%**
EU-28	0.4%	3.4%	0.1%	1.7%	1.2%	0.1%
Czech Republic	0.7%	12.1%	0.2%	1.3%	2.3%	0.1%
Denmark	0.6%	4.7%	0.4%	2.0%	1.0%	0.1%
Finland	0.3%	5.3%	0.2%	4.4%	7.3%	0.4%
Netherlands	0.7%	9.4%	0.2%	3.5%	1.7%	0.3%
Austria	0.3%	5.8%	0.1%	0.5%	0.4%	0.1%
Germany	0.3%	1.3%	0.0%	1.2%	0.6%	0.0%
Ireland	1.2%	7.4%	0.2%	15.1%	3.4%	0.4%
Portugal	0.3%	3.3%	0.4%	1.2%	0.8%	0.0%
Slovenia	0.7%	7.8%	1.1%	0.7%	0.3%	0.0%
Italy	0.1%	1.1%	0.0%	0.2%	0.2%	0.0%

Table 42 International comparison of patent activity of the Czech Republic, EU-28 and selected EU Member States in individual areas of advanced technologies in the specialisation indicator. The values in the table show the percentage difference in the importance of advanced technology areas in a given country (group of countries) and in the world average. The figure is set for priority patent applications filed between 2018 and 2021. The indicator is described in more detail in the methodology section in Chapter 9.1.4.4. Source: PATSTAT, autumn 2023

Country	Advanced manufacturing technologies	Advanced material technologies	Biotechnologies	Digital technologies	Information and communication technologies	Quantum technologies
EU-28	-66.5%	-61.8%	-64.9%	-68.9%	-64.2%	-51.1%
Czech Republic	-42.5%	36.2%	-43.4%	-77.1%	-33.1%	-57.3%
Denmark	-49.6%	-47.4%	8.7%	-64.5%	-69.7%	-56.1%
Finland	-73.0%	-40.2%	-42.5%	-20.0%	112.9%	104.7%
Netherlands	-46.5%	5.9%	-36.2%	-36.5%	-49.2%	34.8%
Austria	-78.2%	-34.4%	-78.3%	-90.1%	-88.6%	-41.7%
Germany	-74.2%	-84.8%	-88.4%	-77.5%	-81.0%	-74.8%
Ireland	-8.4%	-17.0%	-39.1%	174.6%	0.6%	110.3%
Portugal	-76.0%	-63.2%	13.5%	-77.8%	-76.0%	-100.0%
Slovenia	-48.2%	-12.0%	205.6%	-88.0%	-90.3%	-100.0%
Italy	-90.0%	-87.7%	-90.5%	-95.5%	-93.8%	-100.0%

6.2 The Czech Republic's position in digital technologies

Comparison of the Czech Republic with the EU average and its member states in the composite indicator "Digital Economy and Society Index" (Digital Economy and Society Index[22] , DESI 2022) [21] can be found in Figure 24. The Czech Republic ranks nineteenth out of 27 countries, which is five places below the EU average. The value of the index for the Czech Republic is roughly at the level of Italy and Cyprus. Among the new EU member states, all the Baltic countries, Slovenia and Malta are ahead of the Czech Republic (the value of the DESI 2022 index is based on the values of the individual indicators, usually from 2021)..

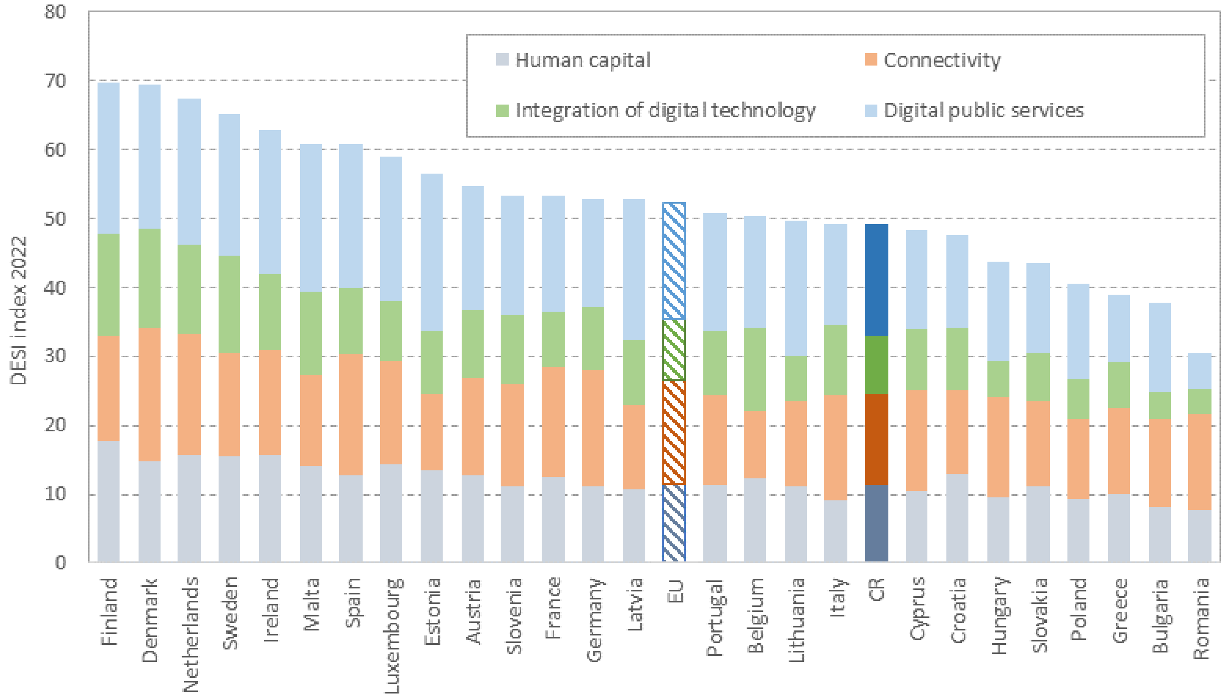

Figure 24 Comparison of the Czech Republic with the EU average and individual Member States in the Digital Economy and Society Index 2022 (DESI 2022). Source: Source: DESI 2022 [21]

Figure 25 compares the position of the Czech Republic relative to the average of EU member states in each dimension. The Czech Republic is approximately at the EU average in the Human Capital dimension. In the other dimensions, the Czech Republic is below the European average, most notably in the Connectivity dimension (about 12% below the EU average). In the Integration of Digital Technology, the Czech Republic is about 6% below the EU average, and in the Digital Public Services dimension, the Czech Republic is about 4% behind the EU average. The Czech Republic's position is assessed in more detail in Table 43.

[22] From 2023, the DESI index will be included in the Digital Decade Status Report.

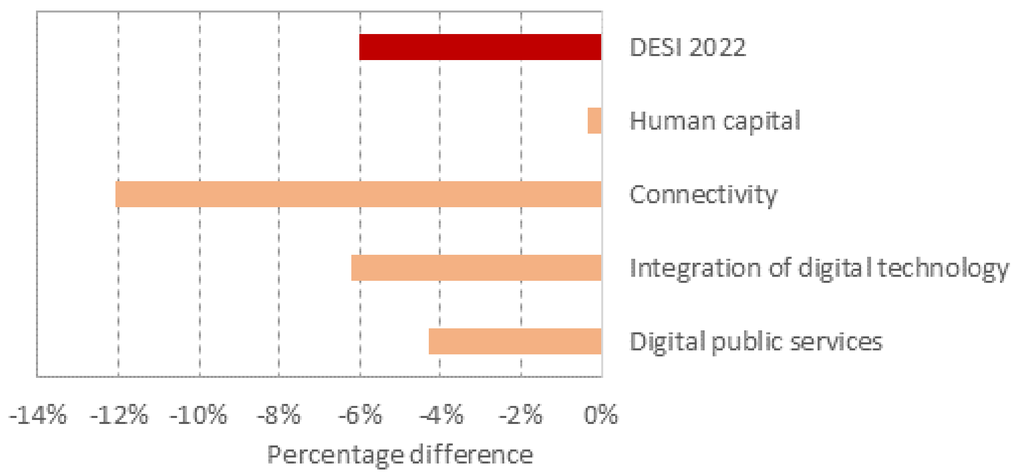

Figure 25 Comparison of the Czech Republic and the EU in the four dimensions tracked in DESI 2022. Data for the determination of values are generally from 2021. Source: DESI 2022 [21]

Due to the inclusion of DESI in the Digital Decade Status Report in 2023 [22] the methodology and indicators monitored have changed. Table 43 shows a comparison of the Czech Republic with the average of the Member States in the indicators currently monitored in DESI 2023 (see the DESI 2023 methodology document [23] and DESI 2023 dashboard [24]). The indicators are divided in the table into dimensions and sub-dimensions monitored in DESI 2023.

In some dimensions of DESI 2023, the Czech Republic is at the EU average, in some it is above the European average, and in others, it is far below the average of the EU Member States (see Table 43). In most of the indicators included in the Digital Skills dimension, the Czech Republic is at the level of the EU average. It is slightly above average in the share of people with basic digital skills, including the representation of women. However, the Czech Republic is well below the EU average in the number of female ICT specialists. In terms of digital infrastructure, the Czech Republic is at the level of the European average in mobile broadband in all indicators monitored. However, in the indicators monitored in the fixed broadband sub-dimension, the Czech Republic is well below the EU average (see Table 43).

In the dimension of digital transformation of enterprises, the Czech Republic is well below the EU average in most indicators in its sub-dimension Digital technologies for businesses (except for Cloud computing). Given the growing importance of digital technologies for the development of competitiveness (see Chapter 4), it is alarming that Czech enterprises make far less use of digital technologies such as artificial intelligence and big data compared to European enterprises, even in the context of the importance of these technologies in responding to the current GSC (see Chapter 3.4). The Czech Republic performs above average in the e-commerce sub-dimension - turnover from electronic transactions is approximately 50% higher than the EU average (see Table 43). This may be related to the increase in e-commerce at the time when the COVID-19 anti-proliferation measures were introduced.

In the last dimension, Digitalisation of public services, the Czech Republic is at the EU level in digital public services for citizens and businesses (it is above average in the number of users). On the contrary, it is below average in indicators characterising the user environment and user-friendliness. The Czech Republic is also below the average of the Member States in access to electronic health records (see Table 43). Further information on the Czech Republic's position in digital technologies in relation to the Digital Decade goals can be found in the DESI 2023 dashboard [24] and in the report on the status of the Digital Decade goals [22].

Table 43 Comparison of the current values of the indicators monitored in DESI 2023 in the Czech Republic and the average of the EU Member States. The last column shows the percentage difference between the Czech Republic and the EU. Indicators are grouped by DESI 2023 dimensions and sub-dimensions. Source: DESI 2023 [24]

Dimension	Sub-dimension	Indicator	Czech Republic	EU	Percentage of EU
Digital skills	Internet user skills	Internet use	89.7	88.6	1%
		At least basic digital skills	59.7	53.9	11%
		Above basic digital skills	24.1	26.5	-9%
		At least basic digital content creation skills	65.9	66.2	0%
		Enterprises providing ICT training	23.1	22.4	3%
		Females having at least basic digital skills	59.7	52.3	14%
	Advanced skills and development	ICT specialists	4.5	4.6	-2%
		ICT graduates		4.2	
		Female ICT specialists	10.9	18.9	-42%
Digital infrastructure	Fixed broadband	At least 100 Mbps broadband take-up	31.0	55.1	-44%
		At least 1 Gbps broadband take-up	1.3	13.8	-91%
		Fixed Very High Capacity Network (VHCN) coverage	53.2	73.4	-28%
		Fibre to the Premises (FTTP) coverage	37.4	56.5	-34%
	Mobile broadband	Mobile broadband take-up	85.4	86.5	-1%
		Overall 5G coverage	82.6	81.2	2%
		5G spectrum	66.7	68.2	-2%
Digital transformation of businesses	Digital intensity	SMEs with at least a basic level of digital intensity	68.0	69.1	-2%
	Digital technologies for businesses	Electronic information sharing	37.7	38.0	-1%
		Social media	24.0	29.3	-18%
		Big data	9.1	14.2	-36%
		Cloud	40.0	34.0	18%
		AI	4.5	7.9	-43%
		e-Invoices	12.2	32.2	-62%
	e-Commerce	SMEs selling online	22.8	19.1	19%
		e-Commerce turnover	17.2	11.3	52%
		Selling online cross-border	11.2	8.7	29%
Digitalisation of public services	e-Government	e-Government users	86.0	74.2	16%
		Digital public services for citizens	76.2	77.0	-1%
		Digital public services for businesses	83.8	83.7	0%
		Pre-filled forms	41.9	68.2	-38%
		Transparency of service delivery, design and pers. data	57.3	64.7	-11%
		User support	68.0	83.6	-19%
		Mobile friendliness	80.1	93.3	-14%
	e-Health	Access to e-health records	47.4	71.7	-34%

6.3 Quantitative description of the impact of advanced technologies on identified societal challenges

The impact of advanced technologies on the identified GSCs cannot be reliably quantified, as their contribution is indistinguishable from the influence of other factors such as systemic measures, other interventions, market dynamics, and more. These other factors may significantly overshadow the contribution of specific advanced technologies. Consequently, only a relative comparison of the contribution of individual advanced technologies to addressing GSCs is possible. Contributions are rated on a four-level scale ranging from zero contribution (no star) to high contribution (three stars). This evaluation uses data from the analysis of advanced technology linkages to GSCs in Chapter 3.4, with detailed information in Chapter 9.3.1 of the appendix section of the report. The methodology for this assessment is described in greater detail in Chapter 9.1.4.5 in the Annex.

The results of this evaluation are summarised in the following tables – in Table 44 the contribution at the level of broader areas of advanced technologies is assessed, and Table 45 shows the contribution of digital technologies and ICT to the GSCs solution at a more detailed level.

As can be seen in Table 44, the largest contribution to tackling GSCs is made by digital technologies, which have a strong presence in projects addressing all identified GSCs. ICT also make a high contribution, particularly in the projects addressing the Technology and Digital Transformation of Society, Energy Transformation and Sustainable Future, and Trust in Democracy, Societal Resilience, Security and Defence GSCs. In GSC Energy Transformation, ICTs are mainly applied in the decentralisation of the energy sector. In GSC Trust in Democracy, Societal Resilience, ICTs are mainly applied in infrastructure security and security of new technologies. In the Technology and Digital Transformation GSC, ICT is applied in all its areas.

In these GSCs, advanced material technologies are also highly applicable. In GSC Energy Transformation, advanced materials are applied in all its areas, especially in the areas of circularity and decarbonisation. In GSC Trust in Democracy, Societal Resilience, their application is mainly in the areas of environmental security and ensuring the functioning of the economy. In GSC Technology and Digital Transformation, the materials are mainly used in the areas of upgrading production and service processes.

Table 44 Quantitative assessment of the contribution of advanced technologies to solving grand societal challenges relevant for the Czech Republic. The contribution is evaluated at four levels - high contribution (three stars, deep green filling), medium contribution (two stars, medium deep filling), low contribution (one star, light filling), no or negligible contribution (no star, light grey underlining). Quantum technologies are not included in the table. Source: e-CORDA, own calculations

GSC / Advanced Technologies	Advanced manufacturing technologies	Advanced material technologies	Biotechnology	Digital technology	Information and communication technologies
Adaptation to climate change	*	**	**	***	**
Preparedness for demographic change and an ageing population	*	**	*	***	**
Energy transformation and a sustainable future	**	***	***	***	***
Trust in democracy, societal resilience, security and defence	**	***	**	***	***

Technological and digital transformation of society	***	***	**	***	***

Biotechnology has the highest presence in projects in the Energy Transformation GSC, especially in energy production (biomass) and in ensuring sustainable development, for example in connection with recycling and the use of environmentally friendly materials (see Table 44). In the GSC Trust in democracy, Resilience of society, biotechnology has a significant contribution to environmental security. Advanced manufacturing technologies are highly applicable in the Technology and Digital Transformation GSC, especially in its area of upgrading production and service processes. More detailed information on the use of specific advanced technologies in GSCs and their areas can be found in the annex to the report in Chapter 9.3.1.

In Table 45 the contribution of digital technologies to the GSCs is evaluated. Here it can be seen that the highest contribution is made by AI-based technologies, which are used in projects addressing all GSC issues. Cybersecurity also has a high contribution in the GSCs Technological and Digital Transformation of Society and Trust in Democracy, Societal Resilience, Security and Defence, which is related to the increasing number of cyber-attacks. Similarly, the contribution of connectivity to addressing these challenges is also high.

Big data technologies have a relatively wide application and can contribute to solving all the identified challenges. This seems to be linked to the increasing adoption of big data technologies in several technological areas and economic sectors. Also, the Internet of Things has a moderately high contribution to addressing several GSC issues, which seems to be related to the fact that technological devices communicate with each other (see Table 45).

Table 45 Quantitative assessment of the contribution of digital technologies and ICTs to solving grand societal challenges relevant to the Czech Republic. The contribution is assessed at four levels - high contribution (three stars, deep green filling), medium contribution (two stars, medium deep filling), low contribution (one star, light filling), no or negligible contribution (no star, light grey filling). Source: e-CORDA, own calculations

GSC / advanced technology	Artificial Intelligence	Augmented/virtual reality	Big Data	Cloud computing	Blockchain	Connectivity	Internet of Things	Cyber security
Adaptation to climate change	***	*	**	*		*	*	**
Preparedness for demographic change and an ageing population	***	*	**			*	**	*
Energy transformation and a sustainable future	***		**	*	*	**	**	*
Trust in democracy, societal resilience, security and defence	***	*	**	*	**	***	**	***
Technological and digital transformation of society	***	**	***	**	**	***	***	***

The above tables with a quantitative assessment of the contribution of advanced technologies to the GSC solution were discussed with representatives of the National Innovation Platforms and other experts at the closing workshop. This workshop is briefly described in the following Chapter.

6.4 Closing workshop

In the final phase of preparing this analysis, a workshop was held with representatives from the National Innovation Platforms and other experts in the field of advanced technologies. At the workshop, the experts were initially presented with the results of the analyses, encompassing the main findings as well as the strengths and weaknesses of the Czech Republic in the field of advanced technologies. This presentation also included an examination of the connections with the GSCs. Afterwards, the conclusions from the quantitative description of the impact of the main digital technologies were discussed with the experts and recommendations were proposed. The experts' views are reflected in the methodological part in Chapter 9.1, in the summary of the most significant findings in Chapter 7.1, and in particular in the draft recommendations in Chapter 7.2. More detailed information from the closing workshop is provided in Chapter 9.6.1 in the Annex to the report.

7 Key findings and draft recommendations

7.1 Overview of the most important findings

7.1.1 Grand societal challenges and advanced technologies

Based on the analysis of strategic and conceptual documents developed both in the Czech Republic and at the EU level, a total of five grand societal challenges pertinent to NRIS3 have been identified, considering the research and application capacities in the Czech Republic:

- `Adaptation to climate change;
- Preparedness for demographic change and an ageing population;
- Energy transition and a sustainable future;
- Trust in democracy, societal resilience, security and defence;
- Technological and digital transformation of the economy and society.

Furthermore, advanced technologies have been identified that can help address these GSCs through the contributions of research and development (R&D). These technologies have been categorized into six main areas:

- Advanced manufacturing technologies;
- Advanced material technologies;
- Biotechnology;
- Digital technology;
- Information and communication technologies;
- Other advanced technologies.

7.1.2 Trends in advanced technologies and their use in GSC

The analysis of publication activity revealed that the number of publications in the most advanced technologies is on the rise. The highest growth is seen in digital technologies, particularly in artificial intelligence (AI), blockchain[23] and augmented/virtual reality. Publication activity in advanced manufacturing technologies in biotechnology is also growing significantly. There is also an increase in publication activity in Information and ICT. The situation is the opposite in advanced materials technologies - publication activity is stagnating in most of the technologies included in this area, while it is slightly decreasing in micro- and nanoelectronics.

Similar trends are evident in patent activity. The number of patent applications in most advanced technologies is increasing, some of them very significantly. Patent activity is increasing significantly in most digital technologies. The largest increase is seen in artificial intelligence, where the number of priority patent applications increased almost fourfold between 2016 and 2021, and its representation in the total number of applications increased threefold. High growth is also evident in advanced manufacturing technologies, particularly in robotics. Patent activity is stagnating in materials technology and biotechnology.

In recent years, research activities have predominantly focused on digital technologies and ICT. As a result, we can anticipate a future expansion of their capabilities and greater utilization in various

[23] In recent years, the increase in blockchain publishing activity has stalled

applications. Discussions at the workshops also revealed that the decline in research activities within certain areas of materials technologies may be attributed to a shift towards quantum technologies.

There are sub-trends detected in some advanced technologies. In the case of advanced manufacturing, robotics and the use of lasers for manufacturing operations are becoming increasingly important. In robotics, machine vision and object recognition/detection are gaining importance. Data storage methods (data media) are also gaining ground. Neural networks and deep learning are increasingly utilized in artificial intelligence, which is, in turn, being more widely applied to cloud computing and the Internet of Things. In big data, real-time data acquisition and processing, data storage and early warning are gaining importance. Data storage is also gaining importance in cloud computing. In cybersecurity, encryption is gaining importance. Security is gaining importance in networking, blockchain, big data and data storage. The significance of digital technologies, especially artificial intelligence, is underscored by their frequent coverage as key subjects in leading technology media.

Advanced technologies are utilized in R&D projects centred on GSC, particularly in areas such as GSC Technological and Digital Transformation of Society, Energy Transformation and Sustainable Future, and Trust in Democracy, Societal Resilience. Of special note are digital technologies like AI, ICT such as cybersecurity, and materials technologies including advanced materials and nanotechnologies, which are highly relevant and applicable.

The application of specific technologies in GSCs depends on the nature of the call and the focus of its sub-areas. In the Energy Transformation and Sustainable Future call, the most applicable technologies are advanced materials technologies (advanced materials and photonics), biotechnologies, artificial intelligence and some ICT (in particular the Internet of Things). Technologies such as cybersecurity and artificial intelligence are the most widely used in the GSC Trust in Democracy, Societal Resilience, Security and Defence. Connectivity and big data also have higher applications.

In the GSC Adaptation to Climate Change, the issue of artificial intelligence and biotechnology is often mentioned in the projects undertaken. Materials technology and cyber security are also highly applicable in some specific areas. The use of artificial intelligence, robotics and the Internet of Things is often mentioned in projects addressing the GSC issue of preparedness for demographic change and ageing. In the Technology and Digital Transformation of Society GSC, digital and ICT such as artificial intelligence, connectivity, cyber security, big data and the Internet of Things are anticipated to be utilized the most.

7.1.3 R&D of advanced technologies in the Czech Republic

R&D in the field of advanced technologies is relatively well developed in the Czech Republic. A high number of entities from all sectors are involved in projects focused on advanced technologies. In particular, universities and some institutes of the CAS play an important role in such oriented research. Faculties and institutes of universities active in the field of mechanical engineering, electrical engineering and ICT play an important role in R&D of advanced manufacturing technologies. A relatively wide range of faculties and departments of universities and a high number of research institutes are involved in R&D in the field of advanced material technologies, which is related to the wide use of materials in various products and industries. R&D in the field of biotechnology mainly involves faculties and institutes active in the field of (bio)chemical, natural and health sciences. The faculties most involved in digital technology projects are electrical engineering faculties, ICT faculties, science and physics faculties and research institutes active in digital technologies. The same is true for ICT R&D.

Businesses are also involved quite intensively in projects focusing on advanced technologies. The greatest participation from enterprises is observed in projects centred on advanced material technologies and advanced manufacturing technologies. Conversely, enterprises are least involved in projects related to quantum technologies.

In the projects supported in the programmes of special-purpose R&D support, cooperation between research organisations (ROs) and subjects from the application sphere is developed. An important role in this cooperation is played by technology-oriented faculties of universities, some institutes of the CAS and research centres supported by the ESIF (especially European Centres of Excellence).

Major HEIs are involved in EU Framework Programme projects, which demonstrates their potential for conducting internationally competitive research. In the EU Framework Programmes, entities from the Czech Republic cooperate with a number of research teams from abroad, including teams from leading foreign research institutes.

7.1.4 The Czech Republic's position in advanced technologies

The international position of the Czech Republic in R&D of advanced technologies is quite satisfactory. Research in the Czech Republic is more focused on the most advanced technologies than in other countries. In this comparison, the Czech Republic is also above the average of EU Member States. The best position of the Czech Republic is in advanced materials technologies, where domestic research is focused significantly more than in other countries. The situation is somewhat worse in digital technologies, where the Czech Republic lags behind both the world average and the EU average.

The weakness of the Czech Republic is low patent activity in advanced technologies. The proportion of patent applications focused on advanced technologies in the total number of patent applications is lower in the Czech Republic than in the world (except for advanced material technologies). Although patent activity is influenced by a number of factors related to the environment in the Czech Republic and differences between industries, the low number of patent applications may also result in lower use of R&D results in business innovation.

The Czech Republic's position in the field of digital technologies is rather unsatisfactory. In the Digital Economy and Society Index (DESI 2022) composite indicator, the Czech Republic ranks nineteenth out of 27 countries, five places below the EU average.

The current values of the indicators monitored in DESI 2023 indicate that the Czech Republic has a relatively satisfactory position in digital skills in European comparison (except for advanced skills), which creates relatively good conditions for the use of digital technologies in society. In this context, it is favourable that mobile broadband connectivity in the Czech Republic is at a higher level than the EU average. The willingness of society to use digital technologies is also reflected in the above-average number of businesses involved in e-commerce and the turnover from these transactions. It is also positive that the Czech Republic is in a satisfactory position in the digitalisation of public services in European comparison.

A significant weakness, however, is the digital transformation of enterprises, where the Czech Republic is still lagging far behind the EU average. Given the growing importance of these technologies, it is alarming that Czech enterprises are making far less use of digital technologies such as artificial intelligence and big data compared to European enterprises, even in the context of their high application to address current GSC.

7.2 Draft recommendations

The proposed recommendations aim to enhance the strengths and address the weaknesses of the Czech Republic in advanced technologies concerning the GSC. These recommendations are structured according to the priorities outlined in the National Research and Innovation Strategy for Smart Specialisation of the Czech Republic 2021-2027 (NRIS3).

7.2.1 NRIS3 cross-cutting priorities

7.2.1.1 Corporate R&D&I

As emerged from the workshop discussions, domestic enterprises (especially small and medium enterprises) still operate at low levels of supply chains and their competitiveness tends to be based in many cases on cheap labour. The use of AI and the introduction of other digital technologies (digitalisation) can make a significant contribution to increasing the efficiency of their activities. As experts believe these technologies should only be considered as a tool, in addition to stimulating businesses to adopt these technologies, other tools should be created to help businesses increase their competitiveness (e.g. technology-focused programmes, creating a suitable business environment, etc.).

The developed links between the HEIs and enterprises, which are evident from the analyses, can also contribute to strengthening the competitiveness of enterprises in the field of advanced technologies. These linkages should be exploited in programmes focused on R&D in advanced technologies, where major HEIs (as sources of knowledge) will cooperate with enterprises in relevant sectors (see also Chapter 7.2.1.2).

As advanced technologies, particularly digital technologies and ICT, continue to evolve, their practical applications are becoming increasingly significant. It is crucial, therefore, to encourage and support the establishment of new companies that are founded on research and development outcomes in these technological fields. At the same time, it is necessary to create a suitable environment for the initial development of start-up companies, for example through the Technology Incubation Programme of the CzechInvest Agency.

7.2.1.2 Public research and development

The analysis revealed that the Czech Republic does not effectively implement the findings of public R&D in practical applications. This is demonstrated by the low number of patent applications in advanced technologies, with the exception of advanced material technologies. For this reason, the use of public research results on advanced technologies in applications and business innovation needs to be stimulated in all mission-oriented programmes (MIPs). This is particularly the case for digital technologies, which can contribute to the majority of mission solutions.

Research centres equipped with high-quality infrastructure and application-oriented facilities, such as European Centres of Excellence and regional R&D centres supported by ESIF, play a crucial role in advancing research and development in modern technologies. These centres foster significant collaboration between public research entities and the business sector. This opportunity should be leveraged when designing mission-oriented programs and tenders. One approach is to establish virtual centres dedicated to mission-oriented R&D, encompassing all stages of the innovation process, from initial research to the application and exploitation of knowledge.

7.2.1.3 People and smart skills

Given the critical importance of these skills for implementing digital technologies, it is essential to encourage students to pursue studies in related fields and enhance their competencies. Experts at the workshops emphasized that producing a sufficient number of graduates with advanced digital skills and ICT expertise is a time-intensive process. Consequently, efforts to develop digital skills and boost the number of ICT graduates must begin well ahead of time.

7.2.1.4 Digital agenda

The Czech Republic lags behind the EU average in a number of indicators monitored in DESI 2023. Significant underperformance is particularly evident in the area of fixed high-speed connectivity.

Although the Czech Republic is above the EU average in mobile high-speed connectivity, experts believe it is necessary to improve the quality and speed of the fixed one, which in some cases is essential for the use of digital technologies.

The Czech Republic faces a particularly challenging situation regarding the adoption of digital technologies by its enterprises. This lag in digital transformation could become a significant constraint on the future application of these technologies. Experts suggest that the low efficiency of companies that have yet to adopt AI and digital technologies will "push" them to embrace these innovations to stay competitive with those that have already integrated such advancements (see also Chapter 7.2.1.1). According to experts, incentives are more appropriate for public administrations, where transparency of digital services, user support, and user-friendliness (like the pre-populated forms) need to be improved. There should also be significant improvements in access to health data (including in the context of the Preparedness for Demographic Change and Ageing mission).

7.2.2 Vertical priorities NRIS3

7.2.2.1 Domains of research and innovation specialisation

Based on the results of the analyses, it is recommended to consider expanding the current definition of key enabling technologies (KETs), specifically "Artificial Intelligence" and "Digital Security and Connectivity," in NRIS3. The analyses indicate that other digital technologies, such as big data, cloud computing, augmented/virtual reality, and blockchain, are increasingly being used to address mission (or GSC) issues. Therefore, it would be appropriate to broaden the KETs to include "Other Digital Technologies," thereby incorporating these advanced technological applications.

Likewise, the use of advanced technologies encompassed in the current KET "Digital Security and Connectivity" is on the rise. In the future, this KET could be divided into two distinct categories, each differing in nature and mission-specific applications (GSC):

- Connectivity and the Internet of Things (IoT)
- Cybersecurity.

7.2.2.2 Social challenges

The two missions "Improving the material, energy and emissions intensity of the economy" and "Strengthening societal resilience to security threats" included in the current NRIS3 should be expanded to include the remaining three GSCs that are relevant to the Czech Republic at present and in the near future:

- Adaptation to climate change
- Preparedness for demographic change and an ageing population
- Technological and digital transformation of society.

As input for structuring new missions, it is possible to use the proposal in Chapter 9.2.1 in the annex part of the report, which will be further developed in the EDP process.

Given that most missions encompass multi-sectoral issues, it is essential to collaborate with relevant stakeholders and experts during the development of any related programmes. The resources and expertise of these relevant providers must be utilized synergistically to address the specific challenges of the NRIS3 mission. For programmes that do not directly target mission issues, it is advisable to launch tenders that align with the programme's focus areas.

When choosing projects, it is advisable to prioritize those that utilize advanced technologies to address the mission's challenges or related areas. These projects are likely to make the most significant contributions toward resolving the mission's issues. To evaluate the effectiveness of advanced technologies in tackling these challenges, it can be helpful to use Table 44 and Table 45 in Chapter 6.3 or more detailed tables in the Annex 9.3.1.

Considering that all the missions included in NRIS3—comprising the current two missions and the three new ones proposed in the first paragraph of this Chapter—are global in nature, it would be advantageous to leverage resources from multiple countries in a synergistic manner. This can be achieved through specifically targeted bilateral or multilateral programs.

Simultaneously, support should be extended to projects that align with the objectives of NRIS3 missions and have successfully passed the evaluation process in the Horizon Europe Framework Programme, the Digital Europe Programme, and other European initiatives, but have not received funding due to budget constraints. These projects, recognized with a "Seal of Excellence[24]", merit particular attention.

[24] https://commission.europa.eu/funding-tenders/find-funding/seal-excellence_en

8 The most important data sources

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9 Annex part

9.1 Methodological approach

9.1.1 Data sources

The analyses were prepared using current statistical data and other data from publicly available databases and information sources as well as from paid databases to which TCP has access. The most important sources used in the evaluation of public contracts include:

- Central Evidence of Projects of the Information System for Research, Experimental Development and Innovation (CEP R&D&I Information System) [25].
- Index of information on the results of the Research, Experimental Development and Innovation Information System (RIV R&D&I Information System) [26].
- The European Commission's e-CORDA (COmmon Research DAtawarehouse) information database on projects supported by the EU Framework Programmes (e-CORDA) [27].
- Clarivate Analytics Web of Science (WoS) publications database [28].
- European Patent Office Worldwide Patent Statistical Database (PATSTAT) published in autumn 2023 [29].

Furthermore, the Register of Economic Subjects (RES) maintained by the Czech Statistical Office (CSO) was used for the analyses [30]. The data were used to assign entities to sectors and to classify them into regions according to their headquarters.

The methodology chosen for the analyses is described in more detail in the following Chapters. For the sake of clarity, some of the methodological procedures are described for the specific analyses.

9.1.2 Matching database records to identified grand societal challenges and advanced technologies

A set of keywords and phrases and their logical combinations were used to match records to identified GSCs and advanced technologies. Keywords and phrases in English were searched for in project titles and abstracts of publications and patent applications. In the case of projects, these keywords and phrases were also searched for in the keywords provided by their applicants. Keyword sets were created for all identified GSCs and advanced technologies or technology areas (see Chapter 2.1.5 and 0).

The keywords used for the search are based on information on the issue of GSCs and advanced technologies in expert studies, analyses and other documents that characterize the GSC or technology. The keywords are based on those that have been used in technology-oriented analyses prepared by Technology Centre Prague in the past.

When developing the keywords, our goal was to maximize the relevance of the database records to the issue while minimizing the inclusion of unrelated or "fake" records. To achieve this, we reviewed random samples of selected records using the paid version of the Chat GPT chatbot and adjusted the keywords based on the outcomes. The inspection of randomly selected records indicates that the proportion of erroneous records is less than 10% (in most cases, below 5%). However, adopting relatively strict selection criteria might result in incomplete coverage of the issue. Consequently, comparisons of absolute values should be taken with some caution.

9.1.3 Approach to the evaluation of data from individual sources and using it for analysis

9.1.3.1 Projects supported by the state grant system

To determine the number of projects supported in the R&D support programmes and the state support provided for their implementation, the database of the Central Evidence of Projects (CEP) of the Information System for Research, Experimental Development and Innovation (R&D&I Information System) was used. [25]. Keywords were used to match the projects to advanced technologies. Searches were carried out in project titles, project annotations and keywords listed for the projects in the CEP.

To determine the number of projects, the state support and the total costs of projects in each year of the monitored period, the annual data reported in the CEP R&D&I Information System were used (i.e. the number of projects, state support and total costs in a given year were determined from all projects that were carried out in that year). Projects in which the development of research infrastructure was supported (i.e. projects supported under the EA, EB, ED, EE, EF and LM programmes) were not included in this analysis. In addition, projects classified as infrastructure ones were excluded, too.

Data on the number of projects in advanced technologies and the support received from the state budget of the Czech Republic were also assigned to the application sectors of NRIS3 [1]. For this assignment, data on the main sector in the three-digit classification of economic activities (NACE 2) in which the project participants are active was used. To assign the NACE sector (and therefore the subject) to the individual application sectors, the conversion table created by TCP during the preparation of the underlying analyses [31] and [32] was used.

The data on the number of implemented projects and the support received from the state budget were used in particular for the evaluation of trends in state support in advanced technologies (Chapter 3.2), which have been monitored in the period since 2016. In order to identify stakeholders in each advanced technology (Chapter 5) and to evaluate the linkages of advanced technologies to the identified GSCs (Chapter 3.4), data on the number of projects underway in 2019 and subsequent years and the state support received were used (projects may have started before 2019).

9.1.3.2 Projects supported by EU Framework Programmes

To assess the number of projects supported under the EU Horizon 2020 (H2020) framework programmes [33] and Horizon Europe (HE) [2] and the contribution received, the European Commission's e-CORDA information database (COmmon Research DAtawarehouse) was used [27]. To match projects supported in the H2020 and HE Framework Programmes to R&D and advanced technologies, keywords were used, similar to those used for projects supported in national R&D programmes. The searches were carried in project titles, project annotations and keywords.

Data on projects supported in the H2020 and HE Framework Programmes were used to assess the linkages of advanced technologies to the identified GSCs and to identify stakeholders. Data on all projects supported in the H2020 framework programme and the HE programme to date were used to assess the linkages of advanced technologies to GSCs.

For the stakeholder analysis, data from the HE programme to date and data from projects supported in the H2020 programme from 2019 onwards were used. The reason for this limitation is to ensure comparability with data from projects supported in the targeted R&D support programmes (evaluation in the same time window).

9.1.3.3 Publication activity

The Clarivate Web of Science (Clarivate WoS) information system and its analytical extension InCites were used for bibliometric analysis [28]. Records of the Article, Review Letter and Proceedings paper types were included in the analysis. Keywords and keyword phrases were searched in the titles and abstracts of the publications.

Data on publication activity were used to assess trends, identify stakeholders and assess the position of the Czech Republic in advanced technologies. Trends in the number of publications in advanced technologies were monitored from 2016 to 2023.

The stakeholder analysis evaluated the number of publications assigned in the R&D&I Information System to projects identified using keywords and phrases in advanced technologies that have been supported since 2019. In addition, the field normalized citation index of publications and the proportion of publications in the top decile and first quartile[25] publications (by citation rate) were evaluated. For the calculations, only results of type "J" (articles in peer-reviewed journals) applied in the Index of results of R&D&I Information System from 2019 onwards, which were registered in WoS (Jimp), were taken into account. The index records were linked to the citation and percentile data of individual publications in WoS using the unique record identifier UT.

The average normalized citation rate of a set of publications of an institution (organizational unit, faculty) was calculated as the average of industry-normalized citation rates of individual publications ("item-oriented" normalization). The advantage of this procedure is that each publication has an equal weight in the final indicator value. On the other hand, however, a few extremely cited publications may contribute disproportionately to the citation score of the evaluated entity. Publications are assigned to each institution (faculty) as a unit regardless of the number of co-author institutions. Average values of field-normalized citation counts are meaningful for sets of publications of at least a few dozen in size. The approach to assessing the Czech Republic's position in advanced technologies is described in more detail in Chapter 9.1.4.4.

9.1.3.4 Patent activity

The EPO Worldwide Patent Statistical Database published by the European Patent Office in autumn 2023 (PATSTAT 2023b) was used to evaluate patent activity [29]. Patent applications were matched to identified GSCs and advanced technologies using keywords searched in the titles and abstracts of patent applications.

Data on the number of patent applications were used to evaluate trends in advanced technologies, to identify stakeholders and to assess the position of the Czech Republic in advanced technologies. Only the first patent applications (referred to in the text as priority patent applications) that best characterise the development of patent activity and application potential in advanced technologies were included in the trend assessment. Given that patent applications are reported in the PATSTAT database with a long-time lag (usually a year, in some cases more), the trend assessment was carried out over the period from 2016 to 2022 (i.e. one year shorter than the assessment of trends in publication activity). Patent applications were tracked in this analysis by the year of filing.

The stakeholder analysis was carried out in the period 2018 - 2022. In the analysis, similar to the trend tracking, the numbers of priority patent applications with a Czech applicant were evaluated. The year 2018 was chosen with a view to ensuring more data in advanced technologies, the limitation of 2022 is related to the incompleteness of the PATSTAT database in 2023.

The approach to assessing the position of the Czech Republic in advanced technologies in international comparison is described in more detail in Chapter 9.1.4.4. When comparing data internationally, it is important to note that the number of patent applications filed by companies from the Czech Republic is influenced by the strategies of parent companies, which often file patents through their headquarters outside the Czech Republic (typically in the USA). There are also notable differences between the Czech Republic and the EU-15 - while in the EU-15 patent applications are predominantly filed by companies, in the Czech Republic (as in other new Member States) research organisations

[25] The first decile indicates the highest decile, i.e. the 10% most cited publications in the field. The first quartile indicates the top quarter of the most cited publications.

contribute significantly to the number of patent applications. The number of applications filed is also influenced by different practices in certain fields and different ways of protecting intellectual property.

9.1.4 Methodological approach to the specific analyses carried out in the framework of the contract

9.1.4.1 Analysis of emerging trends in advanced technologies

Two methods were used to evaluate the emerging trends:

- Evaluation of the trends in the occurrence of words and phrases characterizing advanced technologies in patent applications;
- Evaluation of current issues in technology-oriented media.

In the **evaluation of the development of the occurrence of words/phrases in** patent applications assigned to individual advanced technologies, the exploratory method identified words and phrases that are meaningful for the advanced technology and at the same time, their occurrence is sufficiently pronounced. For these words and phrases, the number of patent applications in which they occur in each year was then recorded, and the year-on-year fluctuations in the total number of patent applications were also considered. The number of patent applications was normalized by proportional scaling (a normalized intensity of 100 indicates the maximum intensity of occurrence of the most frequent word or phrase for a given advanced technology). The evaluation of the trends in the occurrence of words/phrases was carried out for the period 2018 to 2022. The trends of words and phrases are indicative only; changes in the trend may be due not only to technological reasons but also to linguistic reasons (e.g. a shift in meaning with the increasing complexity of the technology, a retreat from the use of certain words and abbreviations, overuse of currently popular terms, etc.).

In the **analysis of current issues in the direction of advanced technologies** in the field of digital technologies, articles in selected technology media between October 2023 and May 2024 were evaluated. These were technology media in four categories: media from academia, technology media, technology columns of established media, and news on EU policies in relation to technology (a list of the technology media used is provided in the annex in Chapter 9.4.2). In selecting the individual technology media for analysis, the emphasis was not on quantity but on the advanced approach of the selected media to technology. For each category, a representative sample of articles was evaluated and the main themes contained in these articles were identified. The identification of themes was done using Google's Gemini 1.5 big language model [34], which allows hundreds to thousands of articles to be evaluated at a time.

9.1.4.2 Analysis of the linkages of advanced technologies to the identified GSCs

To evaluate the links of advanced technologies to GSCs relevant to the Czech Republic, data for projects supported under the H2020 and HE Framework Programmes and data for projects supported under R&D support programmes were used. The projects were first assigned to the individual GSCs using a set of keywords and phrases. Then, the number of projects in each GSC that also fell into each of the advanced technologies and broader areas of advanced technologies and the share of these projects in the total number of projects assigned to that GSC were determined.

In the case of the evaluation of the links of advanced technologies to R&D in projects implemented in the R&D support programmes, the period from 2014 to 2023 was used (the reason for this extension compared to other analyses was to create a sufficiently large set of projects for the analysis).

Data for the broader areas of advanced technologies are given in Chapter 3.4 and at a more detailed level for individual advanced technologies in the Annex in Chapter 9.3. When comparing the linkages of advanced technologies to GSCs, it is important to note that a single project may be included in more than one GSC and more than one advanced technology, due to the broad definition of GSCs and the overlap between advanced technologies. The proportion of projects from advanced technologies in a GSC also depends to some extent on the total number of projects assigned to a given GSC and a given advanced technology. The linkage of advanced technologies to GSCs may also be influenced by the penetration of each technology into practical applications.

9.1.4.3 Analysis of cooperation

For the analysis of cooperation and linkages between entities active in advanced technologies at the national level, data on the involvement of entities in projects supported in the R&D support programmes in the Central Evidence of Projects (CEP) of the R&D&I Information System, which took place in 2019 and subsequent years (i.e. as in the stakeholder analysis), were used. For the analysis of international collaboration, data on involvement in H2020 Framework Programme projects supported from and including 2019 and in projects supported in the HE programme to date were used. Data were tracked by advanced technology.

For the evaluation of the cooperation, so-called scientometric maps were used, which clearly show the intensity of cooperation, provide visually clearer information about the internal relationships between the individual actors and allow to identify entities that are intensively involved in the cooperation and act as a source of knowledge used by other cooperating entities (knowledge centres, knowledge hubs).

Scientometric maps were constructed using the clustering technique VOS (visualization of similarities) [36], [37]. Each node in the scientometric map represents one collaborating entity. The size of a node (area of the circle) is proportional to the number of collaborative projects. The position of nodes in the plane is determined by the number of connected edges and their weight. Nodes with a high number of connected edges tend to be in the middle of a cluster. The proximity of nodes on the map is an indicator of strong ties, but unlike edges themselves, it does not only take into account pairwise ties but also the average strength of the relationship with other nodes within the cluster. The distances of nodes that are not connected by an edge are arbitrary. In the presented maps, the location was calculated for clarity so that the nodes around the perimeter of the image form a rough ellipse.

The report provides maps of cooperation in broader areas of advanced technologies in dedicated R&D support programmes. In the online version, maps of national and international cooperation in broader technology areas and in individual advanced technologies are available. The online version of the maps can be found at https://svizualizace.tc.cas.cz/NRIS3/.

9.1.4.4 Evaluation of the Czech Republic's position in advanced technologies

For the international comparison of the Czech Republic's position in advanced technologies, data on the number of publications in impacted journals were used to assess whether research activities in the Czech Republic are more oriented towards individual advanced technologies than abroad, or vice versa. Furthermore, data on the number of patent applications filed were used, which in turn shows the position of the Czech Republic in applied R&D and the use of its results in innovation. The indicators used for this evaluation are based on the indicators originally proposed in the studies [13] a [38] for an international comparison of the position of the EU, or its individual Member States, in KETs:

- **The importance of advanced technology in a country's publication/patent activity**, which is defined as the ratio of a country's publications/patent applications in that advanced technology to the total number of publications/patent applications in the country.
-
- **A country's specialisation (focus) in an advanced technology**, which indicates the importance of that advanced technology in that country compared to the importance of that technology in the world. The indicator is defined as the ratio of the importance of the advanced technology in the country (indicator in the first indent) to the importance of this advanced technology in the

world. This ratio is multiplied by 100 - a figure higher than 100 indicates that specialisation in a given advanced technology is higher in that country than the world average (and vice versa).

In the evaluation of the development of the Czech Republic's position in publication activity in advanced technologies, the change in the indicator "Importance" between the two two-year time windows 2017-2018 and 2021-2022 is also evaluated, which shows whether R&D in the Czech Republic is gradually becoming more oriented towards a given technology or vice versa. As the number of priority patent applications filed by entities from the Czech Republic is low, the evolution of patent activity in advanced technologies is not assessed.

The values of the indicators described above for the Czech Republic were compared with the values for the global average, the EU average, and for selected EU Member States. The selection of countries for international comparison included countries with different innovation performance according to the ranking published in the European Innovation Scoreboard (EIS) in 2023 [39]:

- Among the EIS 2023 Innovation leaders, Denmark, as the country with the highest innovation performance in the EU, Finland, and the Netherlands were selected.
- The second group of Strong Innovators included Austria, Germany and Ireland.
- From the third group of moderate innovators, which includes the Czech Republic, Portugal, Slovenia and Italy were selected.

The average of EU Member States is between strong and moderate (average) innovators. The results of this comparison are presented in Chapter 6.1.

The indicators of the Political Programme Digital Decade (PPDD) were used to assess the position of the Czech Republic in digital technologies. [4]. First, the position of the Czech Republic in comparison with the EU average and its individual Member States in the composite indicator "Digital Economy and Society Index 2022" (Digital Economy and Society Index 2022[26] , DESI 2022) and its individual dimensions is evaluated. The data for the calculation of the DESI 2022 and its dimensions are generally from 2021. As the methodology and the indicators monitored have changed from 2023 onwards, the position of the Czech Republic in the indicators monitored in DESI 2023 is also assessed [23].

9.1.4.5 Evaluation of the contribution of advanced technologies to the GSC solution

A quantitative assessment of the impact of advanced technologies on GSCs in Chapter 6.3 is based on the analysis of the linkages of advanced technologies to GSCs developed in Chapter 3.4. The linkages are evaluated at four levels, where the share of projects that simultaneously fall under a given GSC and a given area of advanced technologies out of the total number of projects included in that GSC was decisive for the classification of the linkage into each level:

- High contribution (three stars) - greater than 10%
- medium contribution (two stars) - 4% to 10%
- Low contribution (one star) - 1% to 4%
- no or insignificant contribution (no asterisk) - up to 1%.

After a quantitative assessment of the linkages at the level of broader areas, the linkages of individual digital technologies and ICT to GSC are quantified. To assess the linkages, data from the tables presented in the appendix section of the report in Chapter 9.3 are used. The scale used for this quantification remains identical to the previous case.

[26] From 2023, the DESI index will be included in the Digital Decade Status Report.

9.2 Annexes to Chapter 2

9.2.1 In-depth Characteristics of grand societal challenges relevant to the Czech Republic

The GSCs pertinent to the Czech Republic is organized into several distinct areas and sub-areas (sub-challenges, sub-missions). Within these categories, the research directions are succinctly outlined. Based on the information provided for each GSC, key words and phrases were identified to align the database records with the respective challenges.

In the case of the GSCs Energy Transformation and Sustainable Future and Trust in Democracy, Societal Resilience, Security and Defence, which are also missions in the current NRIS3, their structuring respects the structure (sub-missions), research areas and research directions listed in the NRIS3 in its Annex 1 [9]. The reason is that these missions have already been discussed with experts in the relevant fields and their characteristics (structure into sub-missions, research areas and specific research directions) have been developed on the basis of the EDP. The information given for these missions in NRIS3 is extended to include the areas specified in the document Long-term challenges for Czech society [7] and are not listed in the NRIS3. These two challenges (or NRIS3 missions) are described in Chapter 9.2.1.1 and 9.2.1.2.

A slightly different approach was taken for the remaining three GSCs. Here, their structuring and description are based primarily on the document Long-term Challenges for Czech Society [7]. In addition, some of the information presented in the outputs of the FUTURE-PRO project was used [5] and in the documents prepared for the Horizon Europe framework programme [2]. The aim was to find the areas where R&D should be focused and to characterise them so that keywords could be found to identify relevant records in the databases. A brief characterisation of these GSCs is given in Chapter 9.2.1.3 to 9.2.1.5.

9.2.1.1 Energy transformation and a sustainable future

The mission "Making the economy more material, energy and emissions efficient" of NRIS3 aims to [9] to contribute through research and innovation to the transformation of the Czech economy towards efficient use of raw material and energy resources, optimization of production processes and reduction of dependence on external raw material resources (especially critical ones). The mission is structured into three strategic objectives (missions): Decarbonisation, Decentralisation, and Circularity, for the fulfilment of which the R&D&I themes have been identified through the EDP.

The aim of the **Decarbonisation** sub-mission is to achieve a technological readiness of the Czech economy that will enable the reduction of CO2 emissions by at least 44 Mt CO2 eq. by 2030 (compared to 2005). The mission defines four R&D areas and the following R&D&I directions:

Low-emission energy sources:

- Safe and socially acceptable development of nuclear power - small nuclear reactors, safety of operation with other sources, safe storage and recycling of fuel, public attitudes and behaviour
- Renewable energy sources - integration into the energy mix, efficient solar and wind energy production, geothermal sources, biomass and bio-waste, biofuels and synthetic fuels, use in transport
- Technologies for climate-neutral use of fossil energy sources - CCS/CSU technology, efficient use of coal resources, geological sequestration and CO2 storage in building materials, carbon farming, agrovoltaics

Energy storage, transport and transformation:

- Power-to-X - conversion of surplus electricity, energy transformation and use in other sectors (transport or chemical industry)

- cogeneration - increasing the efficiency of waste heat recovery, industrial thermal energy storage e.g. in salt melts
- Hydrogen technologies - low-carbon hydrogen production, safe storage and transport of hydrogen, integration of the energy mix in transport and industry

Energy efficiency and savings:

- energy in industry - product and process design, energy efficiency of production processes and technologies, energy saving technologies, energy management, circularity, increasing the share of RES, carbon footprint monitoring, energy consumption vs. human labour substitution
- transport and transport infrastructure - mobility, eco-friendly technologies in transport and vehicle production, mobility as a service (MaaS), carbon footprint monitoring
- Construction and building materials - energy performance and emission footprint throughout the whole life cycle of buildings (Whole Life Carbon - WLC), recycling of construction waste, energy networking of buildings, community energy

Low emission technologies in industry:

- alternative technologies in industrial processes where these technologies do not primarily target energy savings or energy efficiency.

The objective of the **Decentralisation** sub-mission is to adapt the electricity grid and other energy networks to the development of local renewable energy sources to create the technological conditions for increasing the share of decentralised energy sources to 25% in 2030. The mission defines two R&D areas and the following R&D directions:

Local production and hardware for network stability.

- Local communities - localization of production and consumption, resource sharing, community energy, backup energy sources and links to centralized sources, Smart Cities, pilot testing (smart neighbourhoods, living labs)
- Involvement of local authorities and local action groups - socially sensitive/inclusive alternatives, funding models
- resource sharing - use of local renewable energy sources (RES), agrovoltaics and bioeconomy (biogas plants), bio-waste, impact studies

Smart management of energy production, distribution and consumption.

- centralised and decentralised energy systems - flexibility and readiness for two-way energy flow, energy transport, smart grids
- Smart metering, digitalisation and automation - cyber-physical systems, decentralized system, communication and relations between manufacturers, distributors and customers
- Cybersecurity

The Circularity sub-mission aims to achieve a technological level of industrial design, manufacturing and processing processes and functioning of the secondary raw materials market that will enable material recycling rates to triple by the year 2040 compared to 2017 levels. The mission defines three R&D areas and the following R&D directions:

Industrial design and materials:

- Ecological product design - special materials and technologies (durability, reliability, reusability, modularity), recycling, material efficiency, waste reduction, remanufacturing and recycling, reuse

- higher use of alternative raw materials - alternative sources of raw materials (secondary raw materials, biomass waste materials, alternative local raw materials and by-products of industrial production), bio-based value chain, substitution of strategic, emission-intensive and non-recyclable materials

Sustainable consumption:

- Efficiency of production processes - efficient use of resources and energy (industrial symbiosis), waste prevention, use of by-products, use of digital tools, especially AI
- Circular business models - product rentals, durability, repairability, upgradability, product life extension, easy disassembly and recycling, circular and green products, services and construction
- Life Cycle Analysis (LCA) of production machines and technologies - LCA tools and prediction of greenhouse gas burden

3R (Reduce, Reuse, Recycle) principles:

- Waste recycling - technologies for mechanical, chemical and thermal decomposition of products into basic raw materials, quality control and availability of secondary raw materials and recyclable products, availability of residual materials, processing of vegetable waste, biogas plants
- Efficient recycling - materials and technology digital passports and product birth certificates (information on composition and recyclability) and tools for predicting product life cycle, expected service interventions, repairs and time suitable for recycling
- prolonging the lifetime of products and technologies - serviceability, prediction of service interventions, design of machines and technologies with longer lifetime

In the Long-term Challenges for Czech Society [7], the following areas are highlighted in the challenge "Energy transformation and sustainable future":

- energy transformation
- independence from fossil fuel imports
- low-emission and low-carbon energy sources
- modernisation of energy infrastructure
- energy distribution and storage
- social environmental awareness.

9.2.1.2 Trust in democracy, societal resilience, security and defence

The NRIS3 mission "Strengthening Societal Resilience to Security Threats" [9] aims to contribute through research and innovation to the acquisition and effective development of innovative knowledge, methods, and technologies. These advancements will enable the Czech Republic's security system and its stakeholders to address both current and future risks stemming from an evolving security landscape. The mission is structured into two strategic objectives (missions) Stability, Reliability and Sustainability of Societal, Economic and Environmental Systems, and Reducing Risks and Increasing Resilience, for the fulfilment of which R&D&I topic areas have been identified through the EDP.

The objective of the sub-mission **Stability, Reliability and Sustainability of Social, Economic and Environmental Systems** is to contribute to the stability, reliability and sustainability of social, economic and environmental systems in terms of security and security innovation. The mission defines three R&D areas and the following R&D&I directions:

Naturogenic threats:

- Increasing the resilience and preparedness of systems against natural hazards - focusing on mitigating natural disasters such as floods, droughts, floods, temperature fluctuations or space weather, for example through the development of smart cities technology
- Increasing the safety and sustainability of environmental systems, for example by reducing water, soil and air pollution or disruption to the structure and function of important ecosystems or the problem of biological invasion
- defining health threats such as epidemics, pandemics, epiphytes or epidemics

Ensuring the economy's smooth operation:

- Increasing energy security through smart grids or technologies to stabilise energy supply
- Diversification of energy sources, stabilisation of the material reserve system, raw material security, strengthening the resilience of supply chains and food security
- mitigating risks associated with industrial espionage and automation of operations

Anthropogenic threats:

- Increasing the resilience and preparedness of systems to anthropogenic threats - emphasis on social science research, mitigating the impact of the spread of disinformation, preventing radicalisation of society
- border security and monitoring, measures for more effective implementation of migration policies, and increased resilience of health and social systems in the face of a sudden increase in migration

The aim of the sub-mission **Reducing Risks and Increasing Resilience** is to increase resilience through research and development, while reducing the risk of emergencies and crisis situations that can have a negative impact on individuals and society, thereby increasing the level of resilience of society. The mission defines four R&D areas and the following R&D directions:

Safe public space:

- Increasing resilience with physical elements such as barriers, lighting or cameras
- public education and preparedness
- streamlining security planning and regulation

Infrastructure security:

- Increasing the resilience of transport infrastructure (e.g. rail, road or aviation infrastructure)
- research into new telecommunications infrastructures through the development of new protocols to improve operational safety management
- assessment of the safety aspects of space research
- investigation of the security aspects of digital infrastructures to be addressed through the research process

Environmental safety:

- Enhancing the resilience of society and infrastructure by researching the Earth's atmosphere and near-space environment

- Enhancing the safety of people and the environment from hazards, such as chemical disasters, by implementing early accident detection and associated threat mitigation strategies
- investigation into the illegal trade of endangered species focusing on policy and regulatory challenges

Security aspects of new technologies (these guidelines are also included in the Technology and Digital Transformation of Society challenge in the LTC):

- security aspects of artificial intelligence
- security aspects of emerging technologies such as cryptocurrencies, blockchain or technologies analysing big data
- the security aspects of cyber systems that support financial infrastructure and the operations of the private and non-governmental sectors
- educating vulnerable groups such as seniors and children about cyber threats

In the Long-term Challenges for Czech Society [7] the following areas are emphasized in the challenge " Trust in Democracy, Societal Resilience, Security and Defence ":

- the changing security situation and the increasing risk of international conflict
- sophisticated cyber-attacks using artificial intelligence and machine learning
- the rise of populism and extremism in Europe
- the spread of fake news and misinformation, which deepens societal polarization
- the changing role and structure of education
- defence technologies and critical infrastructure security
- global challenges requiring cooperation and evidence-based policy

9.2.1.3 Adaptation to climate change

The goal of the GSC Adaptation to Climate Change is to support research and innovation efforts aimed at developing and applying new knowledge, methods, and technologies to tackle both current and future climate-related risks. The structure and characteristics of each focus area are informed by the FCHS document [7] and align with the guidelines set forth in the FUTURE-PRO outputs and the Horizon Europe Framework Programme [2].

This GSC will be divided into three areas for the analysis of advanced technologies that have the potential to address it:

- Impacts of climate change
- Resistance to climate change and extreme weather conditions
- Adaptation to climate change

The above breakdown is based on a search of relevant documents, including in particular the LTC, the outputs of the FUTURE-PRO project and documents produced under the Horizon Europe framework programme.

The Climate Change Impacts area covers the impacts of warming and climate change on society, nature, and infrastructure, including impacts on the economy and society. It also covers impact and risk assessment, preventive measures and their implementation, as well as mitigation of the negative impacts of human activities on climate change.

The area of **Resilience to climate change and extreme weather** includes strengthening resilience to extreme weather events such as flash floods, droughts, fires, temperature extremes, etc. Resilience of critical infrastructures is an important area. Societal (social) resilience is also included.

The Adaptation to Climate Change area focuses on adaptation to climate change in several areas that will be significantly affected by climate change and global warming - the natural environment, agriculture, public health and the health system.

The section on the *natural environment covers* the reduction of the capacity of the landscape to provide ecosystem services, biodiversity, water, water resources and water management, the spread of invasive species, etc. Preventive measures related to the natural environment are also included.

The sub-area *Population Health and Health System* includes the resilience of the health system in relation to climate change and extreme weather events such as heat impacts, extreme events, including physical and mental health of the population, changing living conditions, etc. At the same time, adaptation to specific threats related to climate change, such as new human diseases, increased mortality, new pathogens, bacteria, etc. is also included.

The sub-area *of agriculture* includes in particular adaptation to the problems related to the impacts of climate change on agricultural production and related food production. A significant part of this is ensuring food availability in the context of the impacts of climate change on crop production, including reduced yields and production capacity of the landscape and the emergence of new pests, livestock farming, etc. Organic farming, compliance with good and environmental status standards, optimisation of fertiliser management, etc. are also included.

The energy system sub-area includes, for example, adaptation to changes in energy demand (heating vs. air conditioning), availability of water resources (cooling), etc. The threat to physical infrastructure such as overhead transmission and distribution lines, substations, etc. is also an important component. Furthermore, adaptation to changes related to renewable energy production (especially biomass production) is also included.

Adaptation to climate change is largely related to the management of resources and raw materials. The issue of *circular economy* is included in the GSC Energy transformation and sustainable future.

9.2.1.4 Preparedness for demographic change and an ageing population

The objectives and focus of R&D are based in particular on the characteristics of this long-term challenge for the Czech Republic in the Long-term Challenges for Czech Society [7]. In addition to LTCs, the structure and focus of this GSC takes into account the focus of similar activities in the Horizon Europe programme [2]. The aim of the mission "Preparedness for demographic change and ageing" is to contribute through research and innovation to the acquisition and effective development of innovative knowledge, methods and technologies that enable the social infrastructure of the Czech Republic and its stakeholders to face current and future risks associated with demographic change.

This GSC will be divided into the following areas for the analysis of advanced technologies that have the potential to address it:

- Demographic changes in relation to the social system
- Demographic changes in relation to the health system
- Demographic changes in relation to public finances and economic systems

The area of **Demographic change in relation to the social system** includes the impact of ageing on society in terms of the social system and adaptation to these changes. This area includes an assessment of the preparedness of the social system for an ageing population, declining fertility rates, increasing migration or continuing urbanisation.

The area of **Demographic change in relation to the health system** includes the impact and ageing of the population on society in terms of the health system and adaptation to these changes. This area includes an assessment of the health system's preparedness for increasing life expectancy and the associated physical and psychological health risks.

Demographic change in relation to public finances and economic systems covers the impact of ageing on society in economic terms and adaptation to these changes. This area will include an assessment of the preparedness of public finances for demographic change related, inter alia, to lower tax revenues. This area will also assess the opportunities and risks for the whole economic system in the face of this change.

The labour market sub-area includes the issue of labour market openness (national, generational, gender) and strengthening its flexibility. Labour market flexibility will be necessary as the retirement age increases. Given the declining birth rate, it is essential to either increase employment among economically inactive groups or implement a proactive immigration policy. Evolving lifestyles and advancements in digital infrastructure enable diverse working patterns, which the labor market must adapt to flexibly.

The sub-area *Pensions and insurance* covers the issue of the resilience of the pension system to demographic change. Lower tax revenues, longer lives will put pressure on public budgets. Life and other insurance will also have to adapt to new circumstances. Inadequate immigration policies can increase the strain on public budgets if newcomers struggle to integrate and fail to assimilate into the labour market

The sub-area *Social models includes the* gradual change of social models over time, especially in view of the ageing of the population. Low population dynamics influence individuals' behaviour, subsequently affecting household formation, purchasing power, and lifestyle choices. One notable aspect of evolving lifestyles is the rise of individualism, which can conflict with the needs of the elderly. Families provide essential practical and emotional support for seniors. Without this support, the risk of declining mental and physical health in the elderly increases.

9.2.1.5 Technological and digital transformation of society

The aim of the GSC Technological and Digital Transformation of Society is to contribute through research and innovation to the transformation of the Czech economy towards the efficient use of raw material resources by optimising advanced production processes and using digital tools to find more effective solutions. GSC Technological and digital transformation of society is divided into the following areas:

- Upgrading production and service processes
- Digitalisation of social institutions
- Education for a digital society

The area **Upgrading Production and Service Processes** covers all issues of automation and digitalisation leading to increased productivity.

The area of **Digitalisation of social institutions concerns the** transformation of administrative processes to their digital implementation, digital access to documents, access to civil agendas in a remote way, development of e-government, use of big data for decision-making, etc.

The Education for the Digital Society area aims to transform education with an emphasis on competences needed in the digital age, in basic and further education and in lifelong learning.

Cybersecurity is of course included, as is telemedicine, in another GSC.

9.2.2 Detailed characteristics of advanced manufacturing technologies in the ATI project

Table 46 Advanced technologies for industry. The first column lists the English names used in the documents produced by the ATI project and their numerical designation. Source: Advanced Technologies for Industry (ATI) project [10]

Technology	Characteristics[27]
1. Advanced Manufacturing Technology	Advanced manufacturing technologies involve the use of innovative technologies to improve products or processes. They are divided into two types of technologies: process technologies, which are used to produce other advanced technologies, and manufacturing technologies based on robotics, automation techniques or computer-integrated manufacturing. In the first case, these are manufacturing equipment or processes for the production of specific materials and components. In the latter case, process technologies, measuring, control and testing equipment for machines, machine tools and various areas of automated or IT-based manufacturing technologies.
2. Advanced Materials	Advanced materials lead not only to new and cheaper substitutes for existing materials but also to new products and services with higher added value. Advanced materials offer significant improvements in a wide variety of fields, such as aerospace, transport, construction and healthcare. They facilitate recycling, reduce the carbon footprint and energy consumption, and also reduce the consumption of raw materials.
3. Artificial Intelligence	Artificial intelligence (AI) is the term used to describe systems that perform human cognitive functions (e.g., learning, understanding, reasoning, or interacting). It includes various forms of cognition and understanding (e.g. natural language processing) and human interaction (e.g. signal sensing, smart controls, simulators). The technological base of AI is very heterogeneous. Although some of its aspects, such as sensors, chips, and robots, as well as some applications, such as autonomous driving, logistics or medical tools, refer to hardware components, the main part of AI is based on algorithms and software.
4. Augmented and Virtual Reality	Augmented reality (AR) devices overlay digital information with a person's actual view of reality. Thus, the user sees his or her surroundings and the AR digital content at the same time. Virtual reality devices place end users in an entirely new reality overlaying their view of their existing reality. The augmented reality is enriched with computer-generated perceptual information across multiple sensory, visual or auditory modalities. The user experience is closely intertwined with the physical world and is perceived as an immersive aspect of the real environment.
5. Big Data	Big Data is a term describing the constant increase in the volume of data and the technologies needed to collect, store, manage, and analyse it. From a technological perspective, big data includes the hardware and software that integrates, organizes, manages, analyzes, and presents this data. Big data is characterized by the "four Vs": volume (size of data sets), velocity (high speed of data processing), variety (different types and sources of data), and veracity (high quality of the data being analyzed).
6. Blockchain	A blockchain is a digitally distributed ledger of transactions or records that stores information or data and exists between multiple participants in a peer-to-peer network. The technology allows new transactions to be added to an existing chain of transactions using a secure cryptographic signature. Blockchain protocols aggregate, verify, and transmit information within a blockchain network. Blockchain technology allows data to exist as "nodes" on the network, allowing copies of the record of transactions to exist in a decentralized manner instead of being managed by one centralized institution.

[27] Adapted from Advanced Technologies for Industry [10]

7. Cloud computing	Cloud computing involves the provision of tools and applications, such as data storage, servers, databases and software, over the Internet. Cloud computing services allow users to store files and applications in a virtual location or in the cloud and access all data via the Internet. Public cloud services are available on public networks and are accessible to a largely unlimited range of potential users. They are intended for the broader market, not just for a single enterprise.
8. Connectivity	Connectivity refers to all the technologies and services that allow end users to connect to the network. It encompasses an increasing number of data, wireless and cable protocols and standards, and combinations of these, for a specific application at a specific location. Standard connectivity includes fixed voice and mobile voice telecommunication services that enable fixed or mobile voice communications, as well as fixed and mobile data services that enable data access and transmission over the network. Advanced connectivity refers to IoT technology, where the boundaries of connectivity are expanding beyond cable and mobile services (e.g. 4G, 5G) to large-scale low-power wide area networks (LPWAN) and the development of satellite and short-range wireless technology (e.g. Bluetooth, ZigBee)
9. Industrial biotechnology[28]	Industrial biotechnology refers to the industrial processing and production of chemicals, materials and fuels. It includes the practice of using micro-organisms or their components, such as enzymes, to produce industrially useful products in a more efficient way (e.g. using less energy or with fewer by-products) or to produce substances and chemical building blocks with specific capabilities that cannot be provided by conventional petrochemical processes.
10. Internet of Things	The Internet of Things (IoT) refers to a network of smart, interconnected devices and services that can sense or even listen to user requests. The IoT relies on networked sensors to enable remote connection, monitoring and management of products, systems and networks. The Industrial Internet of Things (IioT) - a subset of the broader Internet of Things (IoT) - focuses on the specialized requirements of industrial applications such as manufacturing and oil and gas or utilities.
11. Micro- and Nanoelectronics	Micro and nanoelectronics deals with semiconductor devices and/or highly miniaturized electronics, subsystems and their integration into larger products and systems. It includes the design, manufacture and testing of components ranging from nanoscale transistors to microsystems integrating multiple functions on a single chip.
12. Mobility	Mobility encompasses both information technologies that enable mobility and enterprise mobility in the sense of technologies that enable borderless working. IT for mobility covers a large number of different technology areas and markets, which include not only vehicles, but also various technologies that enhance people's mobility, such as mobile phones or, for example, satellite technology, navigation and radar, which are also essential technologies for autonomous driving. Enterprise mobility consists of mobile solutions and technologies, including hardware, software and services, that enable borderless working, anytime and from any device. It includes not only providing employees with smartphones or tablets, but also all the tools and applications to transform key processes, from internal operations to customer and supplier operations, both horizontally and vertically.[29]
13. Nanotechnology	Nanotechnology is an umbrella term that encompasses the design and fabrication of devices and systems through the manipulation of shape and size at the nanometer scale. Nanotechnology promises to lead to the development of intelligent nano- and micro-

[28] In the analysis in this report, Biotechnology includes industrial biotechnology as well as medical and life sciences technologies.
[29] In the analyses in this report, mobility is only included in the section labelled "IT for Mobility"

	devices and systems and to major breakthroughs in vital areas such as health, energy, environment and manufacturing.
14. Photonics	Photonics is a multidisciplinary field that deals with light and includes its generation, detection and conduction. Among other things, it provides the technological basis for the economic conversion of sunlight into electrical energy, which is essential for electricity generation. It includes a range of electronic components and devices such as photodiodes, light-emitting diodes and light sources such as light emitting diodes (LEDs) and lasers.
15. Robotics	Robotics involves the design, construction, implementation, and operation of robots to perform a specific task or series of tasks for commercial purposes. These robots can be stationary or mobile but have a limited function that is defined by the intended application. Multi-purpose robots can perform different functions and movements specified by the user according to the desired task. These robots operate autonomously within the parameters of the program and can be fixed, mobile or mobile. Cognitive robots are capable of decision making and reasoning, allowing them to function in complex environments[30].
16. IT for Security/ Cybersecurity	Security products designed to enhance the security of an organisation's network infrastructure - including computers, information systems, internet communications, networks, transactions, personal data and other information, devices, mainframes and the cloud. Cybersecurity products are used to ensure confidentiality, integrity, privacy and security. Through security applications, organizations can provide security management, access control, authentication, malware protection, encryption, data loss prevention (DLP), intrusion detection and prevention (IDP), vulnerability assessment (VA), and other functions.

[30] In the analyses in this report, only autonomous robots or devices using AI are included in robotics

9.3 Annexes to Chapter 3

9.3.1 Links of advanced technologies to identified GSC

In this appendix, the linkages of advanced technologies are evaluated in detail to the identified GSCs (Chapter 2.1.5). The mapping of projects to GSCs and advanced technologies is described in more detail in the methodological part of the study in Chapter 9.1.2.

The results are summarized in tabular form. In the left column of the table, for a given GSC, the areas where research activities should be targeted to address it are listed. In the columns, the individual advanced technologies from Table 6 are listed. The data in these columns indicate the percentage of projects falling into the individual areas of GSC in which the given progressive technology is mentioned (i.e. R&D is carried out in this area, this advanced technology is used, etc.). For quick comparison, the values are highlighted by coloured bars. The data in the tables are based on projects supported under the Horizon Europe Framework Programme to date. For reasons of space, the table is divided into three sub-tables according to the advanced technology fields.

In addition, each Chapter presents a graph comparing the data for projects supported by Horizon Europe (vertical axis) with the same data for projects supported by Horizon 2020 (horizontal axis). The blue diagonal line divides the graph into two parts – if the given advanced technology is located above the blue line, the share of projects from the given GSC, where the issue of the given advanced technology was addressed, was higher in the Horizon Europe program than it was in the Horizon 2020 program, and vice versa.

9.3.1.1 Energy transformation and a sustainable future

The results of the analysis of the links of advanced technologies to the GSC Energy Transformation and Sustainable Future (GSC Energy Transformation for short) in projects supported by the HE programme are presented in Table 47. The data in the first row, highlighted in light red, show that the projects assigned to the Energy Transformation GSC are mostly involved in R&D in the field of advanced materials (more than 20% of the projects assigned to this GSC) and artificial intelligence (about 17% of the projects). In 12% of the projects assigned to the Energy Transformation GSC, R&D in biotechnology was carried out, and in more than 11% of the projects, R&D in photonics was carried out.

R&D in the field of advanced materials has been mostly carried out in projects falling under the Circularity sub-mission, which includes, among others, materials recycling, reuse and reduction of materials consumption (3R). Advanced materials also frequently appear in projects under the Decarbonisation sub-mission.

Table 47 Links of advanced technologies to the GSC Energy Transformation and Sustainable Future (GSC Energy transformation). Data are for projects supported under the Horizon Europe Framework Programme to date. Source: e-CORDA

The table is on the next page

MSC - Energy Transformation	Advanced manufacturing technologies		Advanced material technologies			
	Advanced manufacturing	Robotics	Advanced materials	Nano-technology	Micro- and nanoelectronics	Photonics
MSC - Energy Transformation	Robotics	Robotics	20.6%	9.4%	5.1%	11.4%
Decarbonisation	6.2%	2.2%	19.2%	9.9%	5.7%	13.6%
Low emission energy sources	5.2%	1.2%	17.9%	9.6%	4.2%	15.7%
Energy storage, transport and transformation	6.2%	1.8%	22.0%	11.8%	3.8%	9.8%
Energy efficiency and savings	8.1%	3.3%	19.5%	8.5%	6.7%	11.4%
Low emission technologies in industry	0.0%	0.0%	14.3%	7.1%	7.1%	14.3%
Decentralisation	4.1%	3.5%	6.4%	1.7%	1.7%	7.0%
Local generation and hardware for grid stability	5.7%	1.4%	5.7%	0.0%	0.0%	8.6%
Smart management of energy production, distribution	3.5%	4.4%	7.0%	2.6%	2.6%	7.0%
Circularity	9.1%	3.4%	25.8%	7.5%	3.0%	8.0%
Industrial design and materials	6.4%	1.7%	33.3%	9.0%	2.1%	8.5%
Sustainable consumption	8.8%	3.9%	22.9%	7.0%	3.3%	6.1%
3R (Reduce, Reuse, Recycle) principles	11.9%	4.5%	32.6%	7.5%	1.7%	10.0%

MSC - Energy Transformation	Bio-technology	Digital technologies				
	Biotechnology	Artificial Intelligence	Augmented/virtual reality	Big Data	Blockchain	Cloud computing
MSC - Energy Transformation	12.0%	17.2%	0.7%	4.4%	1.0%	0.9%
Decarbonisation	8.6%	16.3%	0.5%	4.1%	0.8%	1.1%
Low emission energy sources	9.7%	12.9%	0.3%	3.0%	0.5%	0.7%
Energy storage, transport and transformation	5.3%	11.6%	0.4%	3.3%	0.4%	0.2%
Energy efficiency and savings	7.1%	22.6%	0.7%	6.1%	1.1%	1.7%
Low emission technologies in industry	14.3%	21.4%	0.0%	7.1%	0.0%	0.0%
Decentralisation	4.7%	26.7%	0.6%	8.7%	4.1%	1.2%
Local generation and hardware for grid stability	2.9%	12.9%	1.4%	7.1%	2.9%	1.4%
Smart management of energy production, distribution	5.3%	34.2%	0.0%	8.8%	4.4%	0.9%
Circularity	20.2%	17.0%	0.9%	4.7%	1.4%	0.5%
Industrial design and materials	26.5%	12.4%	0.0%	1.3%	1.3%	0.0%
Sustainable consumption	20.0%	17.9%	0.7%	5.1%	1.5%	0.6%
3R (Reduce, Reuse, Recycle) principles	16.7%	16.4%	1.2%	3.2%	1.7%	0.5%

MSC - Energy Transformation	Information and communication technologies			Other
	Connectivity	Internet of Things	Cyber security	Quantum technologies
MSC - Energy Transformation	5.3%	7.0%	3.6%	2.3%
Decarbonisation	5.3%	8.1%	3.3%	2.9%
Low emission energy sources	3.6%	5.3%	2.2%	2.5%
Energy storage, transport and transformation	2.7%	4.2%	0.9%	2.0%
Energy efficiency and savings	7.7%	13.7%	5.0%	2.8%
Low emission technologies in industry	0.0%	14.3%	0.0%	0.0%
Decentralisation	12.2%	14.0%	10.5%	0.6%
Local generation and hardware for grid stability	10.0%	8.6%	8.6%	0.0%
Smart management of energy production, distribution	13.2%	15.8%	11.4%	0.9%
Circularity	3.4%	5.7%	3.2%	0.2%
Industrial design and materials	2.1%	2.1%	2.1%	0.4%
Sustainable consumption	3.9%	5.8%	3.5%	0.1%
3R (Reduce, Reuse, Recycle) principles	2.7%	5.7%	3.0%	0.0%

Artificial intelligence is most relevant in the projects in the Decentralization sub-mission, especially in projects focused on smart management of energy production, distribution, and consumption (see Table 47). Artificial intelligence is also more prominent in projects addressing energy efficiency, savings, and low-emission technologies in industry in the Decarbonisation sub-mission. It is also used in projects included in the Circularity sub-mission.

Figure 26 compares the representation of the different advanced technologies in the HE and H2020 Framework Programme projects assigned to the Energy Transition GSC. The figure shows that advanced materials are strongly represented in the projects, while the share of projects where R&D on advanced materials has been carried out or used has increased by about 2 percentage points in the current HE programme compared to the H2020 programme. The most significant increase was in the representation of AI - while in the H2020 programme, AI was mentioned in approximately 9% of projects, in the current HE programme it is already more than 17% of projects. Among the other advanced technologies, biotechnology and advanced manufacturing have also increased their representation in the HE programme[31] (see Figure 26).

Figure 26 Comparison of the use of advanced technologies in projects addressing the GSC Energy Transition and Sustainable Future in the Horizon Europe and Horizon 2020 Framework Programmes. The horizontal axis shows the share of projects in H2020 that simultaneously address the GSC Energy Transformation and Sustainable Future and the given advanced technology in the total number of projects addressing this GSC, the vertical axis shows a similar share in the HE programme. If a given advanced technology is above the diagonal line, the representation of projects using that technology in HE was higher than in H2020. If an advanced technology is below the diagonal line, its representation was higher in H2020. Source: e-CORDA.

[31] When comparing data for HE and H2020 programmes, it is important to note that the representation of advanced technologies in projects may be somewhat influenced by the focus of specific calls for proposals

9.3.1.2 Trust in democracy, societal resilience, security and defence

The links of advanced technologies to the GSC Trust in Democracy, Societal Resilience, Security and Defence (abbreviated Trust in Democracy, Societal Resilience) in projects supported by the HE programme are summarised in Table 48. Technologies such as cyber security and AI have a significantly higher presence in projects assigned to this GSC, with almost a third of the projects.

Table 48 Advanced technology linkages to the GSC Trust in Democracy, Resilience, Security and Defence (GSC Trust in Democracy, Resilience of Society). Data are for projects supported under the Horizon Europe Framework Programme to date. Source: e-CORDA.

Trust in democracy, societal resilience	Advanced manufacturing technologies		Advanced material technologies			
	Advanced manufacturing	Robotics	Advanced materials	Nano-technology	Micro- and nanoelectronics	Photonics
Trust in democracy, resilience of society	5.2%	5.5%	8.1%	4.5%	3.1%	5.5%
Stability, reliability and sustainability of systems	3.5%	2.4%	9.4%	5.6%	2.1%	5.1%
Naturogenic threats	2.9%	2.5%	9.0%	5.5%	2.4%	5.4%
Ensuring the functioning of the economy	10.4%	2.5%	12.9%	6.7%	0.6%	3.7%
Anthropogenic threats	0.0%	1.4%	2.7%	1.4%	0.0%	1.4%
Secure public space	0.0%	0.0%	9.1%	9.1%	0.0%	0.0%
Security of infrastructures	6.1%	10.1%	5.6%	1.7%	4.5%	8.9%
Environmental security	3.2%	2.2%	18.3%	10.8%	5.4%	11.8%
Security aspects of new technologies	10.7%	15.3%	4.3%	0.5%	4.8%	4.3%

Trust in democracy, societal resilience	Bio-technology	Digital technologies				
	Biotechnology	Artificial Intelligence	Augmented/virtual reality	Big Data	Blockchain	Cloud computing
Trust in democracy, resilience of society	6.8%	30.3%	2.4%	9.0%	4.3%	2.7%
Stability, reliability and sustainability of systems	8.8%	20.3%	1.3%	5.6%	2.4%	2.0%
Naturogenic threats	8.9%	19.6%	1.2%	5.7%	1.8%	2.1%
Ensuring the functioning of the economy	11.0%	25.2%	0.6%	7.4%	4.9%	1.8%
Anthropogenic threats	1.4%	21.9%	4.1%	4.1%	0.0%	0.0%
Secure public space	9.1%	27.3%	9.1%	27.3%	0.0%	0.0%
Security of infrastructures	0.0%	41.3%	4.5%	14.0%	6.1%	5.6%
Environmental security	25.8%	16.1%	1.1%	6.5%	0.0%	0.0%
Security aspects of new technologies	1.8%	72.4%	5.4%	20.9%	12.5%	6.4%

Trust in democracy, societal resilience	Information and communication technologies			Other
	Connectivity	Internet of Things	Cyber security	Quantum technologies
Trust in democracy, resilience of society	17.6%	9.2%	30.8%	2.5%
Stability, reliability and sustainability of systems	10.2%	5.4%	21.6%	1.3%
Naturogenic threats	9.3%	5.7%	19.9%	1.2%
Ensuring the functioning of the economy	12.9%	8.0%	22.7%	1.2%
Anthropogenic threats	15.1%	1.4%	38.4%	2.7%
Secure public space	0.0%	0.0%	36.4%	9.1%
Security of infrastructures	39.1%	17.3%	50.3%	6.1%
Environmental security	3.2%	6.5%	11.8%	2.2%
Security aspects of new technologies	37.8%	18.9%	62.0%	4.6%

Cybersecurity is involved in more than 60% of projects addressing the security of new technologies and in more than half of projects focusing on infrastructure security. Artificial Intelligence is most prominent in projects dealing with the security aspects of new technologies (almost three-quarters of projects addressing this area of GSC mentioned AI). AI also has a significant application in the area of infrastructure security (see Table 48).

Other advanced technologies are being applied in some areas of this GSC. For example, biotechnology and advanced materials are being applied in projects aimed at environmental safety and economic security, big data in the area of safe public space (see Table 48).

Figure 27 clearly shows how strongly cybersecurity, AI and connectivity are applied in the projects assigned to the GSC Trust in Democracy, Societal Resilience. Moreover, it is noticeable that the HE programme has seen an increase in the representation of these technologies compared to the H2020 programme (with AI being the most represented).

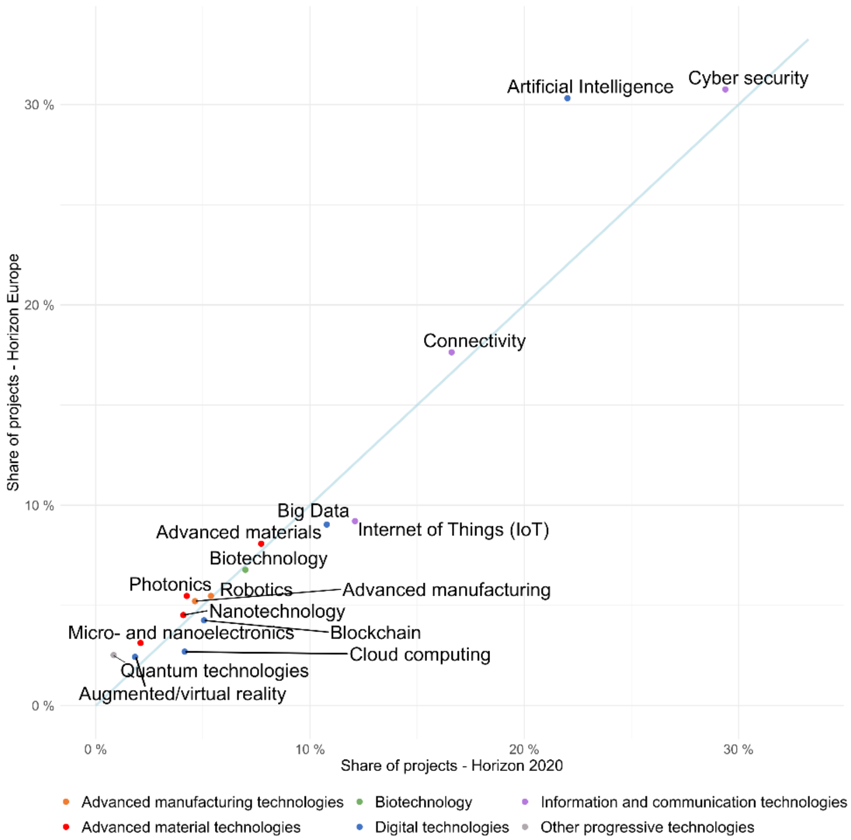

Figure 27 Comparison of the use of advanced technologies in projects focusing on the GSC Trust in Democracy, Societal Resilience, Security and Defence in the Horizon Europe and Horizon 2020 Framework Programmes. The horizontal axis shows the share of projects in H2020 that simultaneously address the GSC Trust in Democracy, Societal Resilience, Security and Defence and the given advanced technologies in the total number of projects addressing this GSC, the vertical axis shows a similar share in the HE programme. If a given advanced technology is above the diagonal line, the representation of projects using that technology was higher in HE than in H2020. If an advanced technology is below the diagonal line, its representation was higher in H2020. Source: e-CORDA.

9.3.1.3 Adaptation to climate change

The linkages of advanced technologies to GSC Adaptation to climate change in projects supported by the HE programme are summarised in Table 49. Artificial Intelligence was represented in the highest number of projects - almost 13% of the projects assigned to the Climate Change Adaptation GSC mentioned AI issues (AI R&D, use of AI, etc.). Moreover, as can be seen in Figure 28, which compares the representation of AI in projects assigned to the Climate Change Adaptation GSC in the HE and H2020 Framework Programmes, the representation of AI in HE projects has increased to almost 13% from around 5% in H2020. The highest representation of AI is seen in environmental projects, with a relatively high representation also in the energy system area.

Biotechnology is also more represented in the projects under the Adaptation to Climate Change GSC, and its representation in the HE programme has increased somewhat compared to the H2020 programme (see Figure 28). The higher representation of biotechnology is evident in the agricultural sector.

Although other advanced technologies do not have a high representation in the total number of projects included in the Adaptation to Climate Change GSC, in some areas of this GSC the representation of specific advanced technologies is relatively high. Advanced technologies, which fall under the broader category of advanced material technologies, play a significant role in energy projects. Here photonics (in the context of renewables) is particularly relevant. In addition to photonics, nanotechnologies are also more widely used in transport (see Table 49).

ICT have a higher application in the field of health. Although cybersecurity is the most applicable, other advanced technologies of this group are also more represented in the health and health system. Cybersecurity also has a higher presence in the transport sector.

Table 49 Linkages of advanced technologies to GSC Adaptation to climate change. Data are for projects supported under the Horizon Europe Framework Programme to date. Source: e-CORDA

Adaptation to climate change	Advanced manufacturing technologies		Advanced material technologies			
	Advanced manufacturing	Robotics	Advanced materials	Nano-technology	Micro- and nanoelectronics	Photonics
Adaptation to climate change	0.9%	0.1%	4.6%	2.8%	0.8%	4.2%
Adaptation to climate change	0.9%	0.1%	4.6%	2.8%	0.8%	4.2%
Impacts of climate change	0.7%	0.2%	2.9%	1.3%	0.4%	3.4%
Resilience to climate change and extreme weather eve	0.5%	0.0%	4.1%	1.4%	0.0%	1.4%
Adaptation to climate change	1.0%	0.0%	3.5%	2.0%	0.3%	3.0%
Climate change - general	0.9%	0.1%	4.6%	2.8%	0.8%	4.2%
Climate change - by sector	1.0%	0.1%	5.5%	3.4%	1.0%	5.0%
Natural environment	1.0%	0.0%	4.2%	1.7%	0.2%	3.5%
Population health and health system	4.3%	0.0%	2.2%	2.2%	0.0%	2.2%
Agriculture	1.6%	0.5%	4.2%	1.6%	1.6%	0.5%
Energy system	1.4%	0.0%	11.4%	9.0%	1.9%	13.3%
Transport	3.5%	0.0%	14.0%	14.0%	3.5%	14.0%

Adaptation to climate change	Bio-technology	Digital technologies				
	Biotechnology	Artificial Intelligence	Augmented/virtual reality	Big Data	Blockchain	Cloud computing
Adaptation to climate change	7.7%	12.6%	0.5%	4.5%	0.2%	1.0%
Adaptation to climate change	7.7%	12.6%	0.5%	4.5%	0.2%	1.0%
Impacts of climate change	7.4%	13.4%	0.9%	4.7%	0.0%	1.1%
Resilience to climate change and extreme weather eve	8.2%	12.3%	0.9%	5.9%	0.0%	0.9%
Adaptation to climate change	8.3%	11.0%	0.8%	5.3%	0.3%	1.0%
Climate change - general	7.7%	12.6%	0.5%	4.5%	0.2%	1.0%
Climate change - by sector	8.8%	12.0%	0.6%	4.5%	0.3%	1.0%
Natural environment	6.5%	11.3%	0.6%	5.0%	0.2%	1.3%
Population health and health system	6.5%	26.1%	4.3%	6.5%	0.0%	0.0%
Agriculture	14.2%	11.1%	0.0%	4.2%	0.5%	0.0%
Energy system	10.0%	12.8%	0.5%	3.8%	0.0%	0.9%
Transport	7.0%	17.5%	1.8%	5.3%	0.0%	0.0%

Adaptation to climate change	Information and communication technologies			Other
	Connectivity	Internet of Things	Cyber security	Quantum technologies
Adaptation to climate change	2.9%	3.5%	5.4%	1.0%
Adaptation to climate change	2.9%	3.5%	5.4%	1.0%
Impacts of climate change	3.1%	2.9%	6.7%	1.1%
Resilience to climate change and extreme weather eve	5.0%	5.9%	9.1%	0.5%
Adaptation to climate change	3.0%	3.3%	5.0%	0.5%
Climate change - general	2.9%	3.5%	5.4%	1.0%
Climate change - by sector	3.0%	3.8%	5.5%	1.3%
Natural environment	2.9%	3.8%	5.6%	0.6%
Population health and health system	6.5%	6.5%	15.2%	0.0%
Agriculture	2.6%	2.1%	7.4%	0.5%
Energy system	2.8%	3.3%	2.8%	2.8%
Transport	5.3%	7.0%	10.5%	3.5%

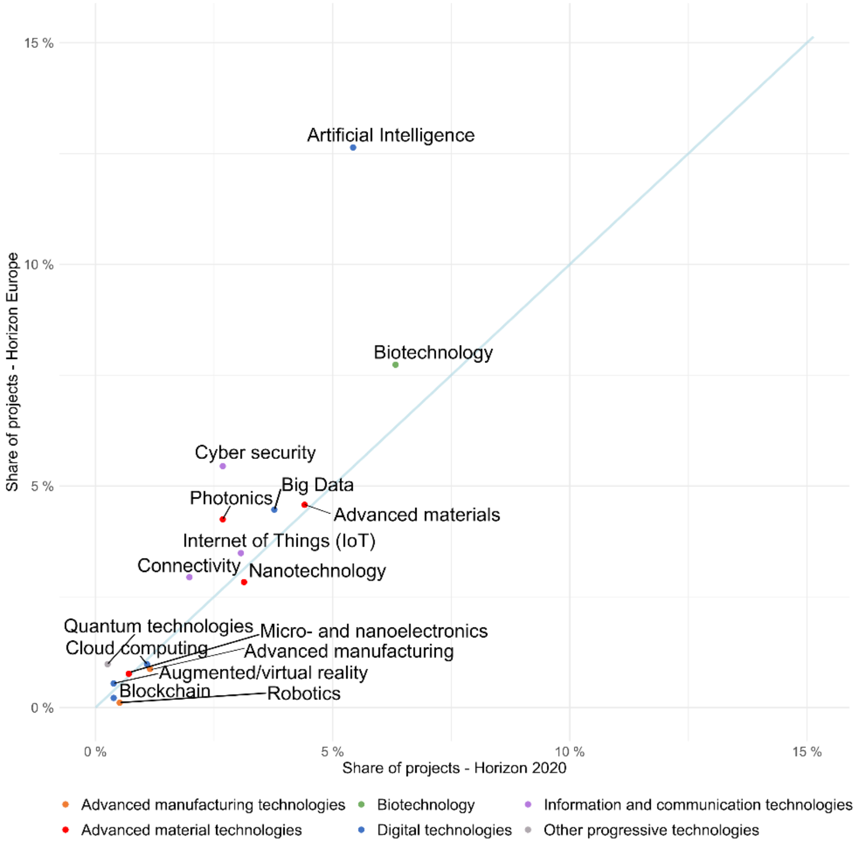

Figure 28 Comparison of the use of advanced technologies in projects addressing the issue of GSC Adaptation to climate change in the Horizon Europe and Horizon 2020 Framework Programmes. The horizontal axis shows the share of projects in H2020 where the issue of the GSC Adaptation to climate change and the given advanced technologies are simultaneously addressed in the total number of projects addressing this GSC issue, the vertical axis shows a similar share in the HE programme. If the advanced technology is above the diagonal line, the representation of projects using this technology in HE was higher than in H2020. If the advanced technology is below the diagonal line, the representation was higher in H2020. Source: e-CORDA

9.3.1.4 Preparedness for demographic change and an ageing population

The linkages of advanced technologies to GSC Preparedness for demographic change and ageing population (abbreviated Preparedness for demographic change) in HE-supported projects are summarised in Table 50. Artificial intelligence has the highest penetration in the projects, being represented in more than 15% of those assigned to this GSC.

As can be seen in Table 50 the application of advanced technologies varies across the different areas of the GSC Preparedness for demographic change. IoT finds its highest application in projects focusing on demographic change and public finance or the economic system (robotics and advanced manufacturing are also more prevalent). Advanced technologies are most applicable in projects related to the health system and public finance. In the GSC Preparedness for demographic change, the representation of most advanced technologies in HE has decreased somewhat compared to H2020 (see Figure 29).

Table 50 Advanced technology linkages to GSC Preparedness for demographic change and ageing population (GSC Preparedness for demographic change). Data are for projects supported under the Horizon Europe Framework Programme to date. Source: e-CORDA

Preparedness for demographic change	Advanced manufacturing technologies		Advanced material technologies			
	Advanced manufacturing	Robotics	Advanced materials	Nano-technology	Micro- and nanoelectronics	Photonics
Preparedness for demographic change and ageing	1.9%	1.9%	4.3%	1.4%	0.0%	0.5%
Demographic change in relation to the social system	2.6%	2.6%	0.0%	0.0%	0.0%	0.0%
Demographic changes in relation to health system	0.6%	0.6%	4.6%	1.1%	0.0%	0.6%
Demographic changes in relation to public finances	9.1%	9.1%	4.5%	4.5%	0.0%	0.0%

Preparedness for demographic change	Bio-technology	Digital technologies				
	Biotechnology	Artificial Intelligence	Augmented/virtual reality	Big Data	Blockchain	Cloud computing
Preparedness for demographic change and ageing	3.4%	15.5%	1.4%	4.8%	0.0%	0.5%
Demographic change in relation to the social system	2.6%	10.5%	2.6%	5.3%	0.0%	0.0%
Demographic changes in relation to health system	3.4%	15.4%	1.1%	4.6%	0.0%	0.6%
Demographic changes in relation to public finances	4.5%	9.1%	4.5%	0.0%	0.0%	0.0%

Preparedness for demographic change	Information and communication technologies			Other
	Connectivity	Internet of Things	Cyber security	Quantum technologies
Preparedness for demographic change and ageing	2.4%	3.9%	3.4%	0.5%
Demographic change in relation to the social system	5.3%	2.6%	2.6%	0.0%
Demographic changes in relation to health system	1.7%	3.4%	3.4%	0.6%
Demographic changes in relation to public finances	4.5%	18.2%	0.0%	0.0%

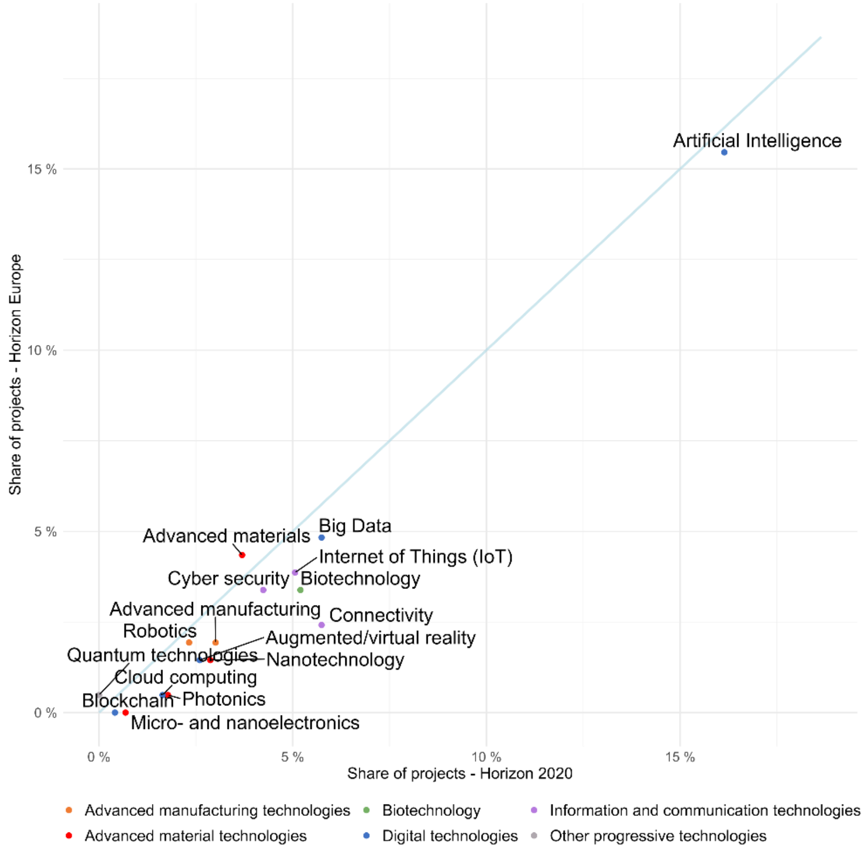

Figure 29 Comparison of the use of advanced technologies in projects focusing on GSC Preparedness for demographic change and ageing population in the Horizon Europe and Horizon 2020 Framework Programmes. The horizontal axis shows the share of projects in H2020 where GSC Preparedness for demographic change and advanced technologies are simultaneously addressed in the total number of projects addressing this GSC, the vertical axis shows a similar share in the HE programme. If a given advanced technology is above the diagonal line, the representation of projects using this technology in HE was higher than in H2020. If an advanced technology is below the diagonal line, its representation was higher in H2020. Source: e-CORDA.

9.3.1.5 Technological and digital transformation of society

The results of the analysis of the links between advanced technologies and the GSC Technological and digital transformation of society (Technological and Digital Transformation) in projects supported by the HE programme are presented in Table 51. Given the focus of this GSC, digital technologies and information and communication technologies are predominantly utilised in the projects. Among digital technologies, it is in particular AI that was represented in more than a quarter of the projects assigned to this GSC in the HE Framework Programme. It is most prominent in upgrading production and service processes, where it was mentioned in almost 28% of projects. Among digital technologies, big data is also frequently mentioned in projects, especially in the context of the digitalisation of social institutions (see Table 51).

Among the ICT, connectivity is the most frequently applied in the projects within this GSC, particularly in the digitalisation of social institutions. As expected, there is also a high representation of projects addressing cybersecurity issues. The Internet of Things (IoT) also features in projects addressing process upgrades in manufacturing and services (see Table 51).

As can be seen in Table 51, advanced manufacturing technologies, in particular advanced manufacturing, have a relatively high presence in the projects included in the Technology and Digital Transformation GSC. This may be related to process upgrades in manufacturing and services (e.g. use of digital technologies, automation, robotics, etc.).

Figure 30 compares the use of advanced technologies in digital technology transformation projects in the Horizon Europe and Horizon 2020 Framework Programmes. The figure shows not only the high uptake of AI in projects assigned to the Technological and Digital Transformation GSC but also the significant increase in the proportion of projects introducing AI issues in the current HE Framework Programme compared to the previous H2020 programme.

Table 51 Advanced technology linkages to the Technological and digital transformation of society GSC (Technology and Digital Transformation). Data are for projects supported under the Horizon Europe Framework Programme to date. Source: e-CORDA

Technological and digital transformation	**Advanced manufacturing technologies**		**Advanced material technologies**			
	Advanced manufacturing	**Robotics**	**Advanced materials**	**Nano-technology**	**Micro- and nanoelectronics**	**Photonics**
Technological and digital transformation	12.0%	6.0%	5.5%	2.0%	3.5%	4.2%
Upgrading production and service processes	14.7%	7.2%	6.5%	2.4%	4.4%	5.0%
Digitalisation of social institutions	0.9%	1.7%	0.9%	0.0%	0.0%	1.3%
Education for a digital society	5.3%	3.2%	2.4%	1.3%	0.3%	1.9%

Technological and digital transformation	**Bio-technology**	**Digital technologies**				
	Biotechnology	**Artificial Intelligence**	**Augmented/virtual reality**	**Big Data**	**Blockchain**	**Cloud computing**
Technological and digital transformation	2.8%	25.4%	4.5%	12.1%	4.1%	6.2%
Upgrading production and service processes	3.2%	27.5%	4.8%	12.3%	4.1%	7.1%
Digitalisation of social institutions	1.3%	21.1%	1.3%	15.9%	6.5%	2.6%
Education for a digital society	1.1%	16.8%	5.3%	8.0%	3.5%	2.9%

Technological and digital transformation	**Information and communication technologies**			**Other**
	Connectivity	**Internet of Things**	**Cyber security**	**Quantum technologies**
Technological and digital transformation	22.3%	14.0%	14.9%	0.5%
Upgrading production and service processes	22.0%	16.1%	15.4%	0.6%
Digitalisation of social institutions	28.0%	9.9%	16.8%	0.0%
Education for a digital society	19.7%	6.1%	12.2%	0.3%

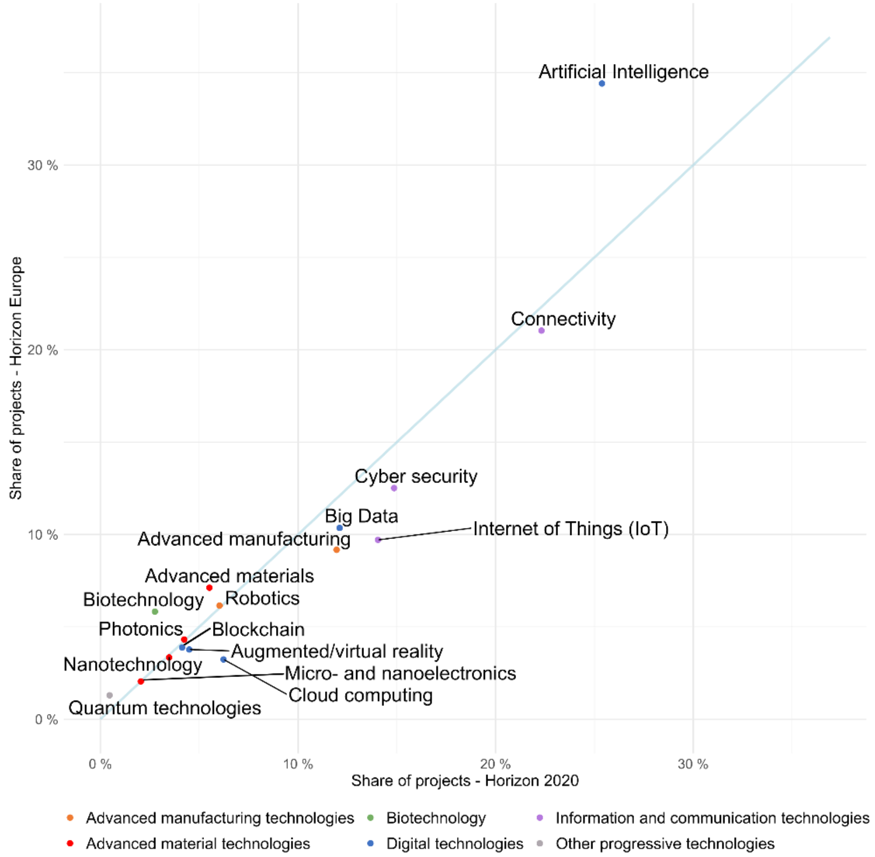

Figure 30 Comparison of the use of advanced technologies in projects addressing the GSC Technological and digital transformation of society in the Horizon Europe and Horizon 2020 Framework Programmes. The horizontal axis shows the share of projects in H2020 that simultaneously address the issue of the Technological and Digital Transformation of Society GSC and the given advanced technologies in the total number of projects addressing this GSC, the vertical axis shows a similar share in the HE programme. If a given advanced technology is above the diagonal line, the representation of projects using that technology in HE was higher than in H2020. If an advanced technology is below the diagonal line, its representation was higher in H2020. Source: e-CORDA.

9.4 Annexes to Chapter 4

9.4.1 Findings from a search aimed at identifying promising R&D directions in advanced technologies

The research aimed to obtain information on promising directions in advanced technologies and their possible use in GSC solutions. In line with the terms of reference, the primary focus was placed on digital technologies and their connection to the identified GSC. The main sources used for this research were studies prepared by the McKinsey Global Institute [11], [17] a [18].

In the study [17] identifies ten cross-cutting (transversal) technologies that apply to virtually all sectors and that can make a significant contribution to their transformation:

- Advanced automation
- The future of connectivity
- Distributed infrastructure
- New generation computing
- Architecture of trust
- Applied AI
- The future of programming
- Advanced materials
- Bio Revolution
- Clean technology

Most of these technologies can be classified as digital technologies. In the following text, the promising directions in these technologies and their potential applications are presented, including the context of their use to address the identified GSC issues (Chapter 2.1.5). Given the transformative power of these technologies, their validity can be expected to extend beyond a five-year horizon. Similarly, GSCs can be expected to have a longer time horizon.

Advanced automation (Next level automation)

This includes, for example, robotic hardware (industrial, collaborative and professional robots), additive manufacturing and virtualization, digital twins, and other directions that help improve operational efficiency, shorten development cycles, and thus reduce time to market. The use and application for GSC solutions are therefore quite broad.

Connectivity

In the future, increasing demands on connectivity, communication speed and reliability can be expected in connection with automation, digitalisation and increasing information flows. According to [17] 5G and IoT technologies will therefore become increasingly important. A promising technology is the use of low-earth-orbit (LEO) satellites [11]. High-speed 5G networks also reduce energy consumption and thus contribute to addressing issues in the Energy and Climate Change Adaptation sectors. At the same time, they enable the effective use of technologies such as cloud and edge computing. They are also a prerequisite for Industry 4.0, smart grids and smart cities, and the development of networks of intercommunicating resources (Internet of Things). There are also applications in mobility and healthcare [11].

Distributed infrastructure

Distributed infrastructure includes cloud/edge computing. These technologies enable increased computing power and data storage, speeding up computing operations and reducing costs for users. They can also reduce data privacy concerns. As can be seen from the analyses carried out, the application of these technologies is broad, and they are already being used in projects targeting all GSCs. While these technologies are already in use, according to [17] they have significant potential for further development and use, including the development of IaaS, PaaS, and SaaS services[32].

New generation computing

It includes quantum computing based on quantum mechanical principles, and neuromorphic systems inspired by the human brain. They allow to overcome the limits of existing computing systems while reducing energy consumption. These technologies can radically accelerate development cycles, finding applications in a wide range of technological fields and economic sectors. They can thus contribute to addressing most of the identified GSCs, in particular the Digital Transformation and Energy GSCs. They also have applications in biomedical research.

Architecture of trust

It provides a framework that allows data to flow through a service-oriented system in a verifiable manner. Technologies covered include zero trust architecture (ZTA), digital identity systems and privacy engineering [11]. Technologies include for example, blockchain, i.e., an environment in which users trust a system without necessarily trusting any of its components. In addition to digital currencies, it can be the basis for other applications such as tracking shipments in international trade. According to [11] trust architecture will "quietly" become an integral part of life. These technologies may find applications in the Trust in Democracy, Societal Resilience, Security and Defence GSC, among others.

Applied AI

According to the study. [17] we can expect expanding applications of computer vision, natural language understanding and generation, virtual assistants, robotic process automation, and advanced machine learning. The ways humans interact with machines can be expected to expand. There are also applications in predictive maintenance, quality control in manufacturing and safety. As the analyses in this study show, AI also has the highest potential to address all GSCs.

An earlier study by the McKinsey Global Institute [18] identified several areas where AI can contribute to social good:

- crisis management - pandemics, epidemics, migration crises, natural and anthropogenic disasters, search and rescue
- Economic equality - agricultural yield and quality, financial inclusion, economic growth initiatives, matching labour supply and demand
- Challenges in education - access and completion, fulfilling student potential, simplifying school administration
- environmental challenges - animal and plant protection, climate change and adaptation, energy efficiency and sustainability, soil, air and water protection
- Equality and inclusion - accessibility and disability, exploitation, marginalised communities
- Health and hunger - prediction and prevention, treatment and long-term care, mental health, hunger
- verification and validation of information - fake news, polarisation

[32] Infrastructure as a Service, Platform as a Service, Software as a Service

- infrastructure management - energy, real estate, transport, urban planning, water and waste management
- public and social sector management - effective public and social sector management, fundraising, public financial management, citizen services
- safety and justice - harm prevention, fair prosecution, policing

Studies on automation and the application of digital technologies also suggest that continued automation and the rise of artificial intelligence will have a significant impact on the labour market. According to the McKinsey Global Institute, there is a need to reform current education systems, reform or reintroduce adult education systems and make lifelong learning affordable.

The future of programming

The landscape for software developers changes thanks to smarter algorithms that require less hand-coding. Sometimes it is referred to as "Software 2.0." These are machine-generated programs developed on low-code or no-code platforms, which help reduce the demand for programmers. In this field according to [11] AI will be applied, not only in the creation of code but also in its inspection and testing. The relevance of these approaches is exceptionally high in the context of digital transformation, particularly in various applications

New generation materials

These materials will be based on significant innovations in terms of properties, manufacturing processes and potential applications. According to the study [17] the following categories of materials have a major impact for a number of industries:

- Nanomaterials such as carbon nanotubes, nanoparticles, graphene, titanium dioxide and others. They have applications in cleantech, aerospace, medical technology and other industries.
- Composites - fibre-reinforced polymers (e.g. glass and carbon), ceramic matrix composite, metal matrix composite, reinforced concrete, translucent concrete, engineered wood, engineered bamboo, wood-plastic composite, cement-bonded wood fibre and syntactic foams. These materials have a wide range of applications in many industries.
- Next generation construction materials - alternative building materials can make a significant contribution to reducing the carbon footprint and emissions of their production. Examples include cross-laminated timber (CLT) or green cement.
- Bio-revolution

The bio-revolution is the result of significant advances in the life sciences and accelerating developments in computing, automation, artificial intelligence and data analytics. It is a wide range of innovations, according to a study [17] promising ones include mapping, measurement and engineering of molecules (biomolecules); biosystems and molecular, tissue and organ engineering; biomachines and the interface between biology and machines; biocomputing, i.e. the use of cells or molecules such as DNA for computation. The impact is expected not only in the health field but especially in the non-health sector, especially in agriculture and consumer products.

Clean technologies of the future

They include established technologies such as solar, wind and hydropower, as well as new and breakthrough technologies such as nuclear fusion, energy storage, and hydrogen generation and storage. According to [17], prospective technologies include carbon capture, utilization, and storage (CCUS), smart grids, and next-generation batteries. These innovations have the potential to transform traditional business models and are already starting to reshape the industry. They will significantly impact the energy sector, transportation, the construction industry (including buildings), infrastructure, and other areas

9.4.2 List of Sources for Articles Included in the Analysis of Current Topics

This appendix includes a list of media that have published articles included in the analysis of current topics in the field of advanced technologies in Chapter 4.2. Only unique articles from these sources were included in the analysis, although multiple sections within some media or institutions are tracked.

9.4.2.1 Academic media

- MIT News – Aeronautical and astronautical engineering
- MIT News – Bioengineering and biotechnology | Biological engineering | Biotechnology
- MIT News – Biology | Genetics | biophysics
- MIT News – Brain and cognitive sciences | Neuroscience
- MIT News – Cancer
- MIT News – Chemistry
- MIT News – Civil and environmental engineering
- MIT News – Climate change | Sustainability | Lorenz Center | Concrete Sustainability Hub | Emissions
- MIT News – Data | Big data | Analytics | Statistics | IDSS | Operations research
- MIT News – Electrical engineering and computer science (EECS) | Electrical Engineering & Computer Science (eecs)
- MIT News – Earth and atmospheric sciences | Earthquakes | Geology | Climate | Climate change | Oceanography and ocean engineering
- MIT News – Energy
- MIT News – Materials science | Materials science and engineering | DMSE
- MIT News – Mechanical engineering
- MIT News – Nanoscience and nanotechnology | MIT.nano
- MIT News – Robotics
- MIT News – Physics
- MIT News – Artificial intelligence
- MIT News – Social sciences | Economics | Linguistics | Political science | Anthropology | Philosophy | Center for International Studies | Security studies and military
- The Stanford Daily
- Science & Technology – Harvard Gazette
- News from www.caltech.edu
- MIT News – Science, Technology, and Society | Technology and society | Program in STS | History of science | History of MIT
- NSF News
- Science / Technology / Engineering – Sandia Labs News Releases

9.4.2.2 Technology media

- All Top News – ScienceDaily
- Top Technology News -- ScienceDaily
- Top Society News -- ScienceDaily
- Top Environment News -- ScienceDaily
- Strange & Offbeat News -- ScienceDaily
- Top Health News -- ScienceDaily
- Business & Industry News -- ScienceDaily
- Latest Science News -- ScienceDaily
- SciTechDaily
- Science – Ars Technica
- Singularity Hub
- ScienceAlert
- Quanta Magazine
- VentureBeat
- The Verge – All Posts
- Engadget is a web magazine with obsessive daily coverage of everything new in gadgets and consumer electronics
- Tech in Asia
- TechCrunch
- TechRadar – All the latest technology news
- Science Latest
- Phys.org – latest science and technology news stories
- New Atlas – Science
- New Atlas – Technology

9.4.2.3 Technology sections of established media

- Forbes – Science
- IEEE Spectrum
- NYT > Science
- Science | The Guardian
- BBC News – Science & Environment
- NYT > Technology
- WSJ.com: WSJD
- New Scientist – Technology
- New Scientist – News
- New Scientist – Earth
- New Scientist – Life
- New Scientist – Physics
- New Scientist – Health

- Scientific American Content: Global
- Scientific American: Technology
- CBC | Technology News

9.4.2.4 Reports on EU policies in relation to technology

- EU Science Hub | JRC news and updates
- ITRE – European Parliament
- Economic and monetary affairs – European Parliament
- DG Research and innovation | All research and innovation news
- DG Energy | News

9.4.3 Minutes of the expert workshop

The expert workshop took place on 24 April 2024 at the TCP premises. The views of its participants are structured according to the grand societal challenges. During the discussion on the contribution of digital technologies to addressing the GSCs, as outlined in the terms of reference, aspects related to other GSCs were also mentioned. These elements are included in the GSC Technology and Digital Transformation of Society, with additional information provided across various GSCs (some information is provided in more GSCs).

9.4.3.1 Technological and digital transformation of society

Workshop participants emphasized the crucial role of digitalisation and digital technologies in business, public administration, and society at large. They noted that digitalisation should be viewed not as an end in itself, but as a means to solve the question of how to produce, rather than what to produce (see Miscellaneous).

Experts also pointed out that it is essential to promote digitalisation in public administration and education, while businesses will adopt digital technologies, especially in the context of the rising cost of human labour, as seen abroad (robotization).

During their discussions, workshop participants validated the data analysis findings, noting that technologies leveraging AI are becoming increasingly significant and are expected to continue growing in importance. Key current trends in AI usage include:

- Emphasis on greater interactivity (human-machine) and predictability (e.g. predictive maintenance, smart logistics, etc.)
- Data economy - solving problems using AI and creating recommendations for implementation by humans
- Help for humans (guides), Smart guidance
- Development of communication

AI possesses broad potential as a versatile technology that can be integrated across various domains. According to experts, AI is anticipated to have significant applications in the following areas:

- Industry - replacement of human labour by robots (autonomous robots), leading to a reduction in the number of workers and higher efficiency, individualisation of production, design for 3D printing
- Healthcare - for example, personalised medicine
- Agriculture - detection, spraying, crop harvesting, etc.

- Energy - smart grids, smart cities (networks, transport)
- AI in-house assistants (e.g. for training new staff)

The Czech Republic is well positioned in some sectors. For example, in the healthcare sector, where a number of companies operate, which represents a great opportunity. There is also potential in the Czech Republic for the use of AI in the sharing economy, where these technologies could be applied to the use of data from public administration registers (data on driving licenses, data on the number of offences, etc.). The application of AI in the Czech Republic is also in the digitalisation of state administration and in the field of education. Experts believe that the development of user applications leveraging big data, including commercial applications, presents a significant opportunity.

According to the experts participating in the workshop, the Czech Republic also posses potential in the area of Smart cities, which was confirmed by the results of data analyses. These include the use of AI in rail transport and vehicles, including buses. Smart cities also represent an opportunity for other sectors (they are a driving force). Investment in the low-attitude economy is increasing abroad. In the Czech Republic, there is considerable experience in this area in drone manufacturing and 3D printing. The Czech Republic also shows potential in the research and development of atmospheric satellites used in the stratosphere for applications such as communication and monitoring.

9.4.3.2 Energy transformation and a sustainable future

Advanced technologies have the potential to contribute to greener and more efficient energy systems, to reducing greenhouse gas emissions, and to sustainable development. Advanced manufacturing technologies enable the development and production of more efficient and environmentally friendly renewable energy devices such as solar panels or wind turbines. Advanced material technologies can lead to the development of lighter and more durable materials for the construction of more energy efficient buildings and infrastructure. Biotechnology can be used to produce biofuels and biochemicals, reducing thus dependence on fossil fuels and minimising greenhouse gas emissions. Digital technologies and information and communication technologies can provide intelligent solutions for managing energy networks, optimising energy consumption, and monitoring environmental impacts.

Workshop participants pointed out that it is important not only to decarbonise the energy sector, but also to decentralise energy production, reliably distribute energy and ensure its availability, including affordability, and achieve an acceptable energy mix. However, it is important to remember that the majority of energy consumption is heat, while only a smaller portion is electricity. As the Czech Republic is one of the countries with high energy intensity, the goal should be a "smart" energy sector, where AI will play an important role.

9.4.3.3 Adaptation to climate change

Workshop participants highlighted the impacts of climate change on health and nature. In the context of rising temperatures, they highlighted the importance of protecting water resources and water management (use of biotechnology). There are also significant impacts of climate change on agriculture. In the context of labour shortages, robotics is becoming increasingly important as a means of reducing the impact (spraying, harvesting, pest detection, etc.). Biotechnology can help to protect biodiversity and restore ecosystems, for example by developing more resilient plants or improving agricultural techniques for sustainable farming.

Enhancing adaptation measures to address the impacts of climate change will also facilitate the use of advanced manufacturing technologies to create devices for monitoring and predicting climate changes, such as sensors that track ecosystem health and weather conditions. Digital technologies and ICT can provide platforms for collecting, analysing, and sharing data on climate change, helping to better understand and adapt to these changes.

Materials are also an opportunity in this area, where efforts should be made to minimise their consumption and reduce the use of raw materials. From an environmental point of view, plastics (and microplastics) are somewhat problematic, despite their undeniable advantages. Although plastics are highly recyclable and can be disposed of, the problem is the attitude of a society that does not know how to handle plastics in an environmentally friendly way. In this context, however, it is important to consider that approximately 10% of oil is used for their production, while 90% is used for fuel production.

9.4.3.4 Preparedness for demographic change and an aging population

In the context of an aging population, biotechnologies such as genetics (gene medicine, gene technologies) are of great importance for this GSC. As human life expectancy (longevity) increases, these technologies will become increasingly important. According to experts, there are good prerequisites and potential for the development of these areas in the Czech Republic (for example, the discovery of new drugs). Personalized medicine will also play an important role in the future. The Czech Republic is well placed to develop virtual reality and gaming techniques. Another opportunity is the gene editing technology known as CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats), which is used for targeted genome interventions with high precision.

9.4.3.5 Trust in democracy, societal resilience, security and defence

The experts confirmed the great importance of digital technologies for addressing the issues included in this GSC. They also pointed out the importance of quantum technologies in cybersecurity, especially in the field of cryptography (e.g. quantum computers in the context of password cracking). Quantum communication is also gaining importance. Advanced manufacturing technologies offer the potential for the development and production of sophisticated devices for monitoring and protecting public space, contributing to the safety and security of citizens. Digital technologies and ICT can provide tools for improving transparency in government, enhancing communication between government and citizens, and increasing resilience to disinformation and cyber threats. These technologies can also contribute to strengthening democratic institutions, increasing transparency and accountability in public administration.

9.4.4 Miscellaneous

As technological development is constantly accelerating, workshop participants highlighted the importance of education. In this context, inspiring examples from abroad (Germany, Austria) were cited. In the Czech Republic, know-how is also disappearing due to the retirement of older experienced workers. Digital technologies, especially artificial intelligence, are of great importance for the "preservation" of knowledge (see also GSC Technological and digital transformation of society).

Attention also needs to be paid to the development of firms to increase competitiveness. Therefore, it is necessary to focus on what to produce and what can contribute to increasing the competitiveness of enterprises and their shift in supply chains (an example is the production of electron microscopes in Brno, where their manufacturer has moved to a world leader). It is also important to focus on emerging sectors of the economy, such as the space and quantum industries, which offer abundant opportunities for start-ups.

Materials research is important for the development of competitiveness, as materials are used in a wide range of technologies (they are cross-cutting). In this context, an area focusing on technologies contributing to competitiveness could be included and analytically pursued in the future. However, in international comparisons, the quality of Czech management presents certain challenges for company development, particularly in project acquisition and the effective utilization of financial resources to meet objectives.

The inclusion of advanced technologies in broader technological areas was also discussed with experts. As quantum technologies included in the Other Advanced Technologies area are based on applications of physics principles, the experts proposed to call this area "Advanced Technologies based on Applied Physics". The advanced technology "Micro- and nanoelectronics and photonics" is classified under "Advanced Materials Technologies". In the opinion of the experts, it should be considered for reassignment to another broader technology area.

Experts pointed out the problematic interpretation of the conclusions of patent analyses. The number of patent applications filed by Czech companies is influenced by the strategy of the parent company, which often files applications through its headquarters outside the Czech Republic (typically in the USA). There are also differences between the Czech Republic and the EU-15 - while in the EU-15 patent applications are predominantly filed by companies, in the Czech Republic (as in other new Member States) research organisations contribute significantly to the number of patent applications. The number of patent applications is also influenced by different protection methods or practices in different technological areas. Based on discussions with TCP staff, these will be considered in the methodological part of the report.

9.5 Annexes to Chapter 5

9.5.1 Overview of the most important stakeholders from the research sector in individual regions of the Czech Republic

The following tables provide an overview of the research organisations (RO) in each region of the Czech Republic, which have been involved in R&D projects running in 2019 - 2023. For each RO, the total number of projects in which it has been involved and the number of projects in each area of advanced technologies is given[33]. The tables show only the ROs that participated in three or more projects. The Karlovy Vary Region is missing from the overview since no RO was involved in any project.

[33] Since a project could have been assigned to more than one technology area using keywords, the sum of the projects assigned to the technology areas may be greater than the total number of projects in a given VO.

Prague, the Capital City	**Number of projects**						
Research Organisation (abbreviated)	**Total**	**Advanced manufacturing technologies**	**Advanced material technologies**	**Biotechnology**	**Digital technologies**	**Information and communication technologies**	**Quantum technologies**
Czech Technical University in Prague	638	127	327	17	221	119	18
Charles University	432	21	241	62	100	37	31
University of Chemical Technology in Prague	274	12	203	68	15	11	6
Institute of Physics of the CAS, v. v. i.	201	7	182	9	7	4	22
Institute of Macromolecular Chemistry of the CAS, v. v. i	122	4	116	11	2	2	5
Institute of Microbiology of the CAS, v. v. i.	107	1	25	81	1	2	0
J. Heyrovsky Institute of Physical Chemistry of the CAS,	95	2	87	13	6	2	8
Czech University of Agriculture in Prague	65	6	21	26	15	8	0
Institute of Organic Chemistry and Biochemistry of the	53	1	38	10	2	1	6
Institute of Chemical Processes of the CAS, v. v. i.	39	0	27	13	1	1	0
Institute of Physiology of the CAS, v. v. i.	37	1	20	15	8	0	0
Institute of Plasma Physics of the CAS, v. v. i.	36	6	34	3	3	0	3
Institute of Information Theory and Automation of the C	32	5	7	0	25	7	0
Institute of Photonics and Electronics of the CAS, v. v. i.	31	0	31	0	0	0	2
Institute of Experimental Medicine of the CAS, v. v. i.	31	0	25	7	2	0	0
Institute of Molecular Genetics of the CAS, v. v. i.	24	0	10	14	1	0	1
Institute of Thermomechanics of the CAS, v. v. i.	23	6	19	2	4	1	0
CESNET, interest association of legal entities	23	0	7	0	7	16	2
General University Hospital in Prague	20	1	9	9	3	0	0
University of Economics in Prague	18	1	1	0	13	7	0
Institute of Informatics of the CAS, v. v. i.	18	2	1	0	16	1	0
Research Institute of Plant Production, v. v. i.	17	1	4	12	1	1	0
University Hospital in Motol	14	1	8	3	5	0	0
Research Institute of Brewing and Malting, a.s.	13	0	2	10	1	0	0
Institute of Clinical and Experimental Medicine	13	0	10	1	2	0	0
University Hospital Královské Vinohrady	13	0	8	0	4	1	0
Institute of Experimental Botany of the CAS, v. v. i.	13	0	4	9	0	0	0
Institute of Theoretical and Applied Mechanics of the C	12	0	9	1	3	1	0
State Institute of Health	12	0	5	4	2	2	0
Research and Testing Institute of Aviation, a.s.	11	1	8	0	1	3	0
Institute of Structure and Mechanics of Rocks of the CA	11	0	9	2	1	0	0
National Library of the Czech Republic	9	1	1	0	4	4	0
Dairy Research Institute s.r.o.	8	0	1	8	0	0	0
Czech Geological Survey	8	0	5	3	0	1	0
Institute of Philosophy of the CAS, v. v. i.	8	1	1	0	7	1	0
Institute of State and Law of the CAS, v. v. i.	8	1	0	0	6	3	0
Research Institute of Agricultural Technology, v. v. i.	8	2	3	3	1	3	0
Library of the CAS, v. v. i.	8	1	0	0	4	3	0
National Heritage Institute	8	0	4	0	2	3	0
Food Research Institute Prague, v. v. i.	7	0	3	6	0	0	0
Research Institute of Melioration and Soil Protection, v.	7	0	3	4	2	0	0
Institute of Archaeology of the CAS, Prague, v. v. i.	7	0	3	0	3	1	0
Institute of Mathematics of the CAS, v. v. i.	7	0	3	0	1	1	2
State Institute of Radiation Protection, v. v. i.	7	0	5	1	3	1	0
Research Institute of Animal Production, v. v. i.	6	1	2	3	1	1	0
Institute of Haematology and Blood Transfusion Prague	6	0	3	3	0	0	0
National Museum	5	0	1	0	2	2	0
Institute of Sociology of the CAS, v. v. i.	5	1	0	1	3	2	0
Institute for the Czech Language of the CAS, v. v. i.	5	0	3	0	1	1	0
Institute of Hydrodynamics of the CAS, v. v. i.	5	1	3	1	2	1	0
Institute of Geology of the CAS, v. v. i.	4	0	3	1	0	0	0
Academy of Performing Arts in Prague	4	1	0	0	3	3	0
Institute for the Study of Totalitarian Regimes	4	0	0	0	1	3	0
AMBIS College, a.s.	4	0	1	0	2	1	0
Institute for Czech Literature of the CAS, v. v. i.	4	0	0	0	3	1	0
Institute for Contemporary History of the CAS, v. v. i.	4	0	1	0	1	3	0
Centre for a Secure State z.s.	4	0	0	0	4	0	0
Central Military Hospital - VFN Prague	3	0	2	0	1	0	0
Memorial of National Literature	3	0	0	0	1	2	0
Masaryk Institute and Archives of the CAS, v. v. i.	3	0	0	0	1	2	0

Central Bohemian Region	Number of projects						
Research Organisation (abbreviated)	Total	Advanced manufacturing technologies	Advanced material technologies	Biotechnology	Digital technologies	Information and communication technologies	Quantum technologies
Institute of Inorganic Chemistry of the CAS, v. v. i.	29	0	26	3	0	0	3
SVÚM a.s.	28	10	22	0	0	1	0
Institute of Biotechnology of the CAS, v. v. i.	25	0	10	14	2	0	0
Centrum výzkumu Řež s.r.o.	25	3	22	0	0	1	0
National Institute of Mental Health	22	0	2	2	15	3	0
Institute of Nuclear Physics of the CAS, v. v. i.	19	1	16	0	1	1	2
Institute of Botany of the CAS, v. v. i.	16	1	3	10	3	0	0
Research Institute of Geodesy, Topograf. and Cartograf	12	0	4	0	7	5	0
Institute of Animal Physiology and Genetics of the CAS,	11	0	7	4	0	0	0
S. Tarouca Research Institute for Landscape and Hortic	8	0	3	3	2	0	0
State Institute of Nuclear, Chemical and Biological Prot	5	0	4	0	2	2	0
Institute of Astronomy of the CAS, v. v. i.	4	0	4	0	0	0	0
ŠKODA AUTO University	3	1	0	0	2	2	0

South Bohemian Region	Number of projects						
Research Organisation (abbreviated)	Total	Advanced manufacturing technologies	Advanced material technologies	Biotechnology	Digital technologies	Information and communication technologies	Quantum technologies
University of South Bohemia in České Budějovice	67	9	20	28	19	6	2
Biological Centre of the CAS, v. v. i.	65	2	17	39	8	6	2
University of Technology and Economics in Č. Budějovi	12	4	5	0	4	2	0

Plzeň Region	Number of projects						
Research Organisation (abbreviated)	Total	Advanced manufacturing technologies	Advanced material technologies	Biotechnology	Digital technologies	Information and communication technologies	Quantum technologies
University of West Bohemia in Pilsen	167	49	77	3	64	30	1
COMTES FHT a.s.	40	15	28	0	2	4	0
Research and Testing Institute Plzeň s.r.o.	18	6	8	0	7	0	0

Ústí nad Labem Region	Number of projects						
Research Organisation (abbreviated)	Total	Advanced manufacturing technologies	Advanced material technologies	Biotechnology	Digital technologies	Information and communication technologies	Quantum technologies
Jan Evangelista Purkyně University in Ústí nad Labem	30	3	20	5	3	3	0
ORLEN UniCRE a.s.	17	2	8	8	1	2	0

Liberec Region	Number of projects						
Research Organisation (abbreviated)	Total	Advanced manufacturing technologies	Advanced material technologies	Biotechnology	Digital technologies	Information and communication technologies	Quantum technologies
Technical University of Liberec	159	15	118	22	27	14	0
VÚTS, a.s.	17	6	8	0	4	2	0
MemBrain s.r.o.	4	0	3	1	0	0	0

Hradec Králové Region	Number of projects						
Research Organisation (abbreviated)	Total	Advanced manufacturing technologies	Advanced material technologies	Biotechnology	Digital technologies	Information and communication technologies	Quantum technologies
University of Hradec Kralove	20	2	6	0	12	2	0
University Hospital Hradec Králové	11	0	5	4	2	0	0
VŠÚO HOLOVOUSY s.r.o.	5	1	2	2	2	0	0

Pardubice Region	Number of projects						
Research Organisation (abbreviated)	Total	Advanced manufacturing technologies	Advanced material technologies	Biotechnology	Digital technologies	Information and communication technologies	Quantum technologies
University of Pardubice	85	7	59	5	21	11	0
Centre of Organic Chemistry s.r.o.	16	2	14	2	1	4	0

Vysočina Region	Number of projects						
Research Organisation (abbreviated)	Total	Advanced manufacturing technologies	Advanced material technologies	Biotechnology	Digital technologies	Information and communication technologies	Quantum technologies
Potato Research Institute Havlíčkův Brod, s.r.o.	8	1	3	6	1	0	0
Polytechnic College Jihlava	4	0	3	0	1	1	0

South Moravian Region	Number of projects						
Research Organisation (abbreviated)	Total	Advanced manufacturing technologies	Advanced material technologies	Biotechnology	Digital technologies	Information and communication technologies	Quantum technologies
Brno University of Technology	622	103	350	42	198	144	13
Masaryk University	266	9	114	58	74	47	10
Mendel University in Brno	75	3	40	25	16	7	0
Institute of Instrumentation of the CAS, v. v. i.	45	6	34	7	7	2	6
Czech Metrology Institute	39	4	29	1	4	3	7
Institute of Physics of Materials of the CAS, v. v. i.	38	5	35	1	1	0	5
Research Institute of Veterinary Medicine, v. v. i.	22	0	10	15	0	0	0
Veterinary University Brno	21	0	6	16	0	0	0
Transport Research Centre, v. v. i.	21	1	6	0	14	4	0
St. Anne's University Hospital in Brno	21	0	5	10	7	0	0
University Hospital Brno	18	1	8	7	6	2	0
Institute of Biophysics of the CAS, v. v. i.	17	0	13	6	0	0	0
Institute of Global Change Research of the CAS, v. v. i.	17	0	9	3	4	4	0
Institute of Analytical Chemistry of the CAS, v. v. i.	15	0	11	4	0	0	1
Research Institute of Building Materials, a.s.	14	1	14	0	1	0	0
Military Research Institute, s.p.	12	3	11	0	0	0	0
Moravian Regional Library in Brno	8	1	0	0	6	2	0
Institute of Vertebrate Biology of the CAS, v. v. i.	6	0	2	4	0	0	0
Masaryk Institute of Oncology	5	0	0	2	2	2	0
Agricultural Research, spol. s r.o.	5	0	0	5	0	0	0
Institute of Psychology of the CAS, v. v. i.	3	0	0	0	3	0	0

Olomouc Region	Number of projects						
Research Organisation (abbreviated)	Total	Advanced manufacturing technologies	Advanced material technologies	Biotechnology	Digital technologies	Information and communication technologies	Quantum technologies
Palacký University in Olomouc	160	8	98	29	24	18	44
University Hospital Olomouc	13	1	0	5	8	0	0
CENTRE FOR HYDRAULIC RESEARCH spol. s.r.o.	5	2	5	2	0	0	0

Zlín Region	Number of projects						
Research Organisation (abbreviated)	Total	Advanced manufacturing technologies	Advanced material technologies	Biotechnology	Digital technologies	Information and communication technologies	Quantum technologies
Tomas Bata University in Zlín	78	9	53	10	16	10	1
OSEVA development and research s.r.o.	3	0	1	3	0	0	0

Moravian-Silesian Region	Number of projects						
Research Organisation (abbreviated)	Total	Advanced manufacturing technologies	Advanced material technologies	Biotechnology	Digital technologies	Information and communication technologies	Quantum technologies
VSB - Technical University of Ostrava	193	28	85	18	80	35	4
University of Ostrava	22	1	7	7	11	2	0
MATERIAL AND METALLURGICAL RESEARCH s.r.o.	7	0	4	0	2	1	0
Silesian University in Opava	6	2	2	1	3	3	0
University Hospital Ostrava	6	1	1	2	3	0	0
Institute of Geonics of the CAS, v. v. i.	4	1	4	1	1	1	0

Source: R&D&I Information System

9.5.2 Results of bibliometric analysis of publications in projects focused on advanced technologies

The following tables give an overview of the number of research papers published by institutions from different sectors in each area of advanced technology. For each institution, their quality measured by the field-normalized citation rate is also given. In addition, the proportion of the institution's publications in the first decile and first quartile by citation rate is given. Only institutions with at least 20 publications in a given technology area during the period under review are listed in the tables (in the case of advanced materials technology and biotechnology, where the number of publications is significantly higher than in other areas, institutions with 30 or more publications are included). The methodological approach to the bibliometric analysis is described in the Annex in Chapter 9.1.3.3.

9.5.2.1 Advanced manufacturing technologies

Institution - organisational unit (abbreviated)	Number of publications	Normalized citation rate	Percentage of publications in the 1st decile	Percentage of publications in the 1st quartile
Universities				
VŠB - TUO - IT4Innovations	96	0.59	2%	11%
Brno University of Technology - Faculty of Information Technology	72	0.67	6%	15%
Czech Technical University in Prague - Faculty of Electrical Engineering	49	0.82	8%	24%
VŠB-TUO - Faculty of Electrical Engineering and Computer Science	43	0.56	5%	12%
VŠB-TUO - Faculty of Mechanical Engineering	32	0.70	3%	19%
Czech Technical University in Prague - Faculty of Mechanical Engineering	31	0.69	0%	23%
University of Ostrava - Institute for Research and Applications of Fuzzy Modelling	29	0.83	7%	34%
Tomas Bata University in Zlín - Faculty of Applied Informatics	27	0.51	4%	7%
VŠB-TUO - Centre for Nanotechnology	26	0.27	0%	0%
Tomas Bata University in Zlín - Faculty of Technology	25	0.49	4%	12%
Charles University - Faculty of Mathematics and Physics	25	0.94	8%	24%
BUT in Brno - Faculty of Electrical Engineering and Communication Technologies	25	1.11	8%	44%
BUT in Brno - Faculty of Mechanical Engineering	21	0.81	5%	14%
VŠCHT in Prague - Faculty of Chemical Engineering	21	0.48	0%	10%
CTU in Prague - Czech Institute of Informatics, Robotics and Cybernetics	20	0.67	0%	25%
Czech Academy of Sciences				
Institute of Geonics of the CAS, v. v. i.	24	0.86	13%	13%

Source: Clarivate Web of Science

9.5.2.2 Advanced material technologies

Institution - organisational unit (abbreviated)	Number of publications	Normalized citation rate	Percentage of publications in the 1st decile	Percentage of publications in the 1st quartile
Universities				
VŠCHT in Prague - Faculty of Chemical Technology	720	0.89	8%	25%
BUT in Brno - Central European Institute of Technology BUT	608	0.99	11%	27%
Charles University - Faculty of Mathematics and Physics	517	0.82	8%	21%
Masaryk University - Faculty of Science	506	0.79	6%	21%
Charles University - Faculty of Science	463	0.85	6%	24%
Palacký University in Olomouc - Faculty of Science	433	0.98	11%	26%
Masaryk University - Central European Institute of Technology	274	0.98	9%	32%
Brno University of Technology - Faculty of Electrical Engineering and Comm. Tech.	268	0.76	6%	24%
VŠCHT in Prague - Faculty of Chemical Engineering	256	0.76	4%	22%
Tomas Bata University in Zlín - University Institute	219	0.93	9%	28%
CTU in Prague - Faculty of Nuclear and Physical Engineering	217	0.90	6%	27%
Czech Technical University in Prague - Faculty of Civil Engineering	217	0.78	6%	24%
Charles University - 1st Faculty of Medicine	202	0.77	4%	18%
Mendel University in Brno - Faculty of Agronomy	188	1.02	12%	34%
Czech Technical University in Prague - Faculty of Electrical Engineering	185	0.87	8%	25%
University of Pardubice - Faculty of Chemical Technology	178	0.60	2%	13%
Brno University of Technology - Faculty of Chemistry	163	0.76	6%	20%
Technical University of Ostrava - IT4Innovations	156	0.82	6%	22%
Brno University of Technology - Faculty of Mechanical Engineering	143	0.82	6%	22%
Tomas Bata University in Zlín - Faculty of Technology	136	0.81	7%	24%
Brno University of Technology - Faculty of Civil Engineering	131	0.73	5%	19%
VŠCHT in Prague - Faculty of Food and Biochemical Technology	126	0.90	7%	27%
University of South Bohemia in České Budějovice - Faculty of Science	119	0.99	10%	28%
UP in Olomouc - Czech Institute of Research and Advanced Technologies	117	1.68	29%	55%
VŠB-TUO - Centre for Nanotechnology	115	1.24	19%	35%
Masaryk University - Faculty of Medicine	108	0.79	8%	19%
TU in Liberec - Institute for Nanomaterials, Advanced Technologies and Innovations	104	1.07	14%	39%
UJEP in Ústí nad Labem - Faculty of Science	94	0.67	1%	17%
Czech Technical University in Prague - Faculty of Mechanical Engineering	93	0.58	1%	16%
General University Hospital in Prague	90	0.80	6%	14%
VŠB-TUO - Faculty of Materials Science and Technology	86	0.65	5%	20%
Czech Technical University in Prague - Faculty of Biomedical Engineering	78	0.80	8%	26%
St. Anne's University Hospital in Brno	77	0.83	8%	22%
VŠB-TUO - Faculty of Electrical Engineering and Informatics	75	0.95	13%	17%
Brno University of Technology - Faculty of Information Technology	66	0.56	3%	12%
Charles University - 2nd Faculty of Medicine	65	0.85	5%	22%
University of Chemical Technology in Prague - Rectorate	63	0.83	3%	27%
University Hospital Brno	62	0.96	11%	26%
University of West Bohemia in Pilsen - Faculty of Electrical Engineering	62	0.64	3%	16%
Charles University - Faculty of Pharmacy in Hradec Králové	62	1.05	10%	24%
University of West Bohemia in Pilsen - New Technologies - Research Centre	55	0.84	7%	20%
Technical University of Liberec - Faculty of Textiles	55	0.93	5%	33%
University of West Bohemia in Pilsen - Faculty of Applied Sciences	46	0.81	7%	17%
Veterinary University Brno - Rectorate	46	1.71	26%	41%
Charles University - 3rd Faculty of Medicine	46	0.88	4%	17%
VŠCHT in Prague - Faculty of Environmental Technology	44	0.62	2%	16%
University Hospital in Motol	43	0.72	5%	14%
Charles University - Faculty of Medicine in Pilsen	42	1.21	14%	38%
Veterinary University Brno - Faculty of Veterinary Medicine	41	1.09	17%	32%
VŠB-TUO - Institute of Environmental Technologies	38	0.68	0%	21%
Mendel University in Brno - Faculty of Forestry and Wood Technology	37	1.16	11%	35%
VŠB - TUO - Faculty of Mechanical Engineering	34	0.64	3%	18%
Palacký University in Olomouc - Faculty of Medicine	34	0.82	9%	26%
University Hospital Hradec Králové	34	1.10	18%	26%
Technical University of Liberec - Faculty of Mechanical Engineering	33	0.88	15%	30%
South Bohemian University in Č. Bud. - Faculty of Fisheries and Water Protection	30	1.84	20%	60%

Advanced material technologies - continuation of the table

Institution - organisational unit (abbreviated)	Number of publications	Normalized citation rate	Percentage of publications in the 1st decile	Percentage of publications in the 1st quartile
Czech Academy of Sciences				
Institute of Physics of the CAS, v. v. i.	949	0.81	6%	20%
Institute of Macromolecular Chemistry of the CAS, v. v. i.	420	0.81	5%	19%
J. Heyrovsky Institute of Physical Chemistry of the CAS, v. v. i.	245	0.66	3%	20%
Institute of Physics of Materials of the CAS, v. v. i.	207	0.66	4%	16%
Institute of Organic Chemistry and Biochemistry of the CAS, v. v. i.	201	0.84	9%	23%
Institute of Nuclear Physics of the CAS, v. v. i.	167	0.81	7%	20%
Institute of Instrumentation of the CAS, v. v. i.	108	0.94	13%	27%
Institute of Microbiology of the CAS, v. v. i.	104	0.77	3%	23%
Institute of Plasma Physics of the CAS, v. v. i.	104	1.11	9%	25%
Biological Centre of the CAS, v. v. i.	96	1.42	15%	32%
Institute of Chemical Processes of the CAS, v. v. i.	93	0.65	3%	17%
Institute of Experimental Medicine of the CAS, v. v. i.	85	0.72	2%	18%
Institute of Photonics and Electronics of the CAS, v. v. i.	78	0.97	6%	28%
Institute of Biophysics of the CAS, v. v. i.	77	0.84	10%	23%
Institute of Inorganic Chemistry of the CAS, v. v. i.	75	0.70	4%	16%
Institute of Physiology of the CAS, v. v. i.	75	1.05	7%	25%
Institute of Analytical Chemistry of the CAS, v. v. i.	74	0.98	9%	24%
Institute of Thermomechanics of the CAS, v. v. i.	61	0.85	7%	23%
Institute of Structure and Mechanics of Rocks of the CAS, v. v. i.	49	0.66	4%	18%
Institute of Molecular Genetics of the CAS, v. v. i.	42	1.06	12%	36%
Institute of Experimental Botany of the CAS, v. v. i.	40	1.56	15%	38%
Institute of Biotechnology of the CAS, v. v. i.	34	1.34	15%	35%
Sectoral public research institutions				
Research Institute of Veterinary Medicine, v. v. i.	66	0.77	6%	23%
Others				
Research Centre Řež s.r.o.	98	0.59	5%	11%
Czech Metrology Institute	43	0.74	0%	21%
Institute of Clinical and Experimental Medicine	40	0.67	0%	18%

Source: Clarivate Web of Science

9.5.2.3 Biotechnology

Institution - organisational unit (abbreviated)	Number of publications	Normalized citation rate	Percentage of publications in the 1st decile	Percentage of publications in the 1st quartile
Universities				
Charles University - Faculty of Science	263	1.05	8%	24%
St. Anne's University Hospital in Brno	224	1.03	12%	30%
University of South Bohemia in České Budějovice - Faculty of Science	135	1.05	7%	29%
Charles University - 1st Faculty of Medicine	131	0.91	6%	24%
Masaryk University - Faculty of Science	126	0.98	6%	26%
Masaryk University - Faculty of Medicine	115	0.81	8%	22%
University of Chemical Technology in Prague - Faculty of Food and Biochemical Tech.	108	0.91	9%	20%
VŠB - Technical University of Ostrava - IT4Innovations	94	0.59	2%	12%
Brno University of Technology - Faculty of Information Technology	71	0.68	6%	15%
Masaryk University - Central European Institute of Technology	71	0.99	8%	39%
Charles University - 2nd Faculty of Medicine	70	1.00	7%	20%
Palacký University in Olomouc - Faculty of Science	56	0.89	5%	29%
General University Hospital in Prague	56	0.89	9%	21%
University Hospital Brno	55	0.72	5%	20%
University of Chemical Technology in Prague - Faculty of Chemical Technology	49	0.82	4%	20%
ČZU in Prague - Faculty of Agrobiology, Food and Natural Resources	47	0.90	9%	21%
University Hospital in Motol	44	0.99	9%	18%
Charles University - Faculty of Mathematics and Physics	40	1.19	13%	30%
VŠB-TUO - Faculty of Electrical Engineering and Computer Science	40	0.57	5%	13%
Charles University - Faculty of Pharmacy in Hradec Králové	40	1.08	13%	30%
Brno University of Technology - Central European Institute of Technology BUT	39	1.00	5%	31%
Palacký University in Olomouc - Faculty of Medicine	39	0.78	8%	15%
Brno University of Technology - Faculty of Chemistry	39	1.02	10%	33%
South Bohemian University in České Budějovice - Faculty of Fisheries and Water …	39	0.95	8%	10%
VŠCHT in Prague - Faculty of Chemical Engineering	37	0.77	3%	19%
Mendel University in Brno - Faculty of Agronomy	37	1.00	8%	22%
Charles University - Faculty of Medicine in Pilsen	35	1.14	11%	43%
VŠB-TUO - Centre of Nanotechnology	32	0.51	3%	13%
Czech Academy of Sciences				
Institute of Microbiology of the CAS, v. v. i.	300	1.23	11%	29%
Biological Centre of the CAS, v. v. i.	125	1.00	9%	29%
Institute of Macromolecular Chemistry of the CAS, v. v. i.	74	0.95	7%	20%
Institute of Molecular Genetics of the CAS, v. v. i.	62	0.93	11%	26%
Institute of Physiology of the CAS, v. v. i.	54	0.81	7%	20%
Institute of Organic Chemistry and Biochemistry of the CAS, v. v. i.	48	0.64	2%	10%
Institute of Botany of the CAS, v. v. i.	45	1.14	9%	20%
Institute of Experimental Medicine of the CAS, v. v. i.	44	0.81	5%	18%
Institute of Animal Physiology and Genetics of the CAS, v. v. i.	36	1.06	14%	36%
J. Heyrovsky Institute of Physical Chemistry of the CAS, v. v. i.	34	0.43	0%	9%
Institute of Biotechnology of the CAS, v. v. i.	32	1.25	19%	25%
Sectoral public research institutions				
Research Institute of Veterinary Medicine, v. v. i.	41	1.00	10%	22%
Others				
Research Institute of Brewing and Malting, a.s.	31	0.32	0%	6%

Source: Clarivate Web of Science

9.5.2.4 Digital technology

Institution - organisational unit (abbreviated)	Number of publications	Normalized citation rate	Percentage of publications in the 1st decile	Percentage of publications in the 1st quartile
Universities				
Czech Technical University in Prague - Faculty of Electrical Engineering	167	1.17	11%	28%
Charles University - Faculty of Mathematics and Physics	131	1.42	15%	29%
Technical University of Ostrava - IT4Innovations	108	0.64	3%	13%
Palacký University in Olomouc - Faculty of Science	81	0.76	6%	12%
Brno University of Technology - Faculty of Information Technology	76	0.72	7%	13%
VŠB - TUO - Faculty of Electrical Engineering and Computer Science	70	0.75	7%	17%
University of Ostrava - Institute for Research and Applications of Fuzzy Modelling	59	0.90	12%	34%
Brno University of Technology - Faculty of Electrical Engineering and Communication	46	0.91	9%	22%
VŠB - Technical University of Ostrava - Faculty of Economics	41	1.10	10%	39%
University of Chemical Technology in Prague - Faculty of Chemical Engineering	41	0.85	12%	24%
Czech Technical University in Prague - Faculty of Nuclear and Physical Engineering	41	1.59	22%	29%
Charles University - 1st Faculty of Medicine	40	1.62	15%	30%
Palacký University in Olomouc - Faculty of Medicine	39	1.29	18%	26%
Masaryk University - Faculty of Science	38	1.08	8%	39%
University of West Bohemia in Pilsen - Faculty of Electrical Engineering	36	0.73	3%	19%
Czech Technical University in Prague - CIIRC	36	0.75	6%	25%
Charles University - 3rd Faculty of Medicine	32	1.05	6%	22%
Charles University - Faculty of Science	31	1.27	16%	45%
Tomas Bata University in Zlín - Faculty of Applied Informatics	29	0.48	3%	7%
VŠB - TUO - Centre of Nanotechnology	28	0.27	0%	0%
University Hospital Olomouc	26	1.40	19%	31%
VŠB - Technical University of Ostrava - Faculty of Mechanical Engineering	26	0.66	0%	19%
Masaryk University - Faculty of Informatics	26	0.89	4%	12%
General University Hospital in Prague	25	1.86	16%	32%
St. Anne's University Hospital in Brno	24	0.96	17%	21%
University of West Bohemia in Pilsen - Faculty of Applied Sciences	24	0.60	4%	17%
Brno University of Technology - Faculty of Civil Engineering	23	0.46	0%	4%
Masaryk University - Faculty of Medicine	21	1.21	14%	14%
Czech Academy of Sciences				
Institute of Physics of the CAS, v. v. i.	76	1.88	21%	36%
Institute of Information Theory and Automation of the CAS, v. v. i.	64	0.94	9%	19%
Institute of Informatics of the CAS, v. v. i.	55	0.91	9%	16%
Institute of Geonics of the CAS, v. v. i.	25	0.85	12%	12%
J. Heyrovsky Institute of Physical Chemistry of the CAS, v. v. i.	21	0.94	0%	48%
Others				
National Institute of Mental Health	45	0.90	9%	27%

Source: Clarivate Web of Science

9.5.2.5 Information and communication technologies

Institution - organisational unit (abbreviated)	Number of publications	Normalized citation rate	Percentage of publications in the 1st decile	Percentage of publications in the 1st quartile
Universities				
BUT in Brno - Faculty of Electrical Engineering and Communication Technology	152	0.79	8%	28%
VŠB-TUO - Technical University of Ostrava - IT4Innovations	97	0.58	2%	11%
Czech Technical University in Prague - Faculty of Electrical Engineering	82	0.77	5%	21%
Brno University of Technology - Faculty of Information Technology	65	0.60	5%	14%
VŠB-TUO - Faculty of Electrical Engineering and Informatics	51	0.67	6%	14%
Charles University - Faculty of Mathematics and Physics	49	4.55	18%	37%
Brno University of Technology - Faculty of Mechanical Engineering	45	1.20	16%	31%
CTU in Prague - University Centre for Energy Efficient Buildings	34	0.80	6%	26%
Palacký University in Olomouc - Faculty of Science	32	1.40	16%	34%
VŠCHT in Prague - Faculty of Food and Biochemical Technology	30	1.20	10%	30%
University of Ostrava - Institute for Research and Applications of Fuzzy Modelling	29	0.83	7%	34%
VŠB-TUO - Centre for Nanotechnology	27	0.28	0%	0%
VŠB - Technical University of Ostrava - Faculty of Mechanical Engineering	25	0.69	0%	20%
University of Chemical Technology in Prague - Rectorate	25	1.39	12%	40%
Masaryk University - Faculty of Economics and Administration	24	0.83	8%	21%
Charles University - Faculty of Social Sciences	21	0.87	10%	29%
Charles University - Faculty of Science	20	0.63	0%	25%
Czech Academy of Sciences				
Institute of Physics of the CAS, v. v. i.	40	2.55	30%	53%
Institute of Geonics of the CAS, v. v. i.	24	0.86	13%	13%
Others				
National Institute of Mental Health	28	1.49	18%	39%

Source: Clarivate Web of Science

9.5.2.6 Quantum technologies

Institution - organisational unit (abbreviated)	Number of publications	Normalized citation rate	Percentage of publications in the 1st decile	Percentage of publications in the 1st quartile
Universities				
Palacký University in Olomouc - Faculty of Science	290	0.89	10%	22%
Charles University - Faculty of Mathematics and Physics	124	0.82	6%	20%
Czech Technical University in Prague - Faculty of Nuclear and Physical Engineering	73	0.86	5%	25%
Masaryk University - Faculty of Science	44	1.26	11%	34%
Brno University of Technology - Central European Institute of Technology BUT	28	0.80	4%	14%
University of Chemical Technology in Prague - Faculty of Chemical Engineering	27	0.98	11%	41%
Czech Academy of Sciences				
Institute of Physics of the CAS, v. v. i.	94	0.95	12%	22%
Institute of Nuclear Physics of the CAS, v. v. i.	42	0.82	5%	21%
J. Heyrovsky Institute of Physical Chemistry of the CAS, v. v. i.	39	0.62	3%	21%
Institute of Organic Chemistry and Biochemistry of the CAS, v. v. i.	34	1.16	26%	38%
Institute of Instrumentation of the CAS, v. v. i.	28	1.08	14%	21%
Institute of Mathematics of the CAS, v. v. i.	21	0.74	5%	10%
Institute of Macromolecular Chemistry of the CAS, v. v. i.	20	0.75	5%	10%

Source: Clarivate Web of Science

9.5.3 Patent applicants in advanced technologies

The following tables show the number of priority patent applications filed by Czech entities in each broad area of advanced technologies between 2018 and 2022. Only entities that filed two or more priority patent applications during this period are listed in the tables.

Table 52 Top patent applicants in advanced manufacturing technologies - number of priority patent applications in 2018-2022. Source: PATSTAT, Autumn 2023

Sector	Institution/company	Number of patent applications
Business	COMTES FHT a.s.	2
Business	Škoda Auto a.s.	2
Public/state university, college	Tomas Bata University in Zlín	2

Table 53 Top patent applicants in advanced materials technologies - number of priority patent applications in 2018-2022. Source: PATSTAT, Autumn 2023

Sector	Institution/company	Number of patent applications
Business	PO LIGHTING CZECH s.r.o.	20
Business	Škoda Auto a.s.	10
Business	IQS Group a.s.	7
Business	Centrum organické chemie s.r.o.	6
Business	Contipro a.s.	4
Business	Grade Medical s.r.o.	4
Business	HOFMEISTER s.r.o.	4
Business	ORLEN UniCRE a.s.	4
Business	CRYTUR, spol. s r.o.	3
Business	First Point a.s.	3
Business	HELLA AUTOTECHNIK NOVA, s.r.o.	3
Business	MARP invention s.r.o.	3
Business	AG CHEMI GROUP s.r.o.	2
Business	Centrum výzkumu Řež s.r.o.	2
Business	HYDROSERVIS-UNION a.s.	2
Business	MATRIX a.s.	2
Business	Meopta - optika, s.r.o.	2
Business	MORAVIA PLAST, spol. s r.o.	2
Business	Rieter CZ s.r.o.	2
Business	ROTANA a.s.	2
Business	STMicroelectronics Design and Application s.r.o.	2
Business	VÚTS, a.s.	2
Czech Academy of Sciences	Institute of Physics of the CAS, v. v. i.	23
Czech Academy of Sciences	Institute of Macromolecular Chemistry of the CAS, v. v. i.	6
Czech Academy of Sciences	Institute of Chemical Processes of the CAS, v. v. i.	4
Czech Academy of Sciences	Institute of Plasma Physics of the CAS, v. v. i.	3
Czech Academy of Sciences	Institute of Organic Chemistry and Biochemistry of the CAS	3
Czech Academy of Sciences	Institute of Thermomechanics of the CAS, v. v. i.	3
Czech Academy of Sciences	Institute of Microbiology of the CAS, v. v. i.	2
Czech Academy of Sciences	Institute of Experimental Medicine of the CAS, v. v. i.	2
Czech Academy of Sciences	Institute of Photonics and Electronics of the CAS, v. v. i.	2
Czech Academy of Sciences	Institute of Instrumentation of the CAS, v. v. i.	2
Public/state university, college	Czech Technical University in Prague	27
Public/state university, college	Technical University of Liberec	19
Public/state university, college	Tomas Bata University in Zlín	18
Public/state university, college	University of Mining and Metallurgy - Technical University	12
Public/state university, college	Brno University of Technology	12
Public/state university, college	University of West Bohemia in Pilsen	11
Public/state university, college	Palacký University in Olomouc	10
Public/state university, college	Charles University	9
Public/state university, college	Jan Evangelista Purkyně University in Ústí nad Labem	8
Public/state university, college	University of Chemical Technology in Prague	7
Public/state university, college	University of Pardubice	6
Public/state university, college	Mendel University in Brno	5
Public/state university, college	University of Hradec Králové	3
Public/state university, college	Czech University of Agriculture in Prague	2
Public/state university, college	University of South Bohemia in České Budějovice	2
Public/state university, college	University of Ostrava	2
Private non-profit	Plastics Cluster z.s.	2

Table 54 Top patent applicants in biotechnology - number of priority patent applications in 2018-2022. Source: PATSTAT, Autumn 2023

Sector	Institution/company	Number of patent applications
Public/state university, college	VSB - Technical University of Ostrava	2

Table 55 Top patent applicants in digital technologies - number of priority patent applications in 2018-2022. Source: Source: PATSTAT, Autumn 2023

Sector	Institution/company	Number of patent applications
Business	AVAST Software s.r.o.	6
Public/state university, college	Czech Technical University in Prague	7
Public/state university, college	University of West Bohemia in Pilsen	2

Table 56 Top patent applicants in information and communication technologies - number of priority patent applications in 2018-2022. Source: PATSTAT, Autumn 2023

Sector	Institution/company	Number of patent applications
Business	AVAST Software s.r.o.	31
Business	ADUCID s.r.o.	2
Business	Avast Software s.r.o.	2
Public/state university, college	Czech Technical University in Prague	6

9.6 Annexes to Chapter 6

9.6.1 Minutes of the closing workshop

The closing workshop took place on 20 June 2024. In the first part of the workshop, **expert feedback** was obtained **on the analytical outputs of** the procurement. The participants' suggestions were mainly related to the methodological approach to the analysis. The analysis of patenting activity was discussed, where experts pointed out significant differences between the approach to patenting in the EU, the US, and Asian countries. They also pointed out that there are also significant differences between applicants from the Czech Republic and applicants from the original EU Member States - while in the Czech Republic the number of applications is significantly driven by research organisations, in the original EU Member States the vast majority of patents are applied for by businesses. The low number of patent applications in the Czech Republic is also due to the fact that branches of foreign companies and multinationals file patents through their headquarters abroad. There are also significant differences in access to protection between disciplines or technologies.

Experts have pointed out that the inclusion of photonics in the broader field of advanced materials technologies does not fully reflect reality. Experts also pointed out that research lines falling under photonics are gradually moving into quantum technologies. Experts further highlighted that companies are investing in research and development through tax deductions. However, data on indirect support cannot be categorized by specific technology areas. Additionally, the experts noted that AI serves as a powerful tool enabling companies to enhance their efficiency, which explains its widespread use in projects aimed at the relevant GSCs.

Following the discussion in this section, the methodological part of the report will be modified to define the objectives of the analysis (including the linkages of advanced technologies to GSC) and to describe why the methodology used was chosen. The methodological section will also take into account the above and slightly modify the methodology for determining the link of advanced technologies to the GSC. In the case of photonics, an explanatory note will be added to the table indicating the structure of the advanced technologies and their inclusion in the broader technology areas.

In the second part, the experts reviewed and discussed the **draft recommendations** aimed at either enhancing the strengths or addressing the weaknesses of the Czech Republic in the realm of advanced technologies, particularly in relation to GSCs. In this part of the discussion, the experts pointed out that GSCs should be addressed in cooperation between multiple providers. For this reason, relevant providers and other actors should be involved in the implementation of the conclusions of the analysis and shaping the focus of the programmes. At the same time, it is necessary to address GSCs in a comprehensive manner. An example could be the GSC Preparedness for demographic change and aging - links to the health system (capacity and staffing), the social system, etc.

In addition to programmes and public competitions focused on GSCs, tools must be implemented to enhance the efficiency, competitiveness, and GDP of the Czech Republic (for example, through the use of AI), which will generate resources that will enable the financing of projects aimed at addressing GSCs. Beyond supporting established technological sectors where the Czech Republic excels, attention should also be given to emerging technologies with substantial future potential, such as quantum technologies.

Technologies that are expected to have a significant application in the future, such as digital technologies, ICT, and advanced materials, must be integrated into education to ensure a timely and sufficient supply of skilled workers in these fields. For example, Saxony's focus on developing semiconductor technologies illustrates the importance of aligning educational frameworks with emerging industry demands. Experts also suggested trying to implement appropriate challenges at the appropriate time, following the example of some foreign countries. The experts also stated that the results of the analysis should be made available to the National innovation platforms as soon as possible. The aforementioned suggestions will be considered in the draft recommendation.

9.7 List of abbreviations

Abbreviation	Full name
3R	Reduce, reuse, recycle
AI	Artificial intelligence
AR	Augmented reality
ATI	Advanced Technologies for Industry
BUT	Brno University of Technology
CAS	Czech Academy of Sciences
CATRIN	Catrin - Czech Advanced Technology and Research Institute
CCS	Carbon capture and storage
CCUS	Carbon capture, use and storage
CEITEC	Central European Institute of Technology
CEP	Central evidence of projects
CETE:P	Center for Environmental and Technology Ethics - Prague
CIIRC	Czech Institute of Informatics, Robotics and Cybernetics
CLT	Cross-laminated timber
CO2	Carbon dioxide
CRISPR	Clustered regularly interspaced short palindromic repeats
CSO	Czech Statistical Office
CSU	Carbon capture and utilization
CTU	Czech Technical University
CU	Charles University
CZK	Czech Crown
CZU	Czech University of Life Sciences Prague
EDP	Entrepreneurial discovery process
ELI	ELI Beamlines
EPO	European Patent Office
ESIF	European Structural and Investment Funds
EU	European Union
EU-28	27 countries of the European Union and United Kingdom
GA CR	Czech Science Foundation
GSC	Grand societal challenges
H2020	Horizont 2020
HE	Horizont Europe
HEI	Heigher education institutions

IaaS	Infrastructure as a service
ICT	Information and communication technologies
IoT	Internet og things
KETs	Key enabling technologies
LCA	Life cycle analysis
LEO	Low-earth-orbit
LTC	Long term challenges for Czech Society
MaaS	Mobility as a service
MEYS	Ministry of Education, Youth and Sports
MIT	Ministry of Industry and Trade
MU	Masaryk University
NACE	Statistical Classification of Economic Activities
NPOR	National priorities of oriented research
NRIS3	National research and innovation strategy for smart specialization of the Czech Republic 2021-2027
PaaS	Platform as a service
PATSTAT	EPO Worldwide Patent Statistical Database
PPDD	Policy Programme Digital Decade
R&D&I	Research, development, and innovation
R&D&I Information system	Information system for research, experimental development and innovation
RDIC	Research, Development and Innovation Council
RES	Renewable energy sources
RO	Research organisation
S&T	Science and technology
SaaS	Software as a service
STEM	Science, technology, engineering and mathematics
TA CR	Technology Agency of the Czech Republic
TUL	Technical University of Liberec
UCT, VŠCHT	University of Chemistry and Technology
UJEP	University of Jan Evangelista in Ústí nad Labem
UPOL	Palacký University Olomouc
USB	University of South Bohemia in České Budějovice
v.v.i.	Public research institution
VOS	Visualization of similarities
VR	Virtual reality
VSB -TUO	VSB - Technical University of Ostrava
VÚ	Research institute

WLC	Whole Life Carbon
WoS	Web of Science
ZTA	Zero trust architecture